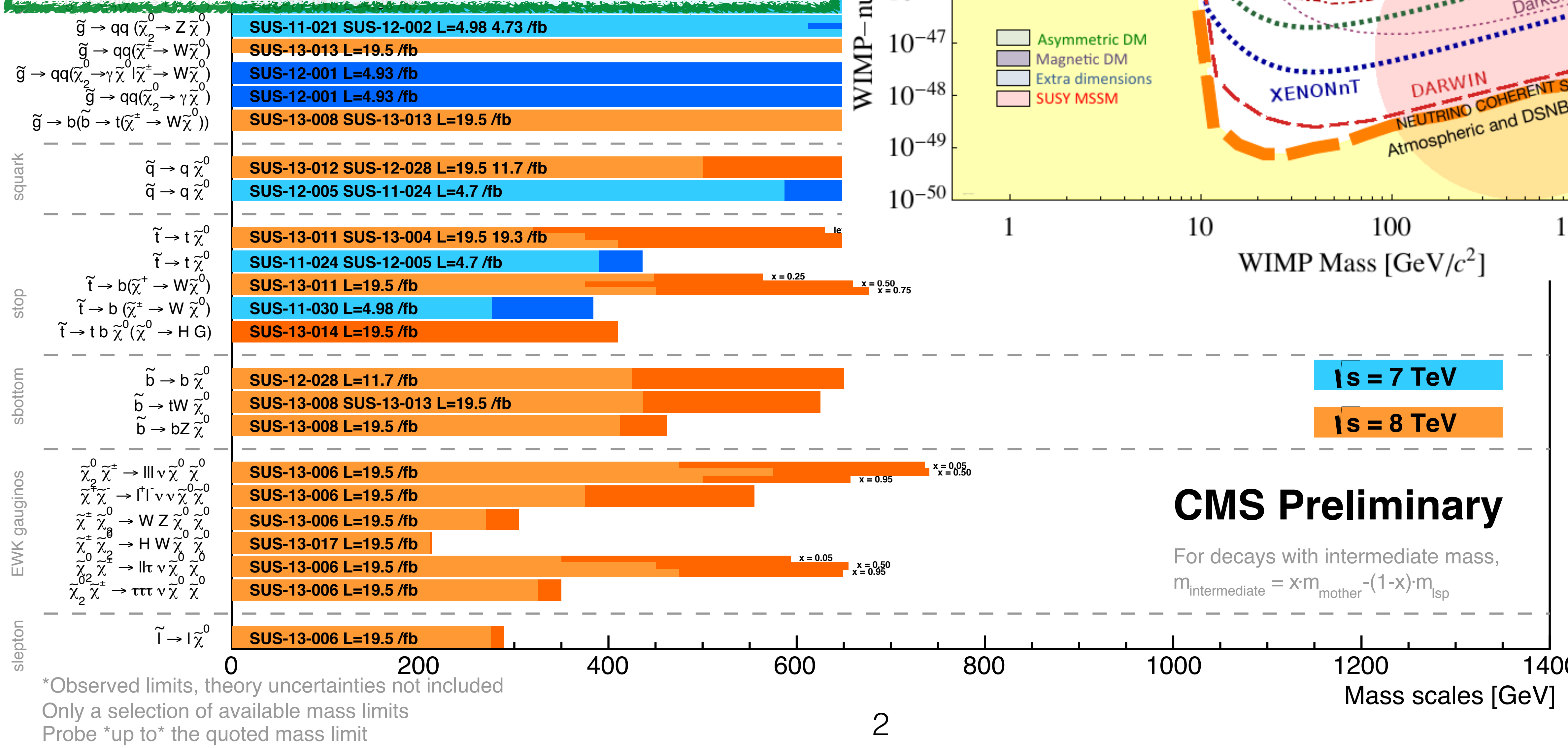
Probing the nonthermal dark matter at hadron colliders with the events containing a single top quark in the final state

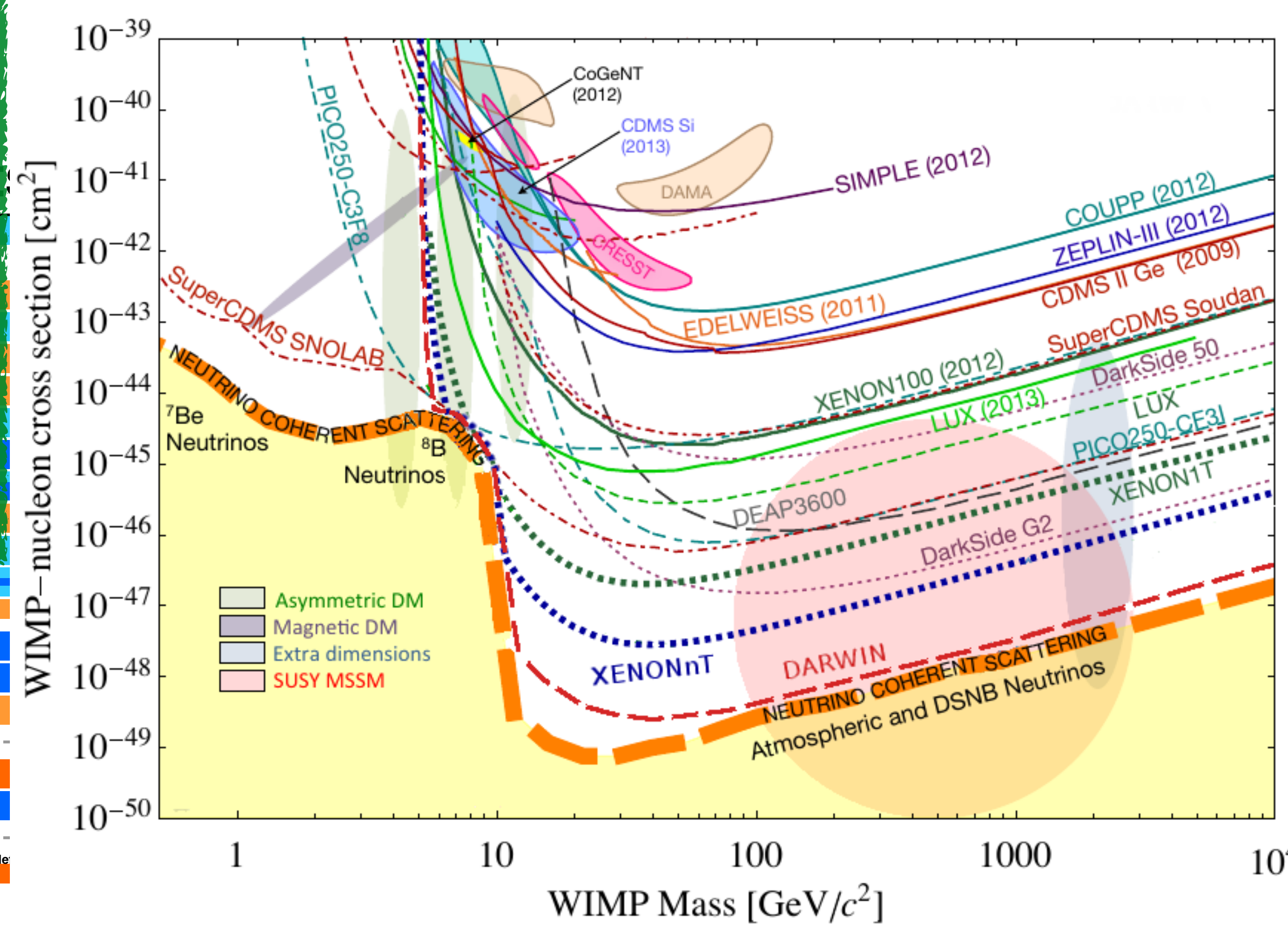
27th Rencontres de Blois

Mykhailo Dalchenko

Physics motivation

- ☑ We need an explanation for baryogenesis
- ☑ Astrophysical observables push WIMPs towards the EWK scale
- ☑ However, such scenarios are heavily restricted by LHC results





Nonthermal scenario

- Add a minimal extension to the SM:
  - scalar color triplet(s)
  - a fermionic DM candidate

R. Allahverdi and B. Dutta, PRD 88 (2013) 023525
B. Dutta, Y. Gao, and T. Kamon, PRD 89 (2014) 096009

$$\mathcal{L}_{int} = \lambda_1^{\alpha,\rho\delta}\epsilon^{ijk}X_{\alpha,i}\bar{d}^c_{\rho,j}\mathbf{P}_R d_{\delta,k} + \lambda_2^{\alpha,\rho}X^*_\alpha \bar{n}_{DM}\mathbf{P}_R u_\rho + C.C.$$

- At least two scalar X are needed for the successful baryogenesis
- X couples to two d-quarks or u-quark and DM
- DM isn't protected by parity, therefore $|m_{DM} - m_p| < m_e$

- Such model allows variety of free parameters:
  - different flavor indices of λ
  - complex phases

→ Need simplification for collider searches

A minimal parametrization

- Assume flavor-blind coupling structure:

$$\lambda_1^{\alpha,\rho\delta} = \lambda_1 \times \lambda_{1X}^{\alpha} \times \lambda_{1R}^{\rho\delta}$$

$$\lambda_{1X}^{\alpha} = (1,1) \qquad \lambda_{1R}^{\rho\delta} = \begin{pmatrix} 0 & 1 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{pmatrix}$$

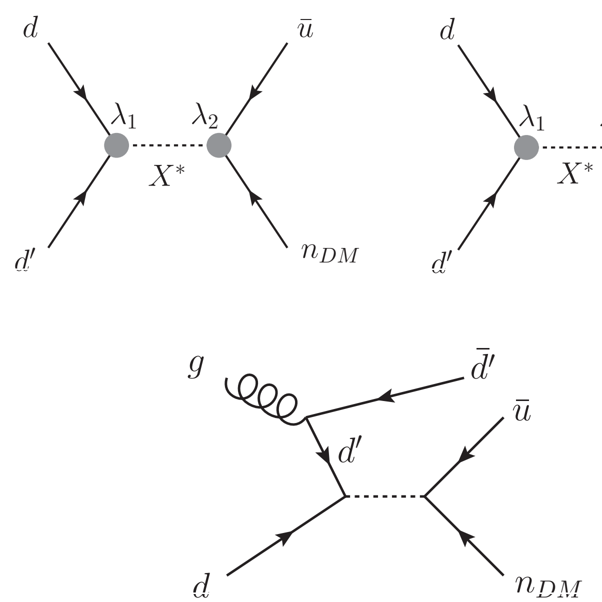
$$\lambda_2^{\alpha,\rho} = \lambda_2 \times \lambda_{2X}^{\alpha} \times \lambda_{2R}^{\rho}$$

$$\lambda_{2X}^{\alpha} = (1,1) \qquad \lambda_{2R}^{\rho} = (1,1,1)$$

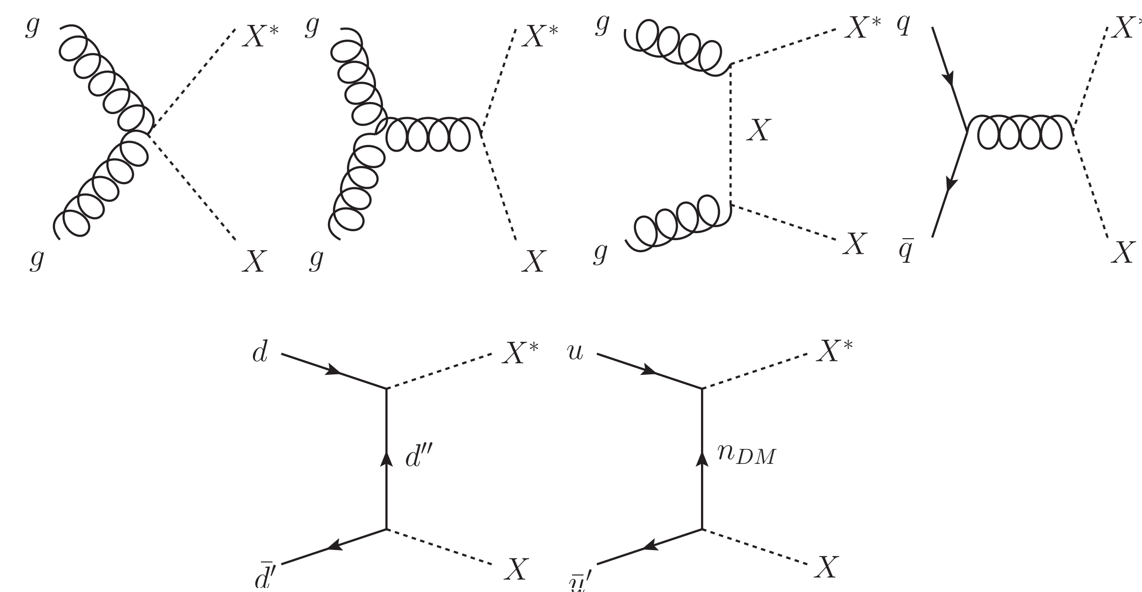
- Complex phases are dropped
  - They only appear in interference at loop level
  - If there's no mass degeneracy then s-channels dominate
  - Interference is negligible if $|\lambda_1| \sim |\lambda_2|$ or $|\lambda_1| \gg |\lambda_2|$

Different topologies

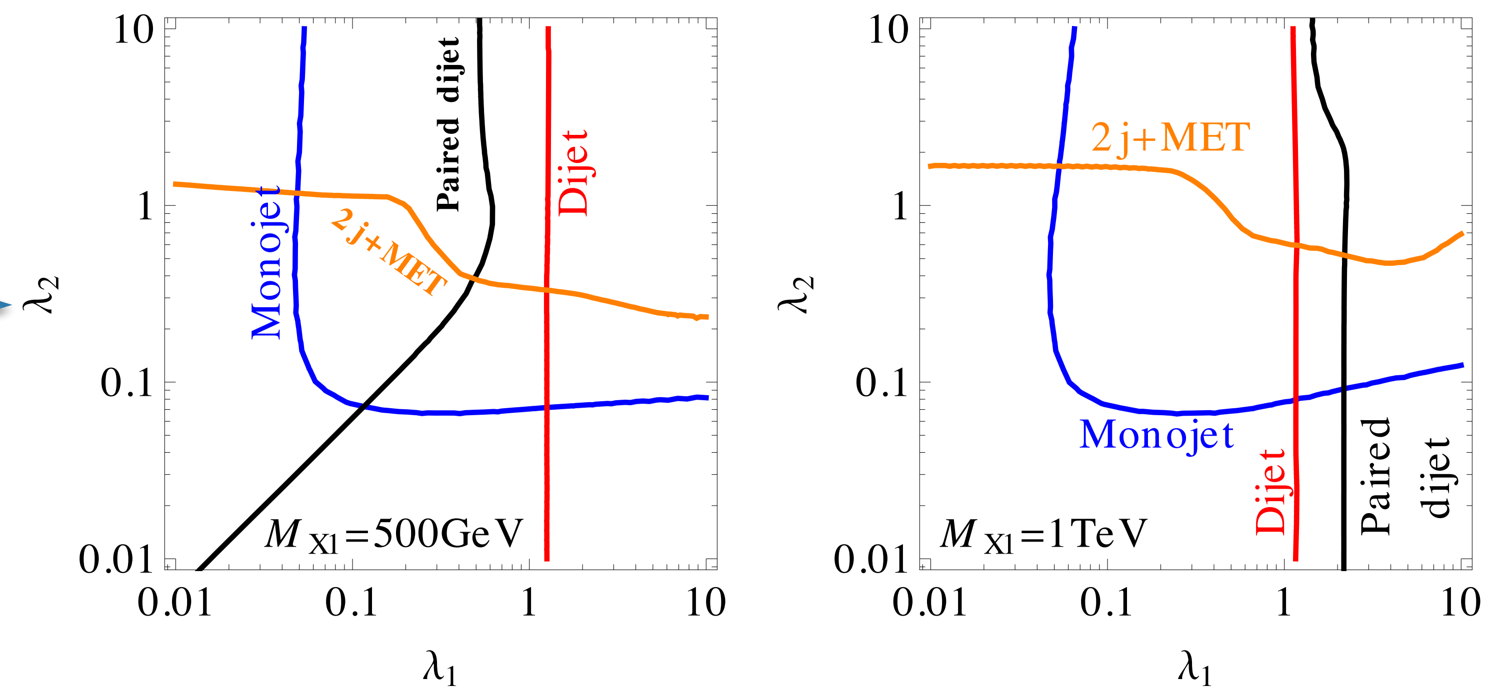
Single X production



Double X production



Various final states limits estimation



Our focus: probe the coupling to third generation, monotop!

Signatures

$$d + d' \to X \to t + n_{DM}$$

n_{DM}: Escapes detection, forms *MET*

$$t \to W + b$$

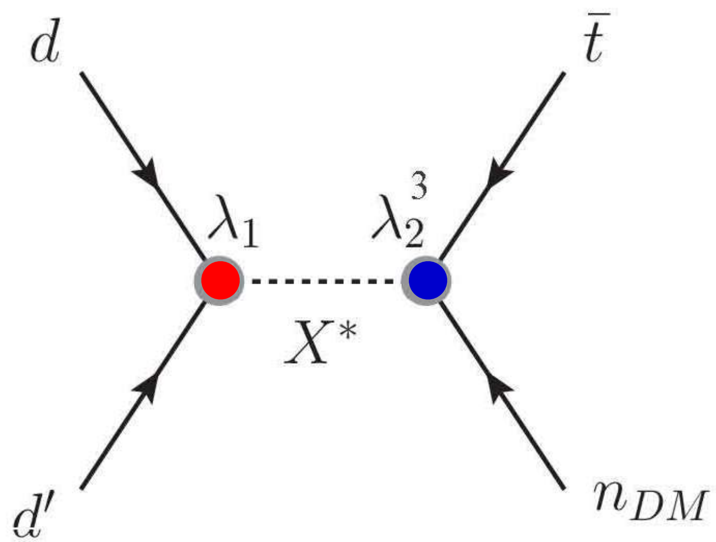
b: b-jet

$$W \to \ell + \nu$$

ℓ: lepton

ν: *MET*

$$W \to 2(light)jets$$



Possible final states:

- ☑ High MET + b-jet + lepton
- ☑ High MET + b-jet + 2 other (preferably light) jets

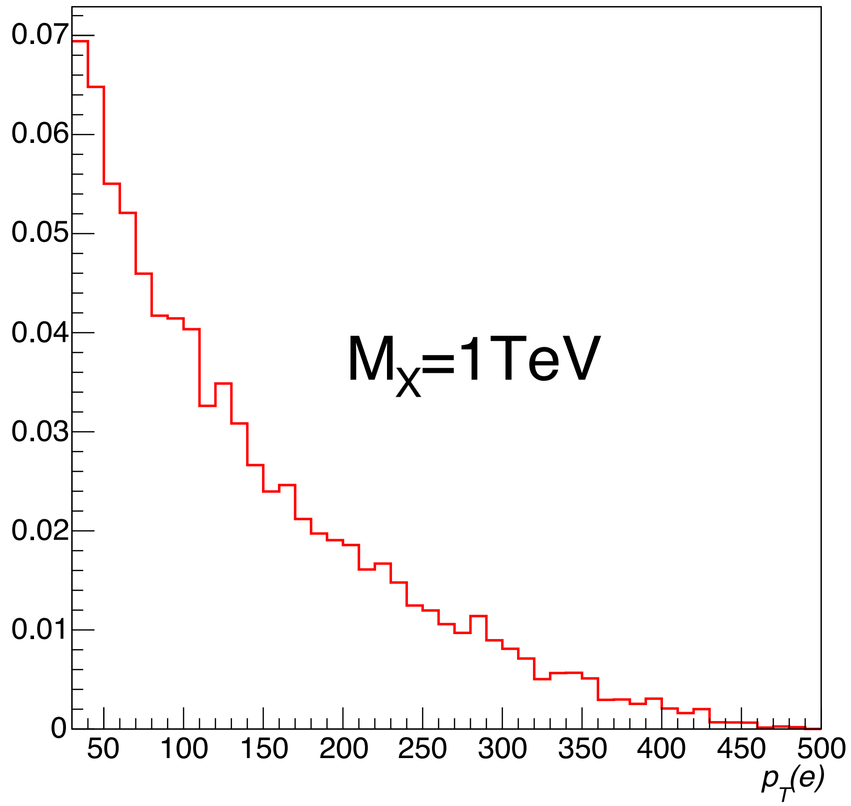
Naive sensitivity estimation gives ~1event/fb for 50% efficiency and $\lambda_1 \approx \lambda_2 \sim 0.1,\ m_X \sim 1TeV$

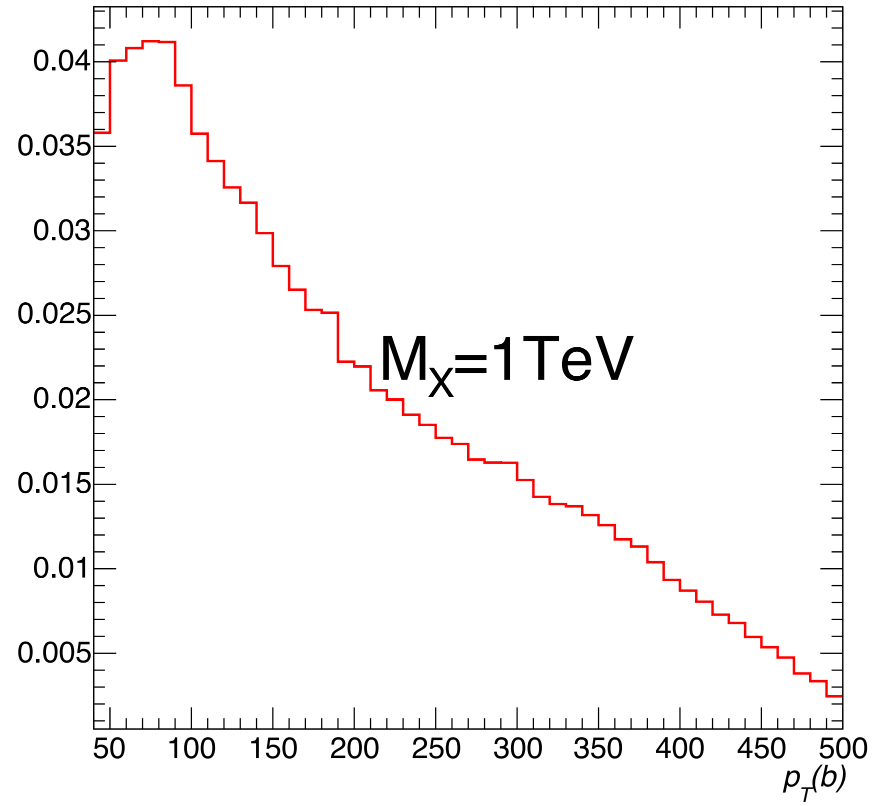
Events generation and detector simulation

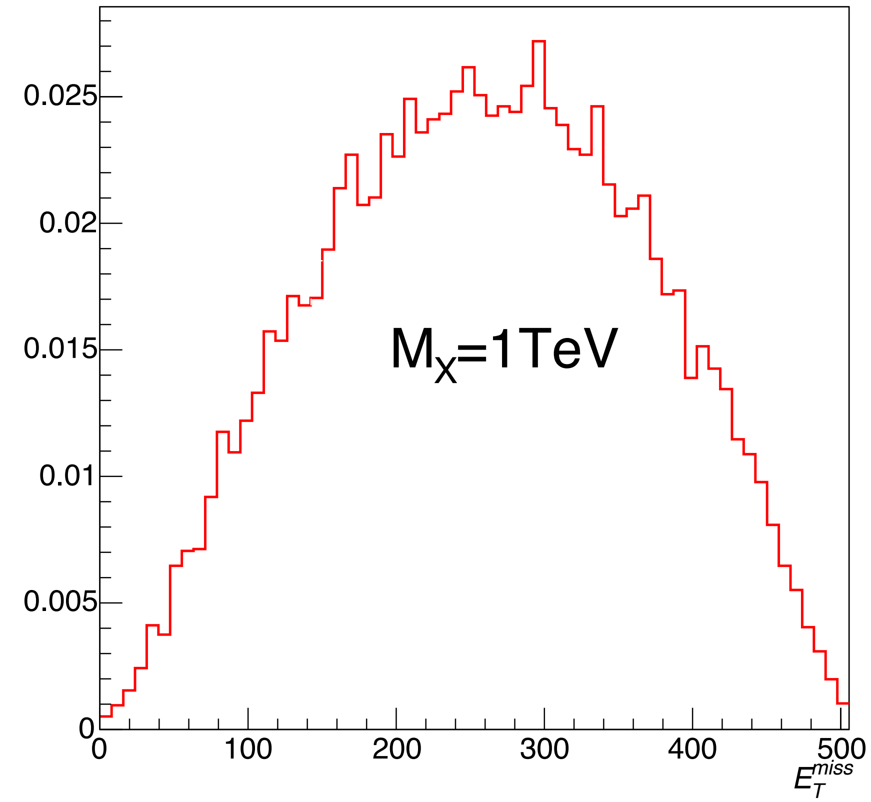
- Generate parton level events with Madgraph 5 v1.5
- Hadronize events with Pythia 8.2
- Simulate the detector with Delphes 3.2:
  - Use standard CMS configuration card
  - Reconstruct jets with FastJet package using anti-Kt
  - B-tagging efficiency ~70(60)% in the barrel(endcaps)
  - Apply $p_T(b) > 60\ GeV$ and $p_T(jet) > 20\ GeV$ selection for jets in hadronic final state
  - Apply $p_T(b) > 30\ GeV$ and $p_T(\ell) > 30\ GeV$ selection in leptonic final state

Event kinematics

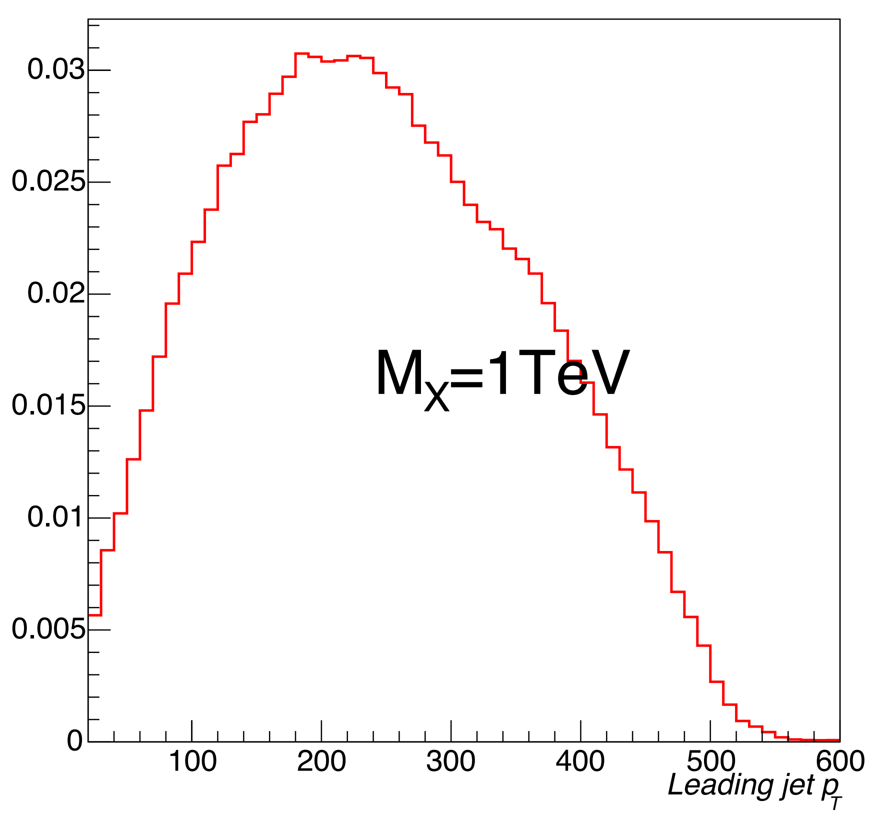
leptonic final state

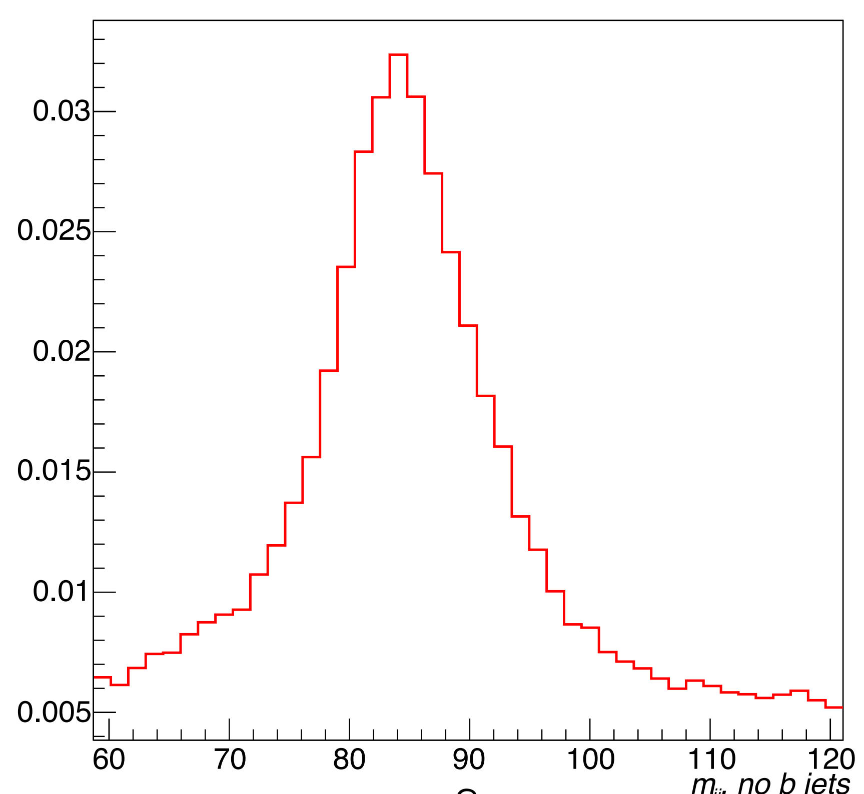


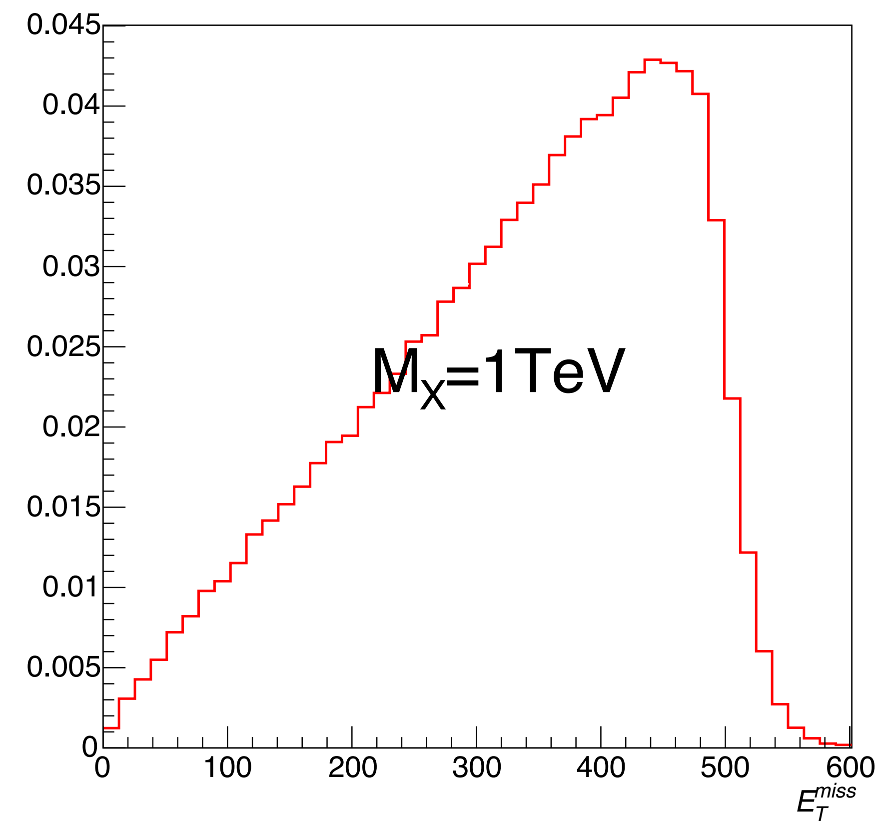




hadronic final state

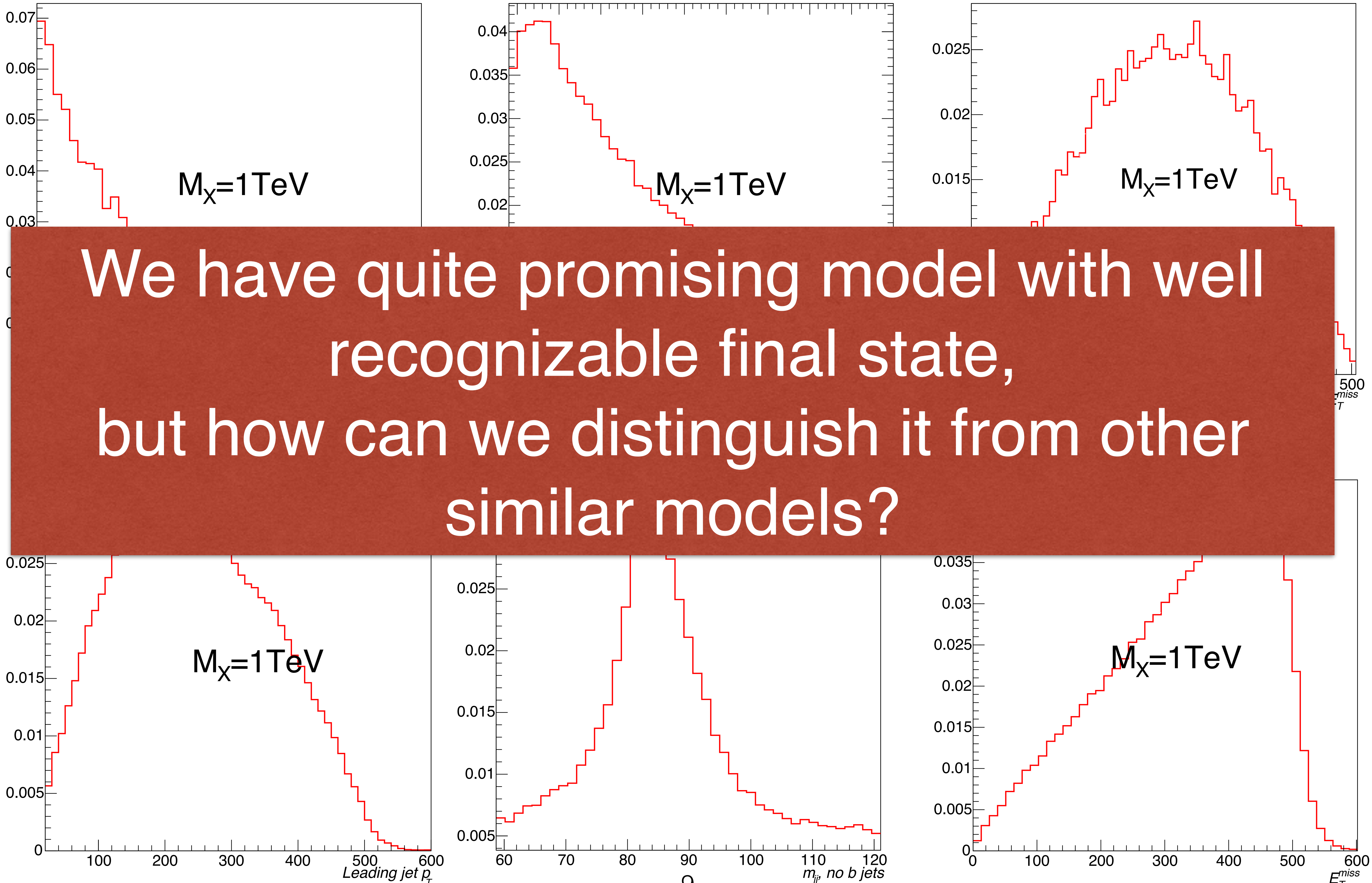






Event kinematics

leptonic final state

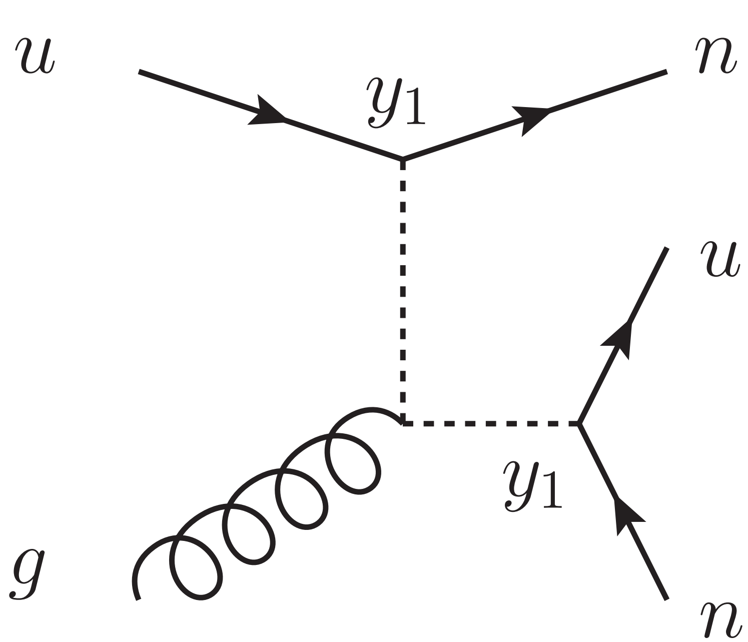


We have quite promising model with well recognizable final state,
but how can we distinguish it from other similar models?

An example of similar model

Let's use isospin doublet instead of isospin singlet

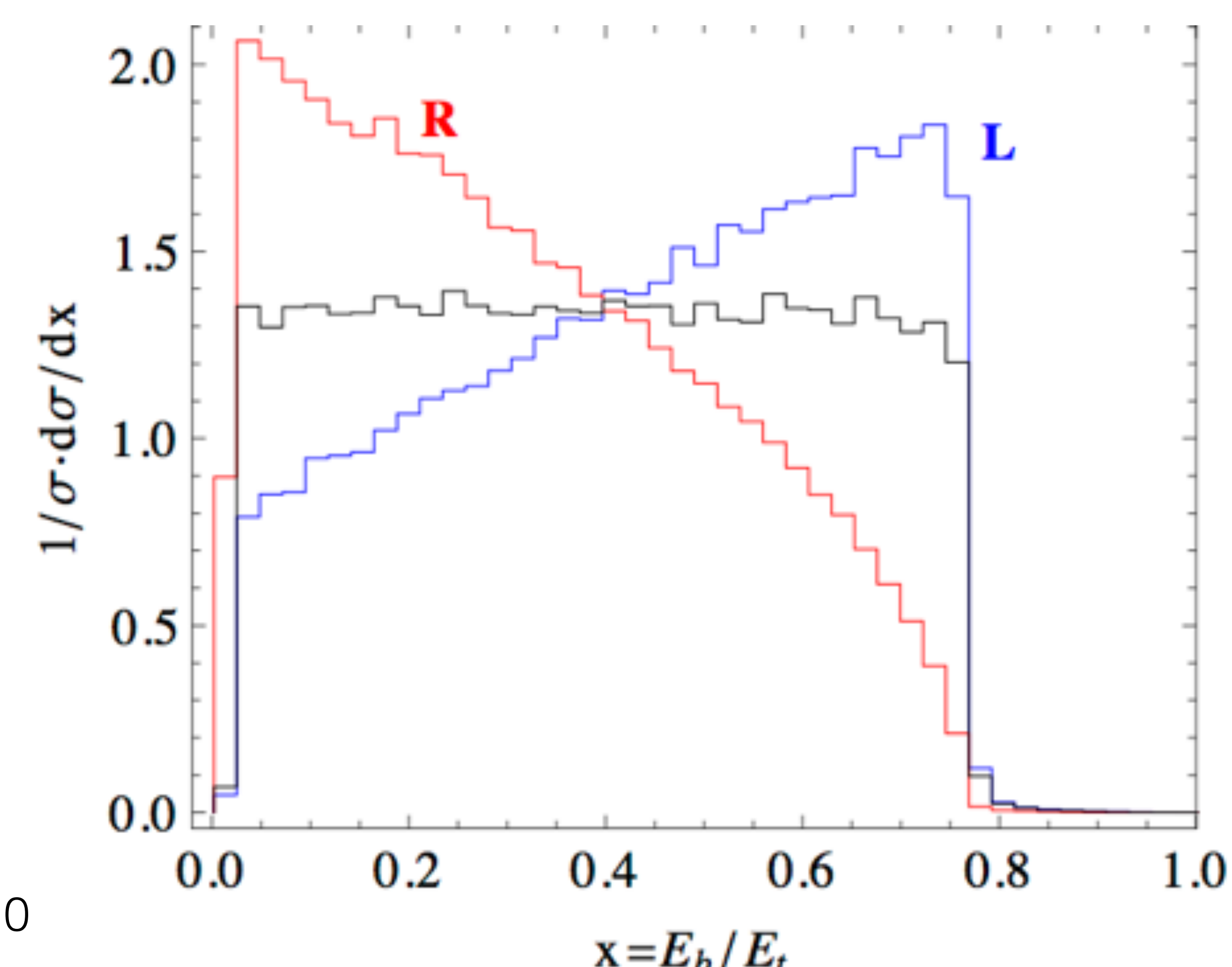
$$\mathcal{L}_{\rm D} \supset y_1^{\alpha,i}\bar{Q}_i n X_\alpha + y_2^{\alpha,i} X_\alpha^\dagger \bar{Y} d_i + y_3^{\alpha,i} X_\alpha \bar{Y} u_i^c + \text{C.C.}$$



$$u + g \to X + n_{DM} \to t + n_{DM} + n_{DM}$$

The reconstructable final state is the same as in case of isospin singlet model

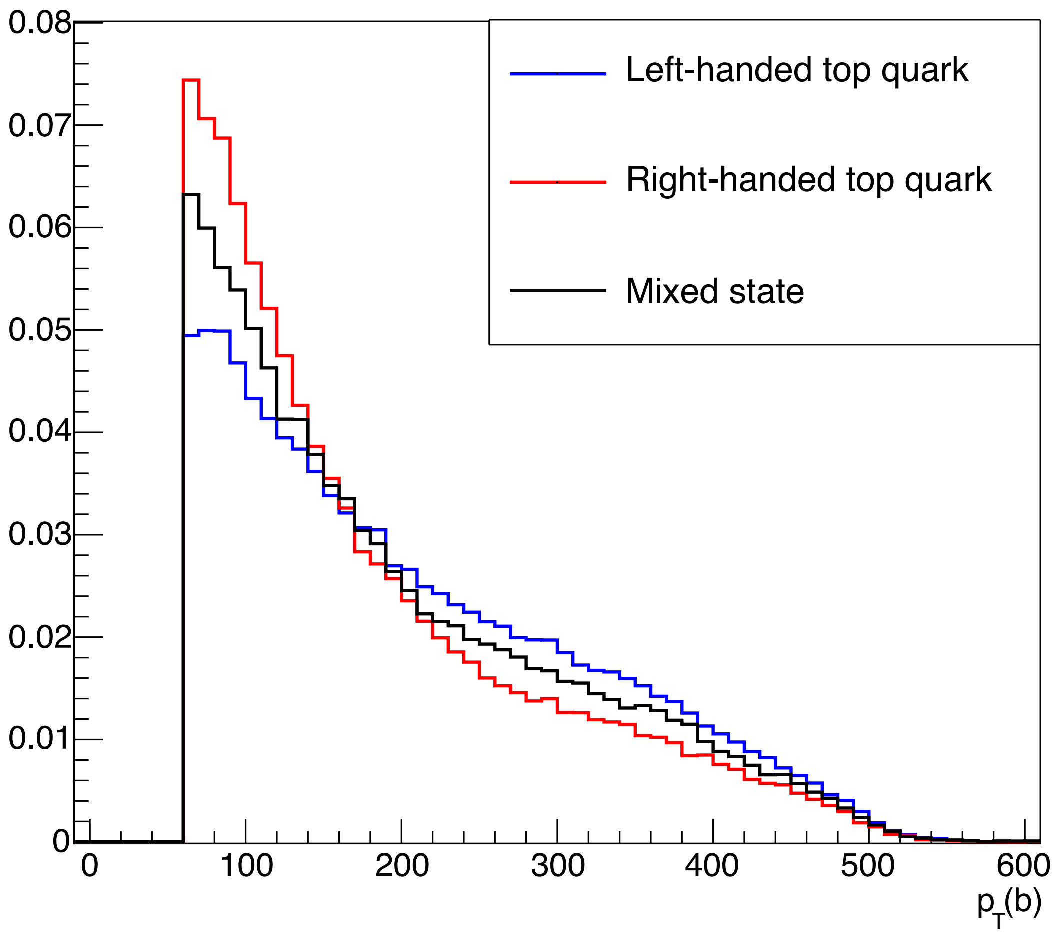
However, top quark chirality from X decay is opposite between the singlet and doublet cases.

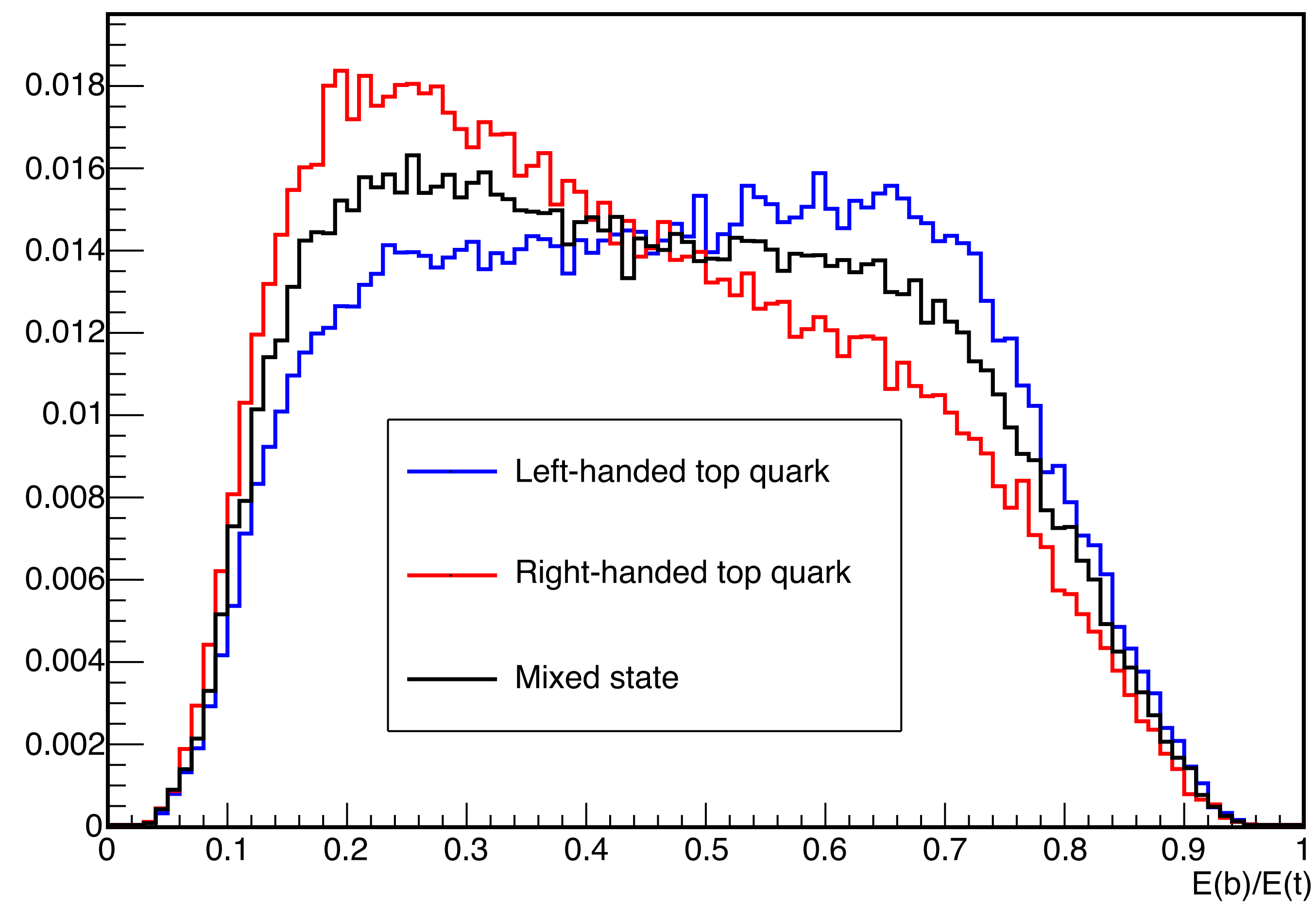


FastSim with Delphes

Hadronic top quark decay

- Flip the chirality and analyze the pT spectrum



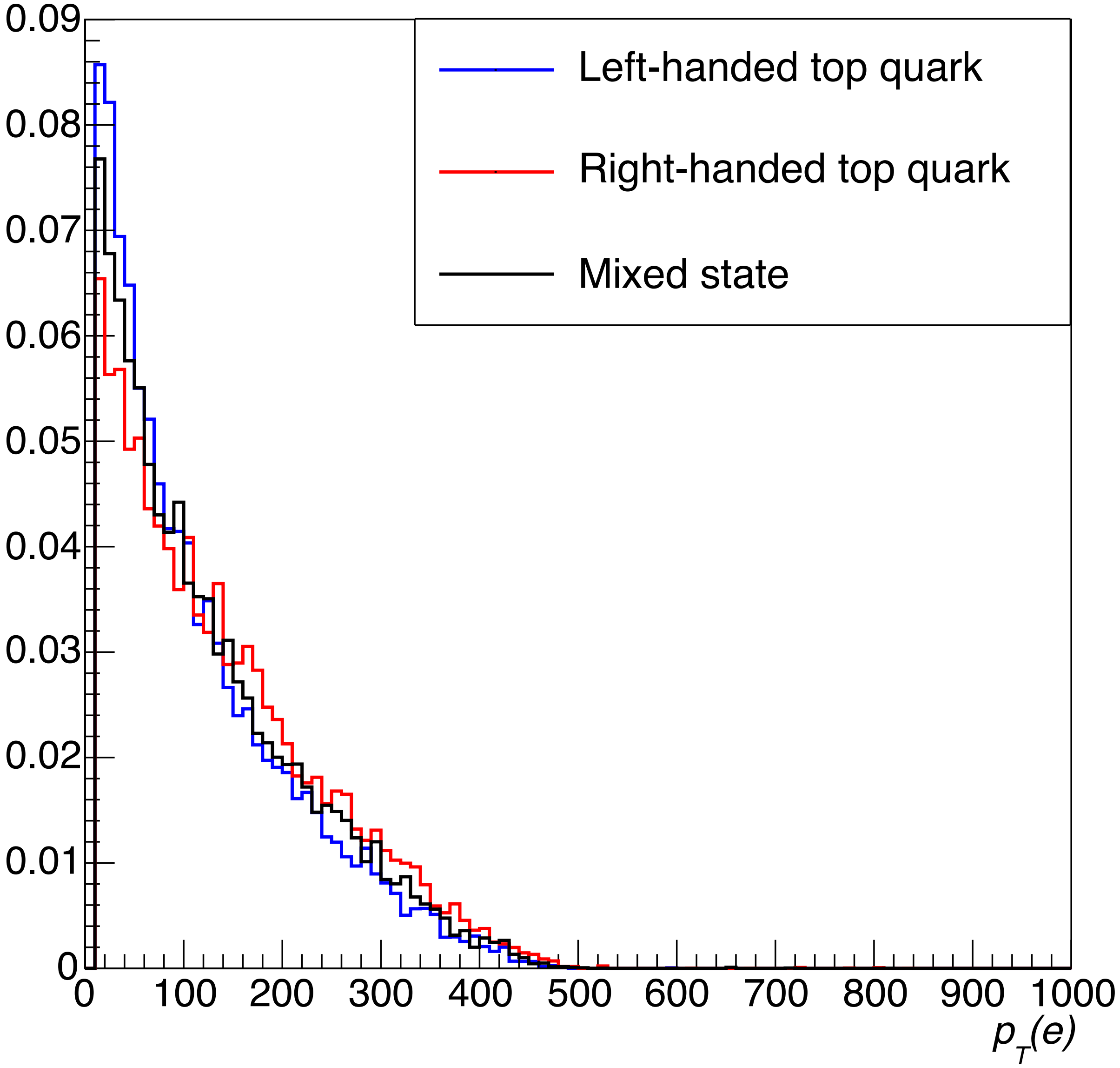


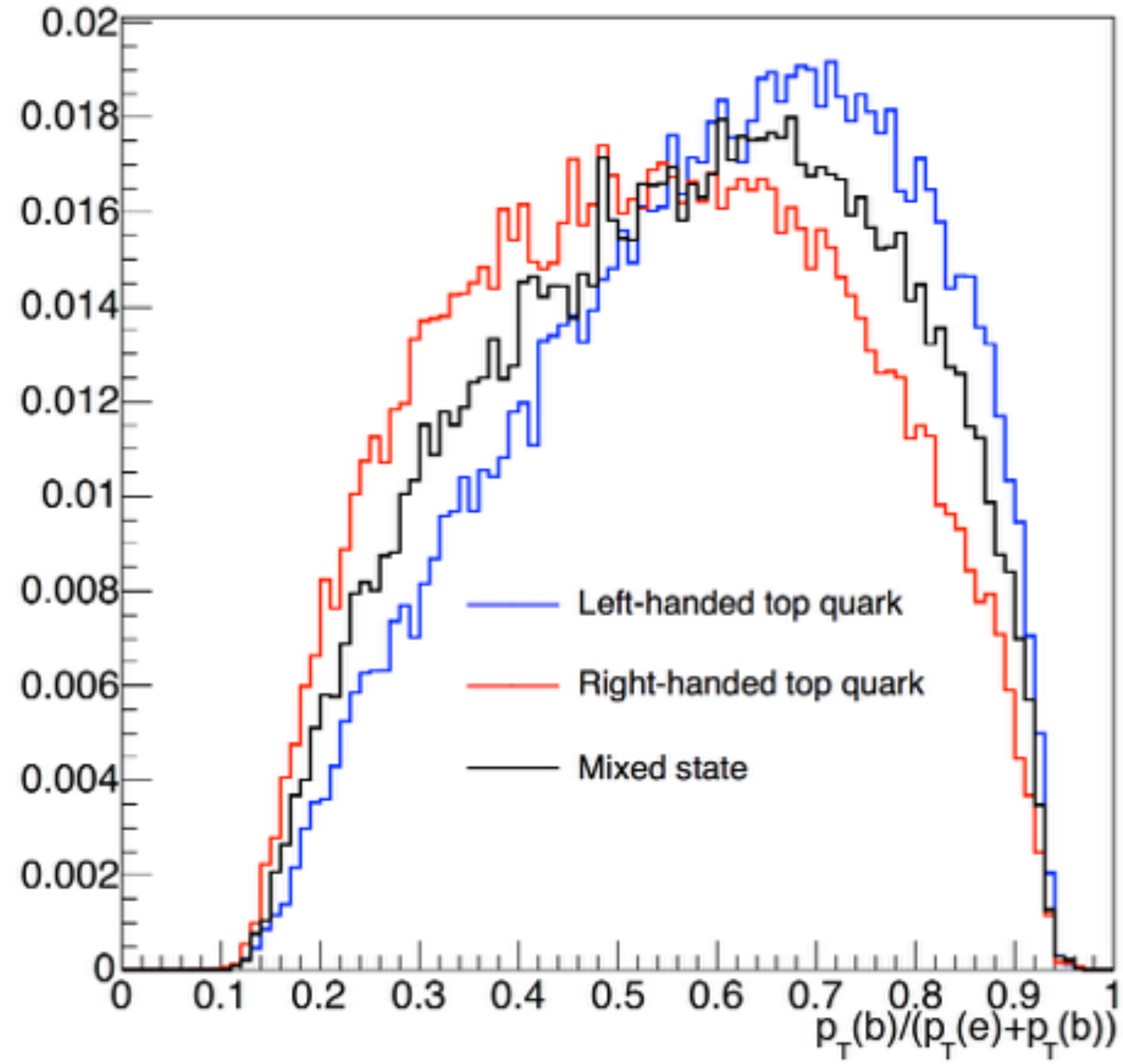
- There's a visible discrimination!

FastSim with Delphes

Leptonic top quark decay

- ☑ Flip the chirality and analyze the pT spectrum

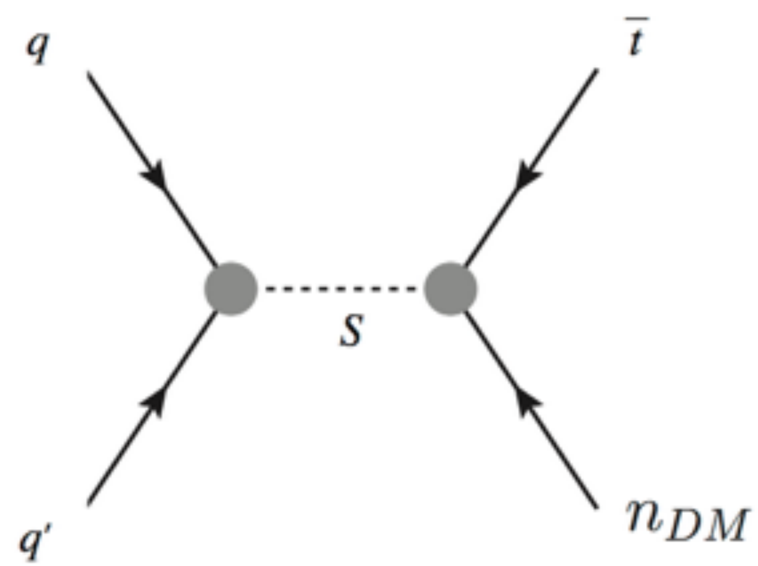




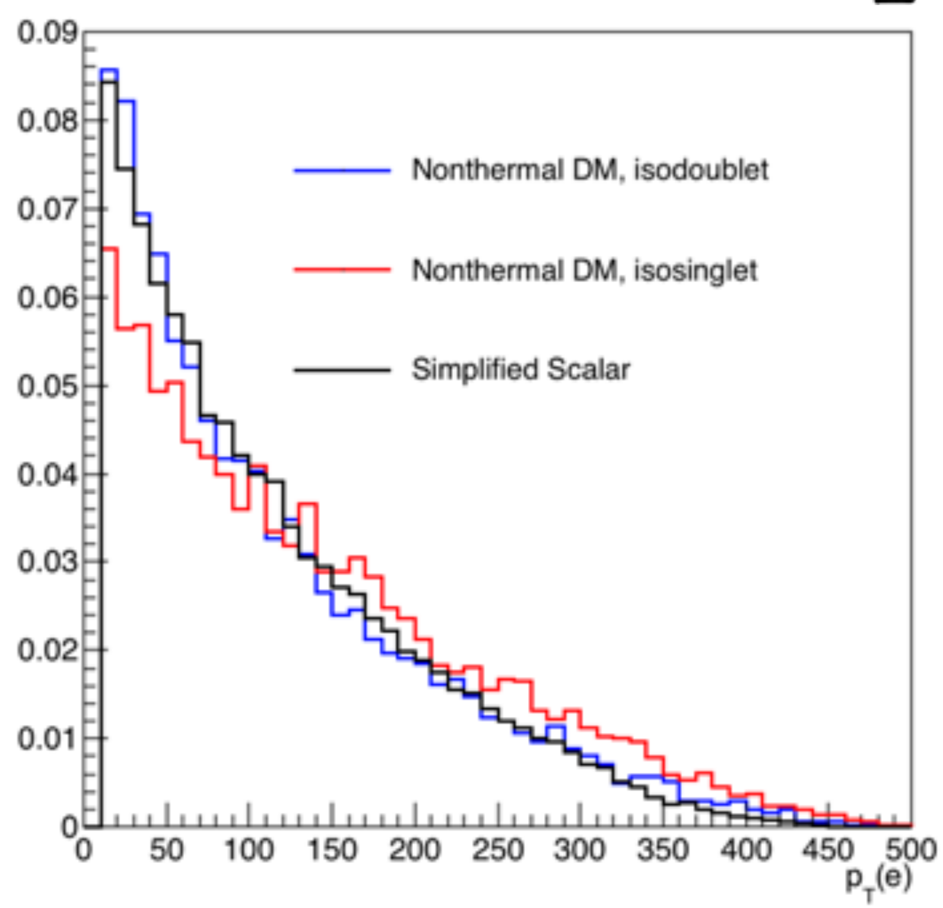
- ☑ There's a visible discrimination!

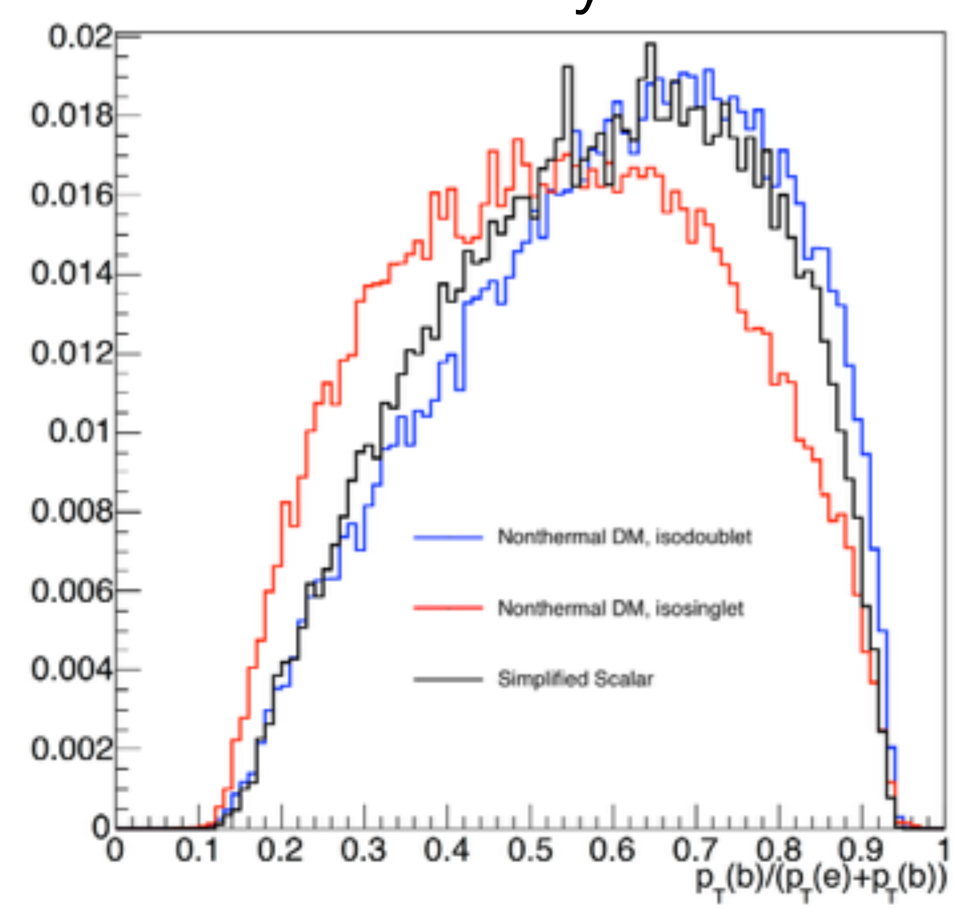
Going further

- Another model with similar final state: simplified model with scalar resonance plus heavy dark matter candidate



- Consider scalar mass $1\ TeV$
- Consider $m_{DM} = 100\ GeV$
- Resulting kinematics is very similar!





Summary

- ☑ Light non-thermal DM model is well motivated Good sensitivity with LHC Run II data is expected

- ☑ Top quark chirality reconstruction allows to distinguish between different NP models with single top quark in the final state
- ☑ Works for both hadronic and leptonic decay modes of the top quark
- ☑ Allows search for the anomalous weak couplings in SM events with single top quark in the final state