NLO effects on stop searches in the compressed region.

by

Marco Hufnagel

in collaboration with

Jan Heisig, Benjamin Nachman

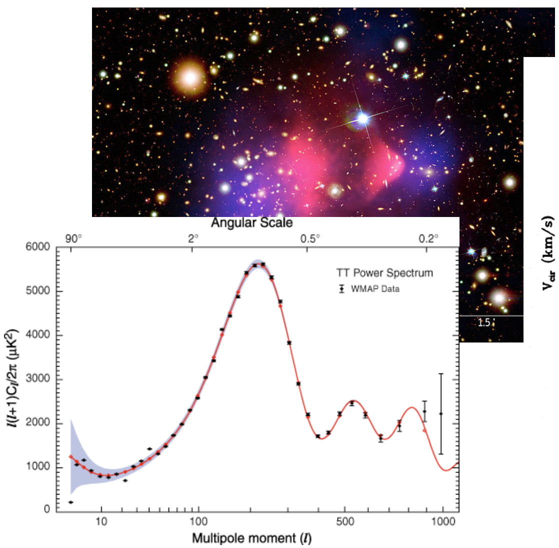
Monday, September 24, 2018

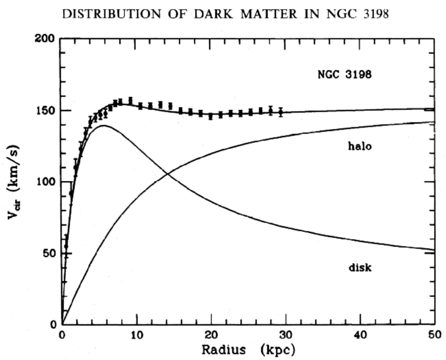
HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

Introduction

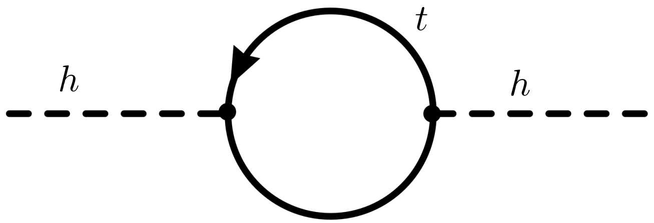
Shortcomings of the Standard Model:

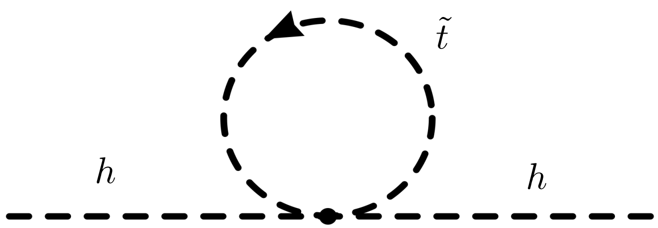
Dark Matter:





Hierarchy Inconvenience:





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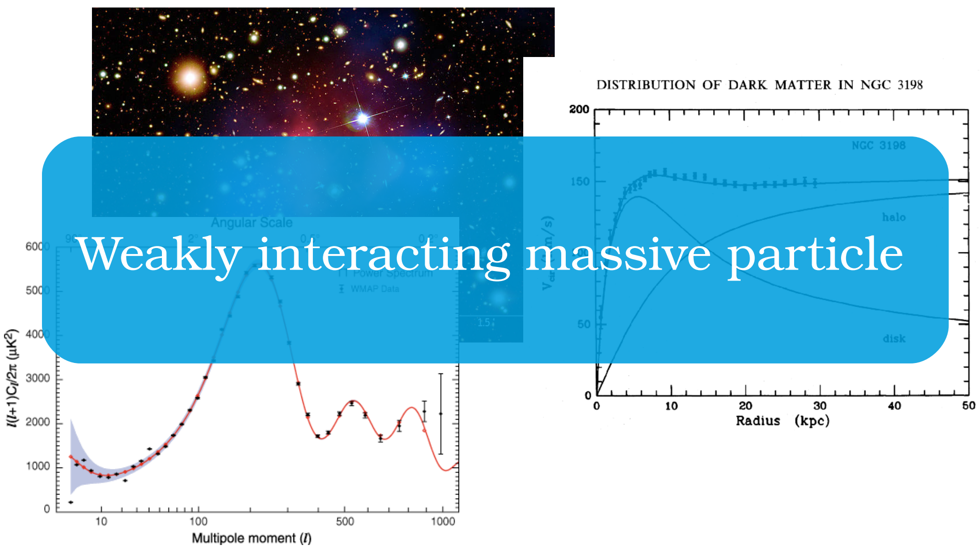

Weakly interacting massive particle

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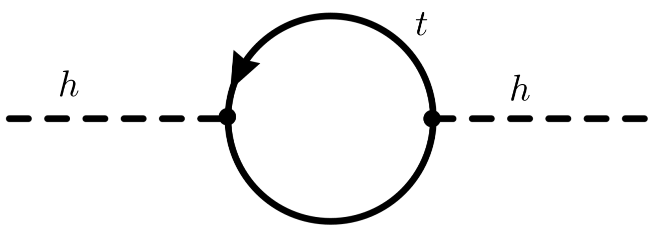

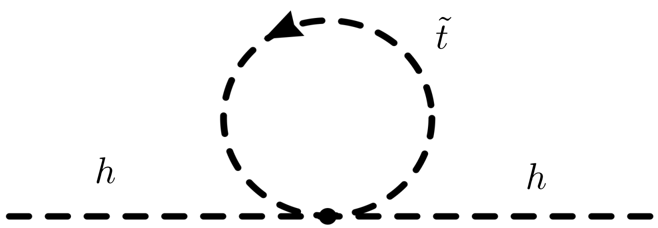

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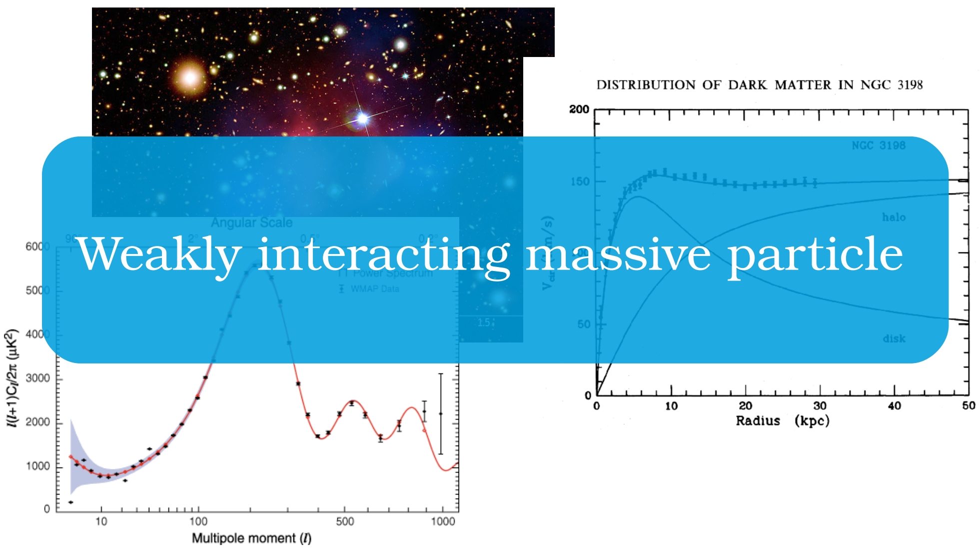

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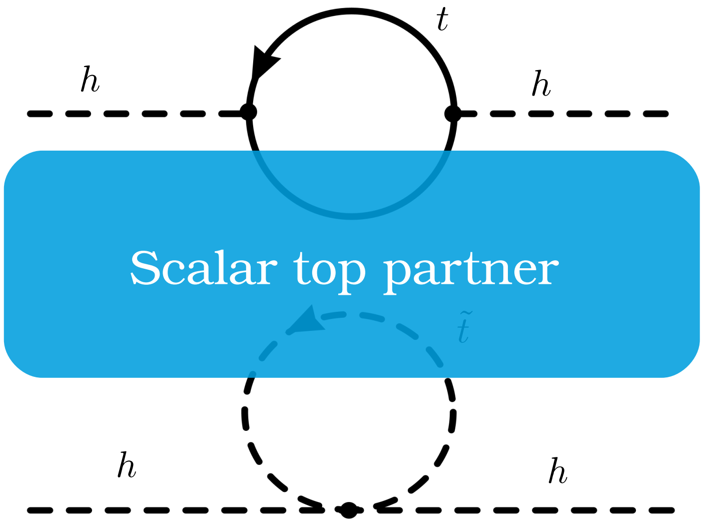

Scalar top partner

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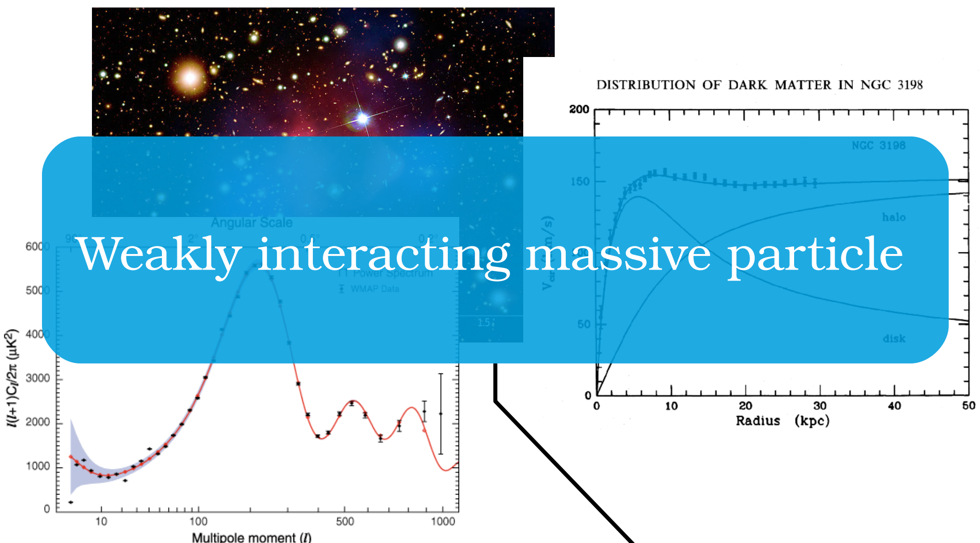

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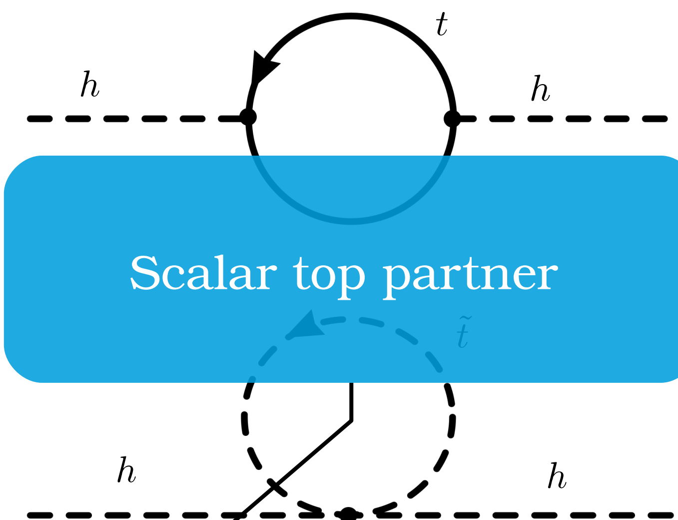

Scalar top partner

Possible Solution: Lightest neutralino & top partner from the MSSM

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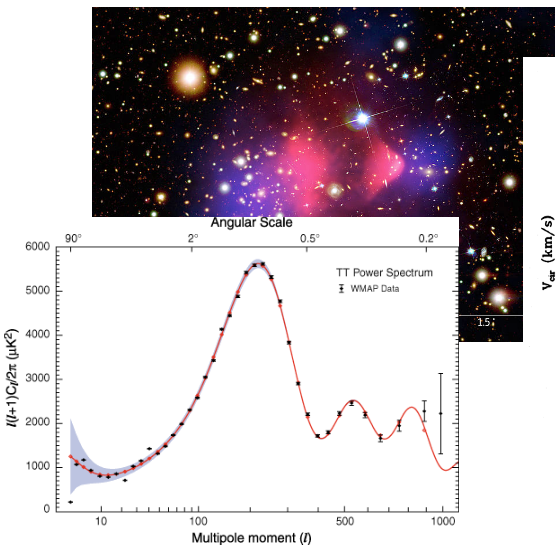

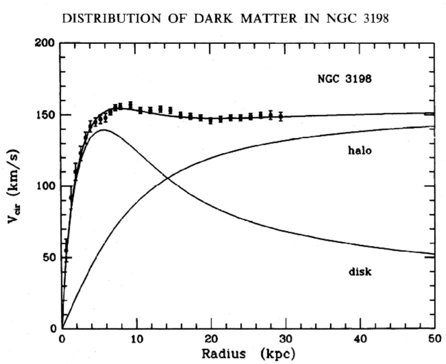

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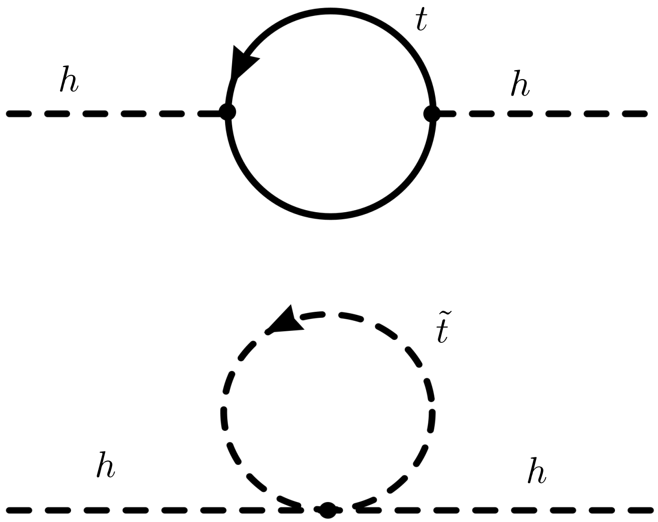

Possible Solution: Lightest neutralino & top partner from the MSSM

$$\mathcal{L} - \mathcal{L}_{\text{SM}} = |D_\mu \tilde{t}|^2 - m_{\tilde{t}}^2 |\tilde{t}|^2 + 1/2 \bar{\chi}(i\not{\partial} - m_\chi)\chi + \left[y_\chi \bar{t}_{\text{R}} \tilde{t} \chi_{\text{L}} + \text{h.c.} \right]$$

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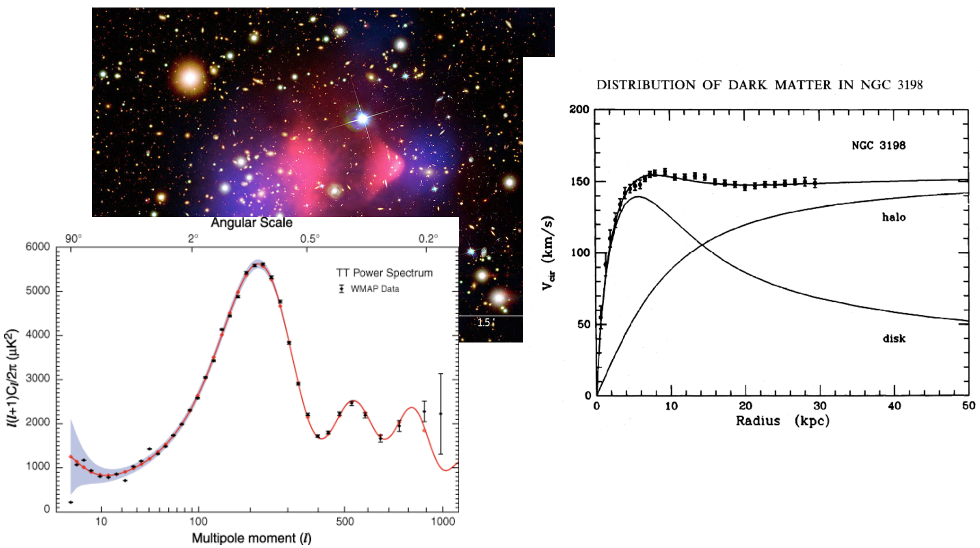

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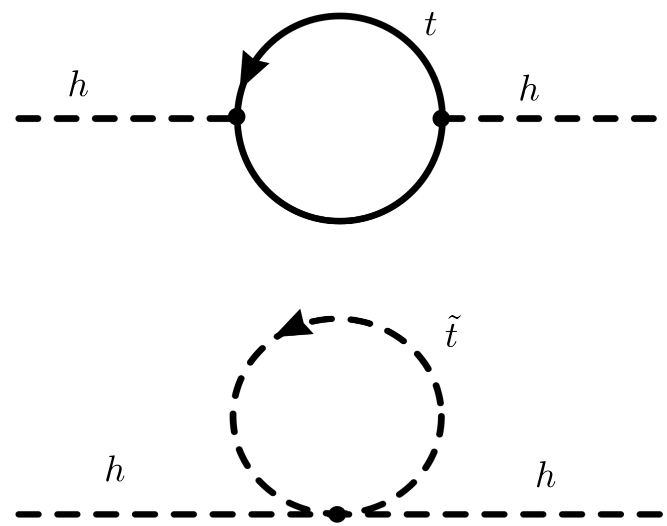

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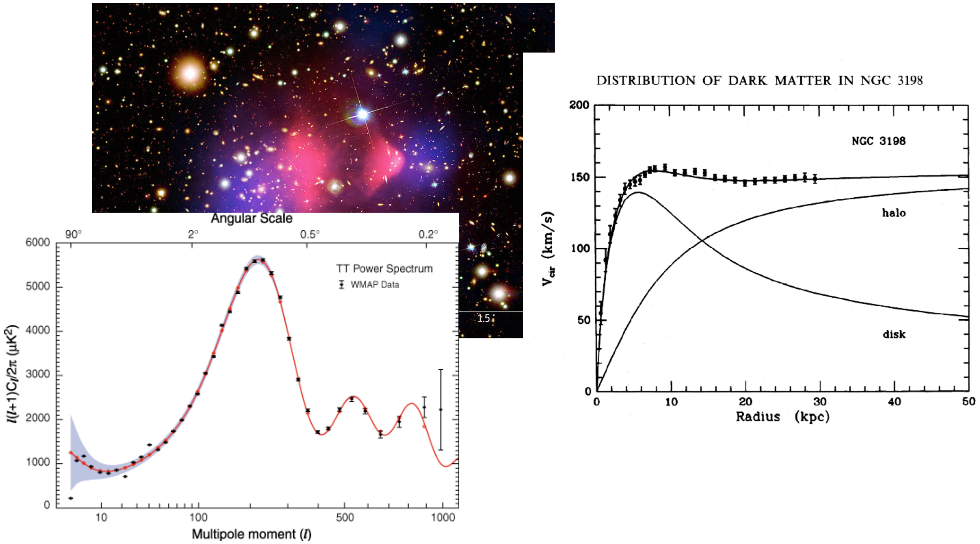

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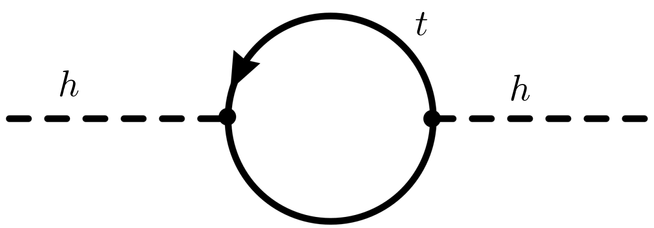

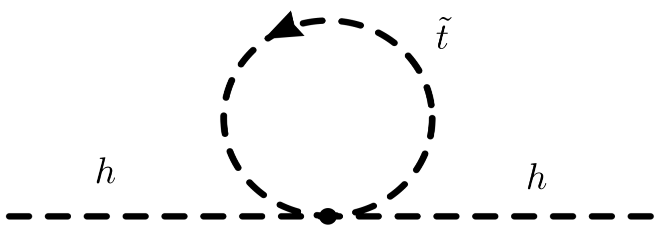

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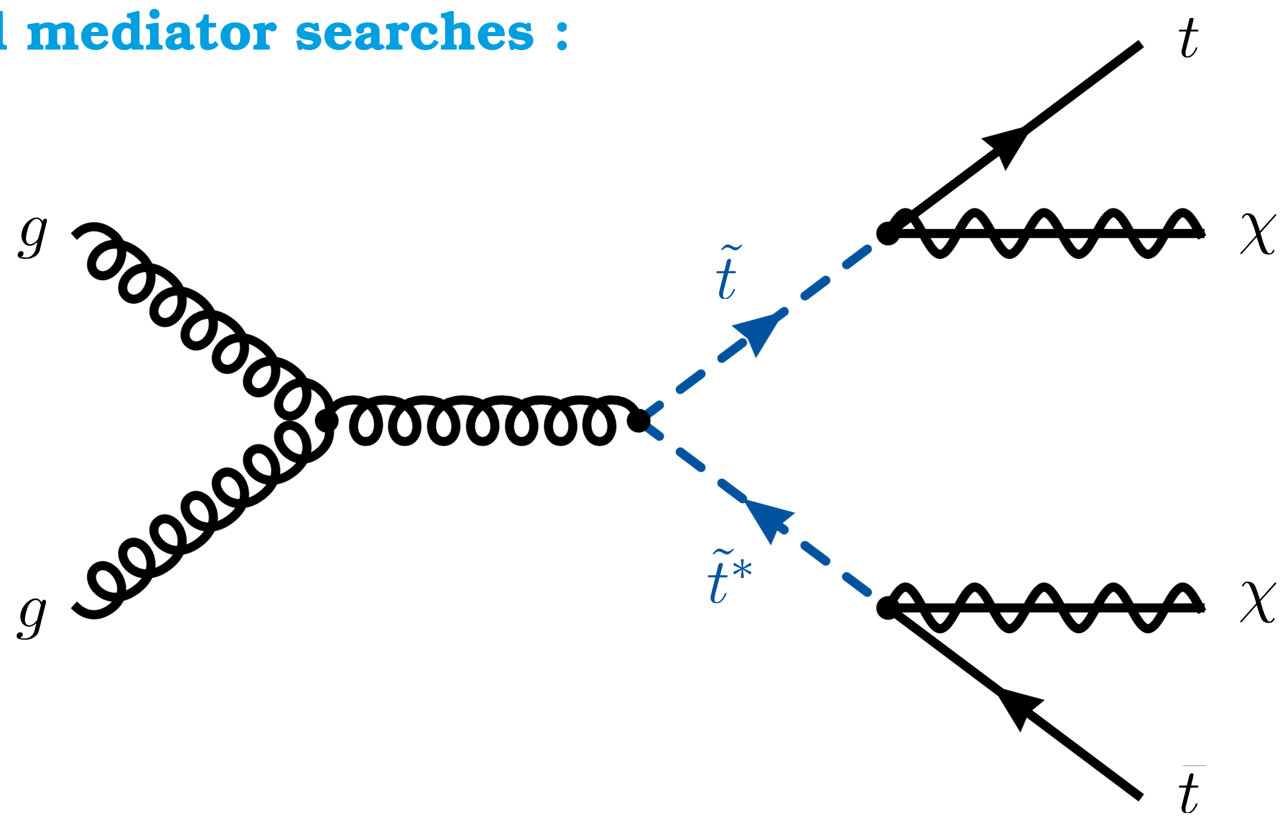
Existing searches at the LHC

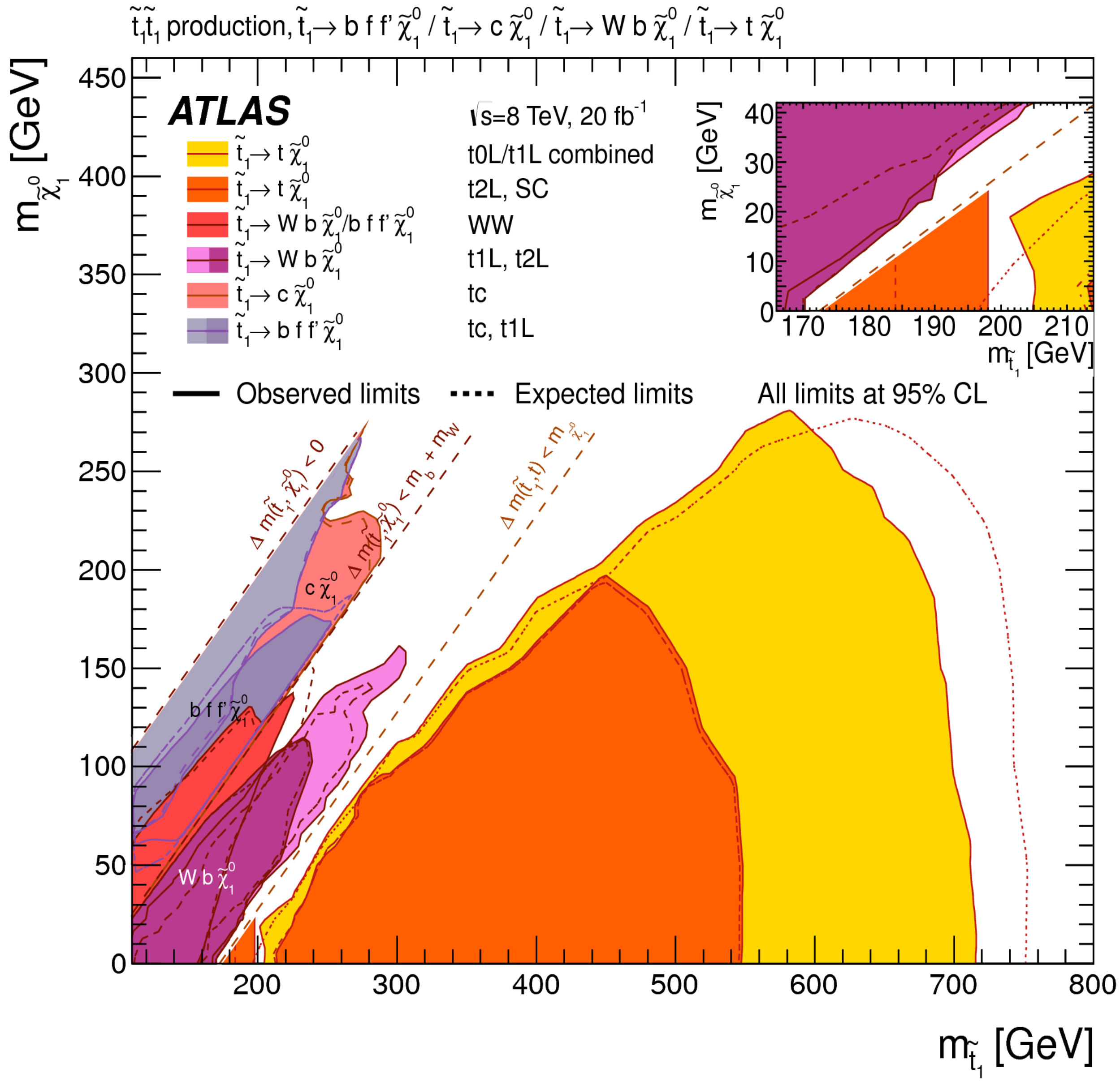
Existing searches at the LHC utilize the production of stop pairs

ATLAS @ arXiv:1506.08616, CMS @ arXiv:1603.00765

Standard mediator searches :

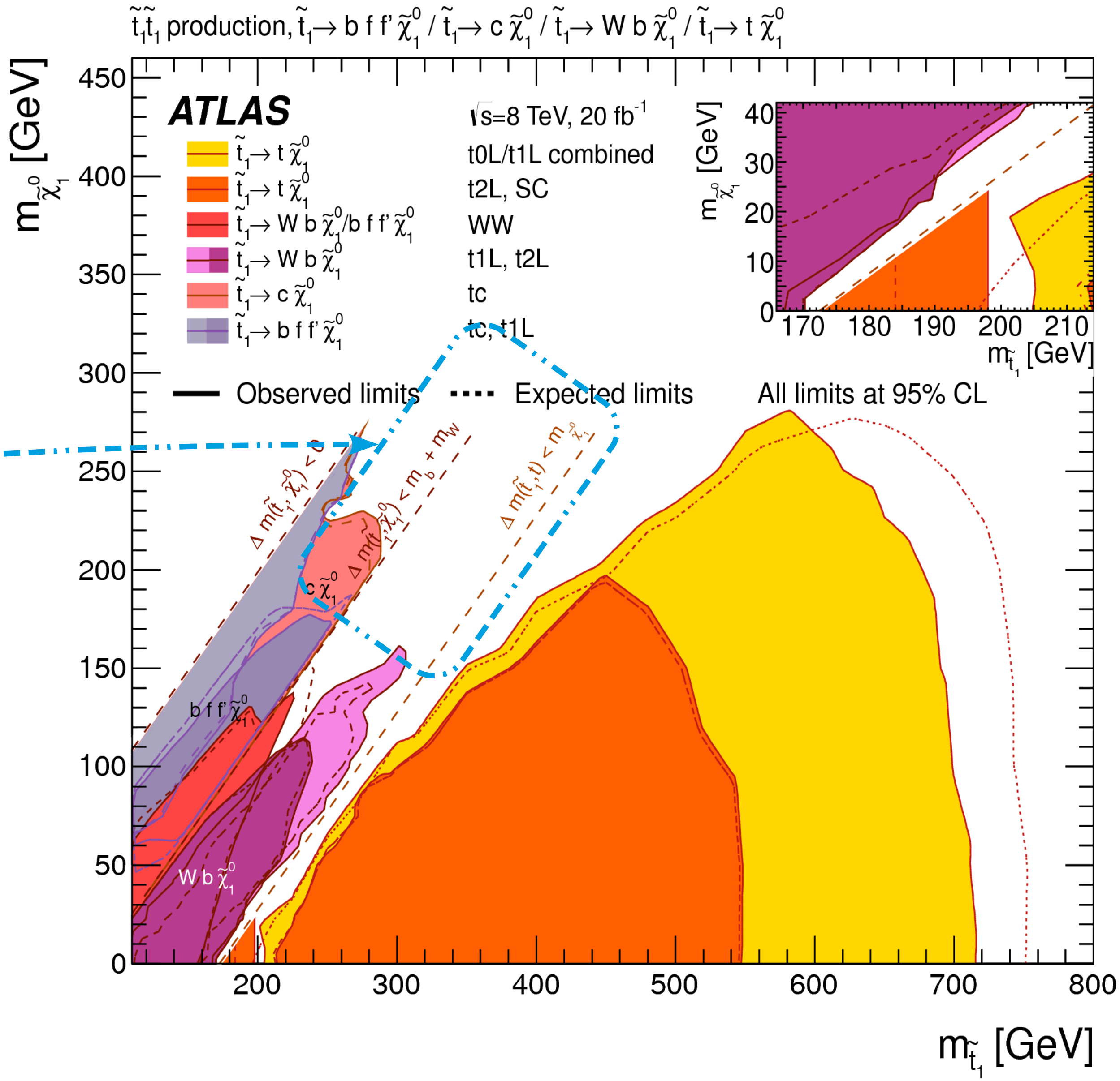


2015



t̃1t̃1 production, t̃1→ b f f' χ̃10 / t̃1→ c χ̃10 / t̃1→ W b χ̃10 / t̃1→ t χ̃10
ATLAS
√s=8 TeV, 20 fb-1
t̃1→ t χ̃10 t0L/t1L combined
t̃1→ t χ̃10 t2L, SC
t̃1→ W b χ̃10/b f f' χ̃10 WW
t̃1→ W b χ̃10 t1L, t2L
t̃1→ c χ̃10 tc
t̃1→ b f f' χ̃10 tc, t1L
Observed limits
Expected limits
All limits at 95% CL
Δ m(t̃1, χ̃10) < 0
Δ m(t̃1, χ̃10) < mb + mW
Δ m(t̃1, t) < mχ̃10
c χ̃10
b f f' χ̃10
W b χ̃10
mχ̃10 [GeV]
mt̃1 [GeV]

2015

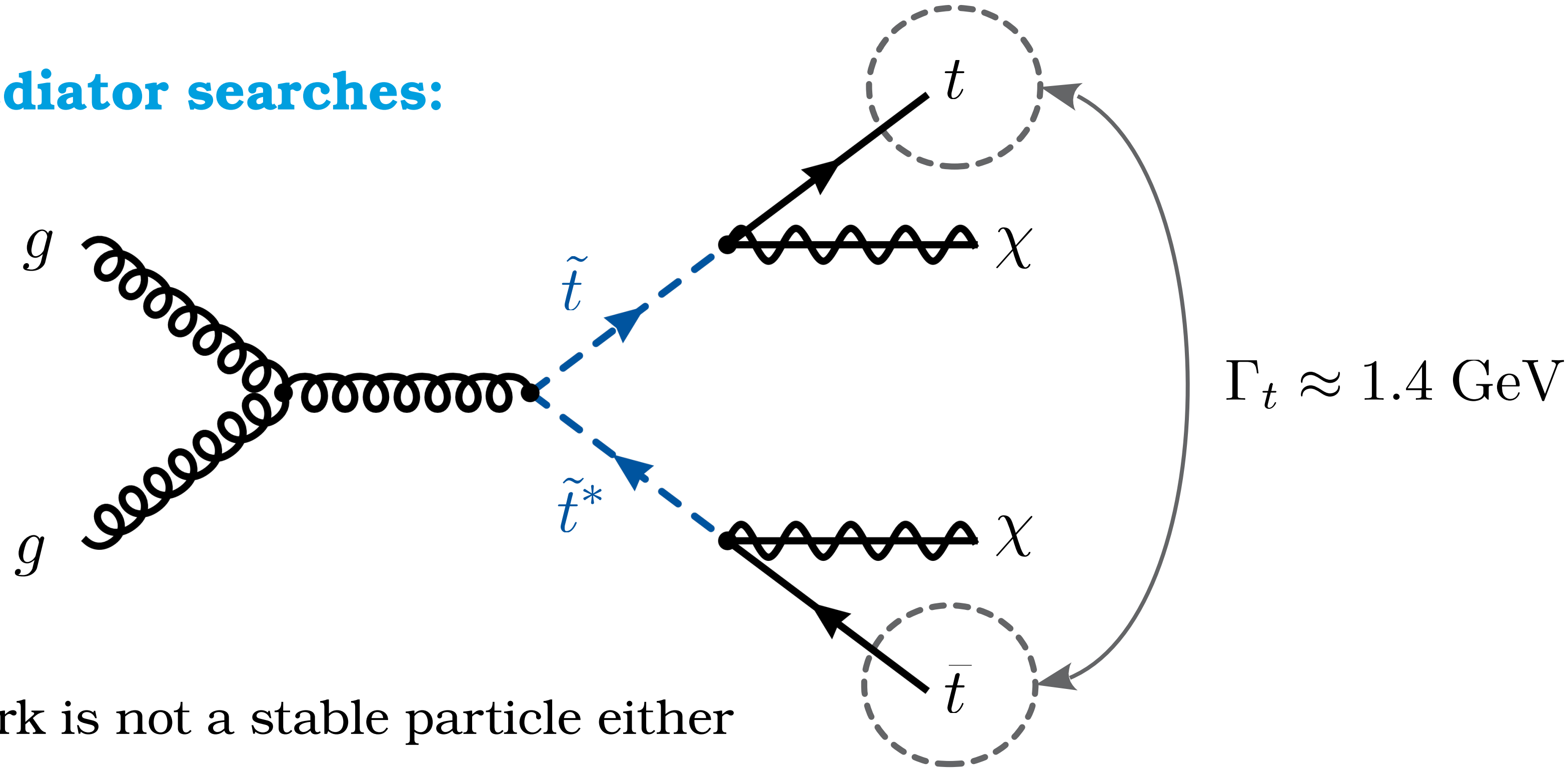


$$\Delta m(\tilde{t}, \chi) \simeq m_W + m_b$$

$$\Delta m(\tilde{t}, \chi) \simeq m_t$$

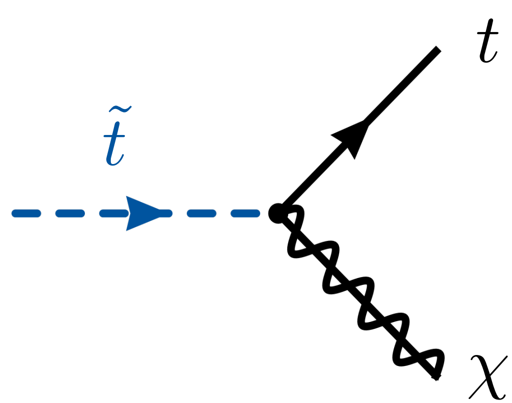
?

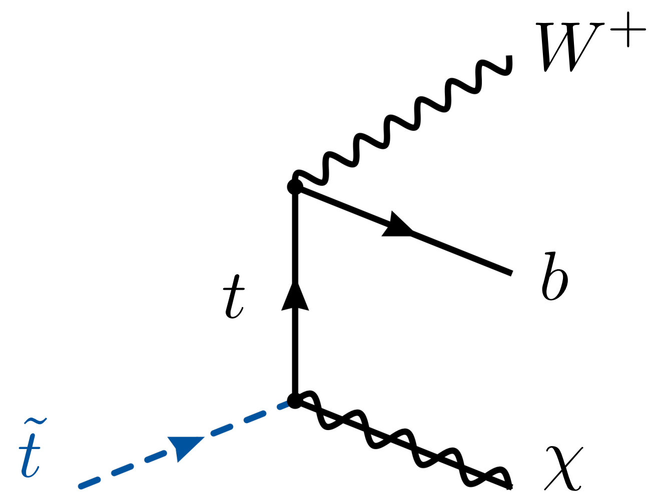
Standard mediator searches:



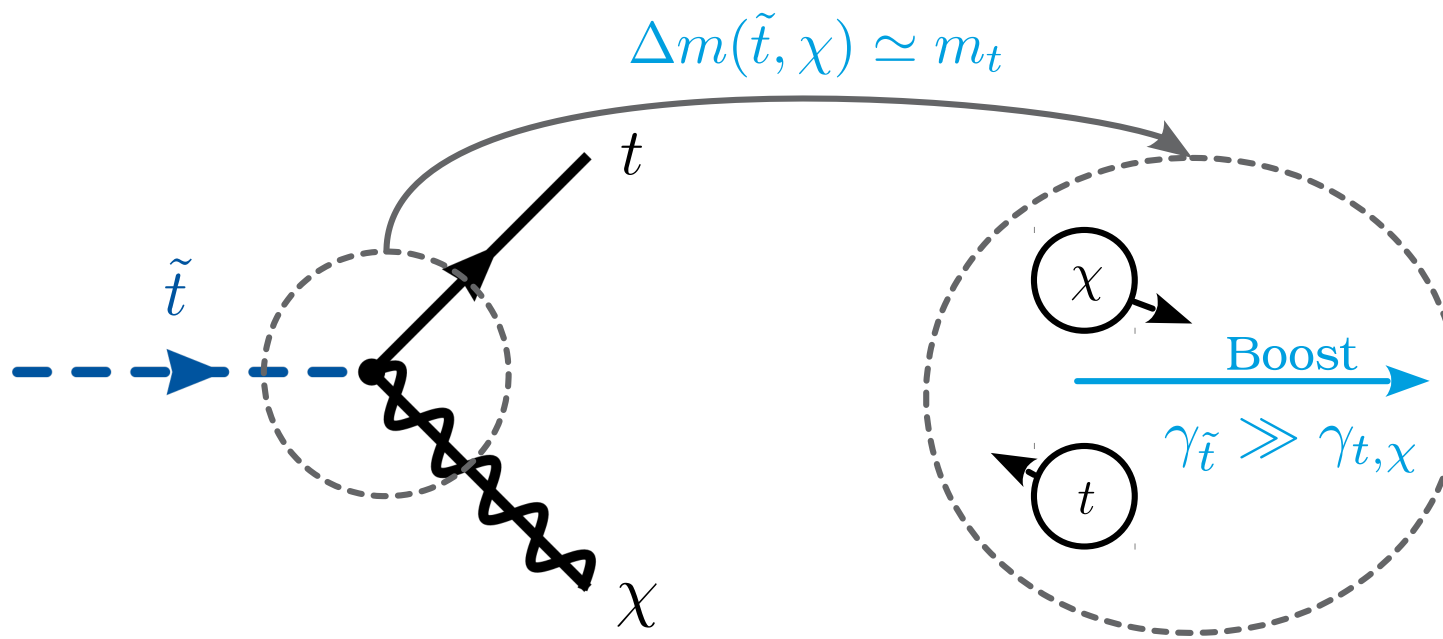
- The top quark is not a stable particle either

  → Might be on- / off-shell depending on the mass configuration





Kinematics in the compressed region (on-shell top)



$$p(\chi)_{\mathrm{RF}} = \begin{pmatrix} m_\chi \\ \vec{0} \end{pmatrix} \underbrace{\rightarrow}_{\text{Boost}} \begin{pmatrix} m_\chi \gamma_{\tilde{t}} \\ m_\chi \gamma_{\tilde{t}} \vec{\beta}_{\tilde{t}} \end{pmatrix}$$

$$p(t)_{\mathrm{RF}} = \begin{pmatrix} m_t \\ \vec{0} \end{pmatrix} \underbrace{\rightarrow}_{\text{Boost}} \begin{pmatrix} m_t \gamma_{\tilde{t}} \\ m_t \gamma_{\tilde{t}} \vec{\beta}_{\tilde{t}} \end{pmatrix}$$

$$\Rightarrow \quad \boxed{\frac{\vec{p}(t)_{\mathrm{LF}}}{m_t} = \frac{\vec{p}(\chi)_{\mathrm{LF}}}{m_\chi}}$$

Parallel alignment!

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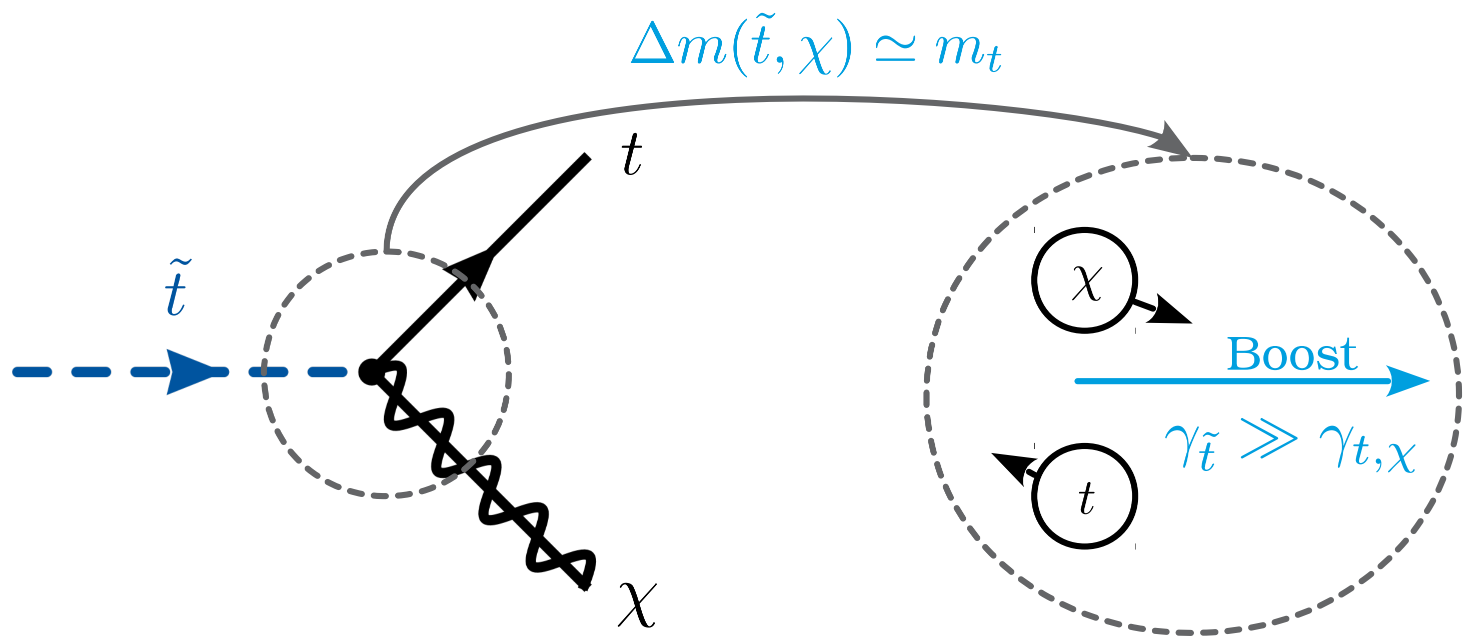

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Kinematics at the detector level : $pp \to \tilde{t}\,\tilde{t}^* \to t\,\bar{t}\,\chi\,\chi$

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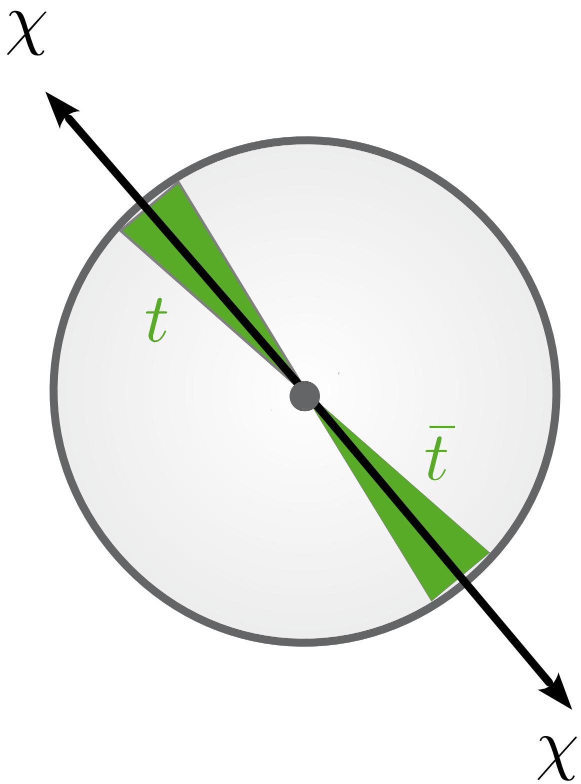
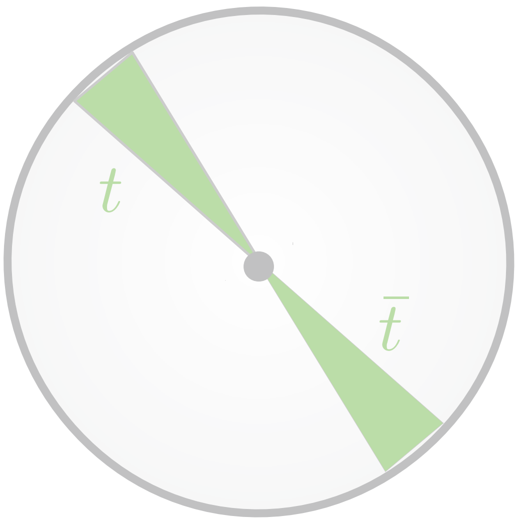


Looks just like
$pp \to t\,\bar{t}$
MET $\simeq 0$



No experimental difference to top pair production for
$\Delta m(\tilde{t}, \chi) \simeq m_t$

Experimental difficulties in the compressed region

Kinematics at the detector level : $pp \to \tilde{t}\,\tilde{t}^* \to t\,\bar{t}\,\chi\,\chi$

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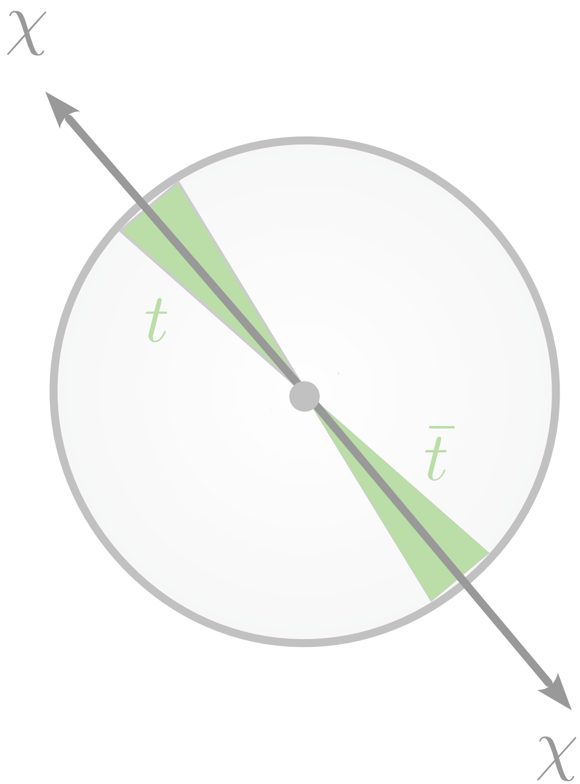

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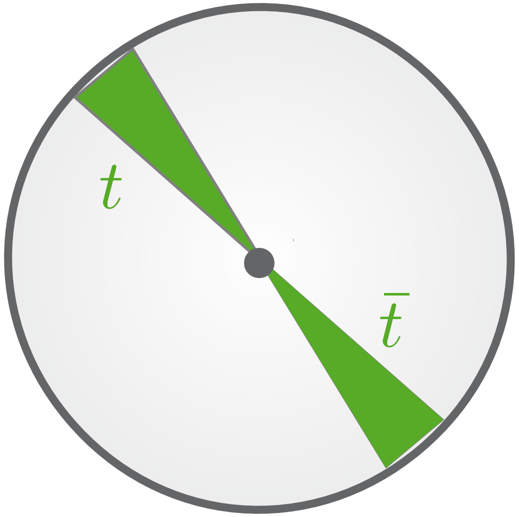
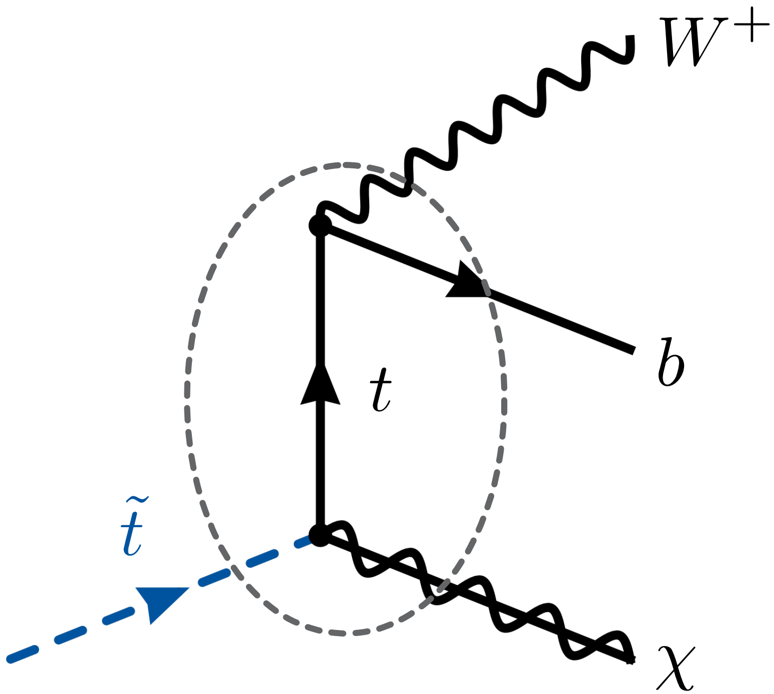


➡ No experimental difference to top pair production for

$\Delta m(\tilde{t}, \chi) \simeq m_t$

Kinematics in the compressed region (off-shell top) :



Similar result :

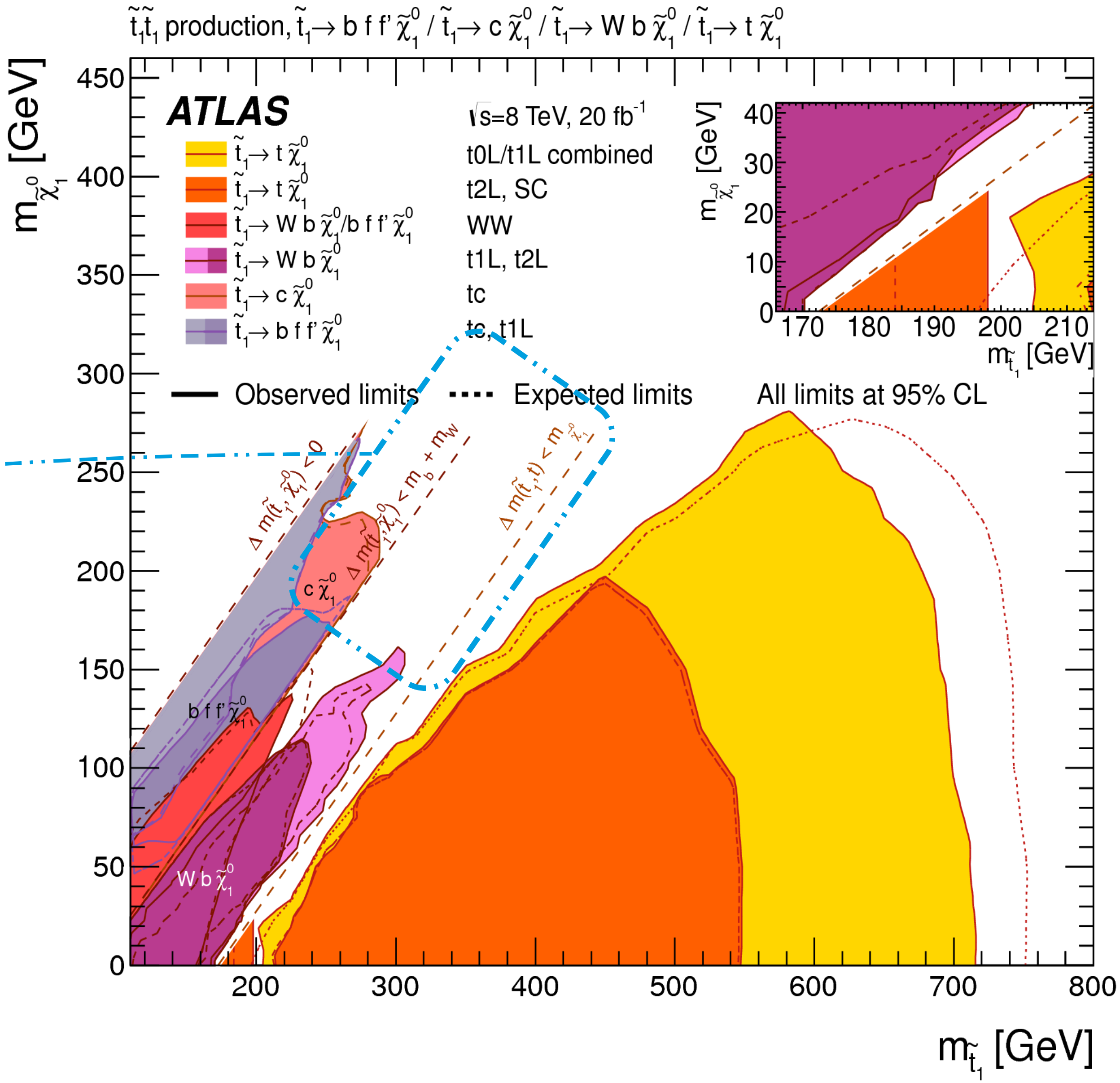
$$\frac{\vec{p}(W)_{\mathrm{LF}}}{m_W} = \frac{\vec{p}(b)_{\mathrm{LF}}}{m_b} = \frac{\vec{p}(\chi)_{\mathrm{LF}}}{m_\chi}$$

Parallel alignment!

No experimental difference to top pair production for

$$\Delta m(\tilde{t}, \chi) \simeq m_W + m_b$$

2015



$$\Delta m(\tilde{t}, \chi) \simeq m_W + m_b$$

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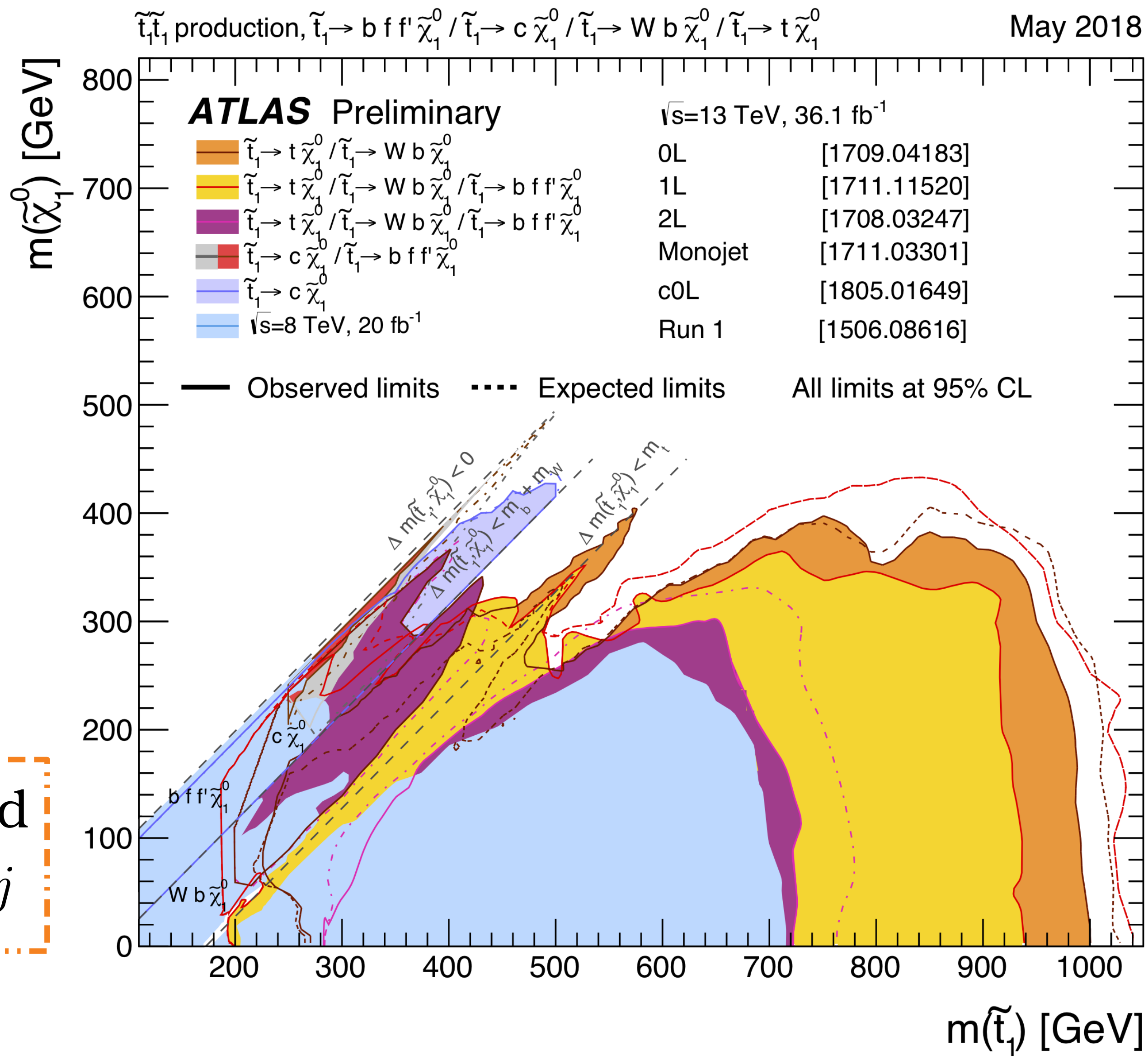
?

2018

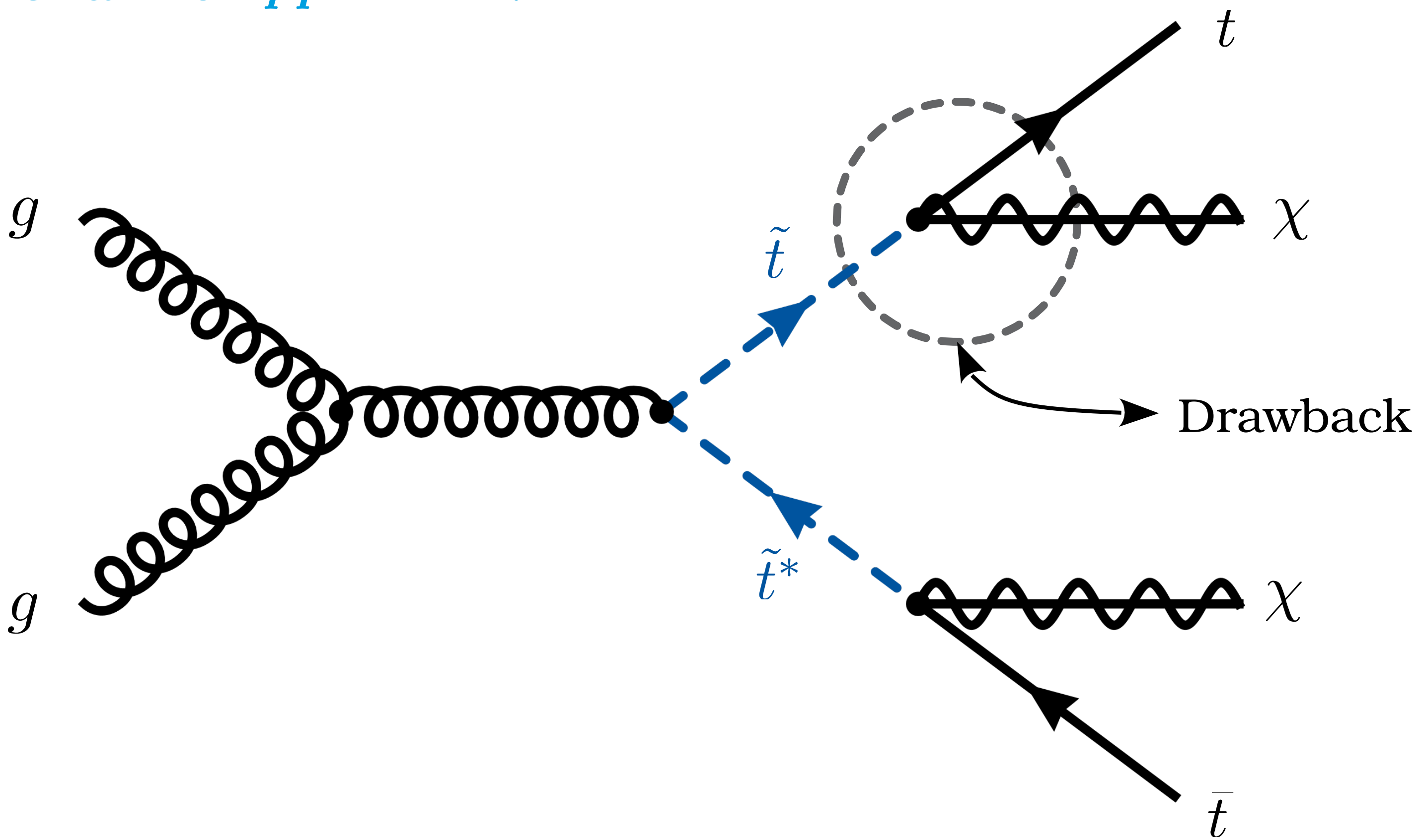


New method:

Probe the compressed region via $pp \to \tilde{t}\tilde{t}^* + j$

Probing the compressed region in $pp \to \tilde{t}\tilde{t}^* j$

Search channel $pp \to \tilde{t}\tilde{t}^*$:



Loophole: Enrich the kinematics by an additional (hard) jet

$\to$ Take advantage of the disadvantage (arXiv:1506.00653)

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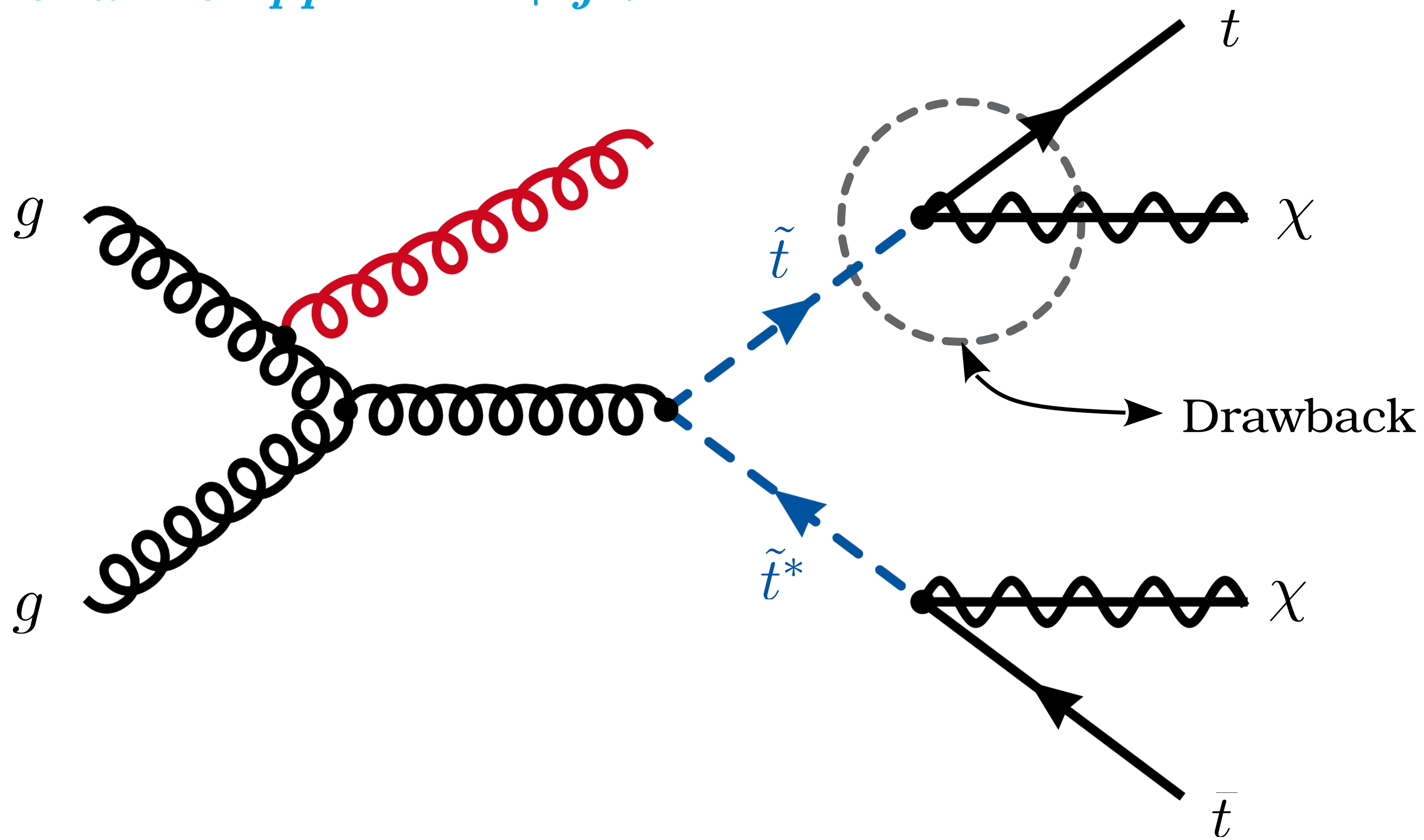

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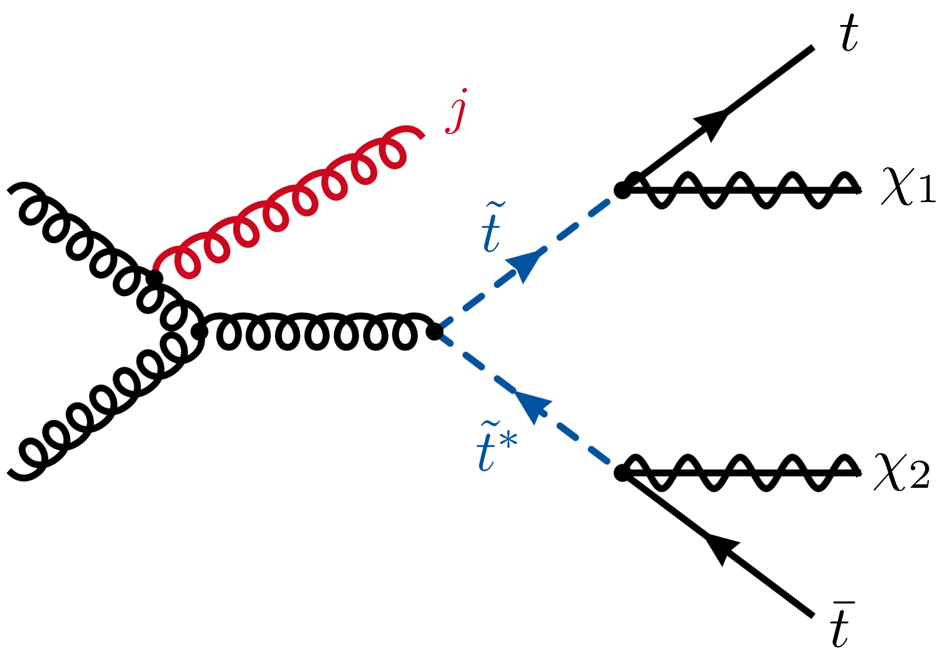
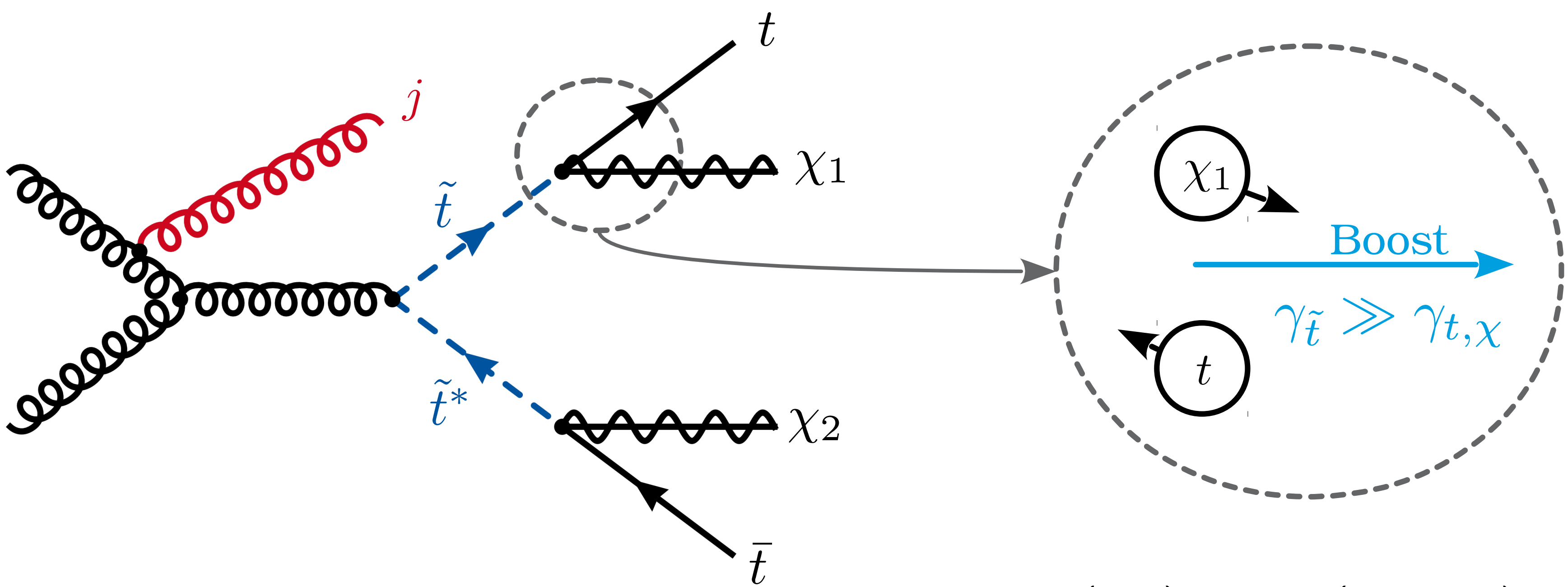


$$-\vec{p}_T(j) = \underbrace{\vec{p}_T(\tilde{t}) + \vec{p}_T(\tilde{t}^*)}_{\text{momentum conservation}}$$

$$\begin{aligned} \vec{p}_{T,\text{miss}} &= \vec{p}_T(\chi_1) + \vec{p}_T(\chi_2) \\ &= \frac{m_\chi}{m_{\tilde{t}}} \left(\vec{p}_T(\tilde{t}) + \vec{p}_T(\tilde{t}^*) \right) \end{aligned} \quad \Rightarrow \quad \boxed{R_M \equiv \frac{|\vec{p}_{T,\text{miss}}|}{|\vec{p}_T(j)|} \simeq \frac{m_\chi}{m_{\tilde{t}}}}$$



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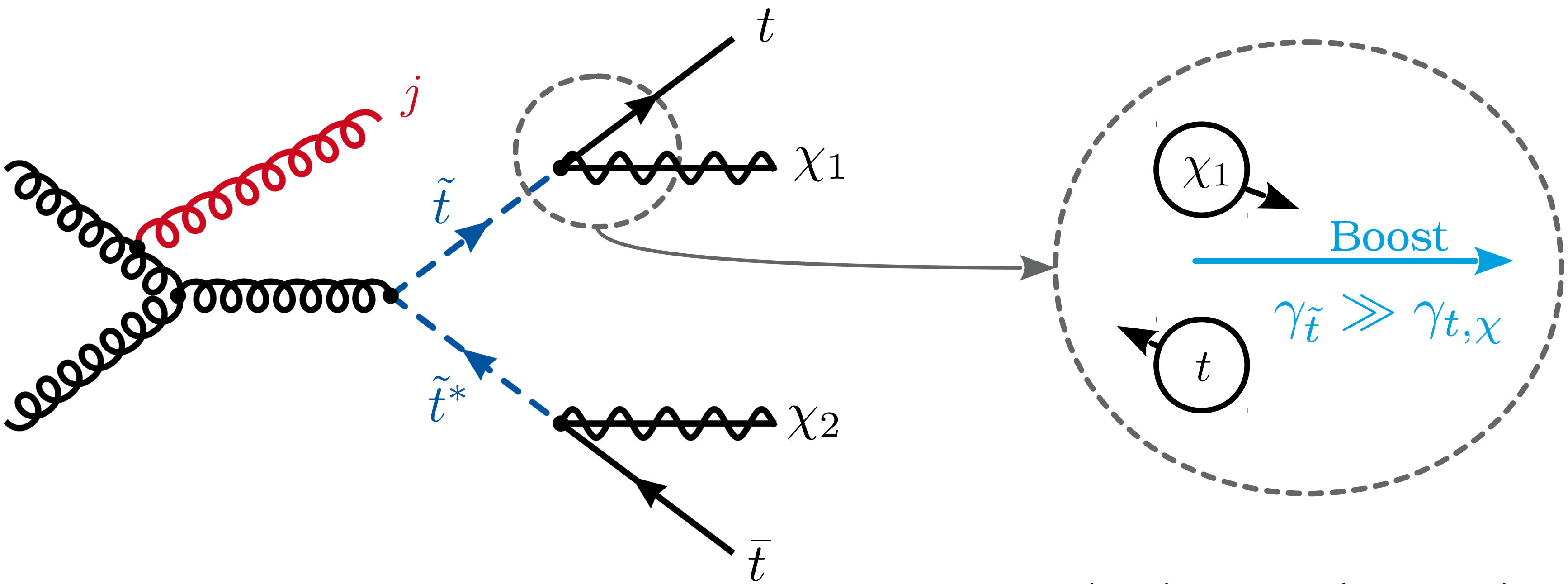

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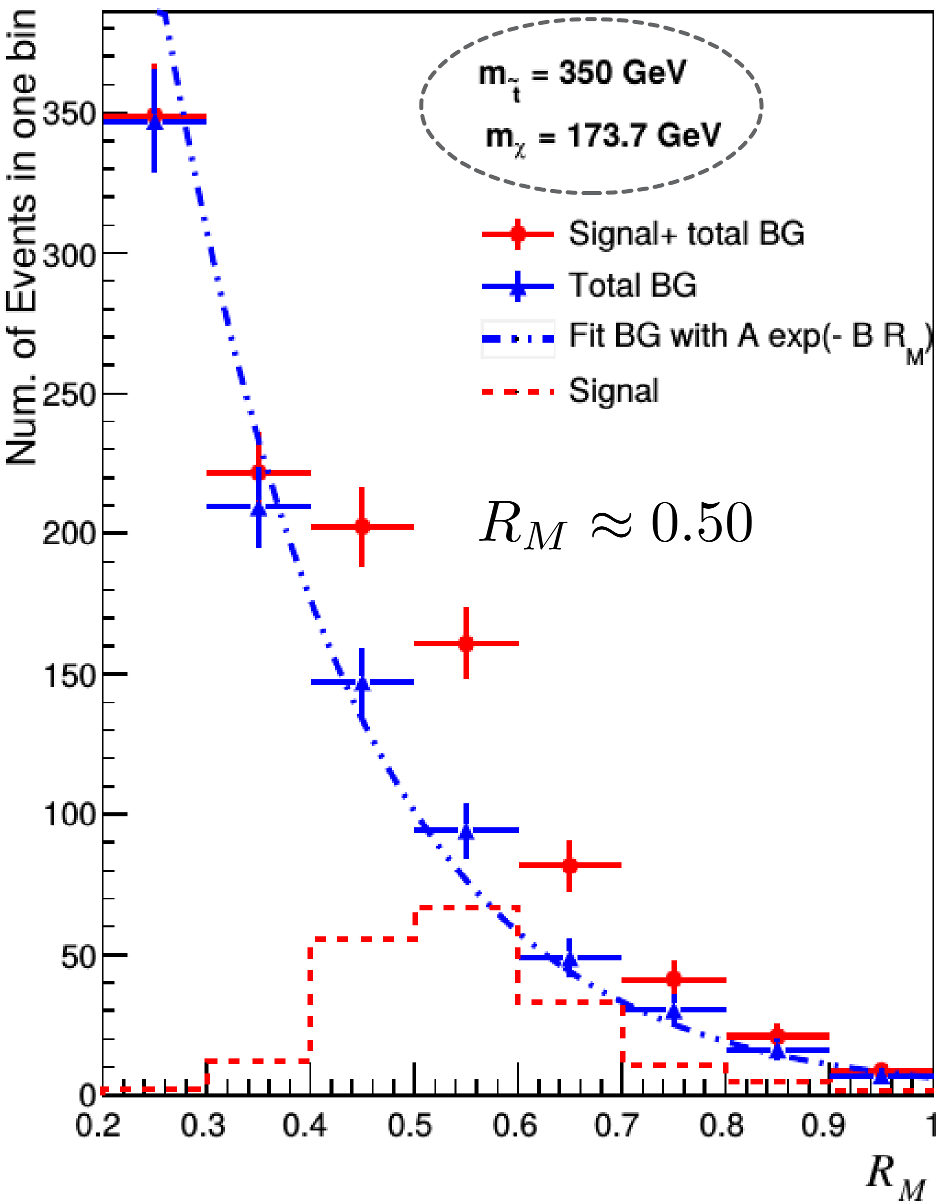


Background :

$t\bar{t}$ with hard ISR jet

QCD multijet

$W + j$, $Z + j$, single top

Detector-level cuts :

N_{jets}	≥ 4
$p_T(j_1)$	> 700 GeV
N_e, N_μ	$= 0$
$p_T(j_{2..4})$	> 60 GeV
$\lvert\phi(j_1) - \phi_{\text{MET}} - \pi\rvert$	< 0.15
$\lvert\phi_{\text{MET}} - \phi(j_{2..4})\rvert$	> 0.2
$N_{\text{b-tags}}$	$\neq 0$
j_1:b-tag	= False

→ The peak-like structure of the signal results in a clear excess

Exclusion/Discovery limits have already been calculated

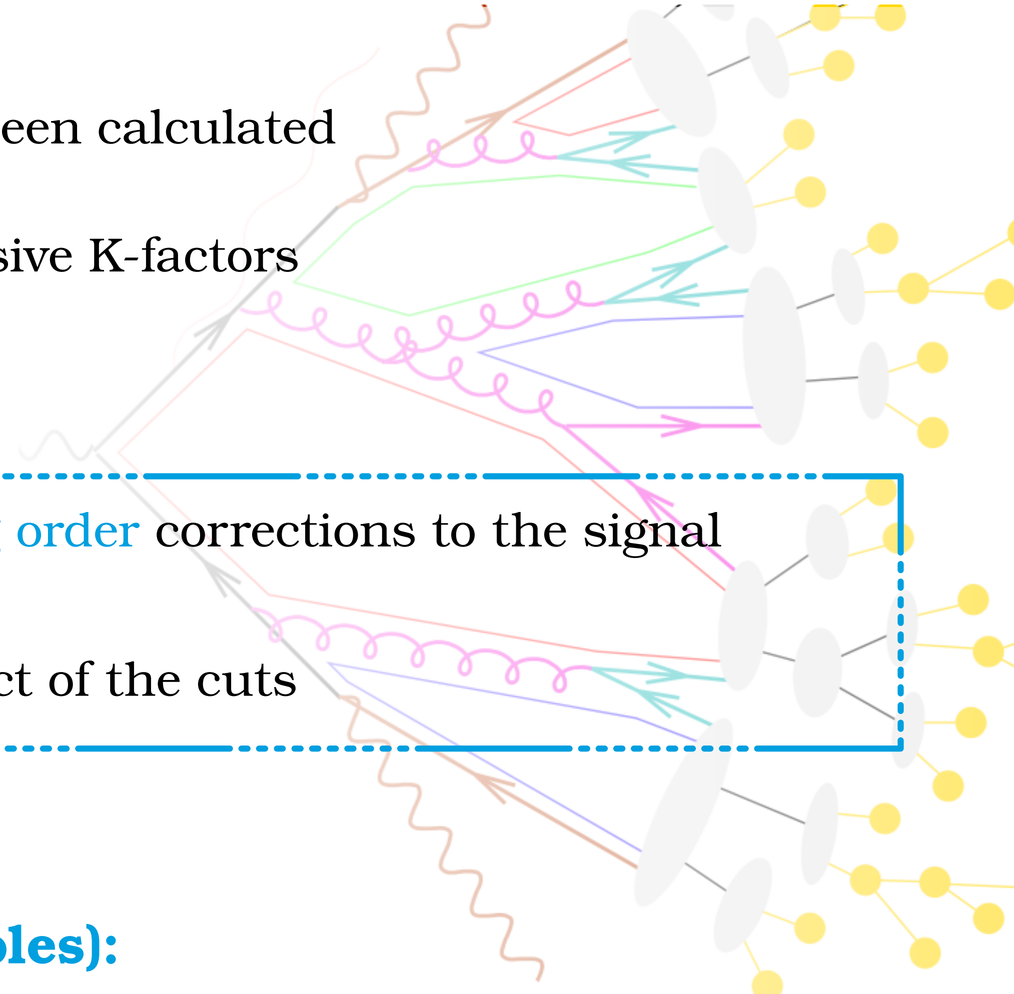
However: Only at leading order with inclusive K-factors

Aim:

Investigate the effects of next-to-leading order corrections to the signal distributions

→ Especially analyze the effect of the cuts

Shortcomings of the analysis



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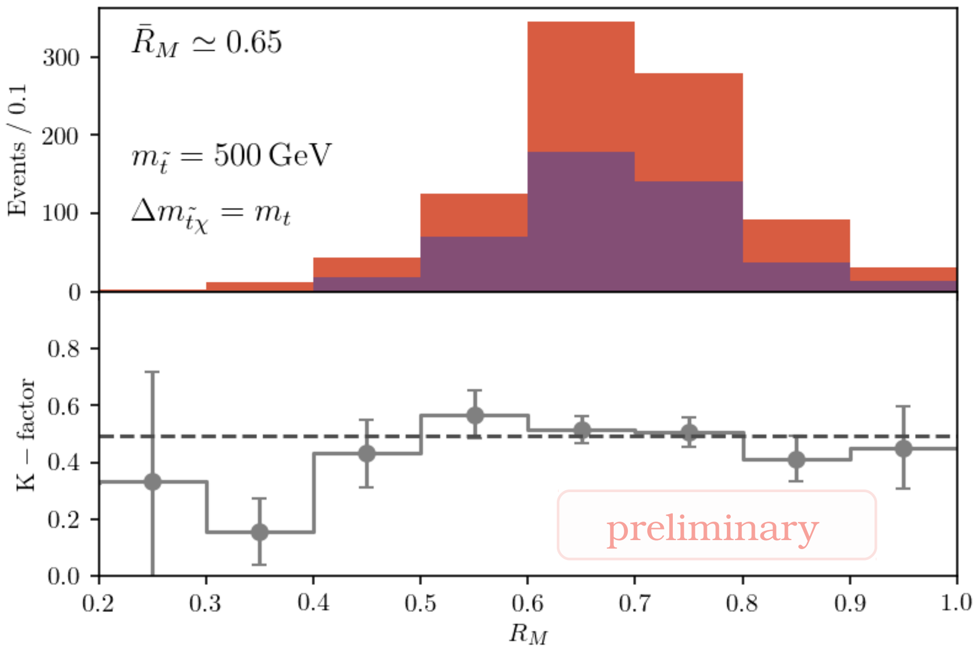
Event generation (Monte Carlo samples):

MadGraph5_aMC $\rightarrow$ MadSpin $\rightarrow$ Pythia8 $\rightarrow$ Delphes3

Effects of NLO corrections



- NLO distribution does not seem to exhibit any new physical features
  → Cross-section seems to be scalable by a global K-factor

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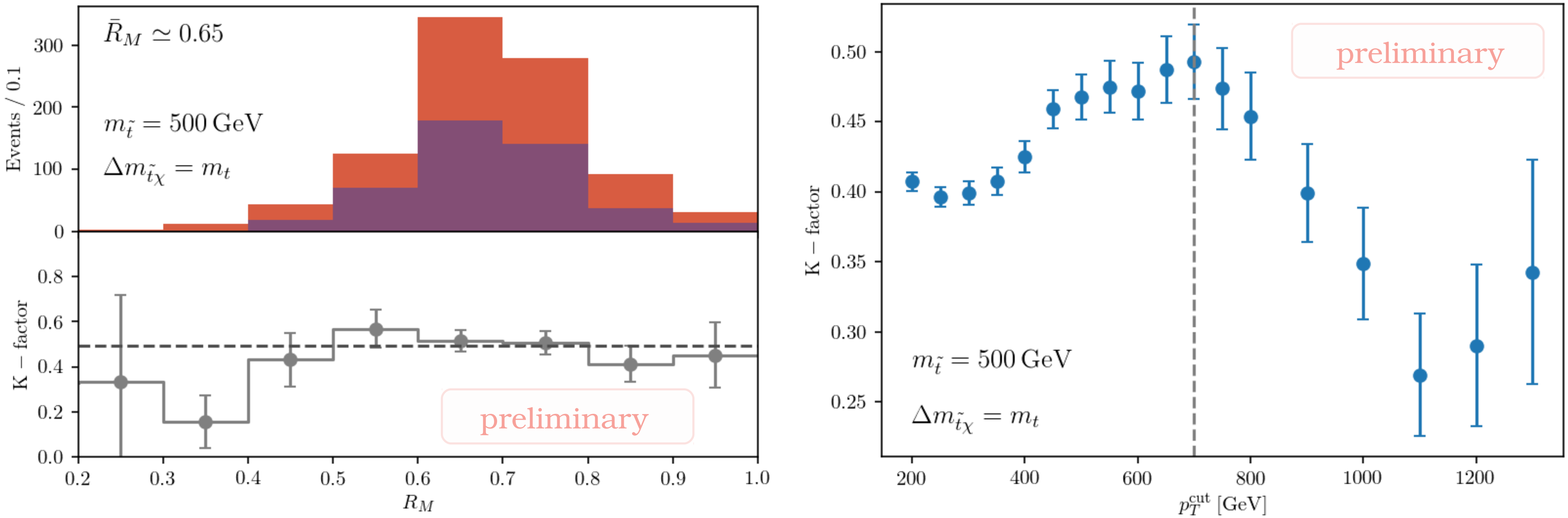
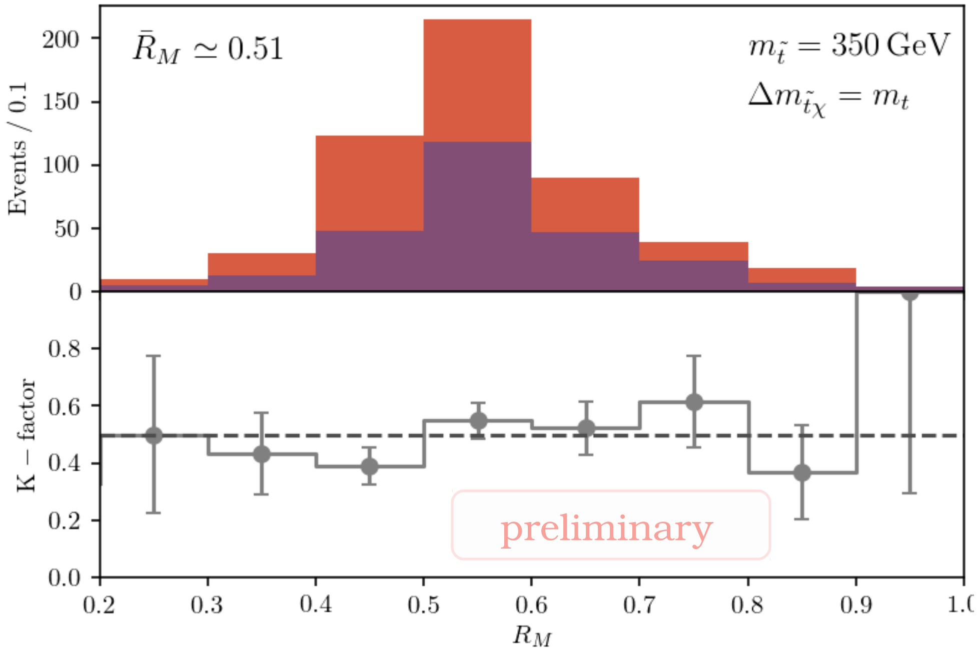
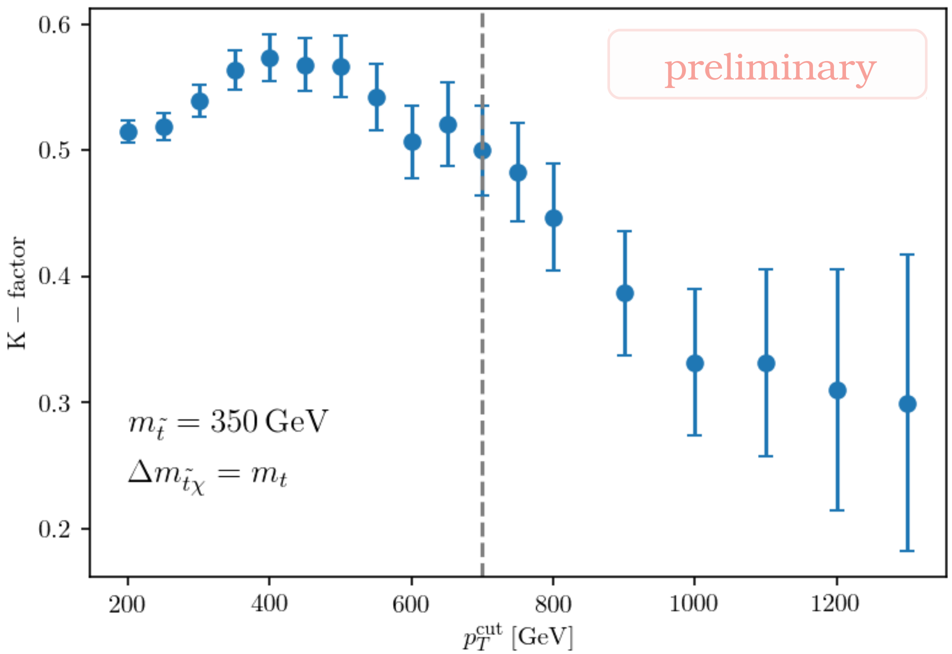


- NLO distribution does not seem to exhibit any new physical features
  $\rightarrow$ Cross-section seems to be scalable by a global K-factor ✔

- However: The K-factor depends on the exact nature of the cut, p_T^{cut}

Effects of NLO corrections

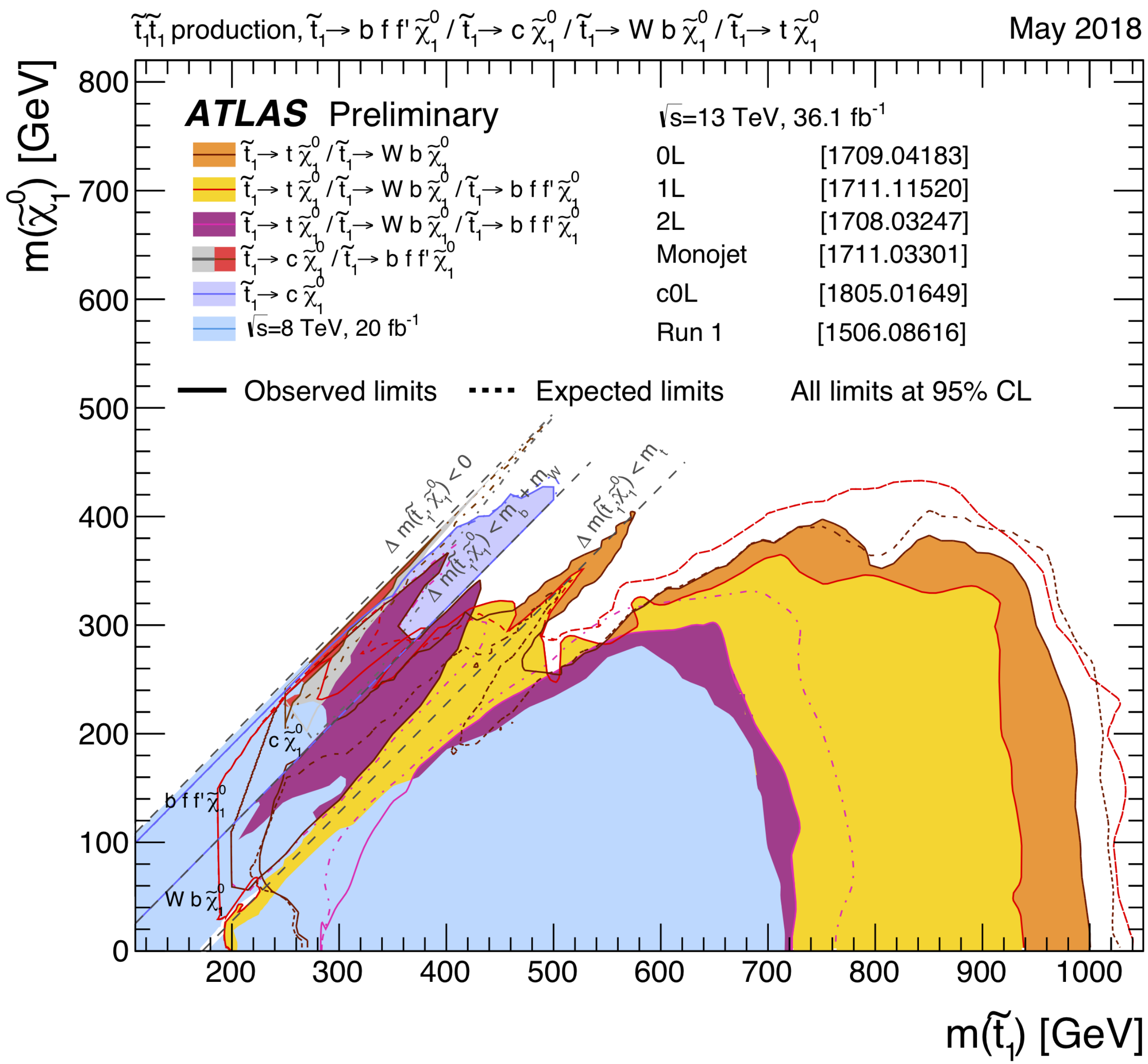




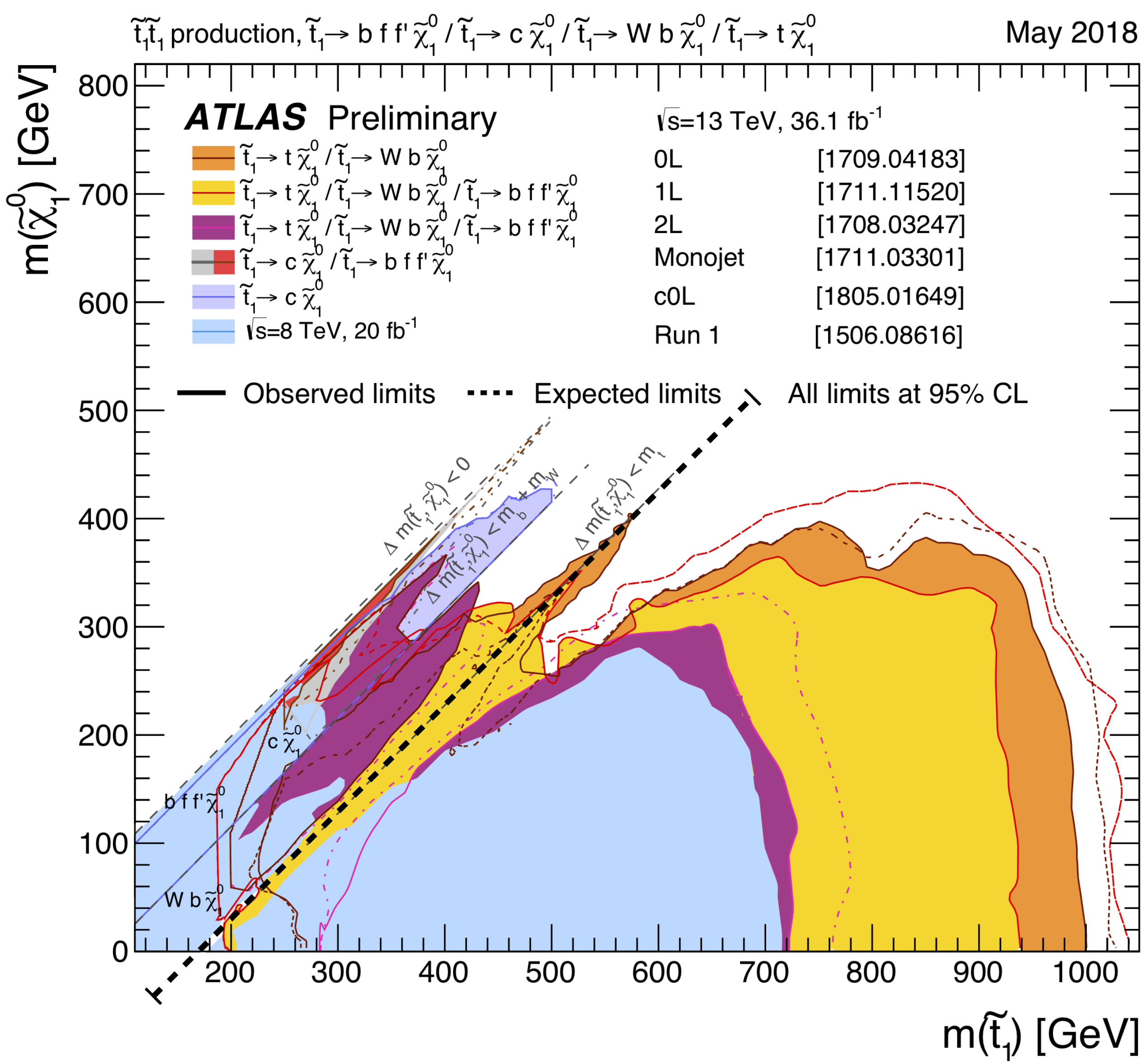
- NLO distribution does not seem to exhibit any new physical features
  → Cross-section seems to be scalable by a global K-factor ✔

- However: The K-factor depends on the exact nature of the cut, p_T^{cut}

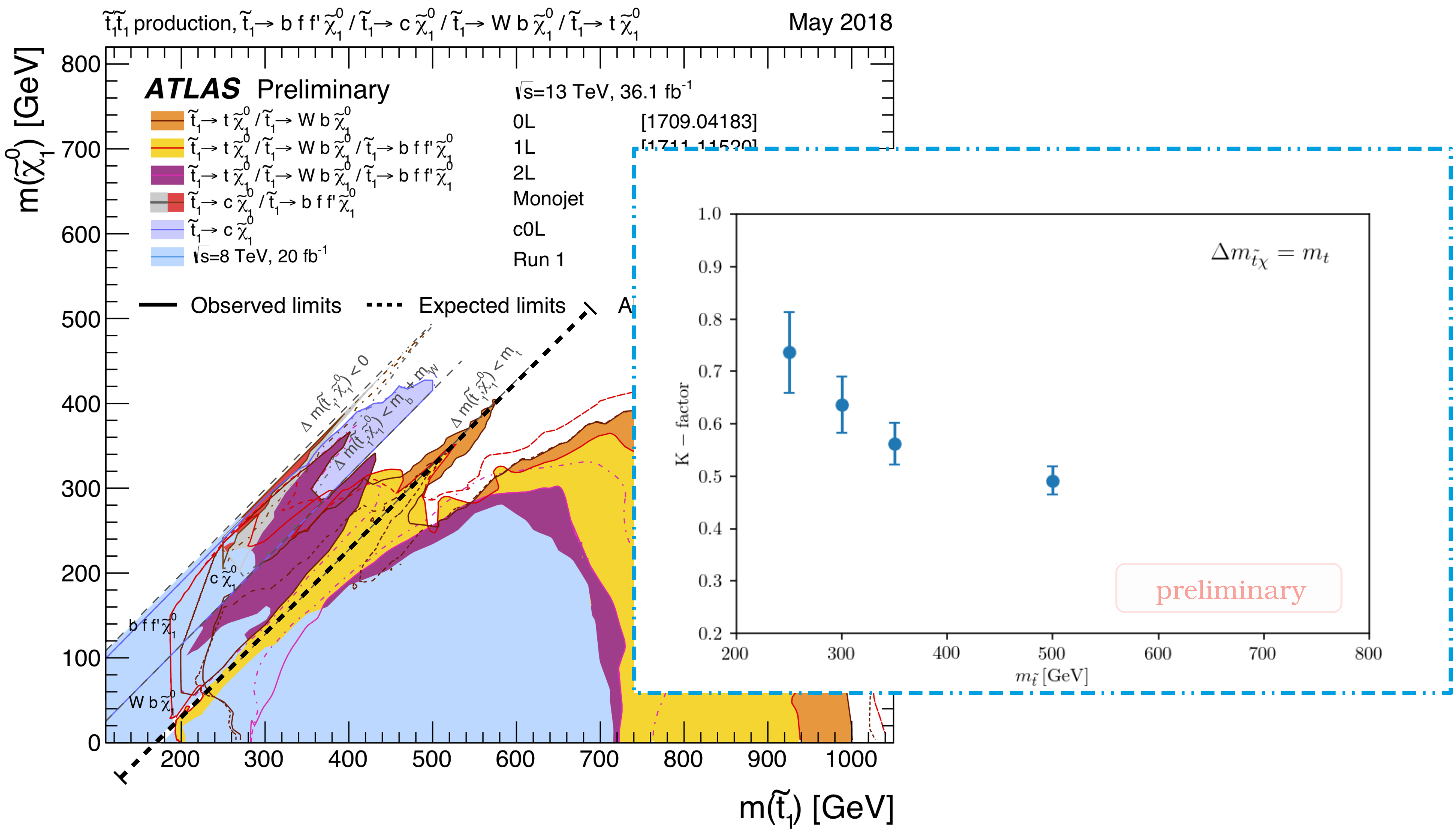
Effects of NLO corrections



Effects of NLO corrections



Effects of NLO corrections



Conclusions

- Using new techniques it has been possible to completely close the compressed region of stop searches
- However: The current limits are sensitive to the exact nature of the cuts → More detailed analysis needed

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Thank you for your attention!