Scalar gluons at Run 2 of the LHC

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*in collaboration with J. Kalinowski and S. Prestel

Motivation

- We are all waiting for the Run 2 of the LHC hoping that new physics is just around the corner but so far
  - tremendous success of the SM - discovery of what looks like a SM Higgs boson
  - no new particles
  - new exclusions
- If one still believes in the BSM physics, the question is:

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- If one still believes in the BSM physics, the question is:

What can happen when we switch on the LHC again?

Color-octet scalars

- Lorentz scalars in the adjoint representation of SU(3) appear in many different models
  - R-symmetric or N=1/N=2 hybrid model
  - technicolor
  - …
- Pair production is (at LO) model independent
- Strongly interacting so large cross section

MadGolem collaboration
PHYSICAL REVIEW D 85, 114024 (2012)

	$\sqrt{S} = 8$ TeV			$\sqrt{S} = 14$ TeV		
m_G [GeV]	σ^{LO} [pb]	σ^{NLO} [pb]	K	σ^{LO} [pb]	σ^{NLO} [pb]	K
200	2.12×10^{2}	3.36×10^{2}	1.58	9.77×10^{2}	1.48×10^{3}	1.52
350	8.16×10^{0}	1.36×10^{1}	1.66	5.44×10^{1}	8.46×10^{1}	1.56
500	7.64×10^{-1}	1.34×10^{0}	1.75	7.14×10^{0}	1.14×10^{1}	1.60
750	3.40×10^{-2}	6.54×10^{-2}	1.93	5.56×10^{-1}	9.29×10^{-1}	1.67
1000	2.47×10^{-3}	5.29×10^{-3}	2.15	7.31×10^{-2}	1.28×10^{-1}	1.75

- Can have quite distinct experimental signature

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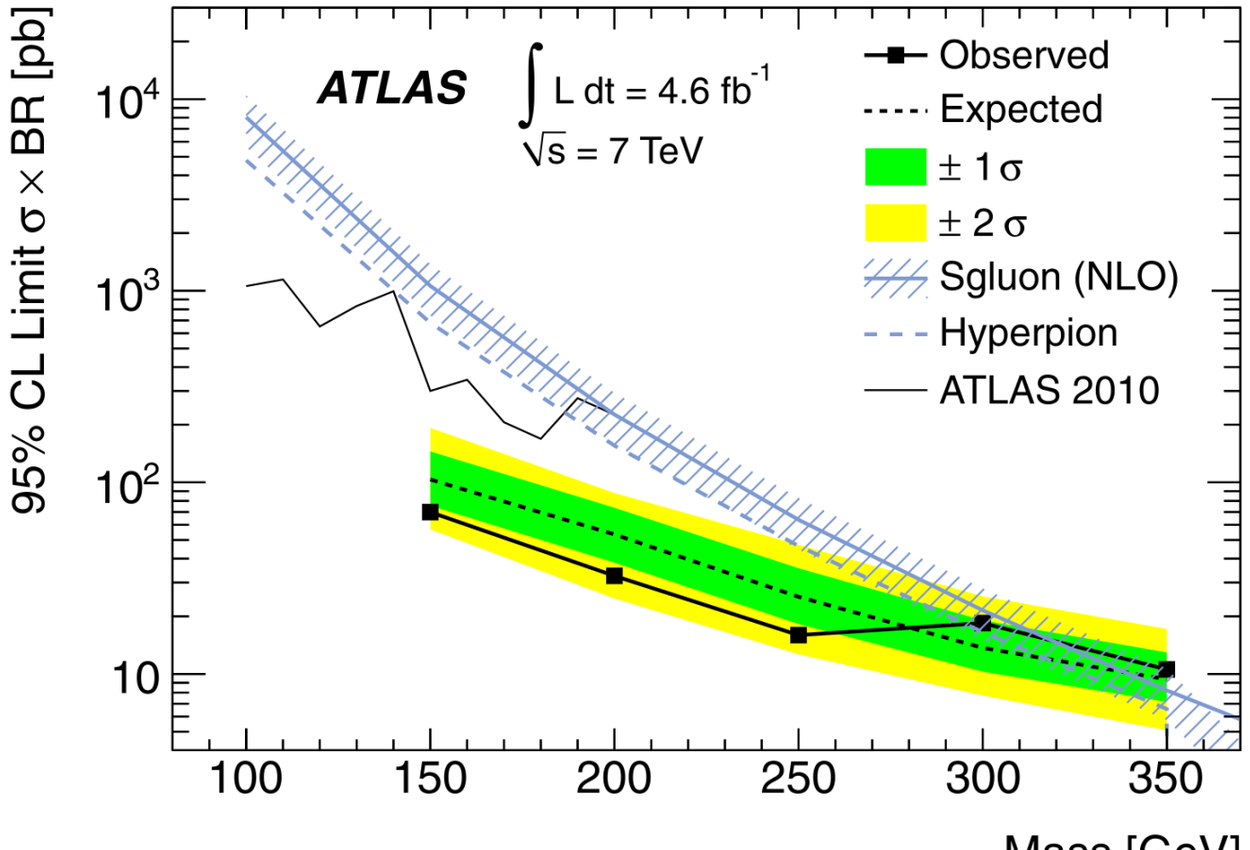
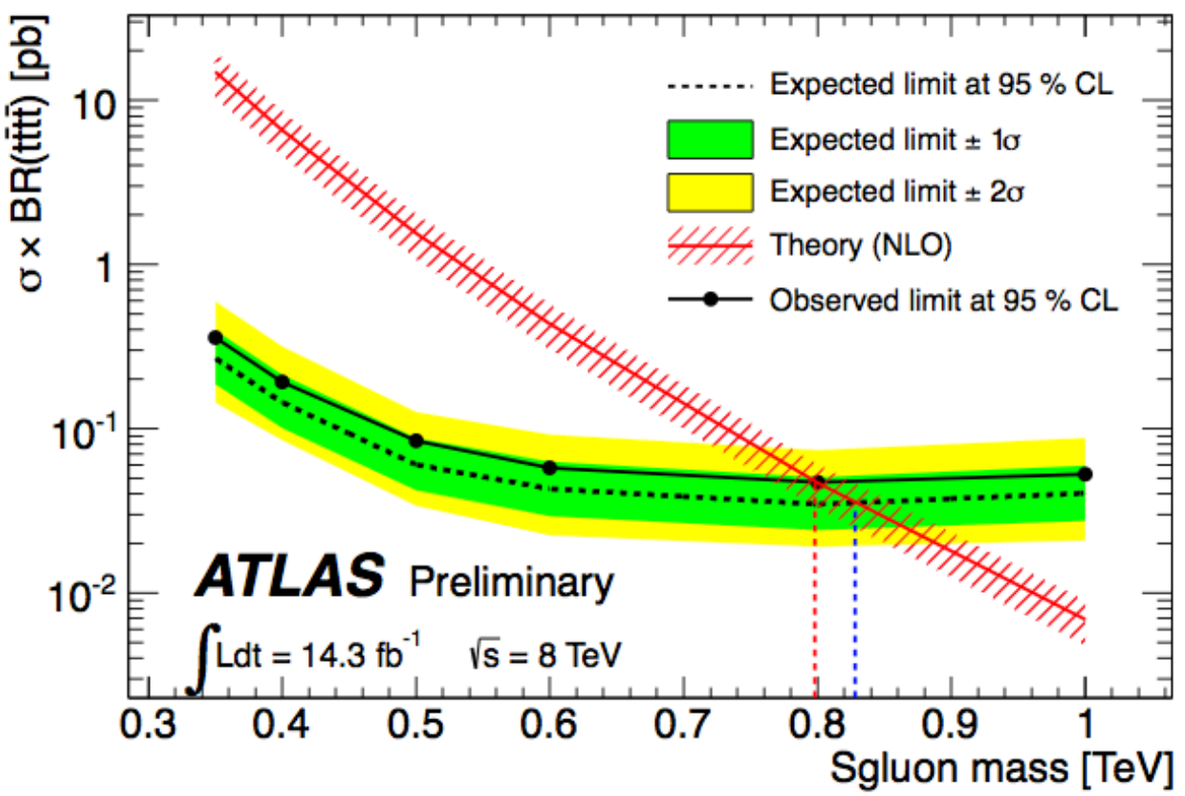
Possible experimental signatures

- di-jet signature for $m_\sigma < 2m_t$ dedicated ATLAS search for colored scalars in 4-jet final states and CMS search for di-jet events



- $2\,t\bar{t}$ pairs as a possible signature for $m_\sigma > 2m_t$



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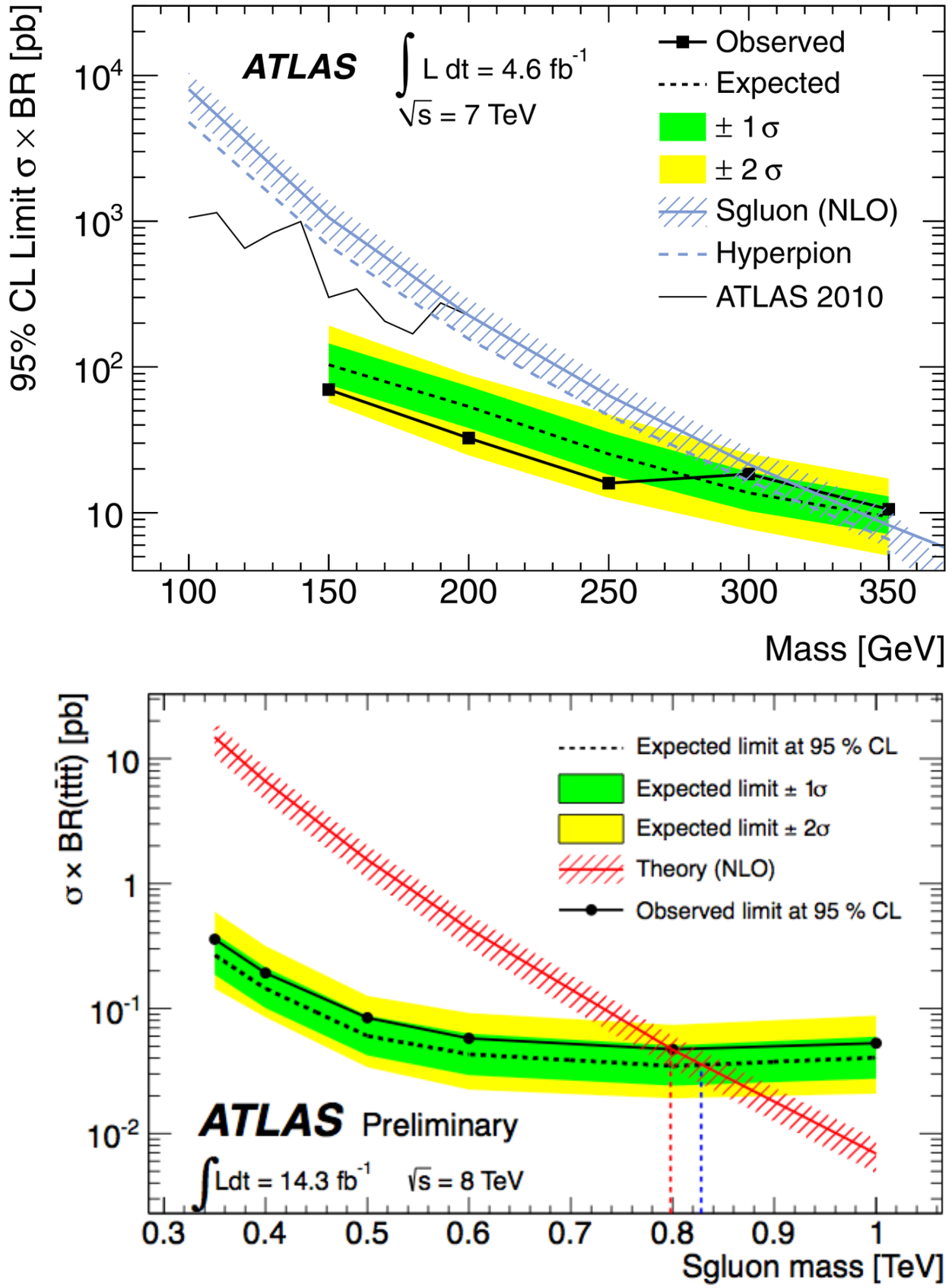


Simulation setup

- the so-called „NLO revolution” - NLO (SM) QCD MC fast, efficient and readily available (e.g. **`aMC@NLO,GoSam,OpenLoops,…`**)

- **UNLOPS** — “Unitarized NLO + PS merging” L. Lönnblad, S. Prestel

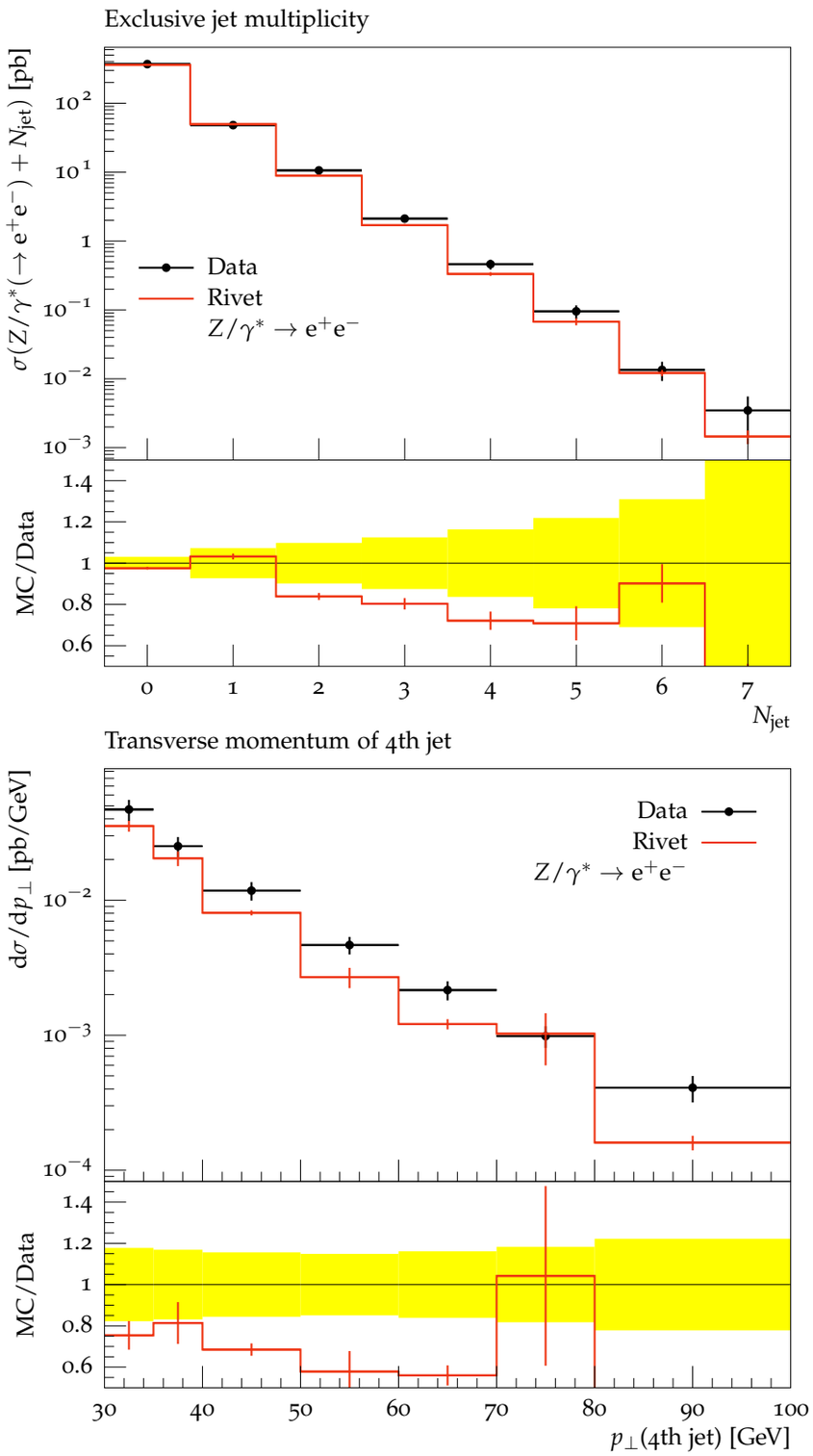
  - “unitarization” by explicit subtraction

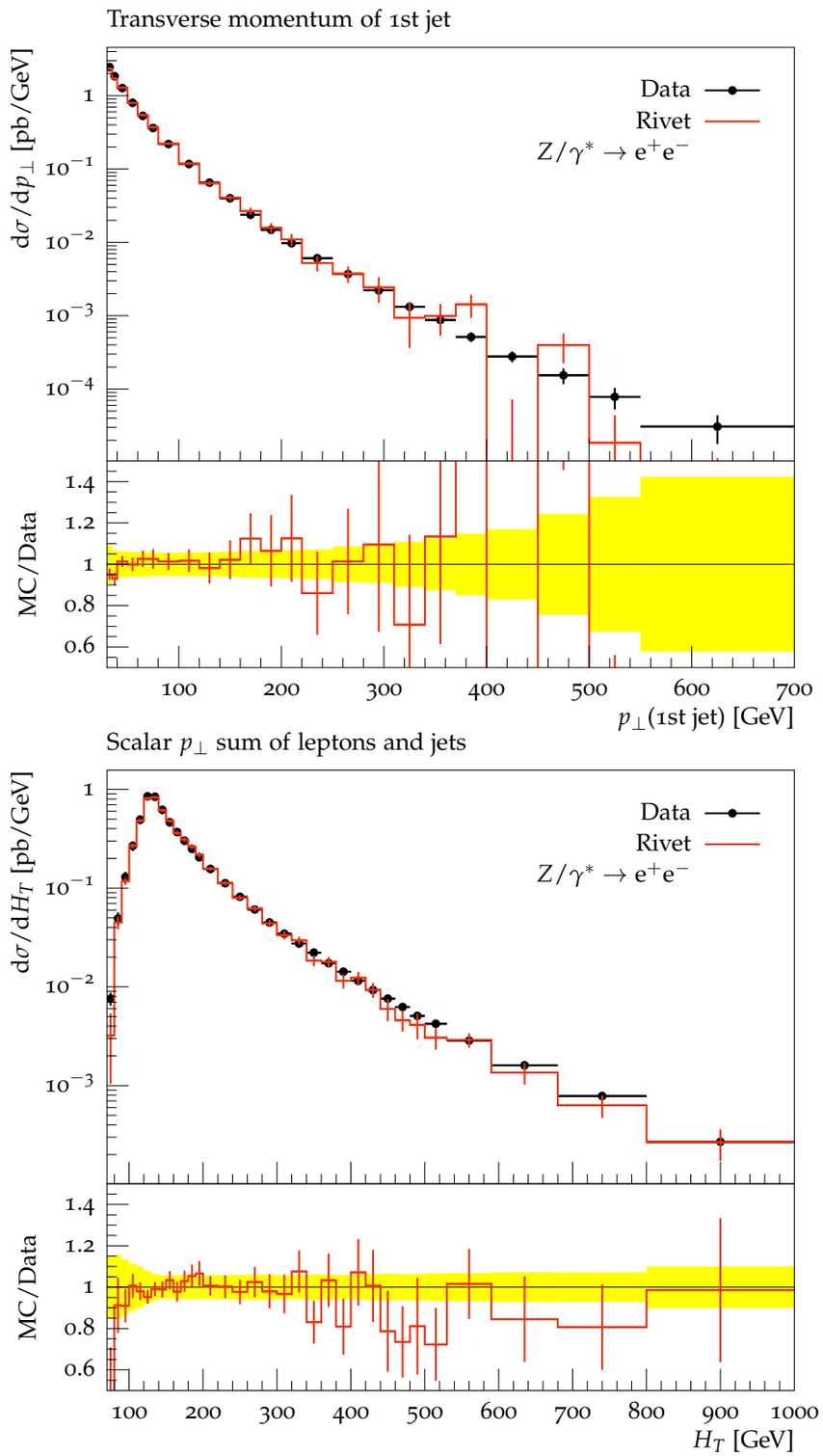
  - can merge arbitrary number N of NLO multiplicities with M>N LO multiplicities

  - implemented in **`PYTHIA8`**

  - works “easily” with **`aMC@NLO`**

Simulation's validation $pp \to e^+e^- @ \sqrt{s} = 7$ TeV LHC





$$\begin{aligned} \text{NLO:} &\quad 1j \\ \text{LO:} &\quad 4j \\ t_{\text{MS}} : &\quad 25\,\text{GeV} \\ \mu_R = \mu_F : &\quad m_Z \\ \text{PDFs:} &\quad \text{CT10} \end{aligned}$$

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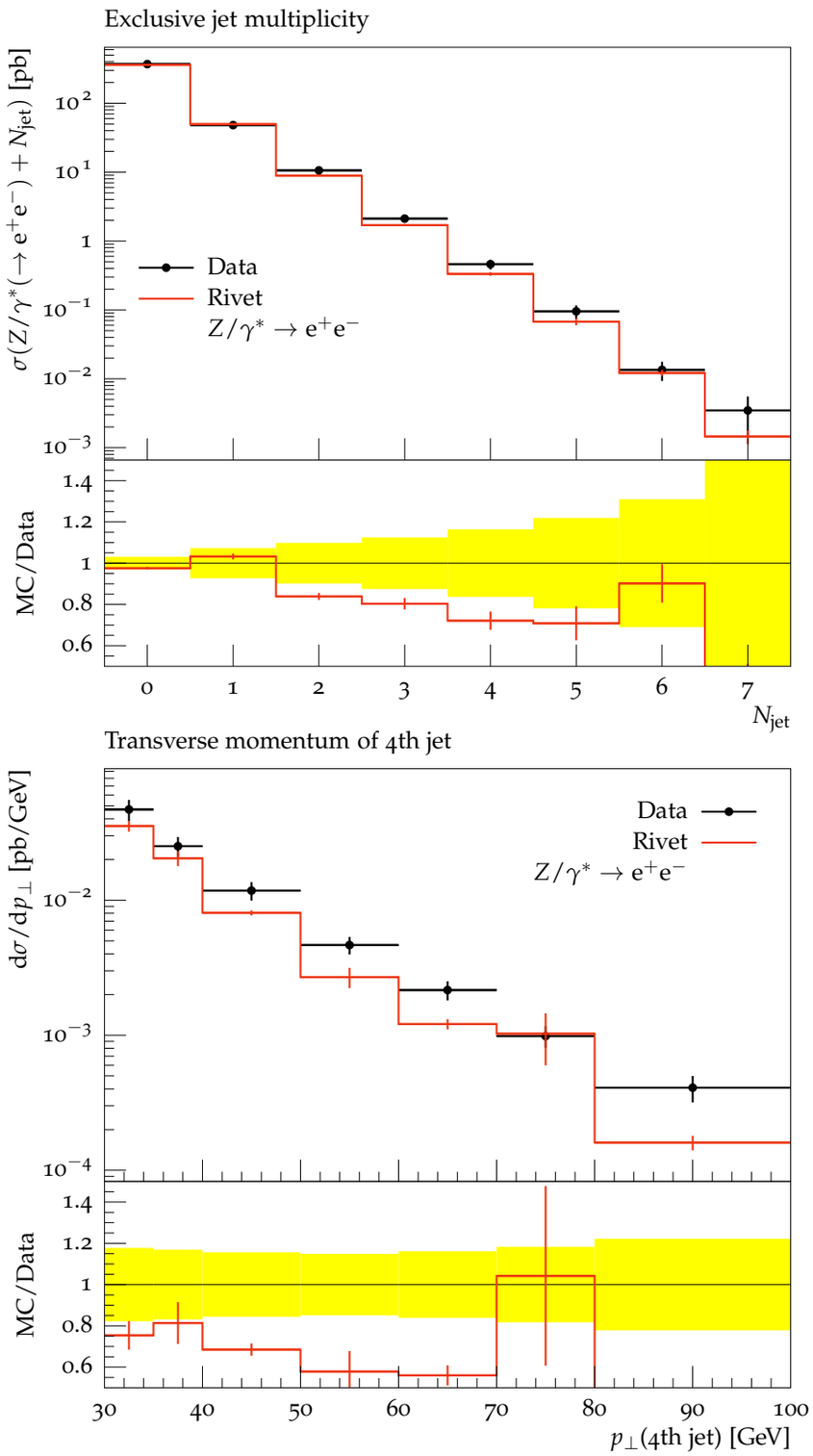

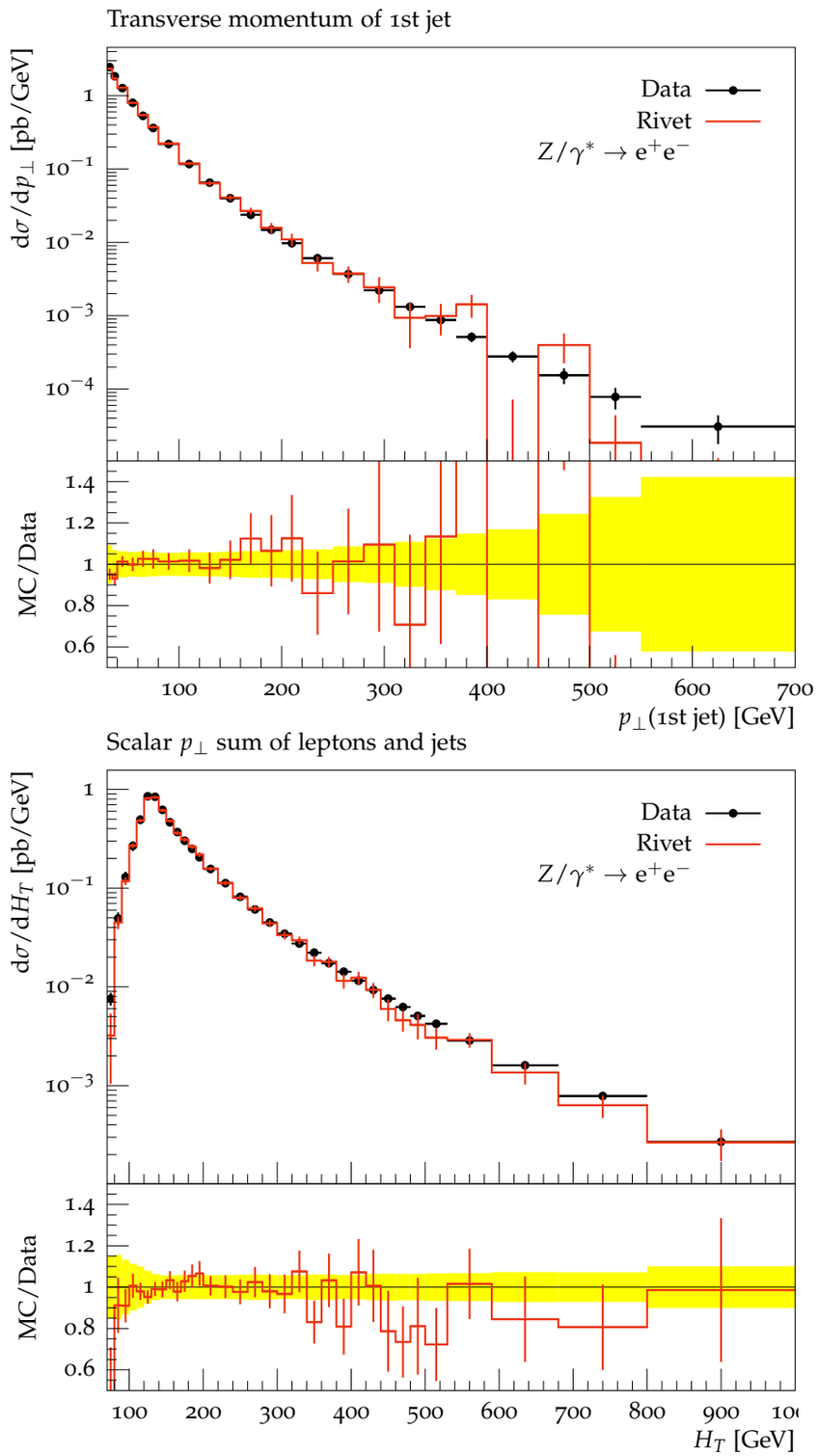

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Experimental signature for $pp \to \sigma\sigma^* \to t\bar{t}t\bar{t}$

- How can a sgluon pair look like for (two different, distinct signatures)
  - 4 massive jets allowing to reconstruct sgluon's mass
  - excess of events with same-sign leptons

	$t\bar{t}t\bar{t}$	$t\bar{t}W^{\pm}$	$t\bar{t}Z$
$\sigma[fb]$	14.7	489+246	987

- „Simple" idea — look for events with same-sign muons

signal

$m_\sigma[\ \mathrm{TeV}]$	$\sigma[fb]$	$\sigma \cdot br[fb]$
1	128	2.5
1.25	23	0.5
1.5	5	0.1

main backgrounds

	$\sigma \cdot br[fb]$
$t\bar{t}t\bar{t}$	0.3
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times branching ratio

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How to reduce background?

- step 1 (preselection) - two same-sign muons
  - $p_\perp$ > 10 GeV, and $|\eta| < 2.4$
  - $p_\perp^{\mathrm{Ratio}}(\Delta R < 0.3) < 0.2$

Allows to discard W, Z and ttbar background*

all further plots made after preselection

- step 2
  - b-tagged jets
  - light jets

In general we expect more b's from signal than from background

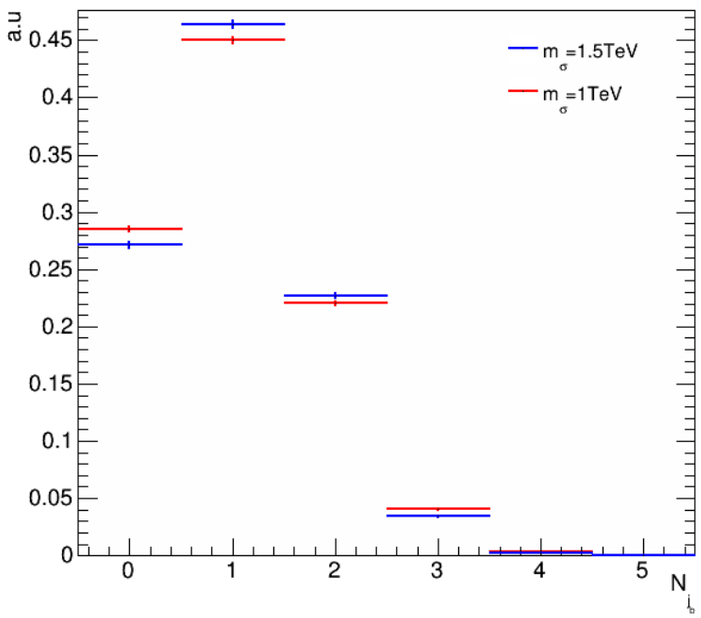
- step 3 - cut optimization
  - missing $p_\perp$

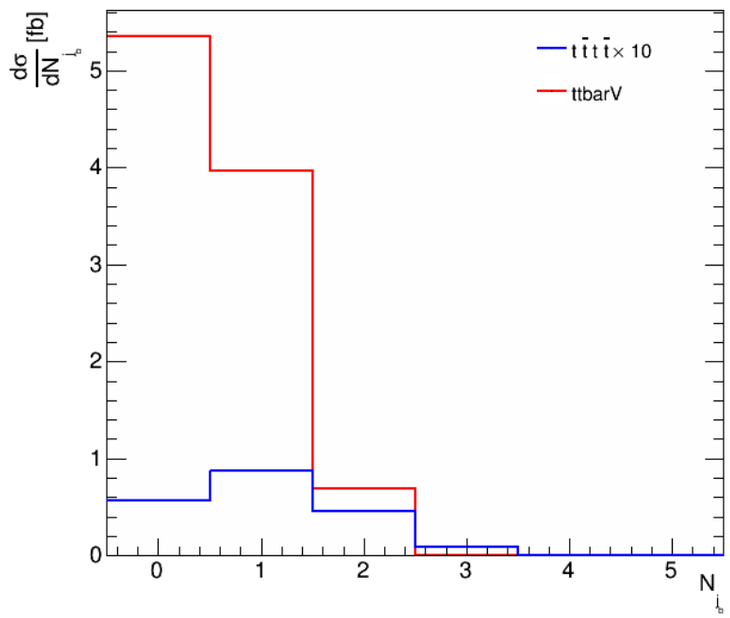
Try to select cuts to maximize S/B ratio

*up to non-promt leptons

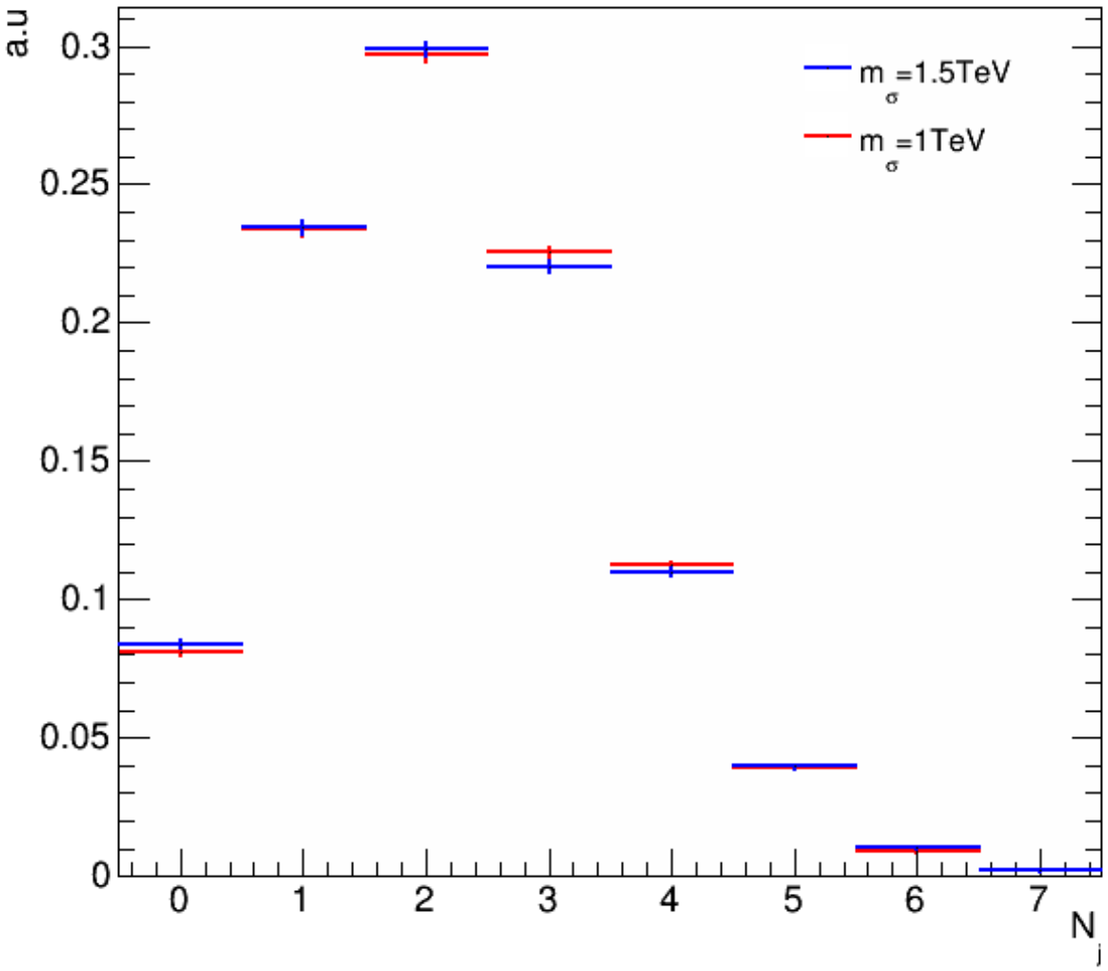
„fat-jets” analysis for b-jets

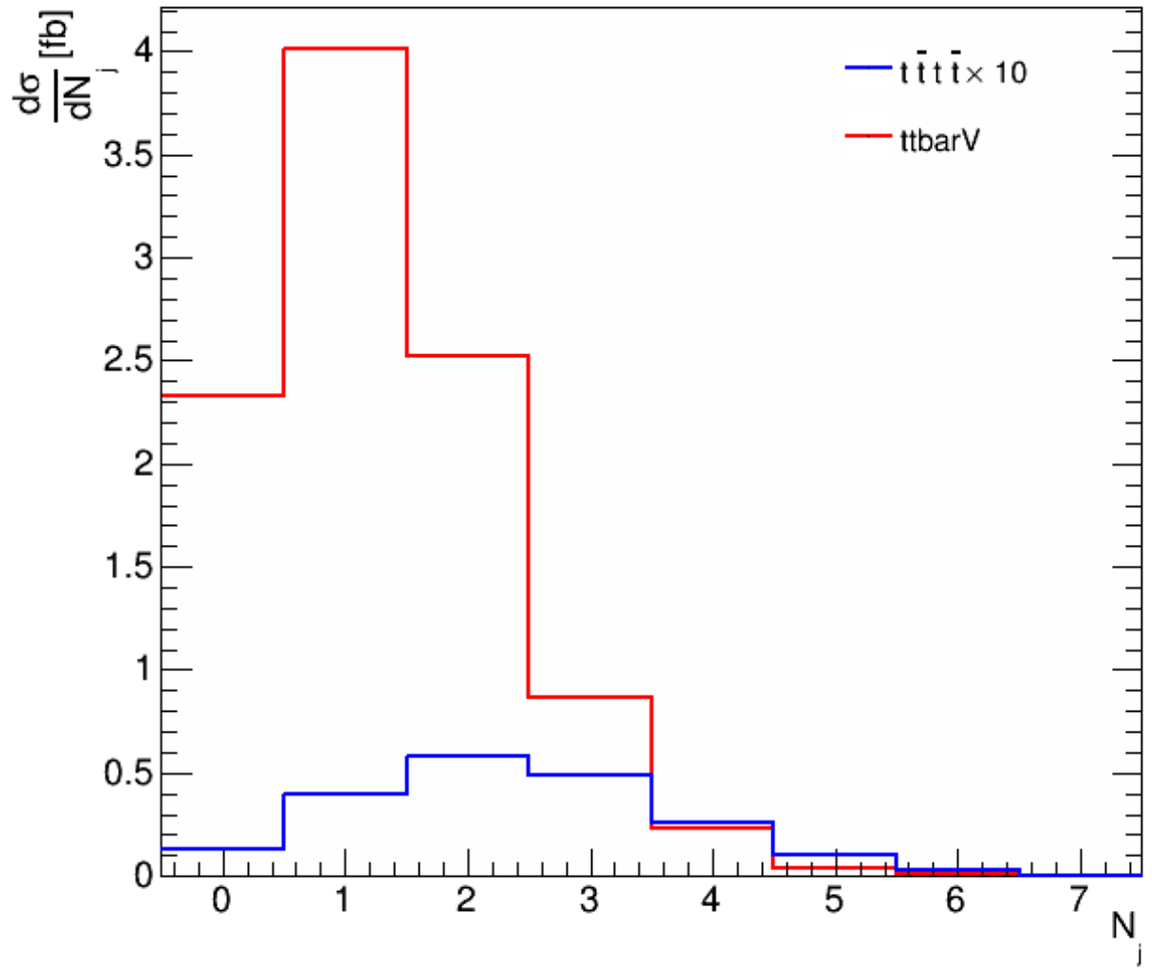
- „Fat-jets” as an observable — Hook, Izaguirre, Lisanti, Wacken (2012)
- b-tagging working point according to Snowmass 2013 projection
  - b-tag efficiency up to 70%
  - c-jet mistag identification rate up to 10%
  - light jet mistag rate 0%
- Number of b-tagged jets with $\Delta R = 1$ and $p_\perp > 50\mathrm{GeV}$





„fat-jets” analysis for light jets

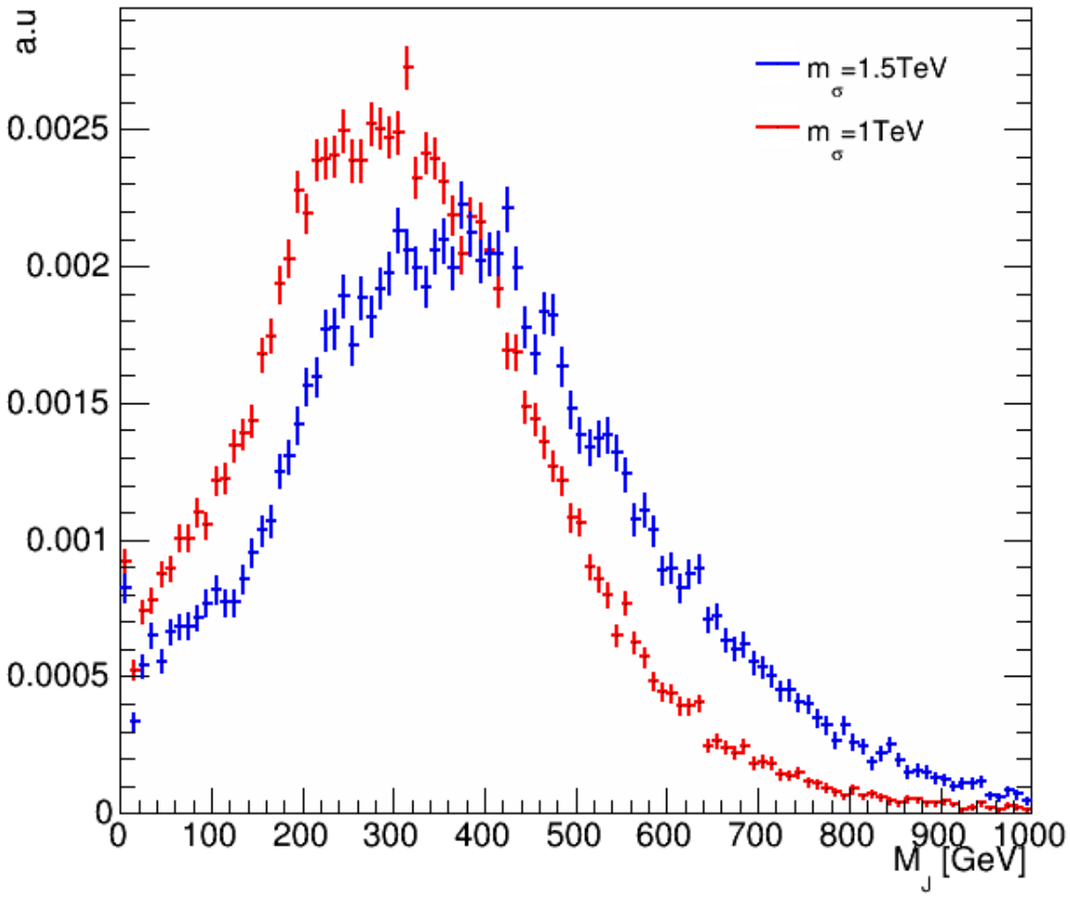


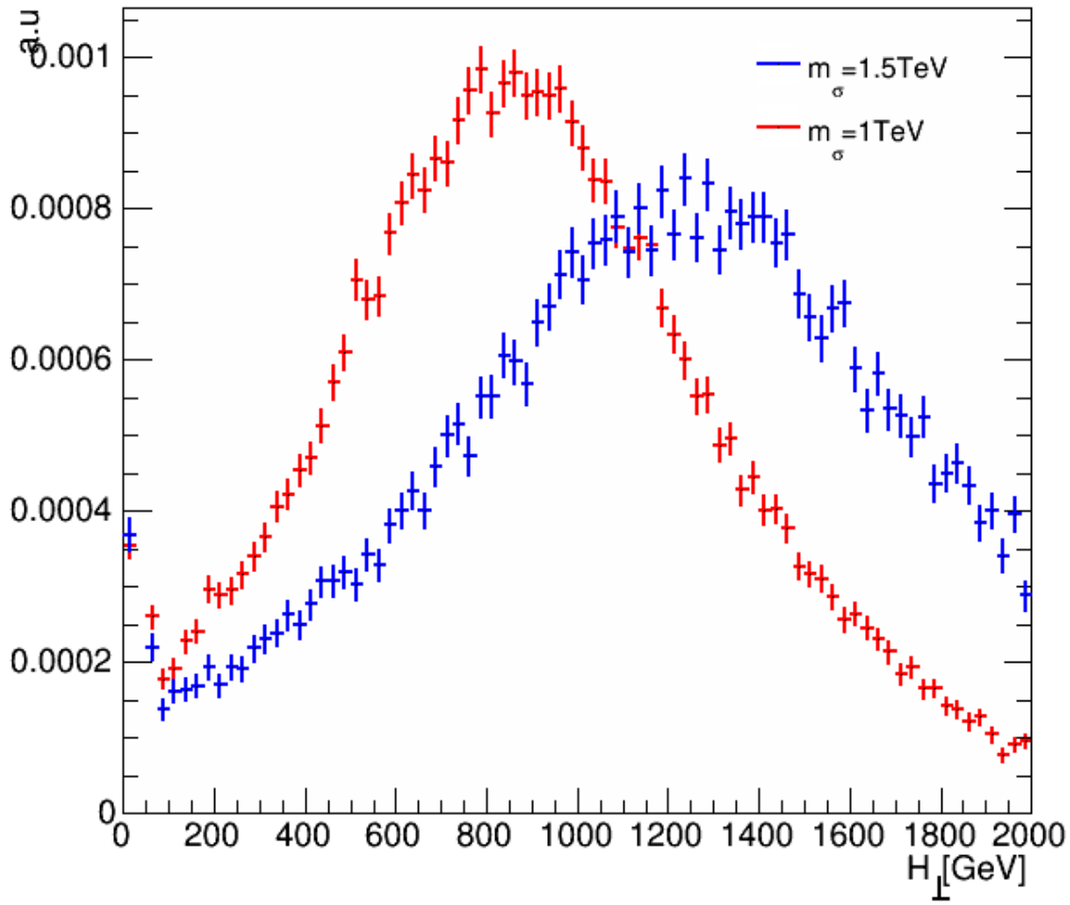


M_J vs. $H_\perp$ as a discriminating variable

PHYSICAL REVIEW D 85, 055029 (2012)

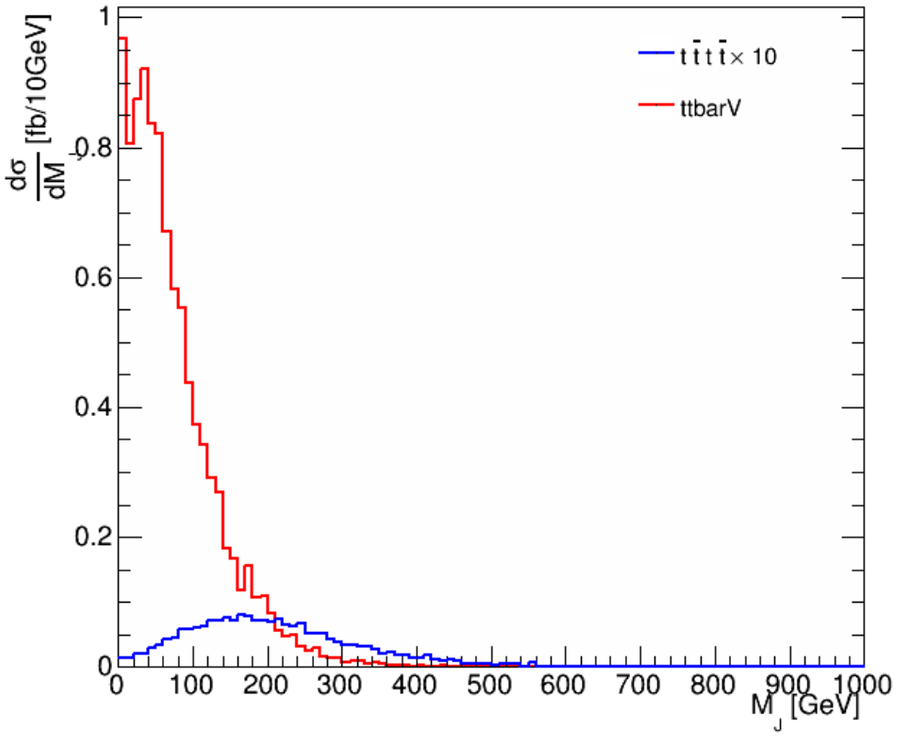
- We expect sum of jet masses for the signal to be concentrated around $2 \times m_t$

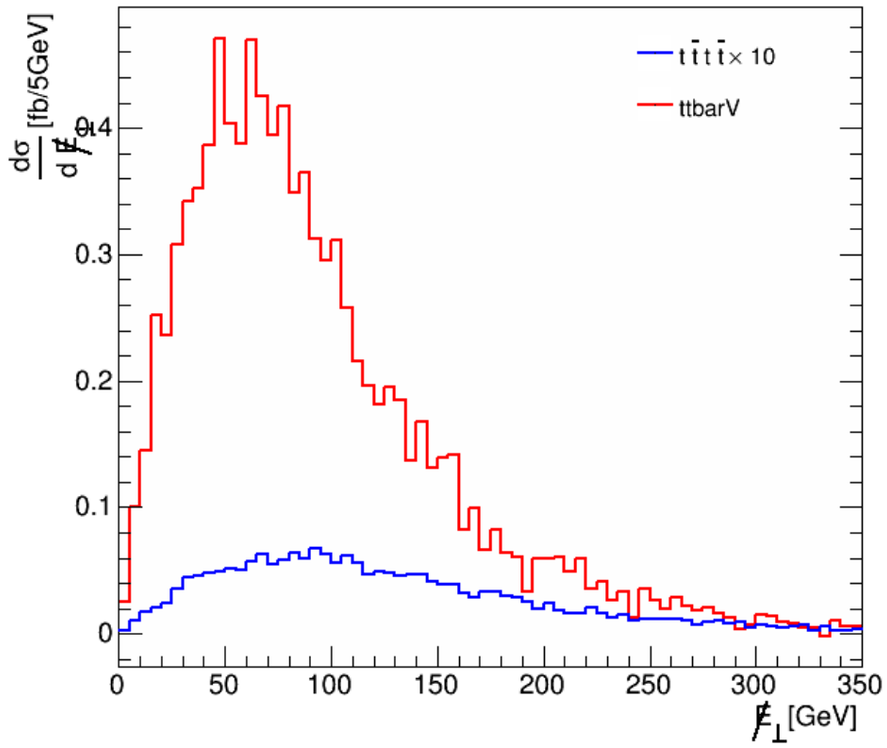




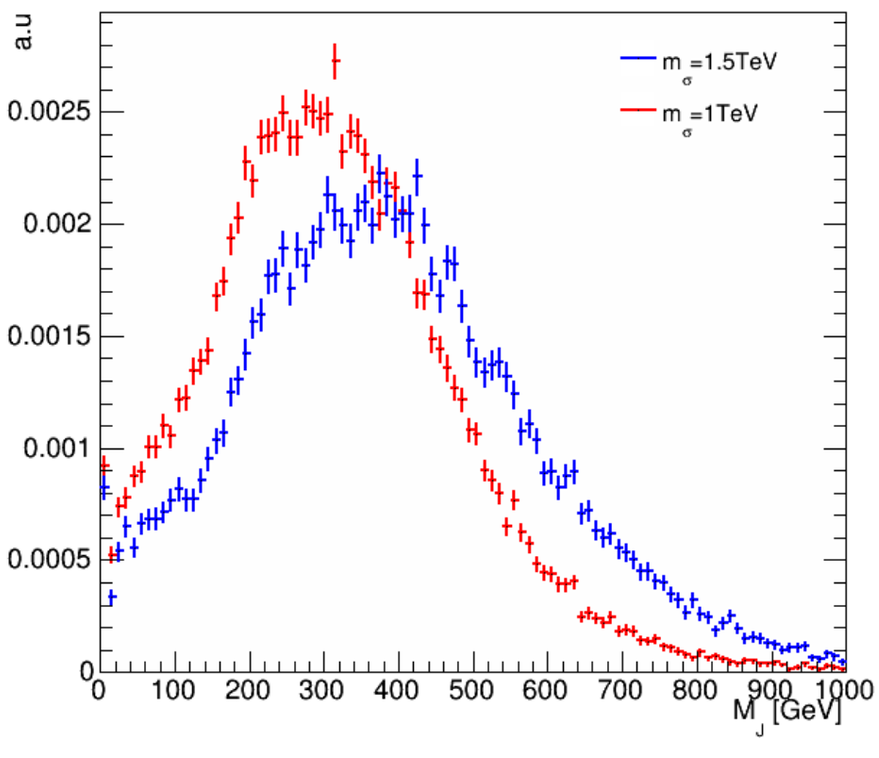
- Smaller variation with sgluon's mass - allows for mass independent search for sgluons

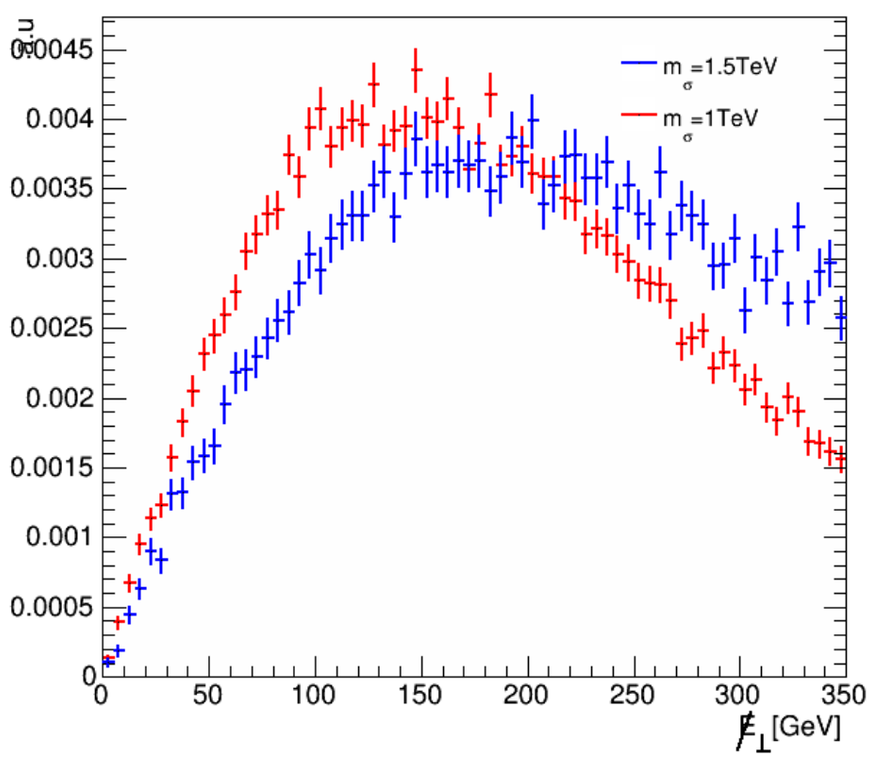
Jet mass and missing $E_\perp$ spectra





backgroud





signal

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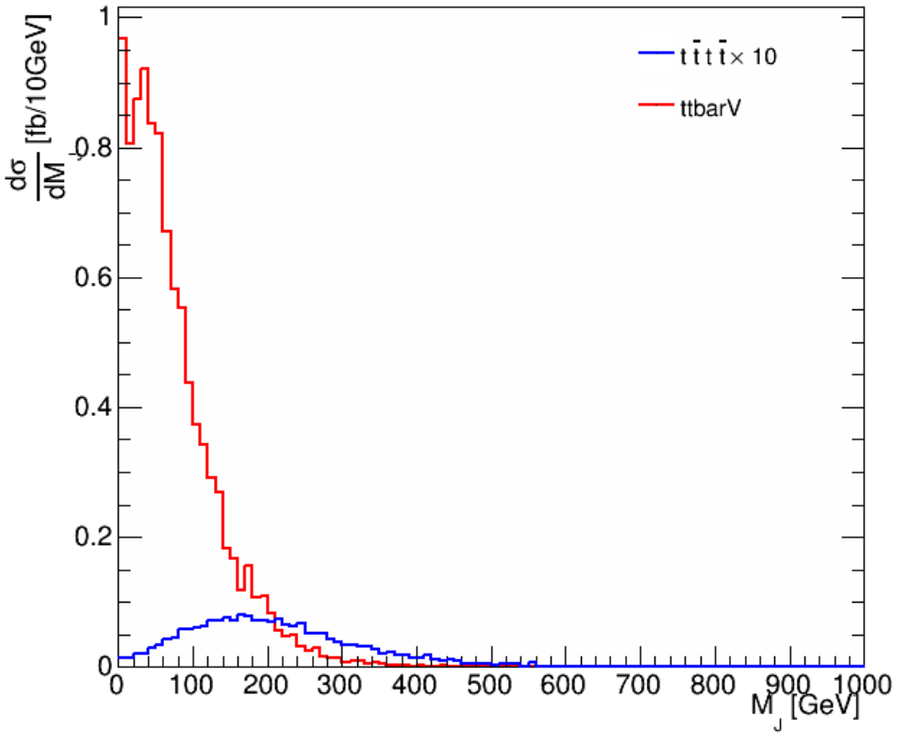

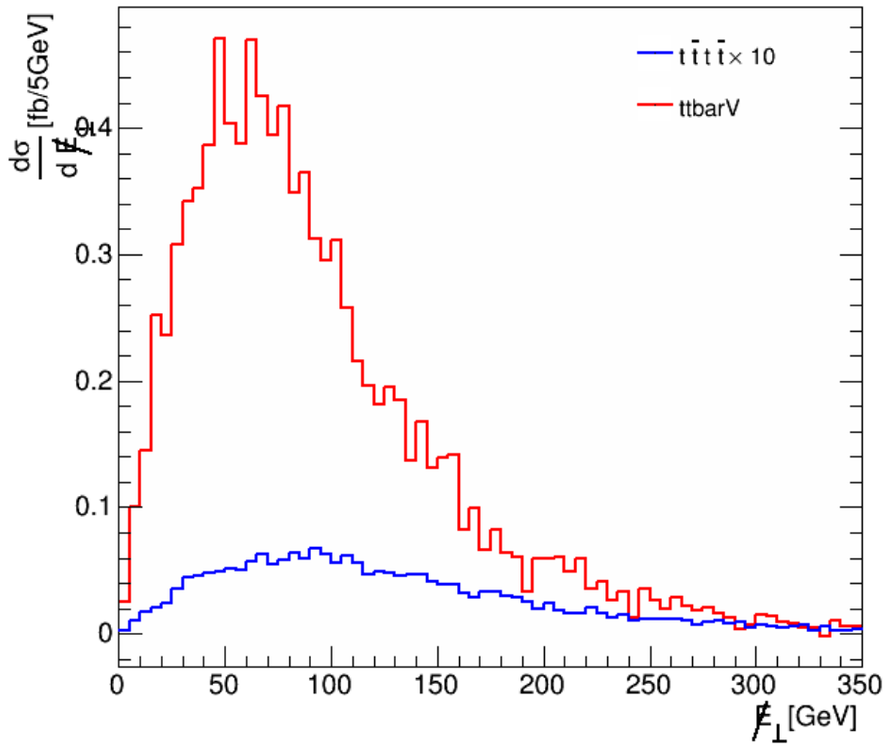

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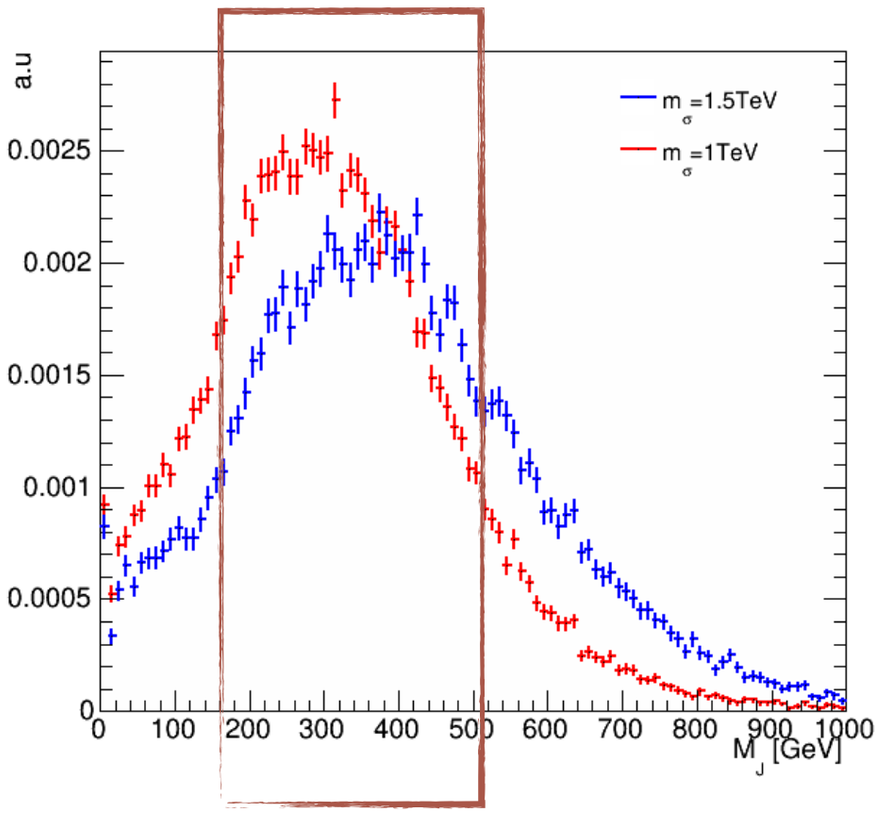

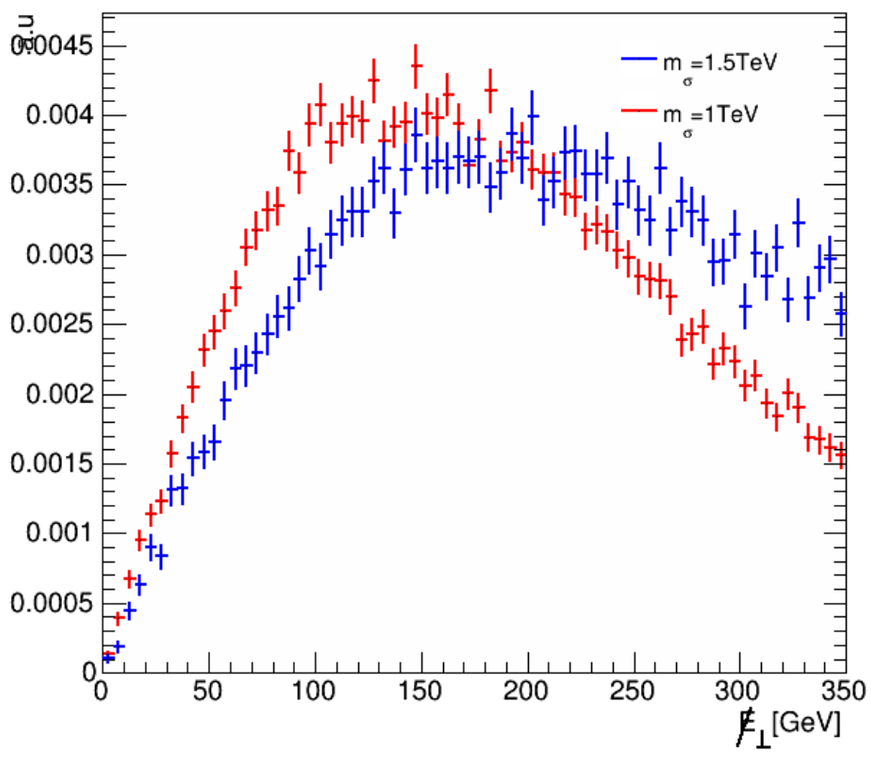

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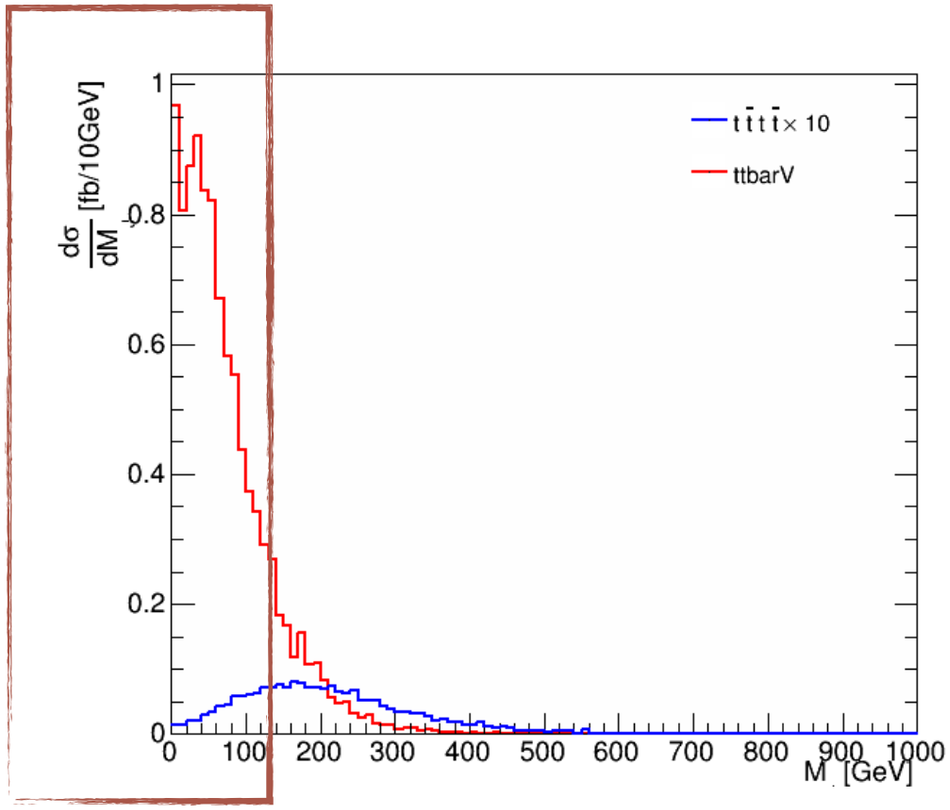

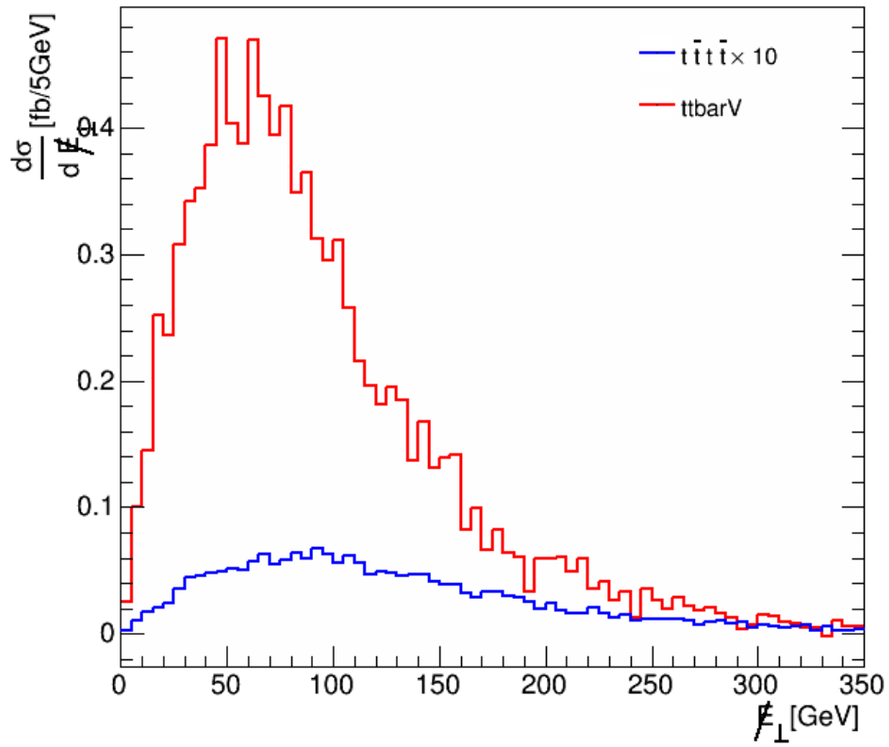

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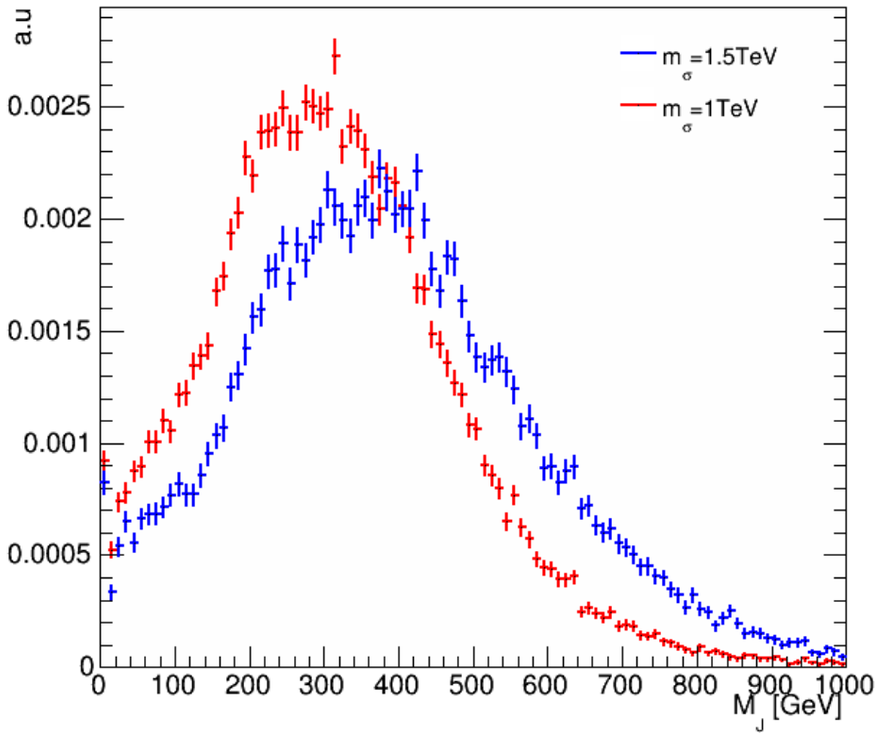
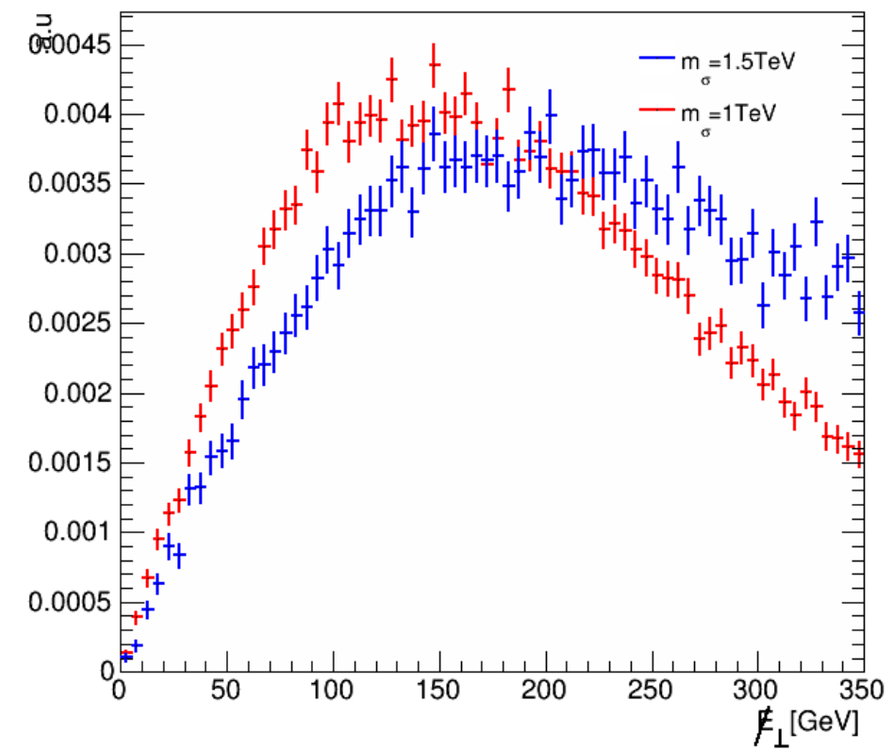
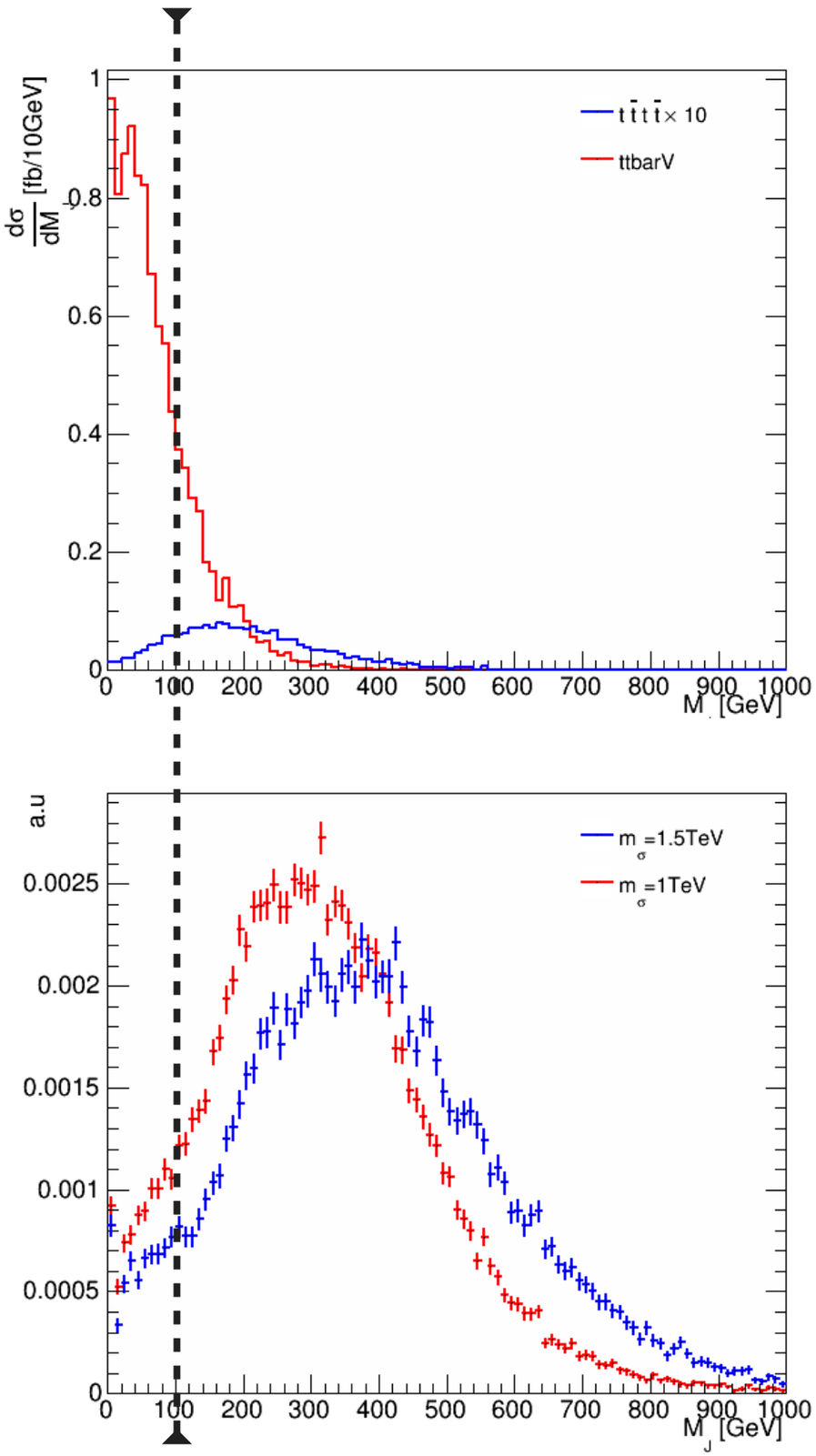
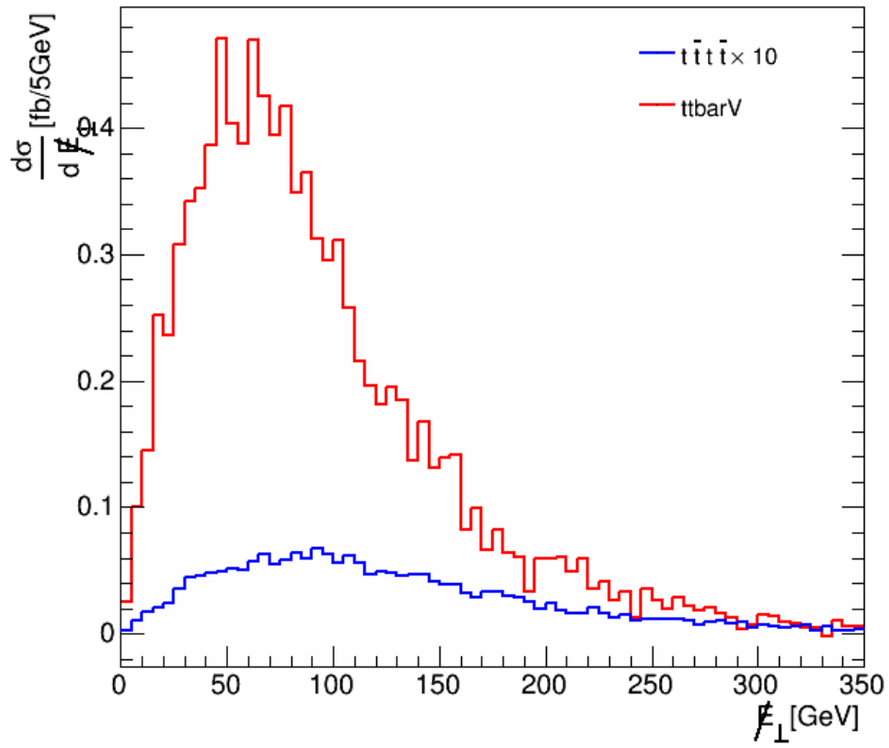




signal

Jet mass and missing $E_\perp$ - Jet mass selection





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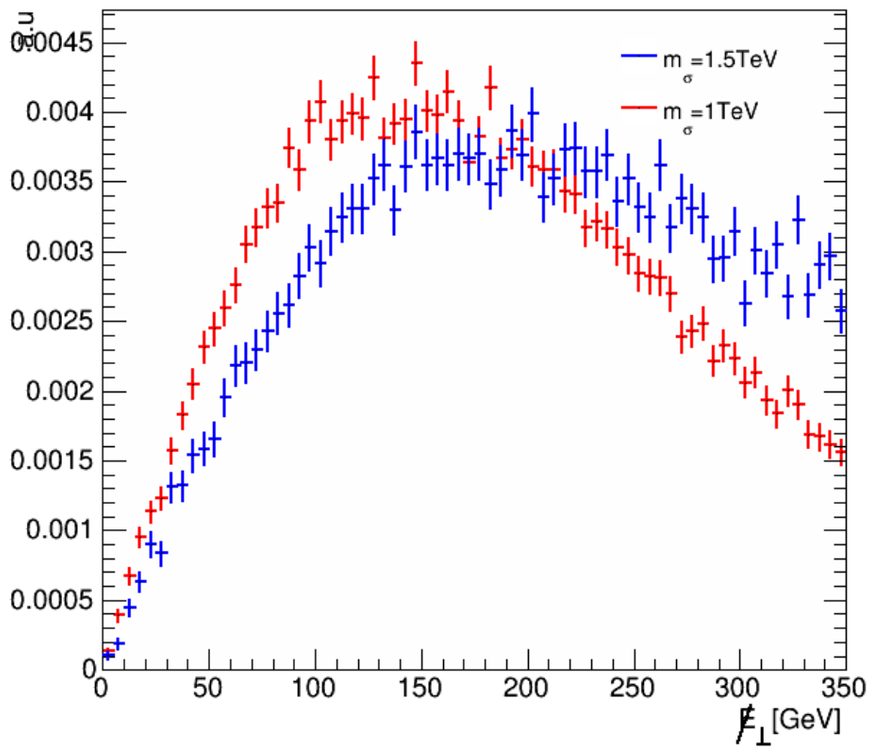
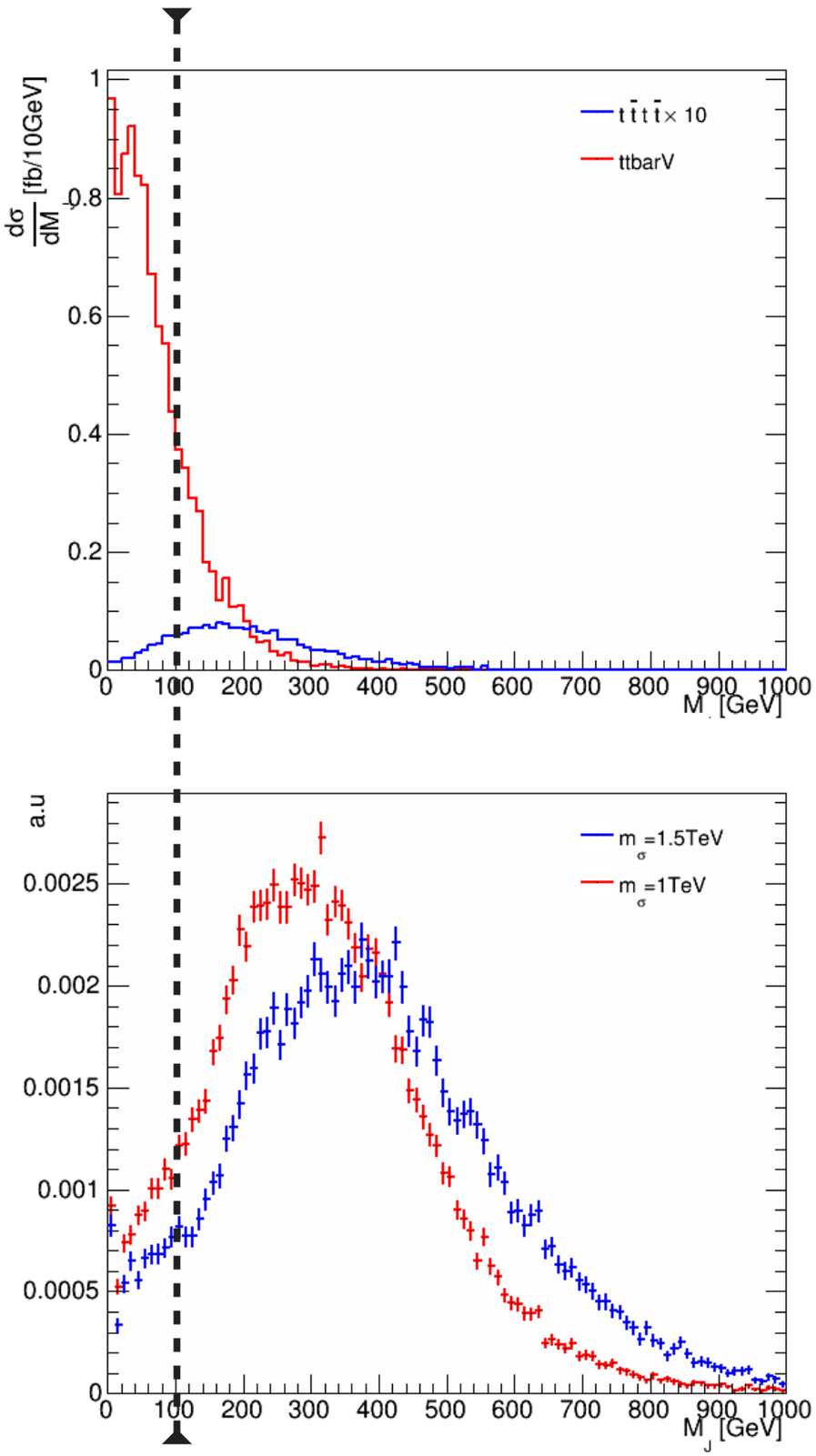
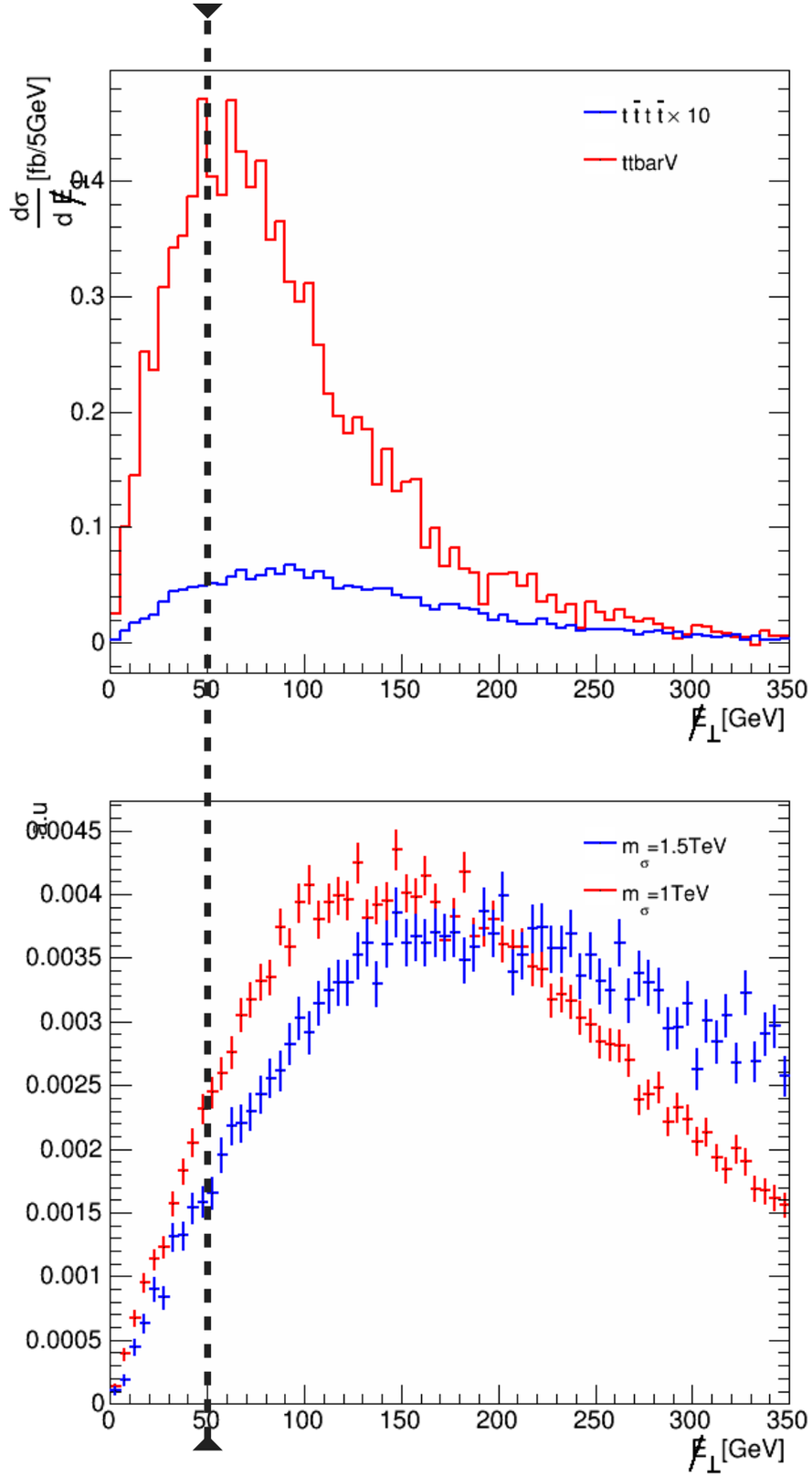


signal

Jet mass and missing $E_\perp$ — final selection

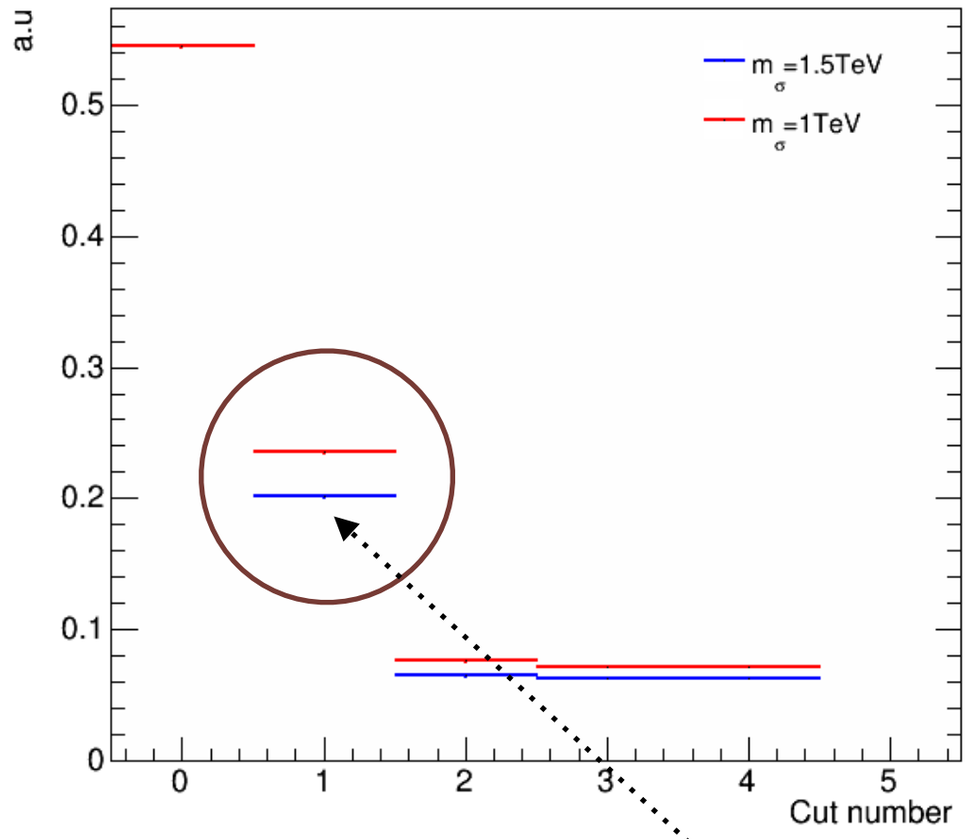


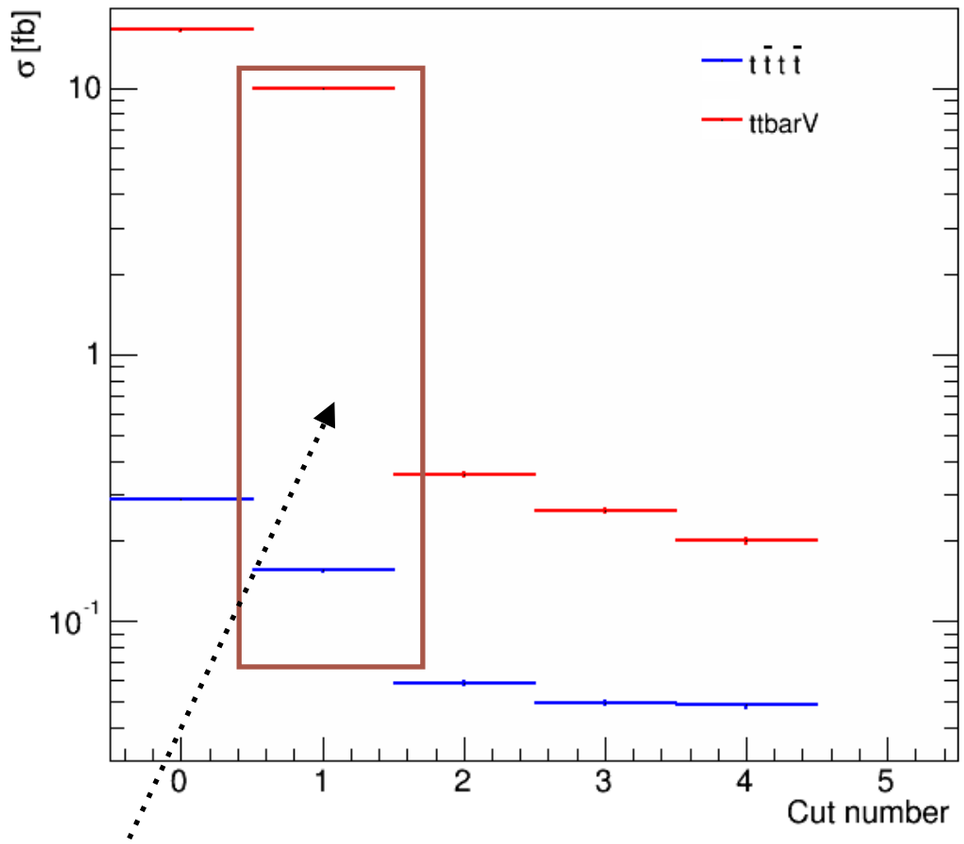


backgroud

signal

Final result





two same-sign isolated muons

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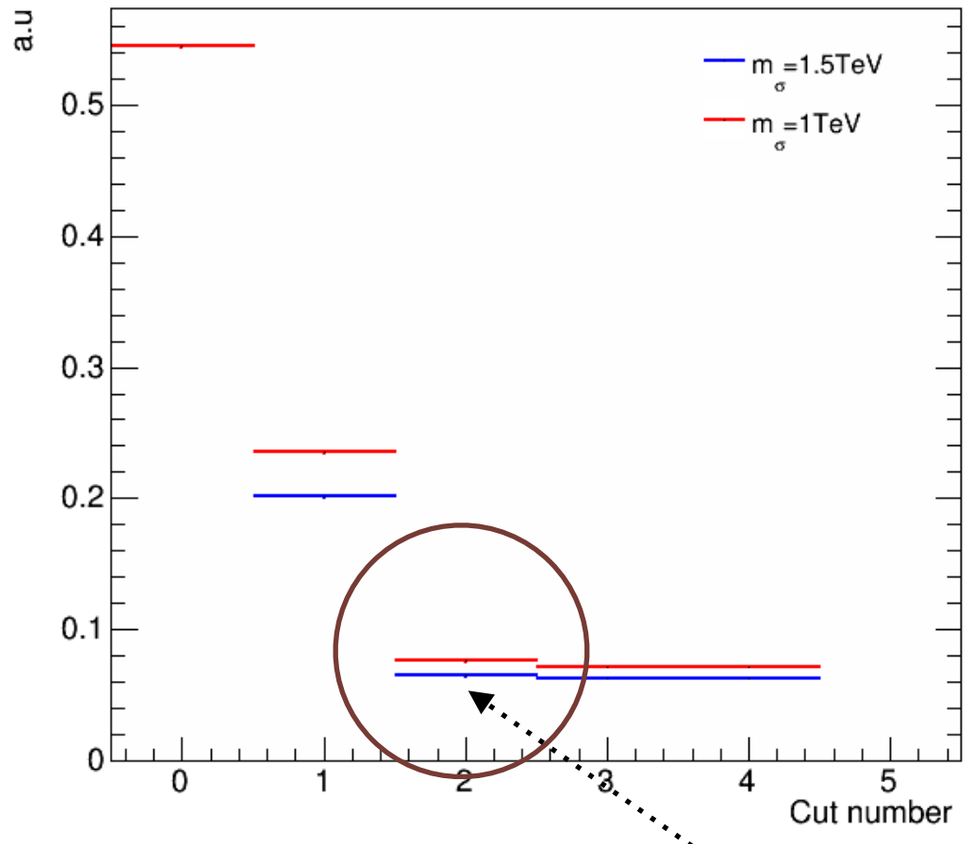

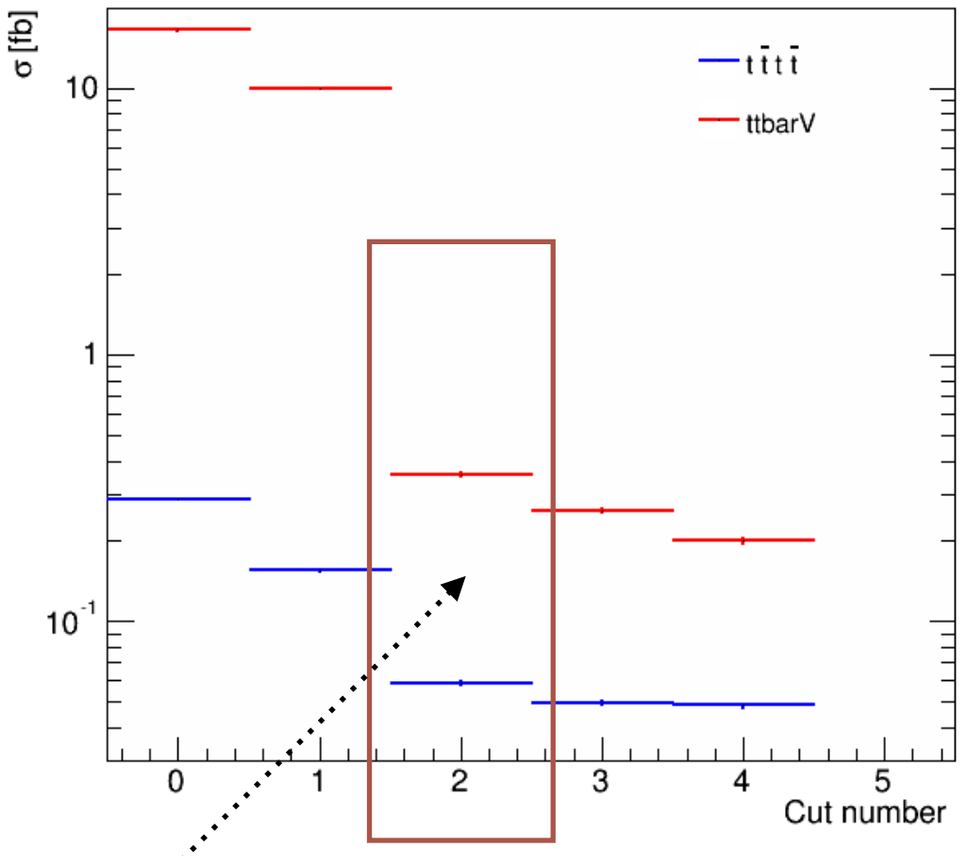

at least 1 b-jet and 2 light jets

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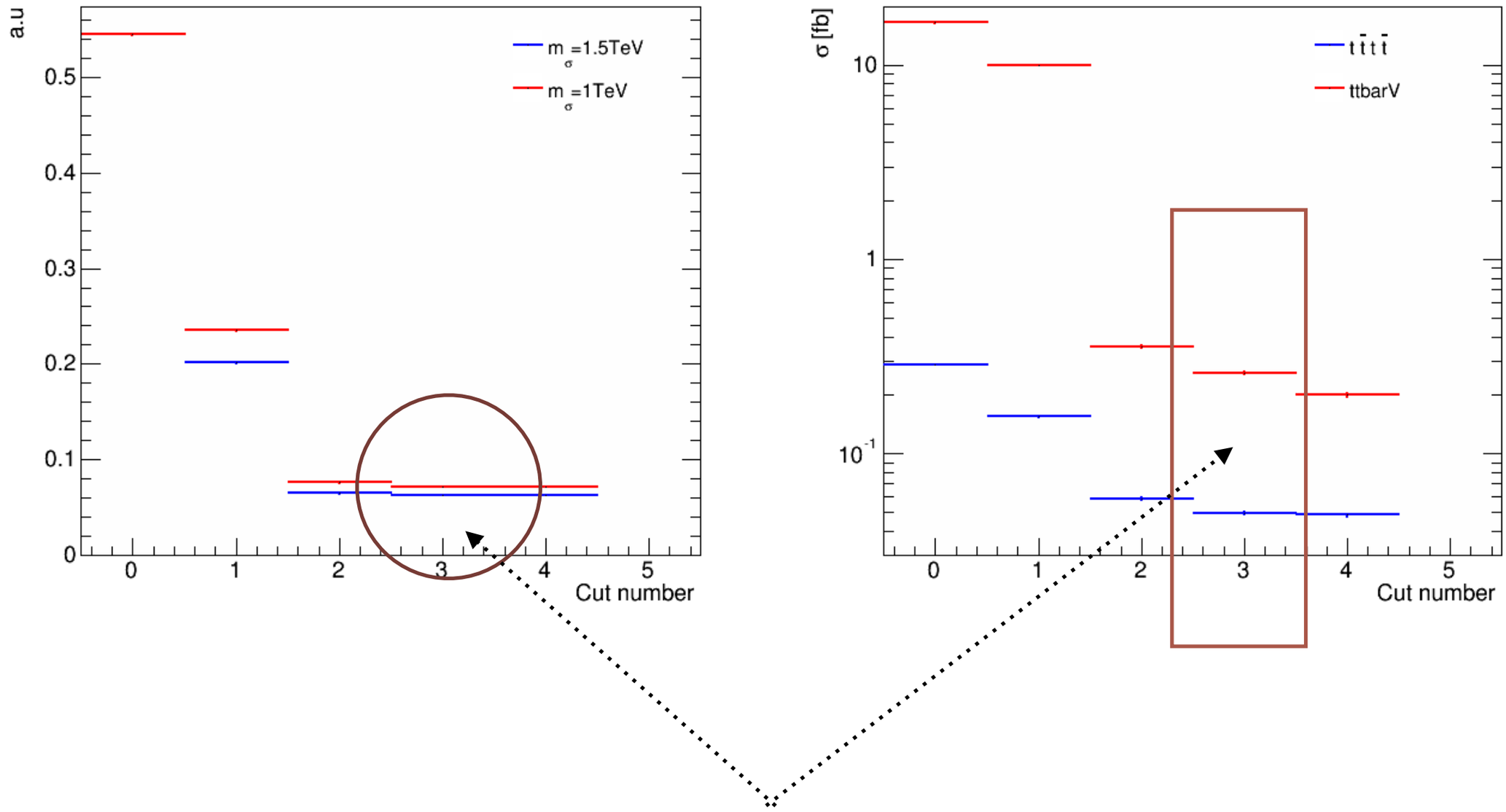
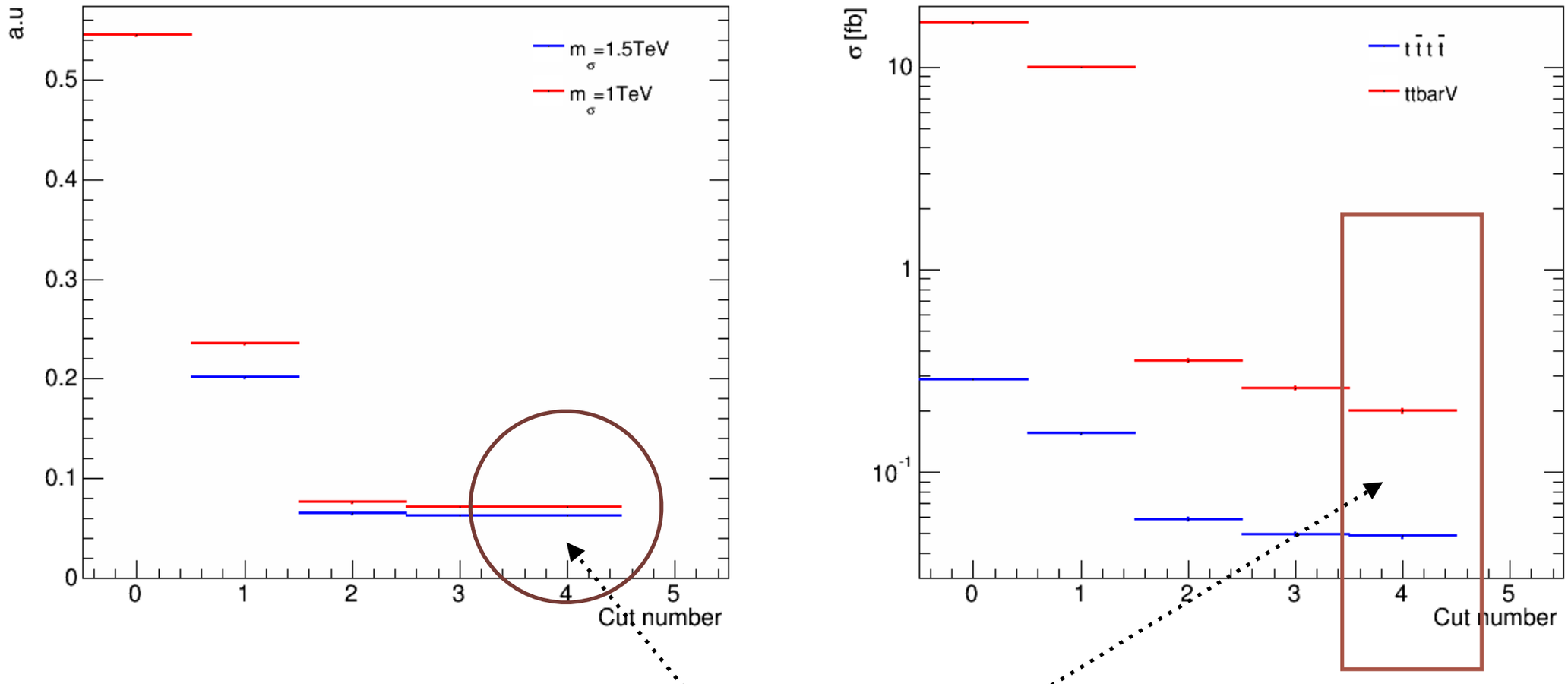


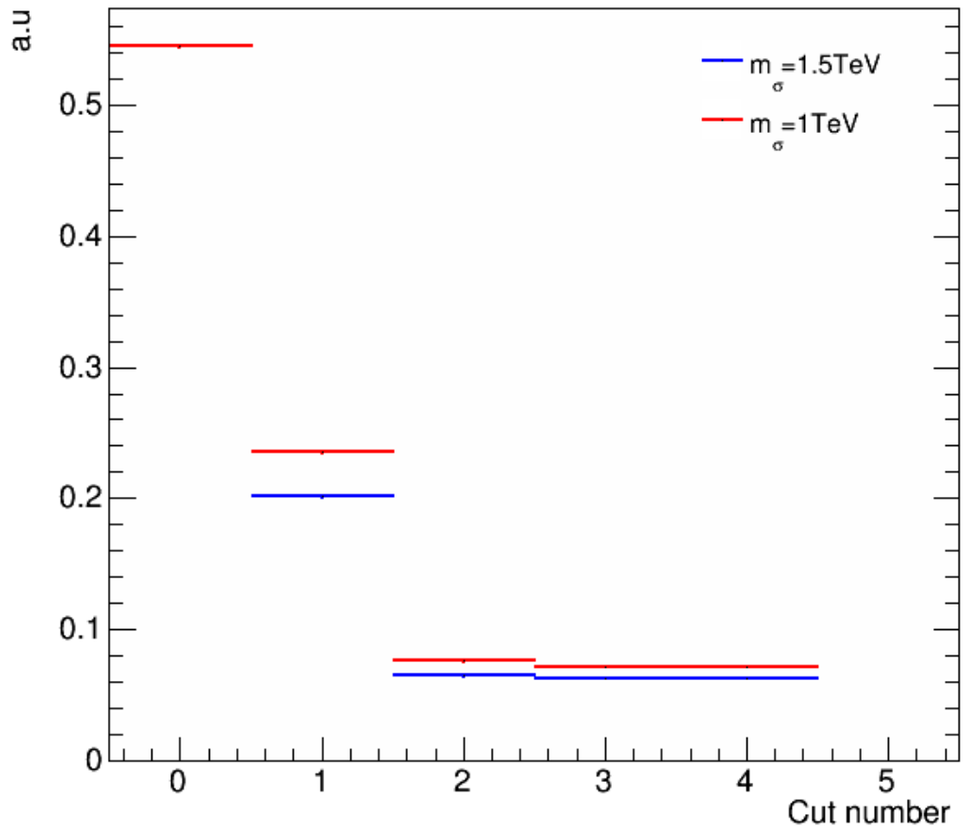
MET > 50 GeV

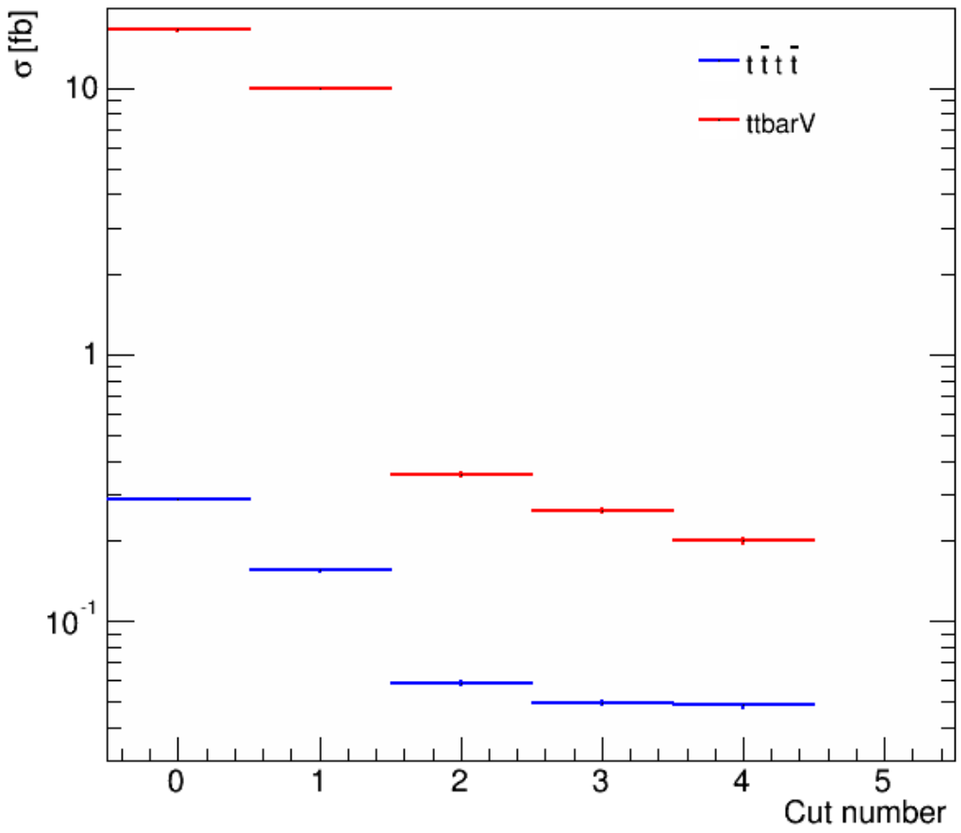
Final result



sum of jet masses > 100 GeV

Final result for 300/fb





	$m_\sigma = 1$ TeV
$S/\sqrt{B+1}$	5.7

- selection efficiency for different masses of sgluon similar
- $S/\sqrt{B+1}$ drops like signal's cross-section

Conclusions and outlook

- Kinematic reach of the 14 TeV LHC at 300/fb allows to probe sgluons with masses up to 1.1 TeV
- Selection optimization is on-going
- Caveat: Importance of pile-up? $\mu = 50, 100?$
- One can also exploit other channels:
  - 4-leptons final state
  - all hadronic decays in the boosted topology - reconstruction of sgluon's mass
  - model dependent single sgluon production