Search for multijet resonances of stop production via RPV couplings

– a search for the needle in the jetstack –

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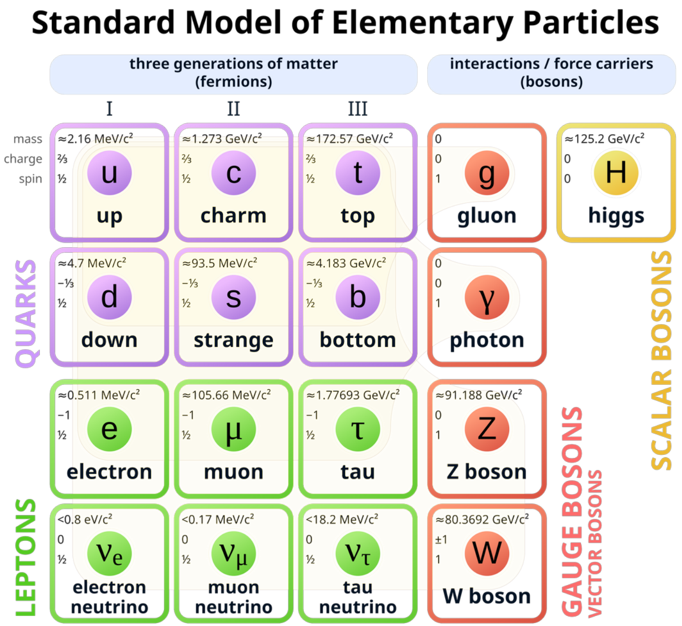
Introduction

The Standard Model (SM) of particle physics

- Our current best (proven) understanding of particle physics
- Formulated to explain discoveries from the 1950-1970s
- Current form since ~1975
- Incredibly successful
  → predicted undiscovered particles
  - top quark (1995, Tevatron)
  - τ neutrino (2000, Tevatron)
  - Higgs boson (2012, LHC)

  → predictions of many parameters are in strong agreement with reality
- 2 families of fermionic matter particles *(quarks, leptons)*, with 3 generations each
- 5 bosonic force carriers that mediate the 3 fundamental interactions *(QED, EW, QCD)*



Problems of the SM

- Despite its success, SM has certain shortcomings:
  - gravitation (no inclusion of General Relativity)
  - no dark-matter candidate
  - no full explanation of matter-antimatter asymmetry
  - hierarchy problem, “naturalness”

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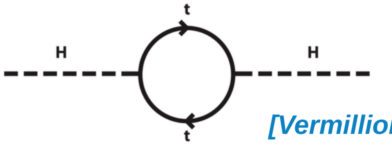
Hierarchy problem

- Higgs potential: $V = \frac{1}{2}\mu^2 \left|\Phi^2\right| + \lambda \left|\Phi^2\right|$
- ½ μ^2 is effectively the Higgs mass squared
- 1-loop corrections already large and depend on square of scale:

$$\mu^2 = \mu^2_{\mathrm{bare}} + \underbrace{\frac{3y_{\mathrm{t}}^2}{8\pi^2}\Lambda^2}_{\gg(\mathcal{O}(100)\ \mathrm{GeV})^2} - \dots$$



[*VermillionBird* (modified), source]

Supersymmetry (SUSY)

- SM particles get superpartners that differ in spin by ½
- New quantity: R-parity
  - +1 for SM particles
  - –1 for superpartners
  - can be conserved or violated (depending on model)

Spin	Standard Model	Superpartner	Spin
1/2	Leptons (e, n_e, …) Quarks (u, d, …)	Sleptons ($\tilde{e}$, $\tilde{n}_e$, …) Squarks ($\tilde{u}$, $\tilde{d}$, …)	0
1	Gluons (g) $W^\pm$ Z^0 Photons (g)	Gluinos ($\tilde{g}$) Wino Zino Photino ($\tilde{g}$)	1/2
0	Higgs (2 Doublets)	Higgsinos	1/2
2	Graviton	Gravitino	3/2

[*J. Haller* (modified)]

symmetry broken
→ mix to form new mass eigenstates

Mixing of gauge eigenstates in SUSY

One note on mixing:

- in SM:
  - mixing between gauge eigenstates after EWSB: $W^1, W^2, W^3, B \longleftrightarrow W^+, W^-, Z, \gamma$
- in SUSY:
  - fermions have bosonic partners (scalars) → not spinors → no chirality
    - example: $t_L, t_R \longleftrightarrow \tilde{t}_L, \tilde{t}_R$
  - $\tilde{t}_L$ and $\tilde{t}_R$ have same quantum numbers → mixing
  - $\tilde{t}_L$ and $\tilde{t}_R$ mix to form mass eigenstates $\tilde{t}_1$ and $\tilde{t}_2$

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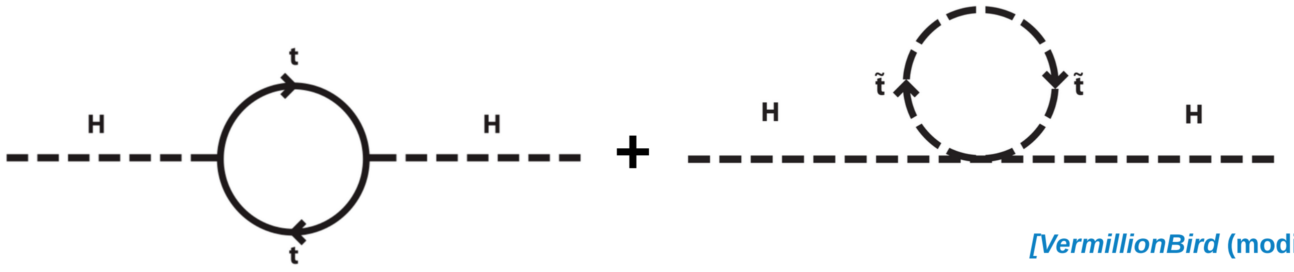
this study is interested in:
$\tilde{t}_1$ (stop), $\tilde{\chi}_1^0$ (neutralino), $\tilde{\chi}_1^+$ (chargino)

Supersymmetry – a solution?

- Consequences:
  - dark matter candidate in the neutralino-1 (often LSP[1])
  - could solve hierarchy problem because SUSY fermion-superpartner (bosons) loops cancel out SM-fermion loops

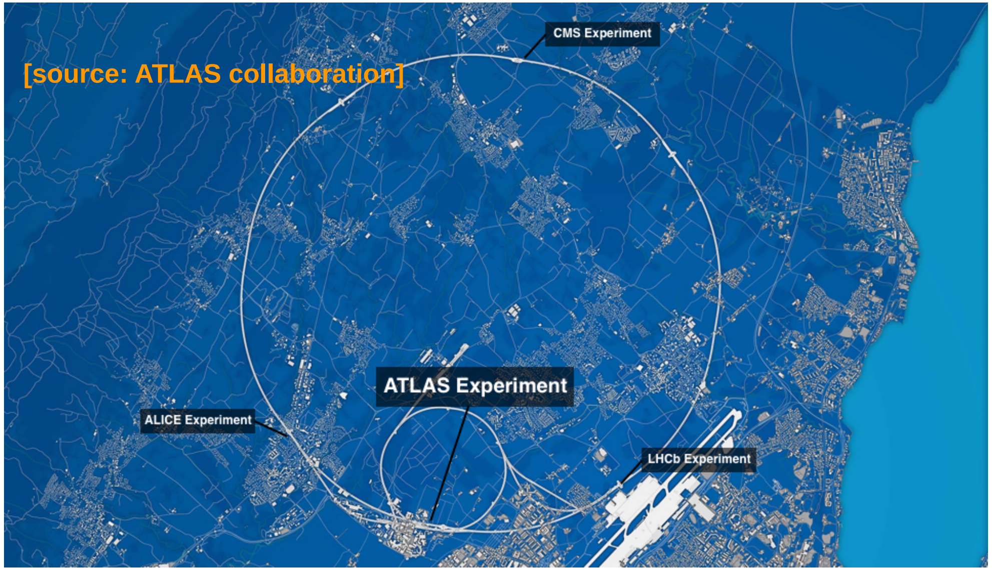


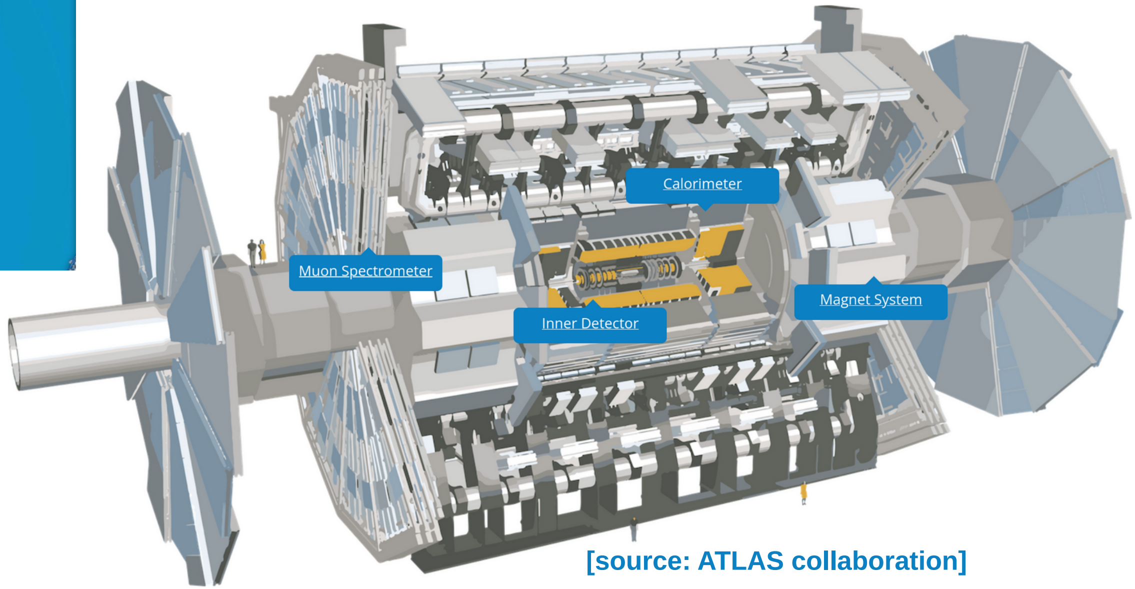
$= 0$ if $O(m_{stop}) = m_t$

[*VermillionBird* (modified), source]

[1]: LSP = lightest supersymmetric particle

The LHC and ATLAS



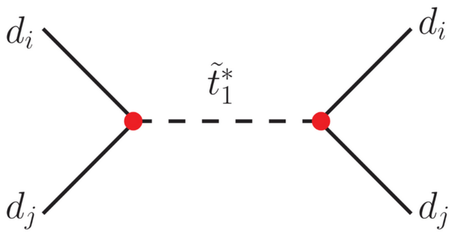


My Project

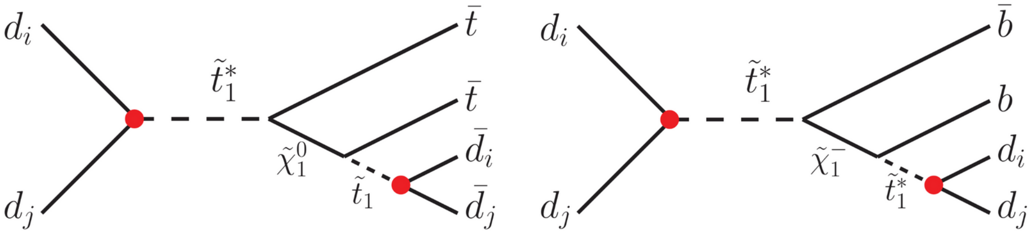
Stop production

Resonant production

2-quark final state



4-quark final states



•: R-parity violating vertex with operator

$$W_{\mathrm{BRPV}} = \frac{\lambda''_{ijk}}{2} \bar{U}_i \bar{D}_j \bar{D}_k$$

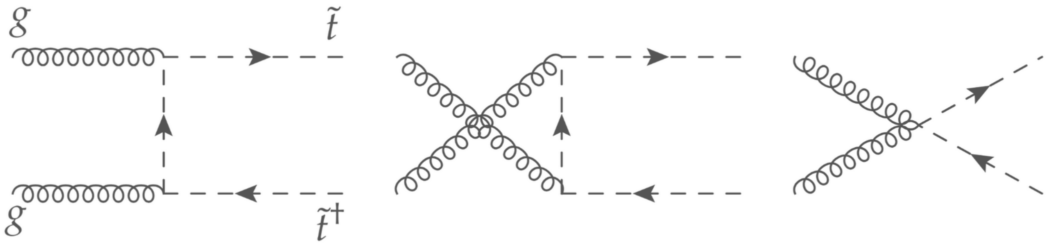
Indices i, j, k give the species of the quarks:

index	1	2	3
species	u/d	c/s	t/b

Only considering stop production:
→ $i = 3$

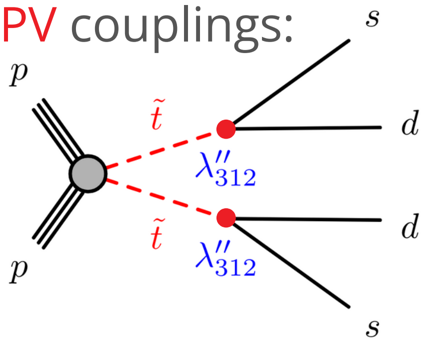
Stop-pair production

- R-parity conserving (RPC)
- Production mostly through QCD (quark/gluon annihilation or similar in the hard scattering)
- Production (at tree level), here example for gluon initial states:



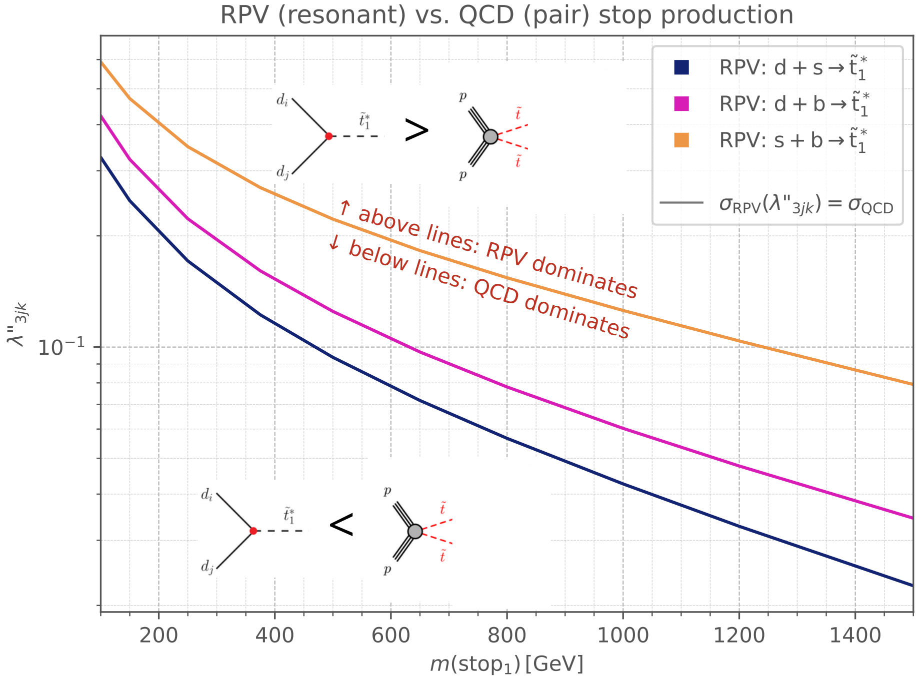
[1]

- Decay via RPV couplings:



[2]

Which process to study?



- Lines show the coupling, for which

$$\lambda^2 \times \sigma_{\mathrm{RPV}}(\lambda = 1.0) = \sigma_{\mathrm{QCD}}$$

- Production via QCD not affected by RPV coupling strength, since this is RPC
- Parameter space above lines of equality
  → RPV > RPC
- Parameter space below lines
  → RPC > RPV
- Production processes likely on par at the likely parameter space
- Production cross section similar
  → no advantage of only considering RPC production

- Also previous limits:
  - relatively strict limits for RPC production
  - limits looser for RPV
  - *(see backup if there is interest)*

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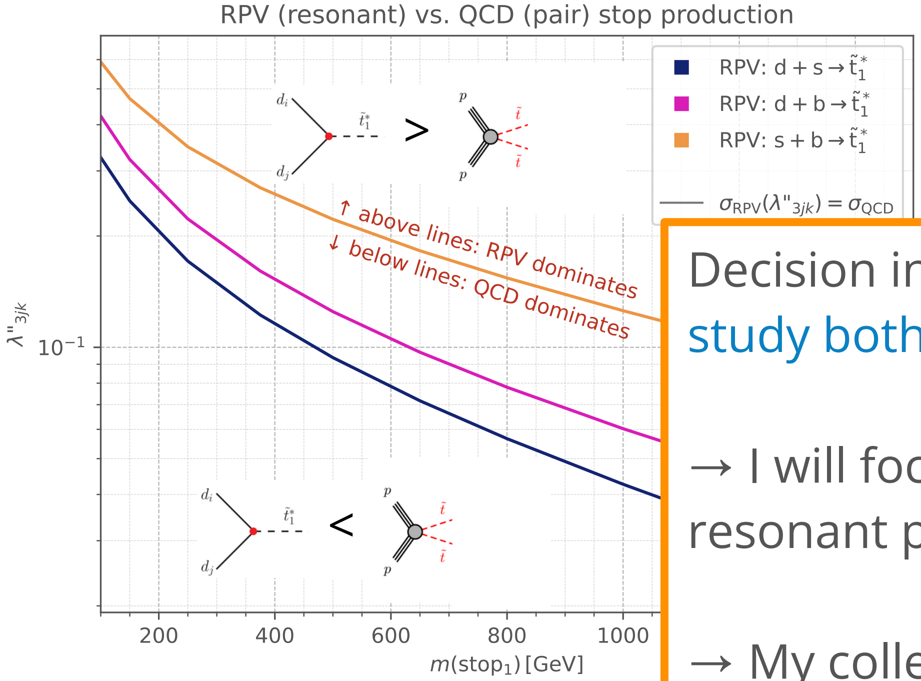

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above lines of equality

below lines

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pace

section similar
ge of only considering RPC

Decision in the end: we will **study both production modes**

→ I will focus on the study of resonant production

→ My colleagues will focus on the study of pair production

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  - limits looser for RPV
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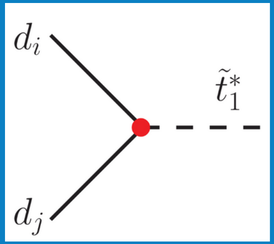
Resonant Production

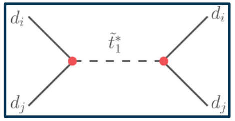


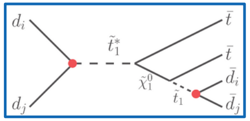
Why this exact process?

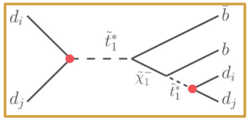
- Biquark decay most likely for large coupling, but completely supressed for small coupling
- Cascade decay via chargino more likely than via neutralino for all masses and coupling strengths
  - due to weaker suppression from kinematics
  - probably the more promising process to examine, but background studies necessary

- For small stop mass and small coupling: stop effectively stable
  → no decays at all here

But which of these decays to study?







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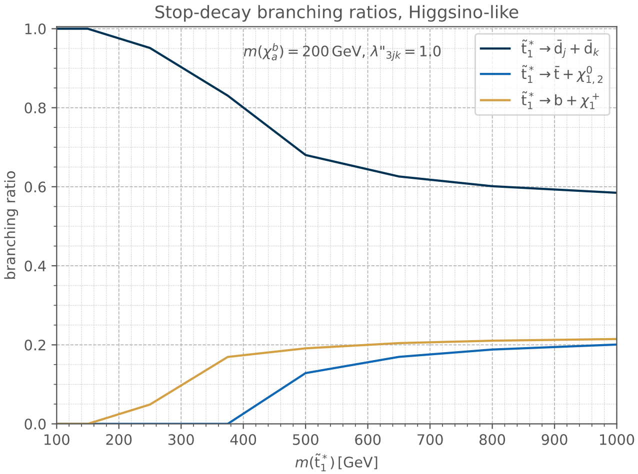

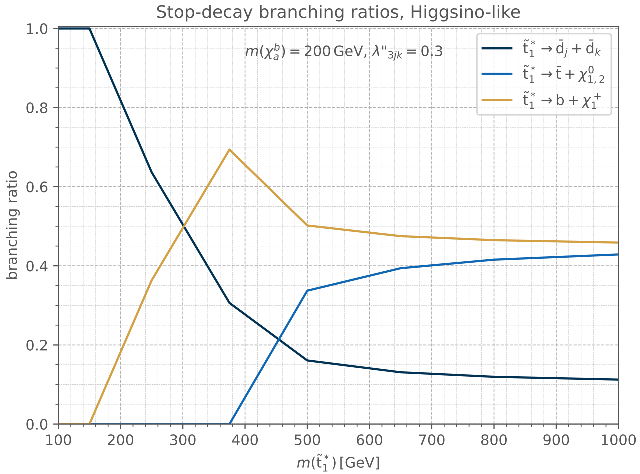

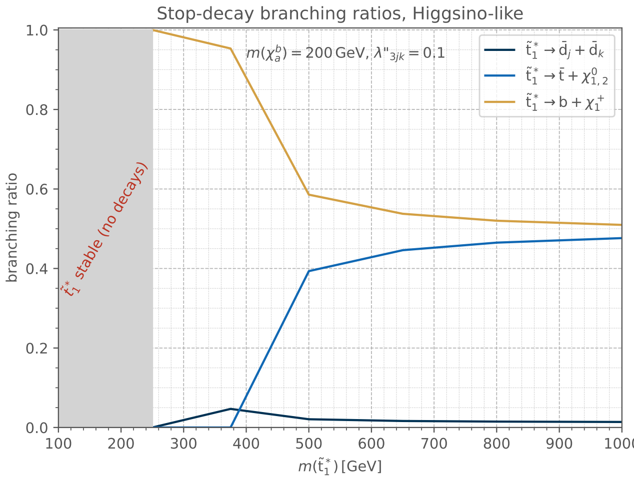

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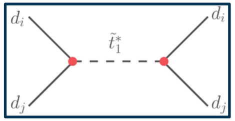
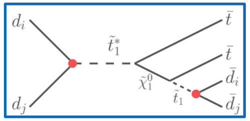
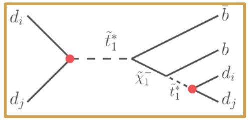
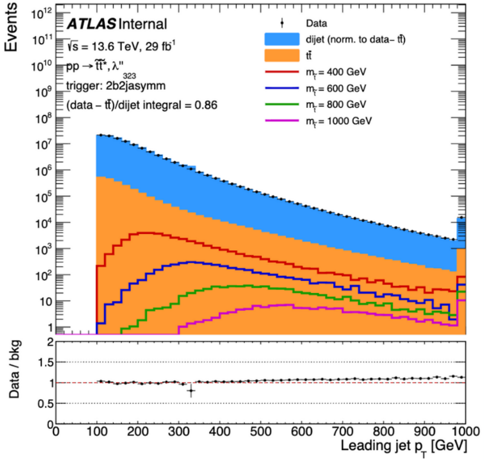
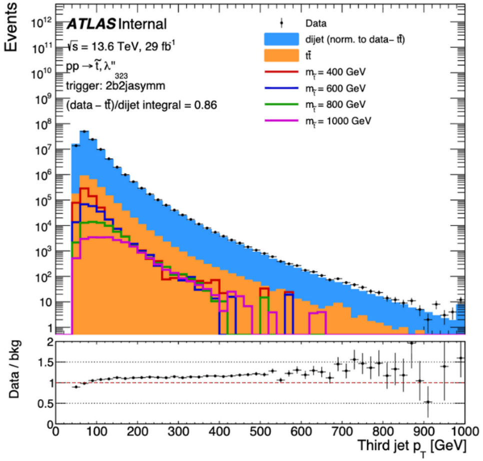


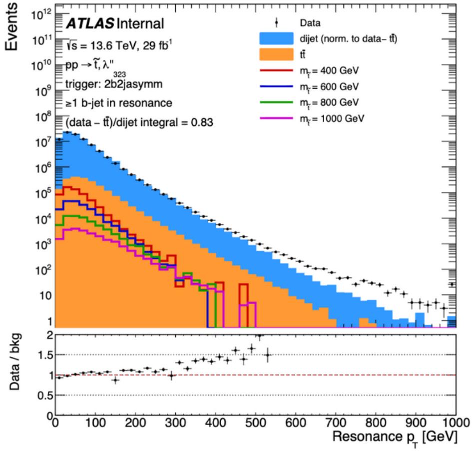


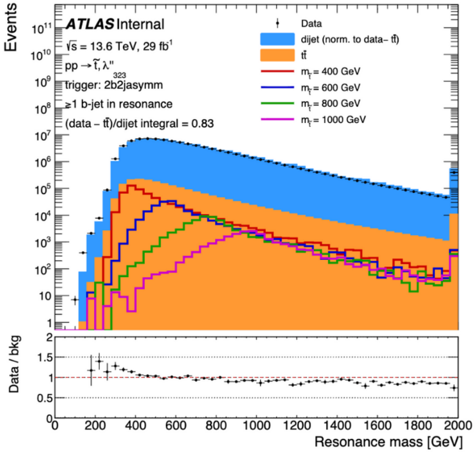


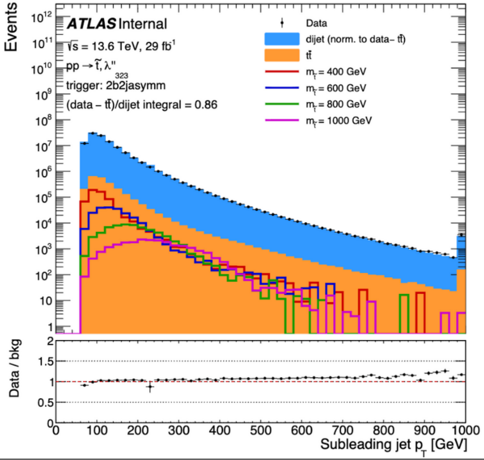
Comparing to background in simulation

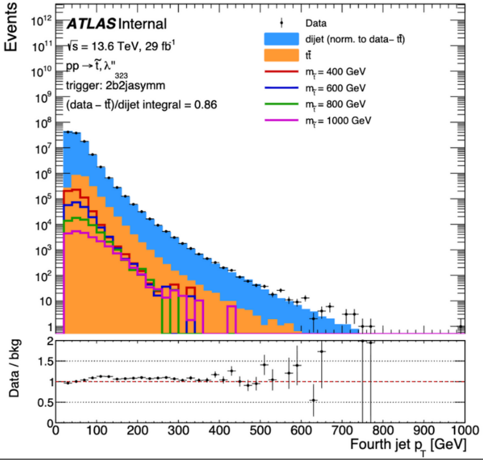








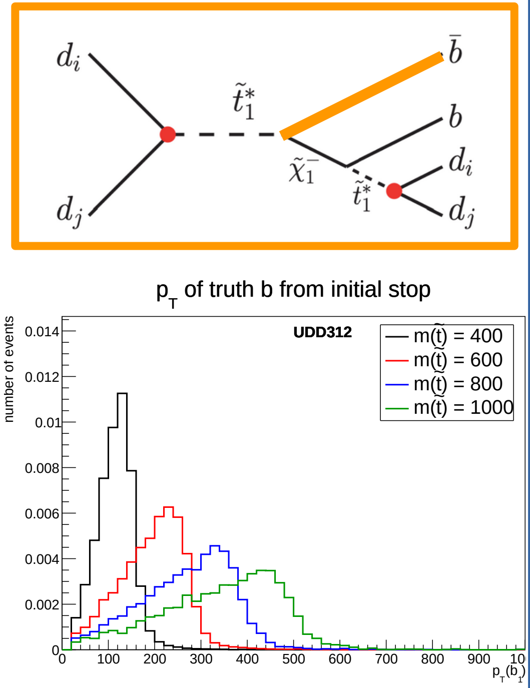


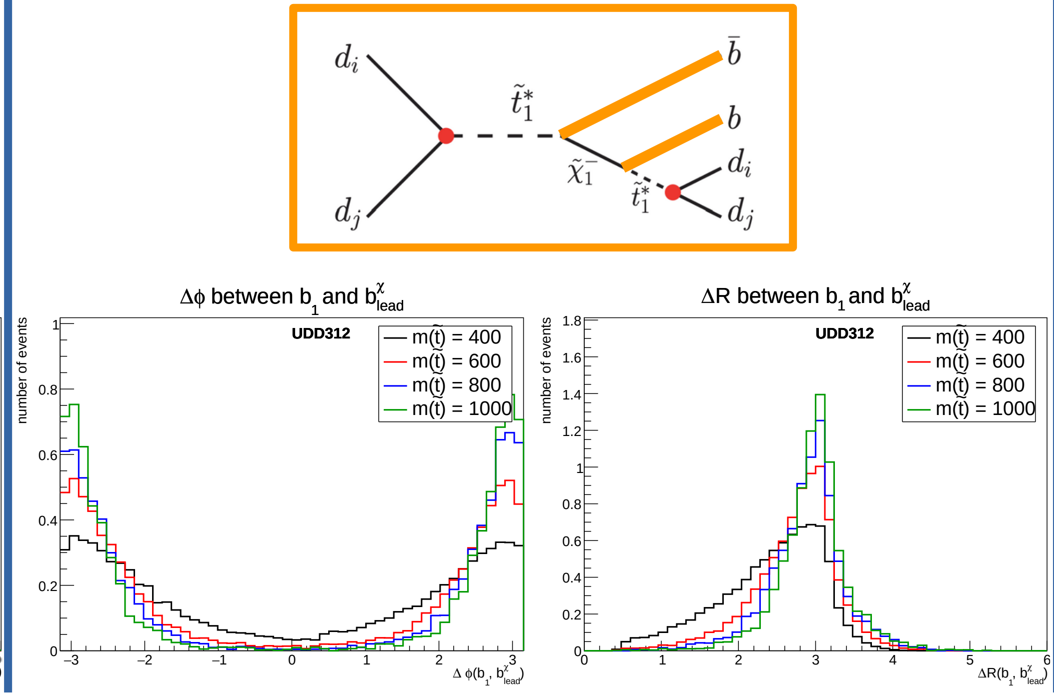


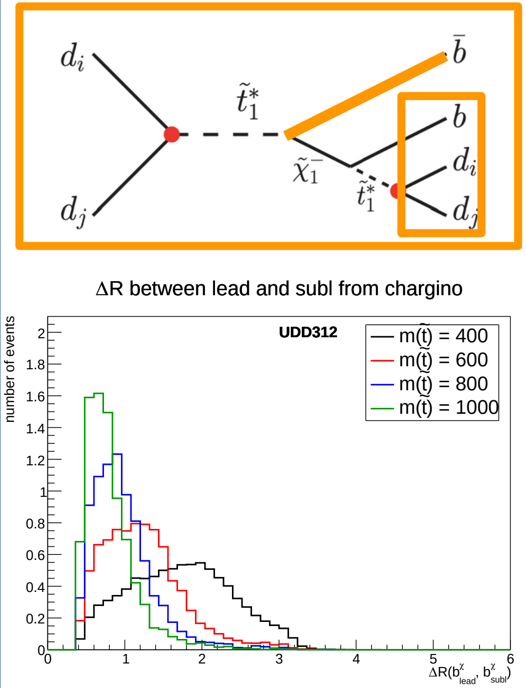
- Need to increase signal-to-background ratio!

Initial simulation studies

- Want to understand the process and develop analysis strategy
- For this, we study truth information from simulation







Conclusion and Outlook

Conclusion and Outlook

- Interesting but complicated process to study
  - complex topology and many unknowns
  - but: this exact process has never been considered
  - could significantly improve current limits on production cross section
- Currently:
  - developing initial analysis strategy
- Next steps:
  - identify background processes
  - study signal/background in simulation
  - apply and refine analysis strategy on experiment data

Thank you!


ATLAS
EXPERIMENT
Run: 364030
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Backup

Current limits