Looking for scalar gluons

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Various Faces of QCD - Kielce, 11th May 2014

in collaboration with J. Kalinowski and S. Prestel

Motivation

- We are all waiting for the 2015 LHC Run 2 phase 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

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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Colored scalars: sgluons

Tree-level couplings

- $\sigma\sigma^* g$ and $\sigma\sigma^* gg$ couplings as required by gauge invariance
- to gluinos $-\sqrt{2}\, i\, g_s\, f^{abc}\, \overline{\tilde{g}'^a_L}\, \tilde{g}^b_R\, \sigma^c_C + \text{h.c.}$
- Dirac gluino mass => trilinear scalar couplings to squarks

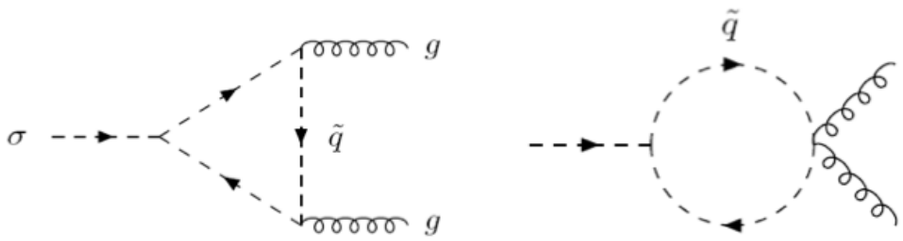
$$-\sqrt{2}\, g_s\, M^D_C\, (\sigma^a_C + \sigma^{a*}_C)\, \left(\tilde{q}^*_L\, \frac{\lambda^a}{2}\, \tilde{q}_L - \tilde{q}^*_R\, \frac{\lambda^a}{2}\, \tilde{q}_R \right)$$

vanish for degenerate L/R squarks

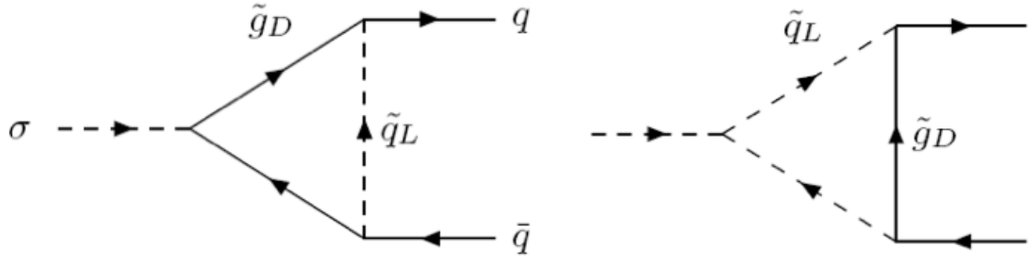
➡ Although R=0, single sgluon cannot be produced at treel level

Loop-induced couplings

- to a gluon or quark pair through diagrams with squarks or gluinos



(gluino loops vanish)

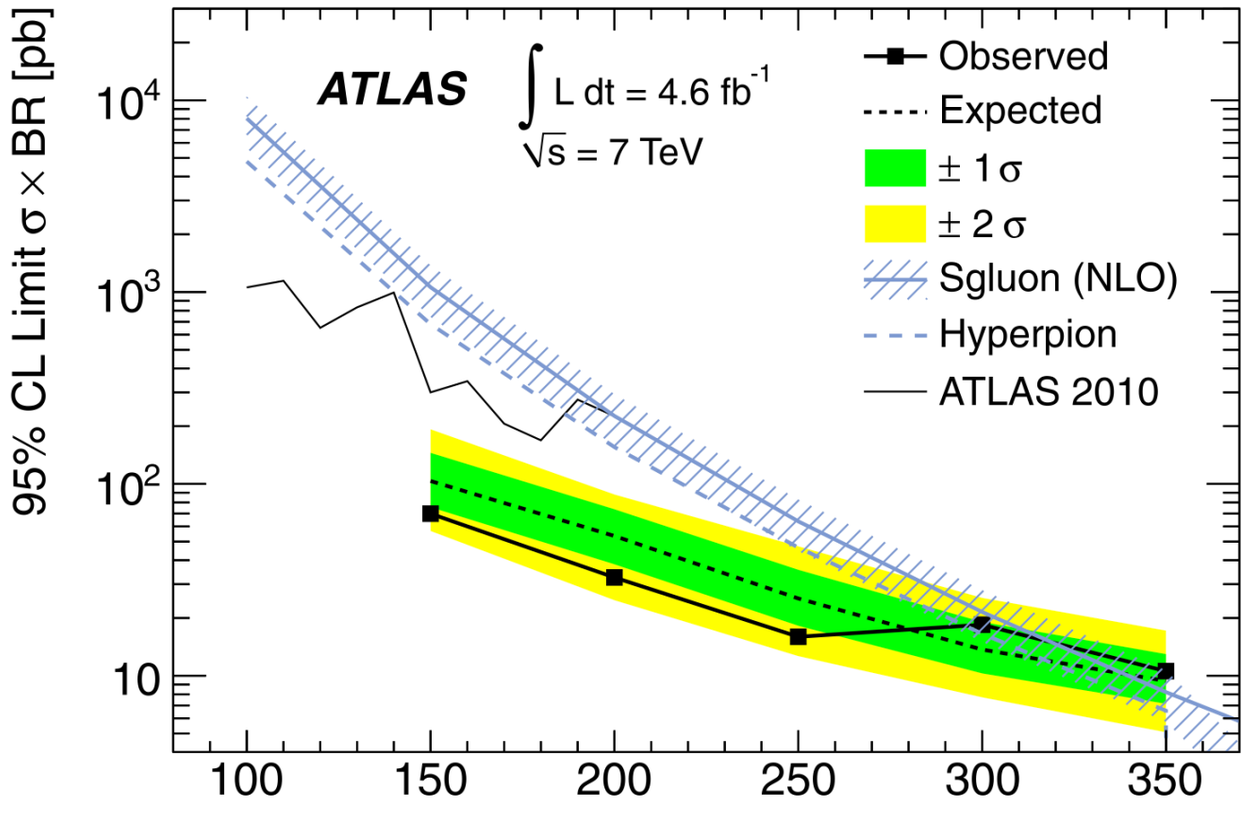


$\sim m_q$

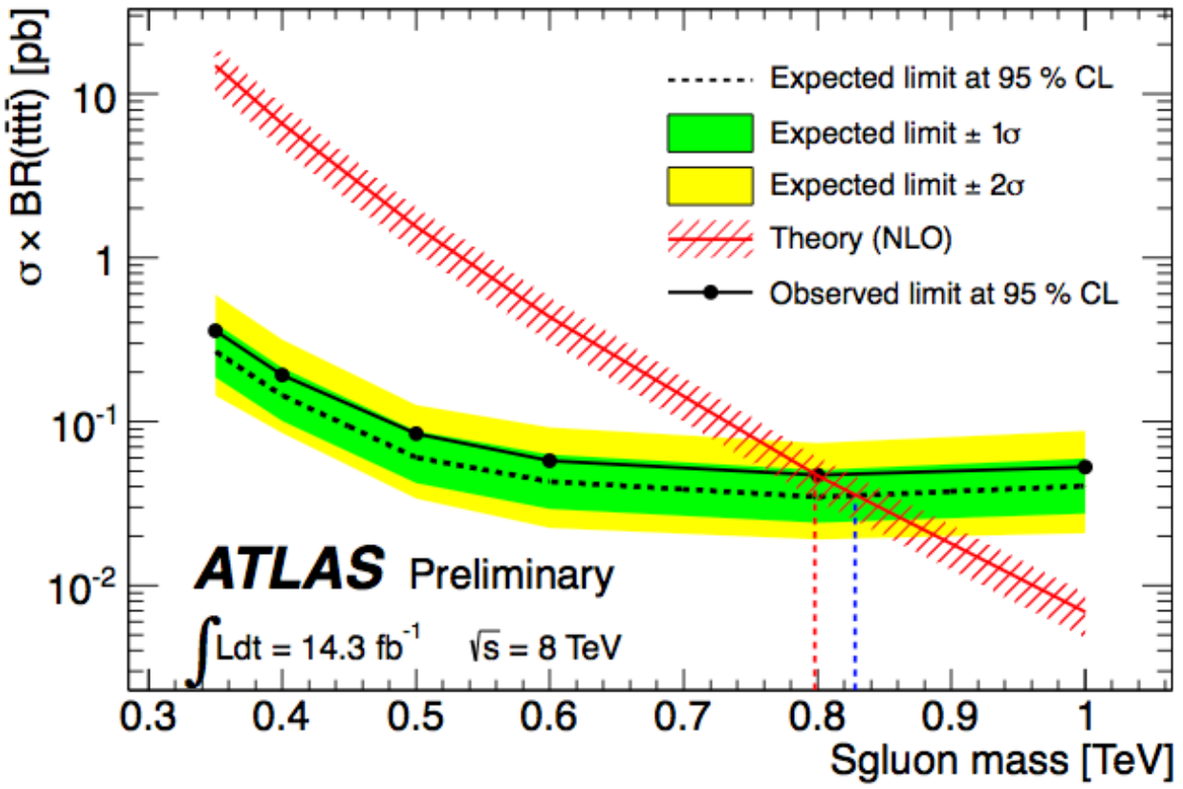
Choi, Drees, JK, Kim, Popenda, Zerwas '09
Plehn,Tait '09

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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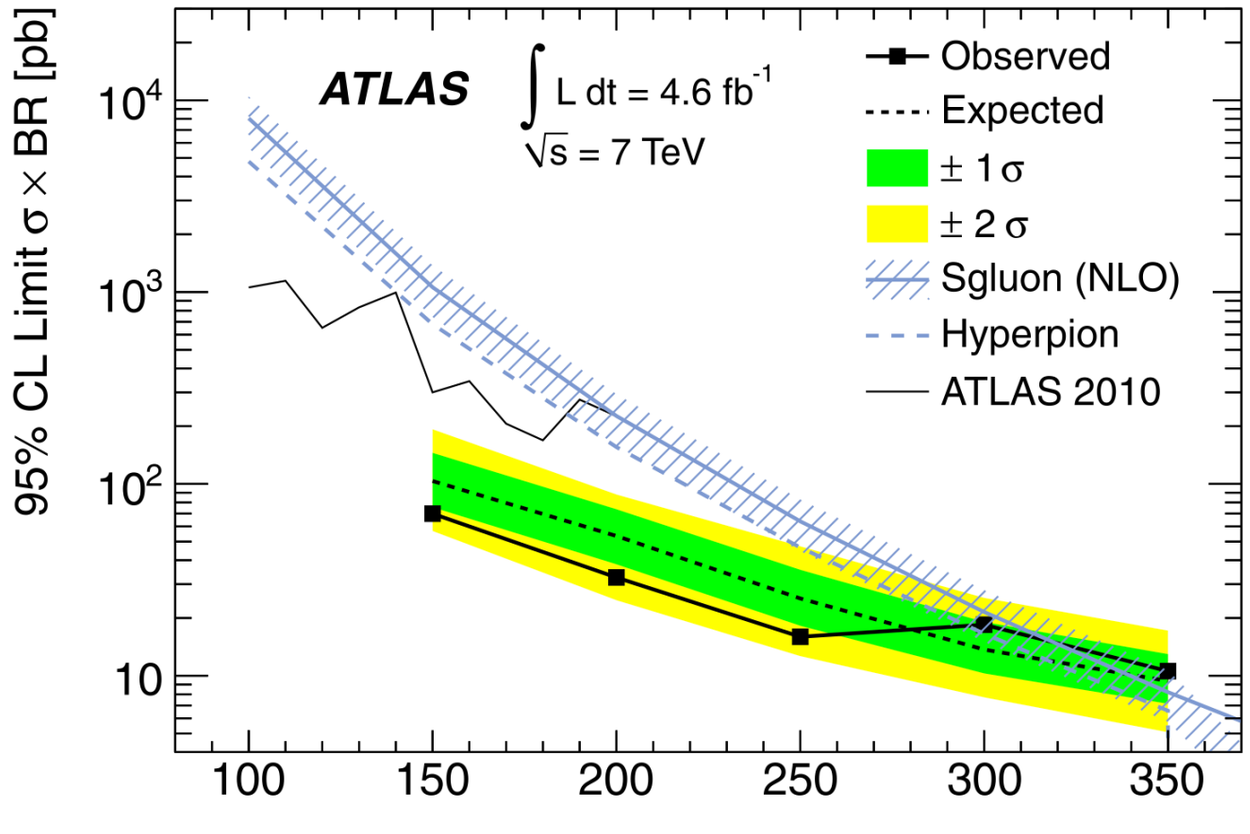

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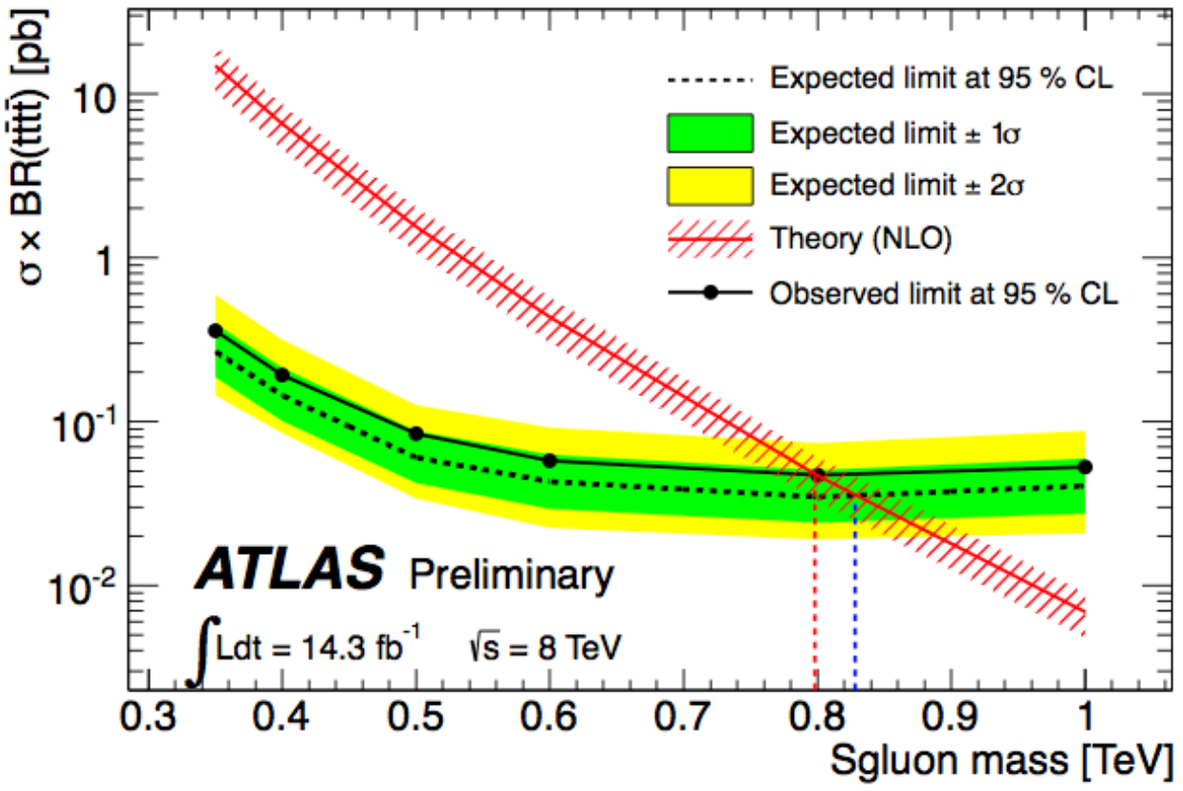


Simulation setup

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

- **UNLOPS** - „Unitarized NLO + PS merging”

  - „unitarization” by explicit subtraction

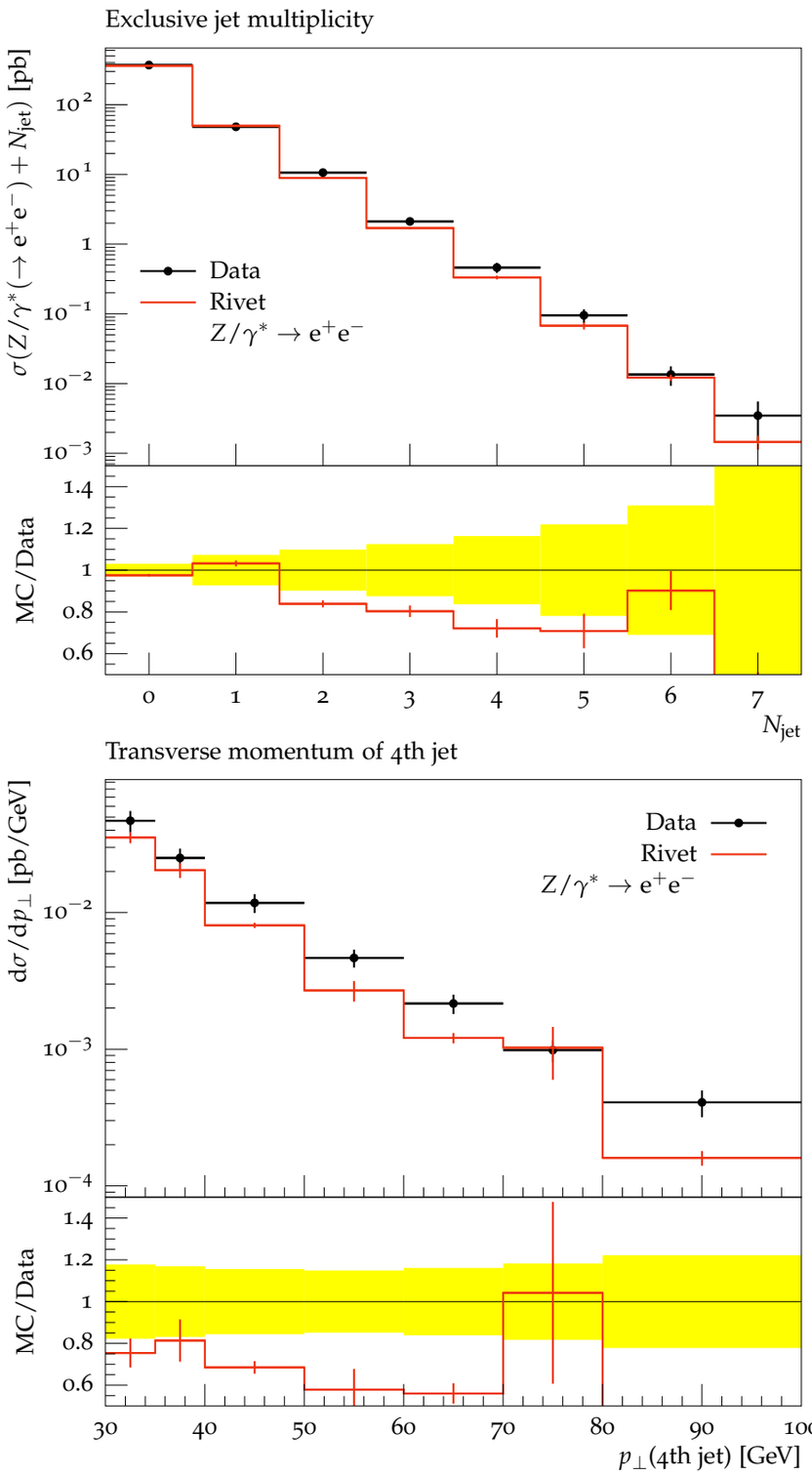
L. Lönnblad, S. Prestel

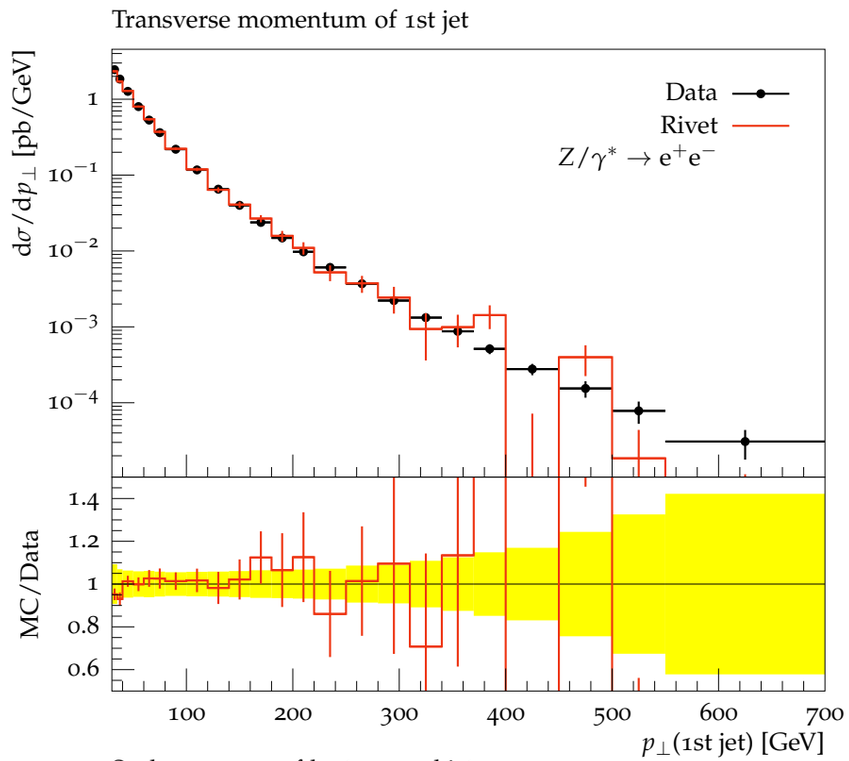
  - can merge arbitrary number N of NLO multiplicities with M>N LO multiplicities

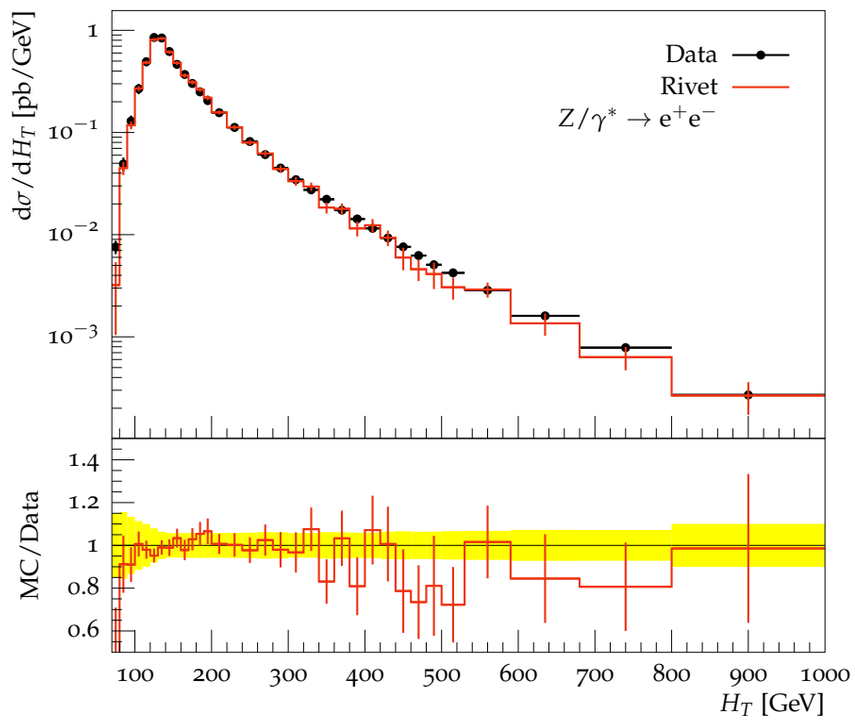
  - implemented in **`PYTHIA8`**

  - after tweaks can be used with **MC@NLO** samples

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







NLO: $1j$

LO: $4j$

t_{MS} : $25\,\mathrm{GeV}$

$\mu_R = \mu_F$: m_Z

PDFs: CT10

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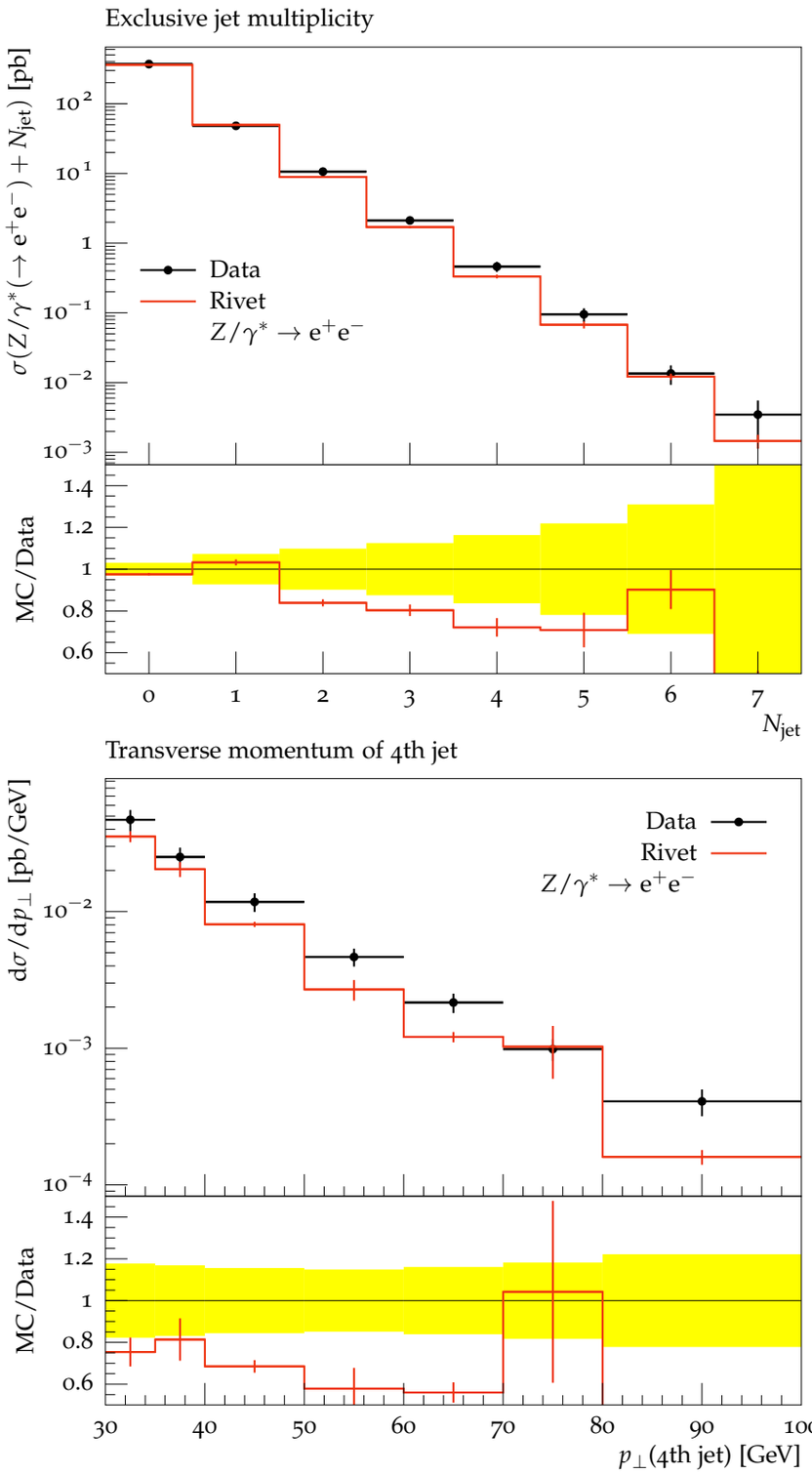
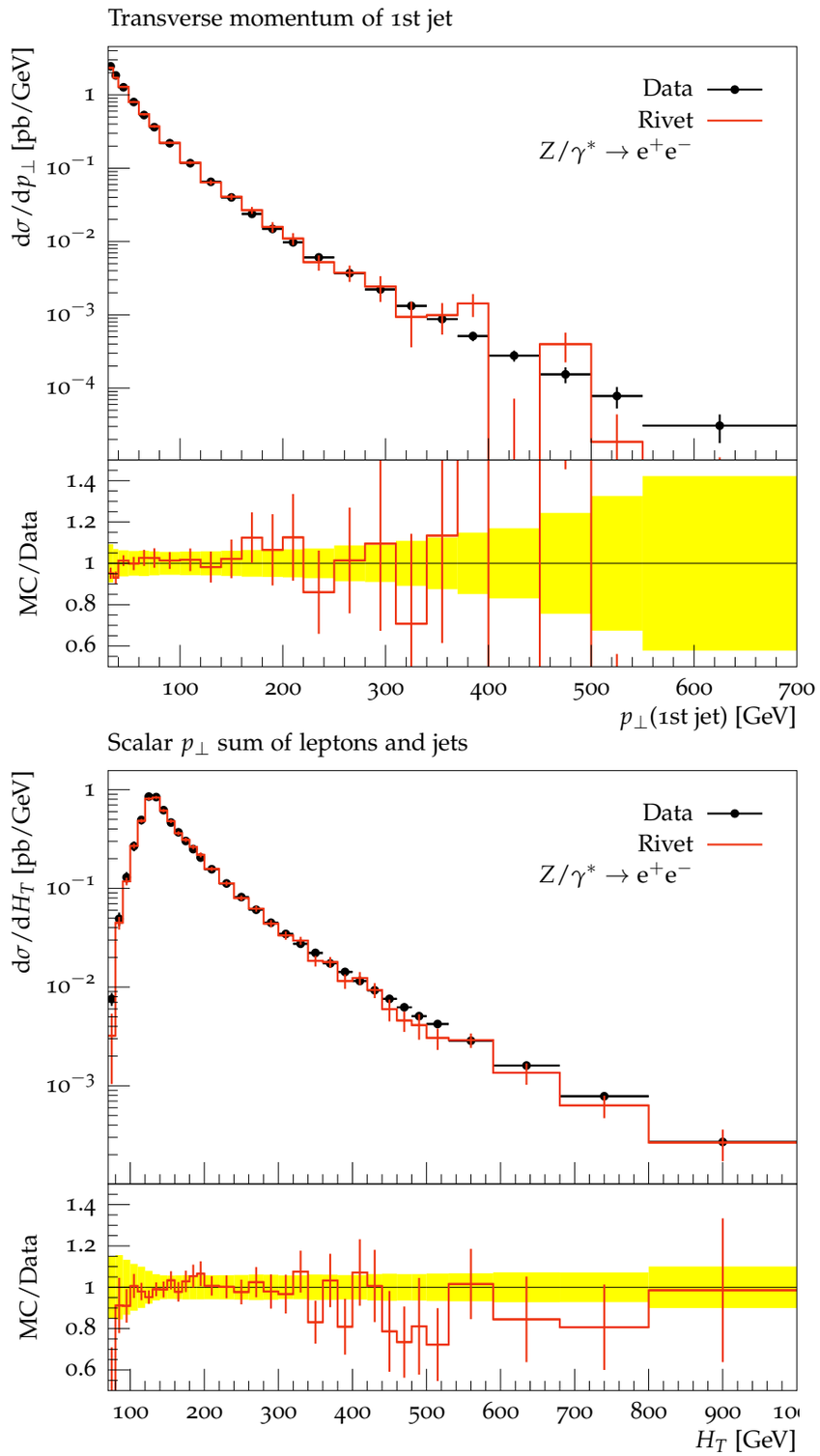




$$\begin{aligned} \text{NLO:} &\quad 1j \\ \text{LO:} &\quad 4j \\ t_{\text{MS}} : &\quad 25\,\text{GeV} \\ \mu_R = \mu_F : &\quad m_Z \\ \text{PDFs:} &\quad \text{CT10} \end{aligned}$$

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
$t\bar{t}W^{\pm}$	6+3
$t\bar{t}Z$	6

times branching ratio

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 plots made after preselection

- step 2
  - b-tagged jets
  - light jets

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

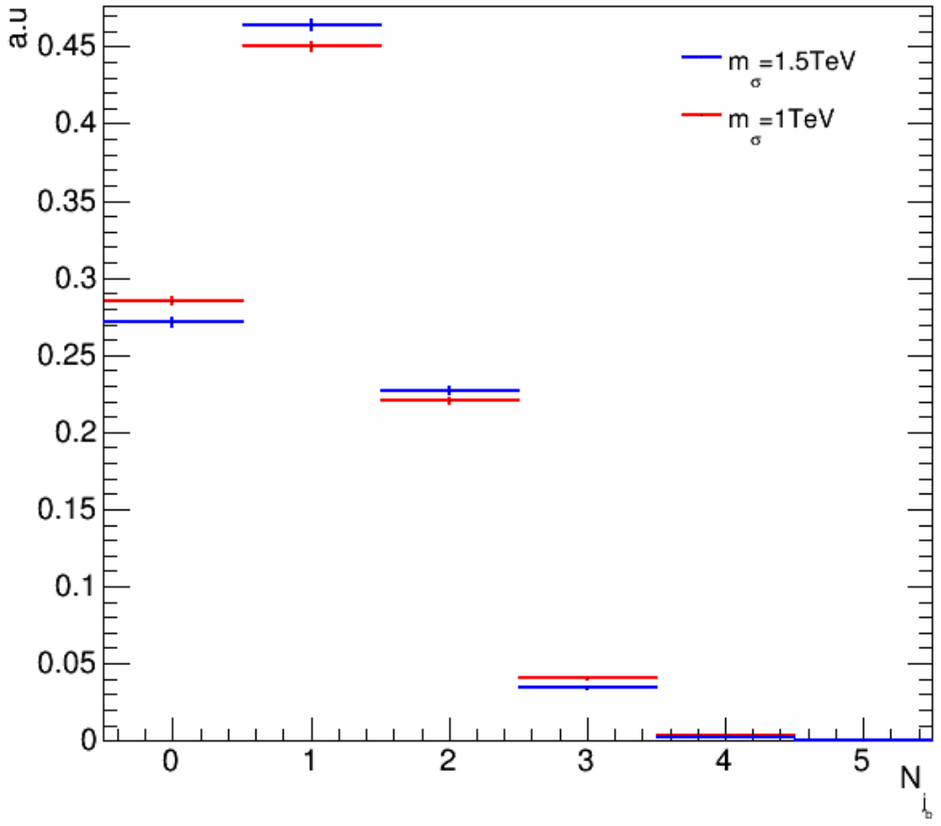
- step 3 - cut optimization
  - missing $p_\perp$
  - large hadronic activity

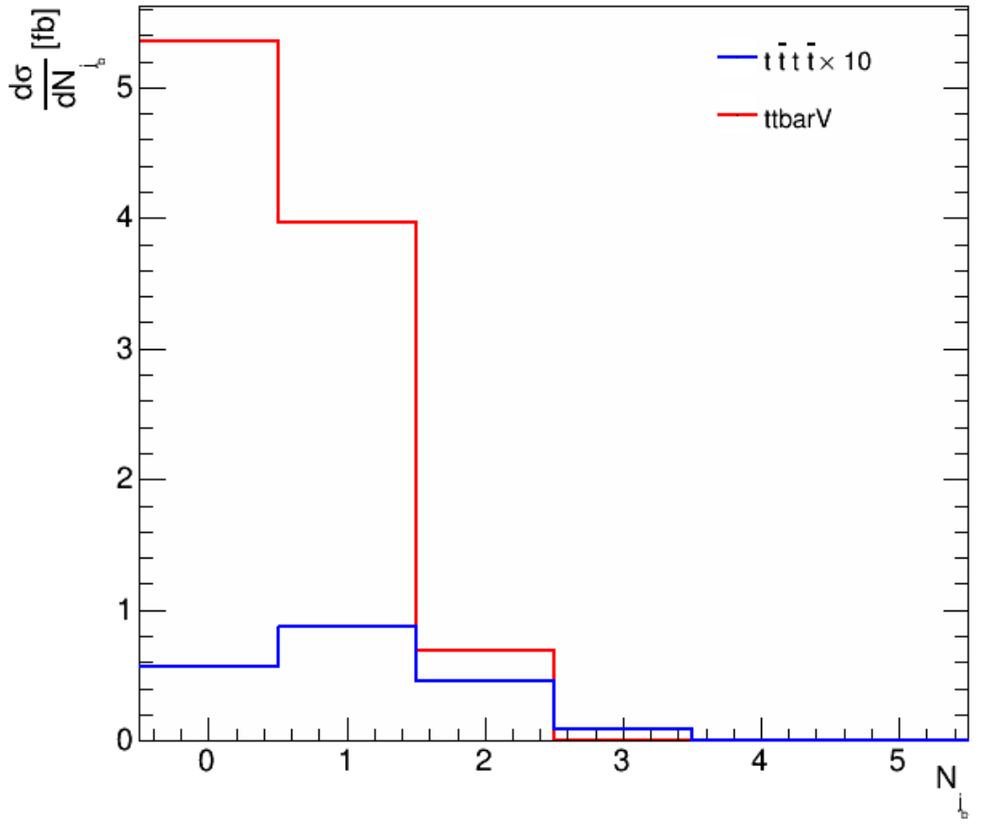
Try to select cuts to maximize S/B ratio

*up to non-promt leptons

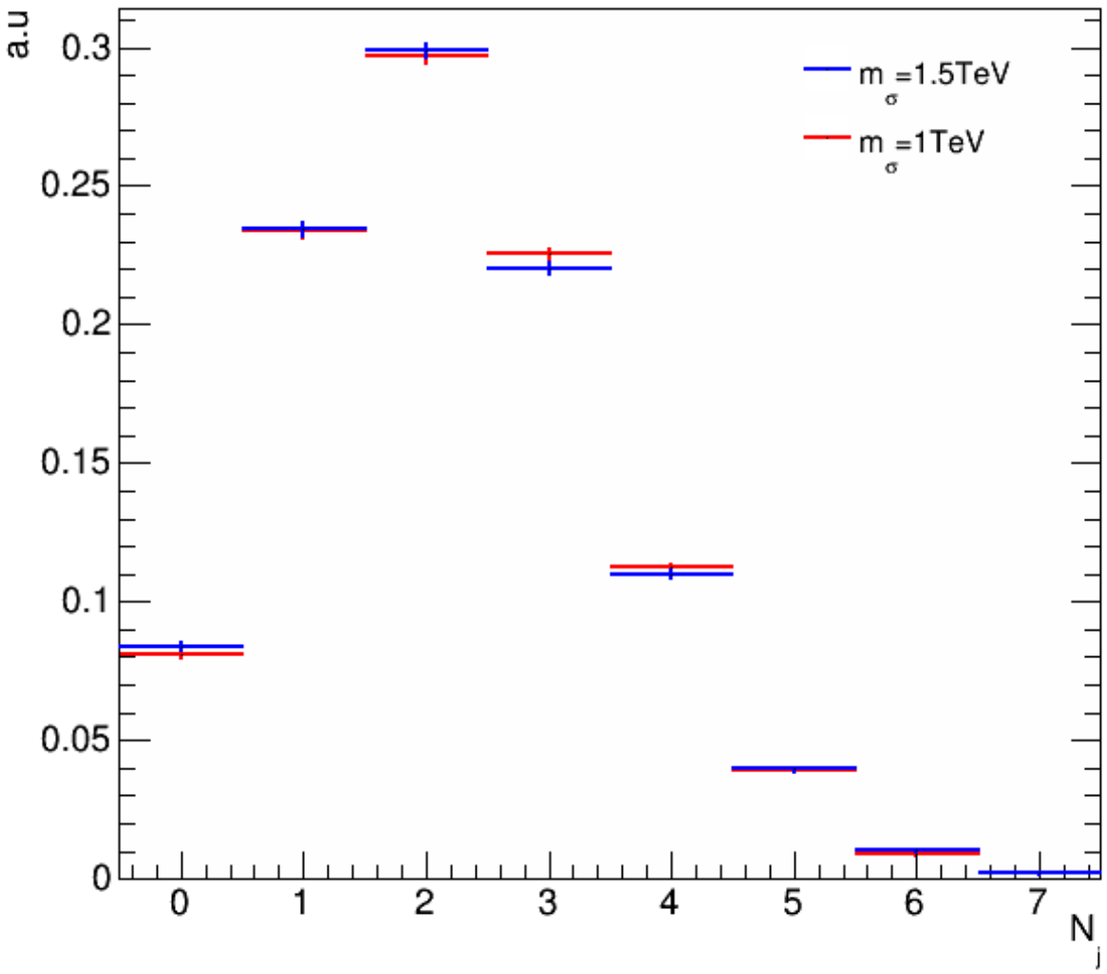
„fat-jets” analysis for b-jets

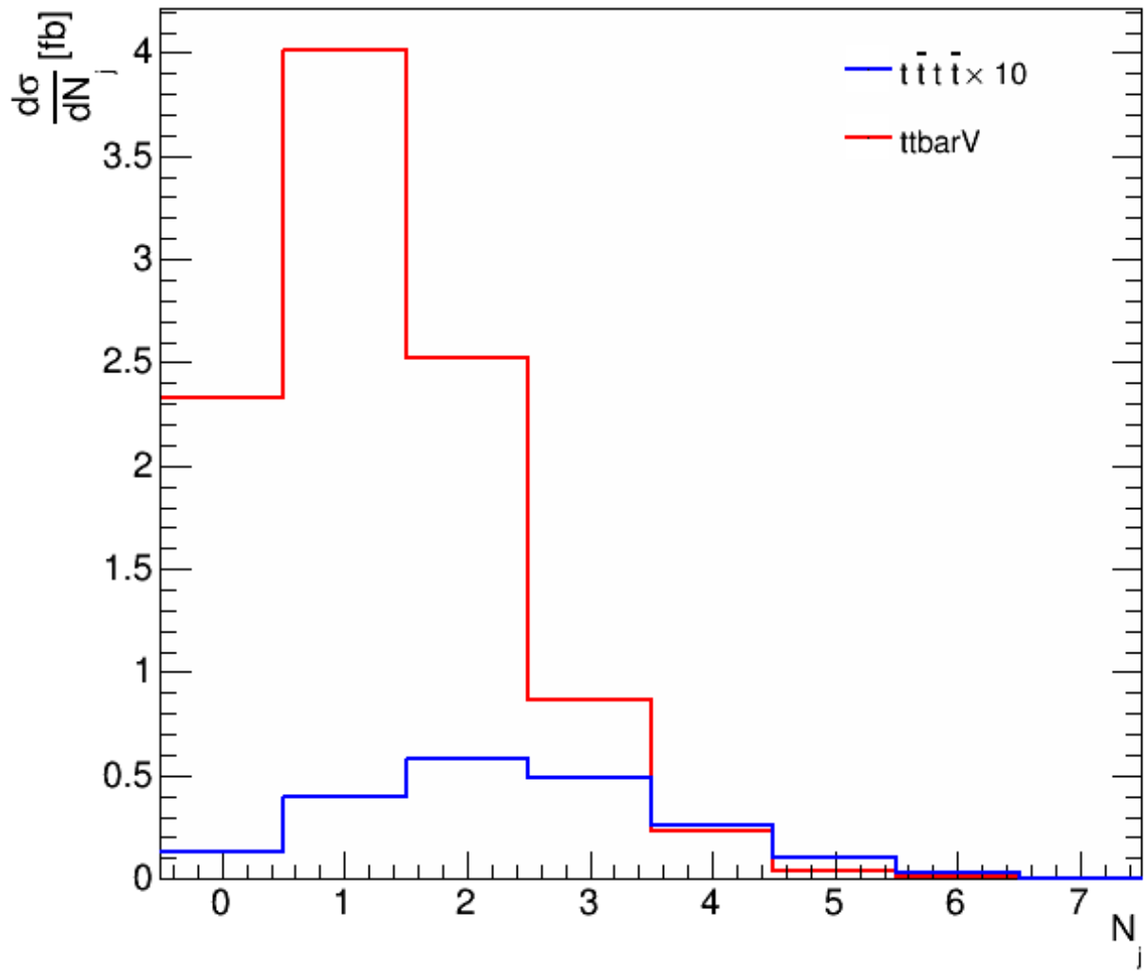
- „Fat-jets” as an observable [Hook, Izaguirre, Lisanti, Wacken - 2012]
- b-tagging working point according to Snowmass 2013 projection
  - b-tag efficiency up to 70%
  - c-jet mistag identification rate up to 10%
  - light jet mistag rate 0%
- Number of b-tagged jets with $\Delta R = 1$ and $p_\perp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





„fat-jets” analysis for light jets

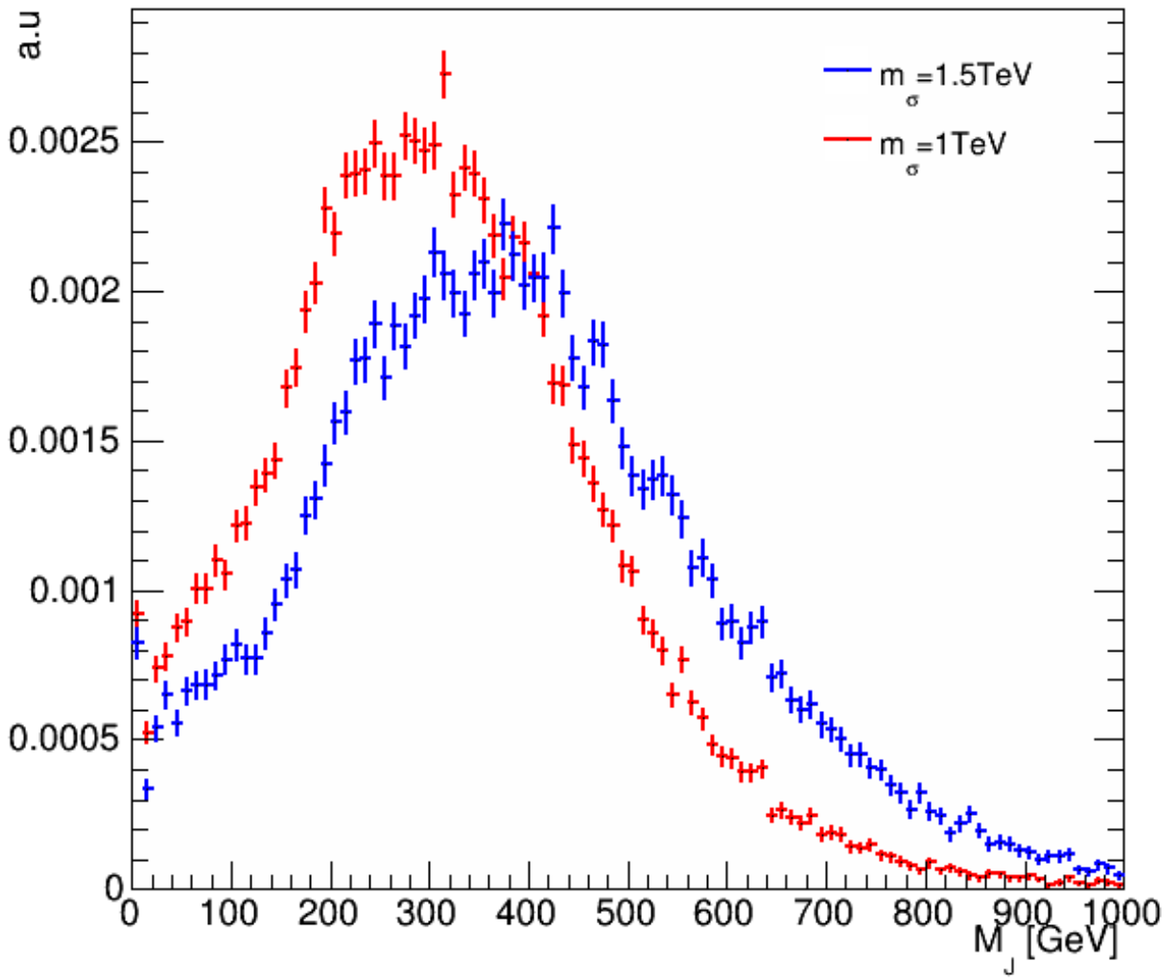


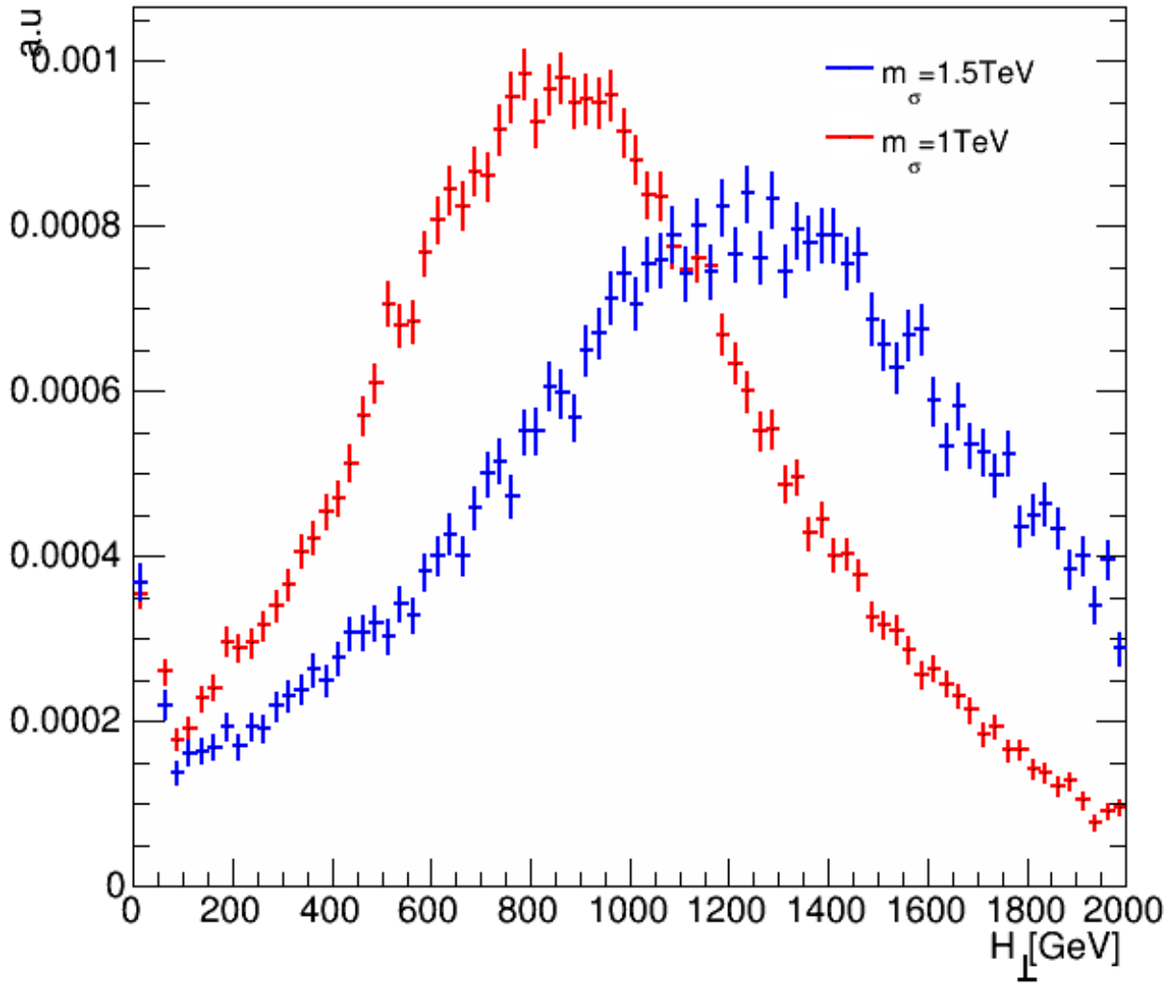


M_J vs. $H_\perp$ as a discriminating variable

PHYSICAL REVIEW D 85, 055029 (2012)

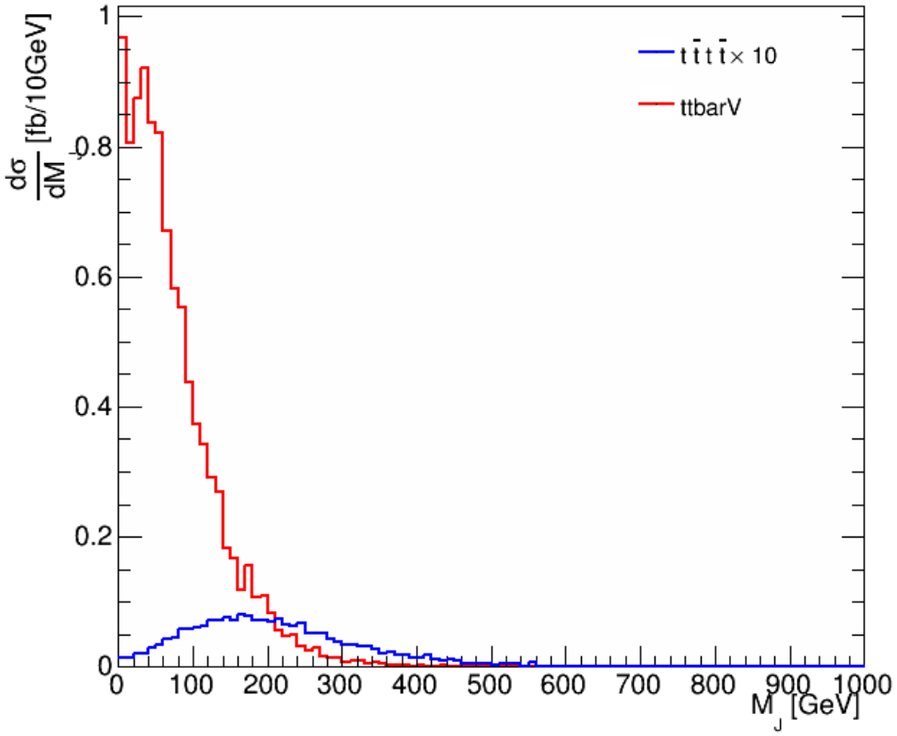
- We expect sum of jet masses for the signal to be concentrated around $2 \times m_t$

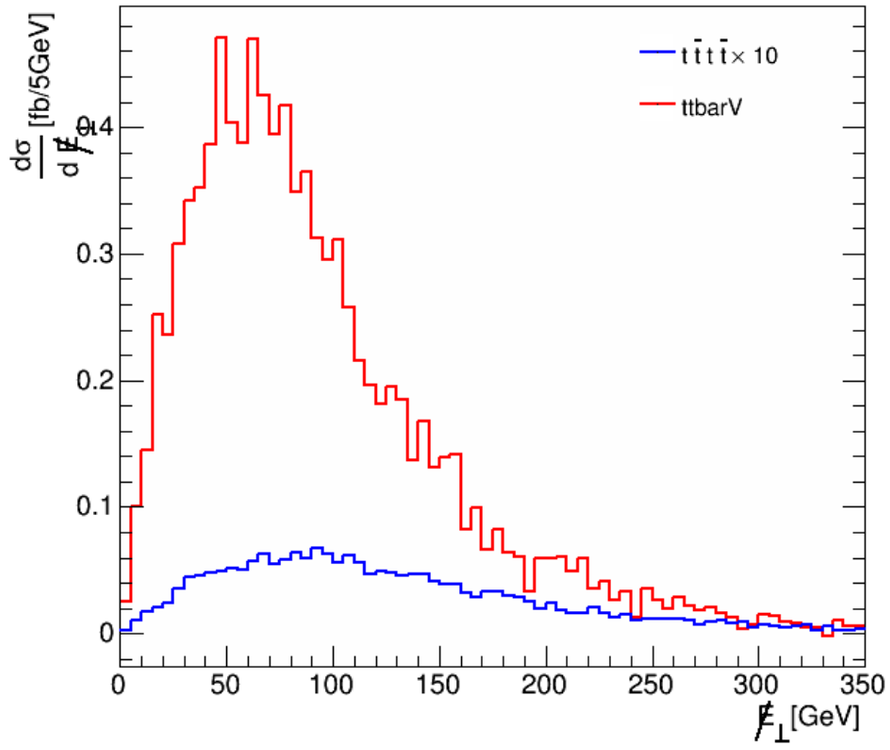




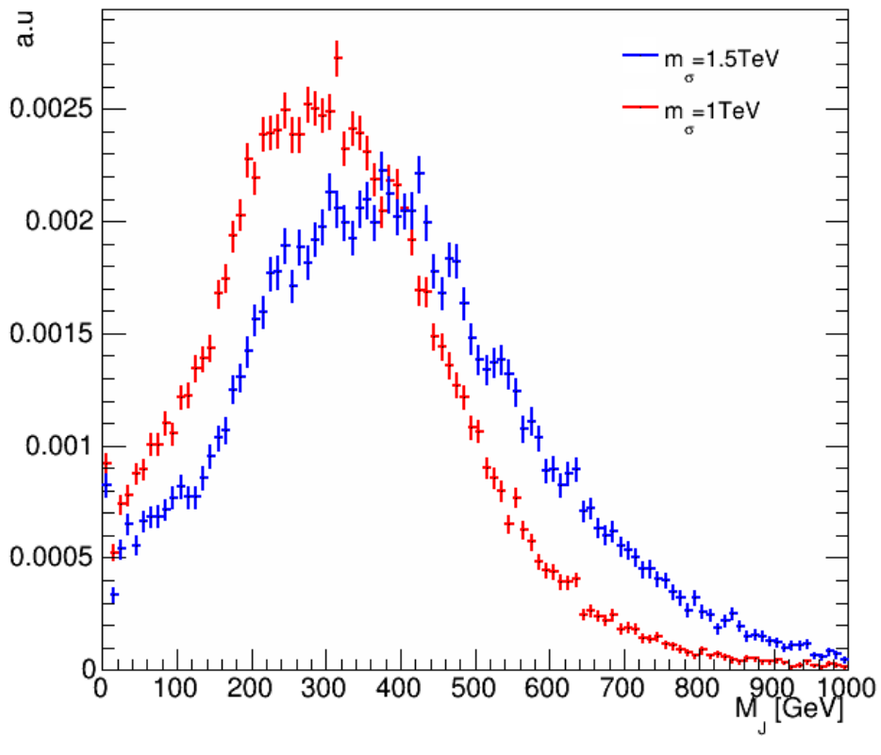
- Smaller variation with sgluon's mass - allows for mass independent search for sgluons

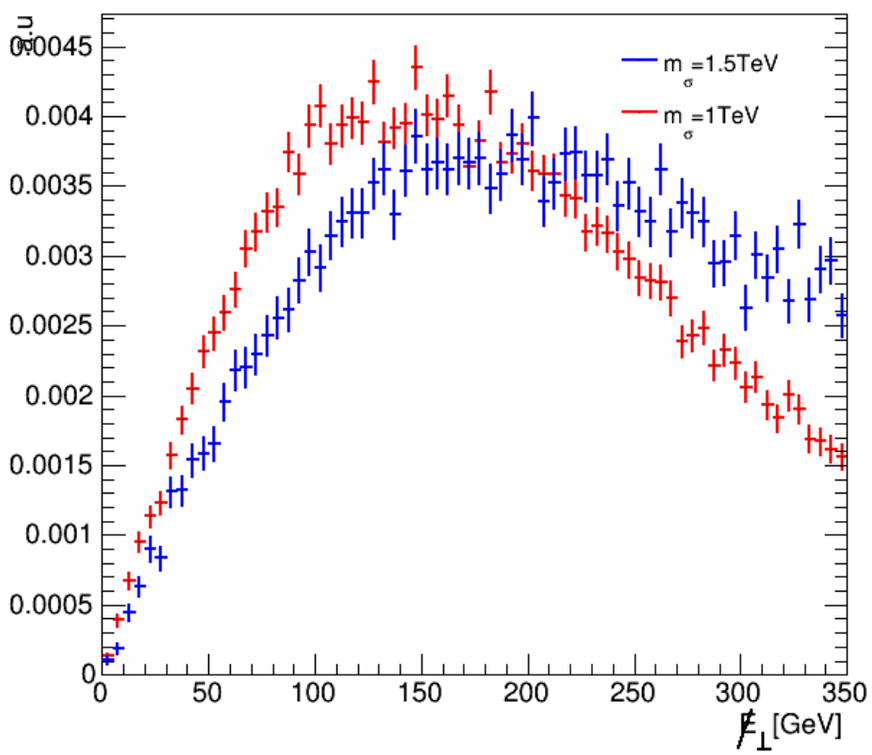
Jet mass and missing $E_\perp$ spectra





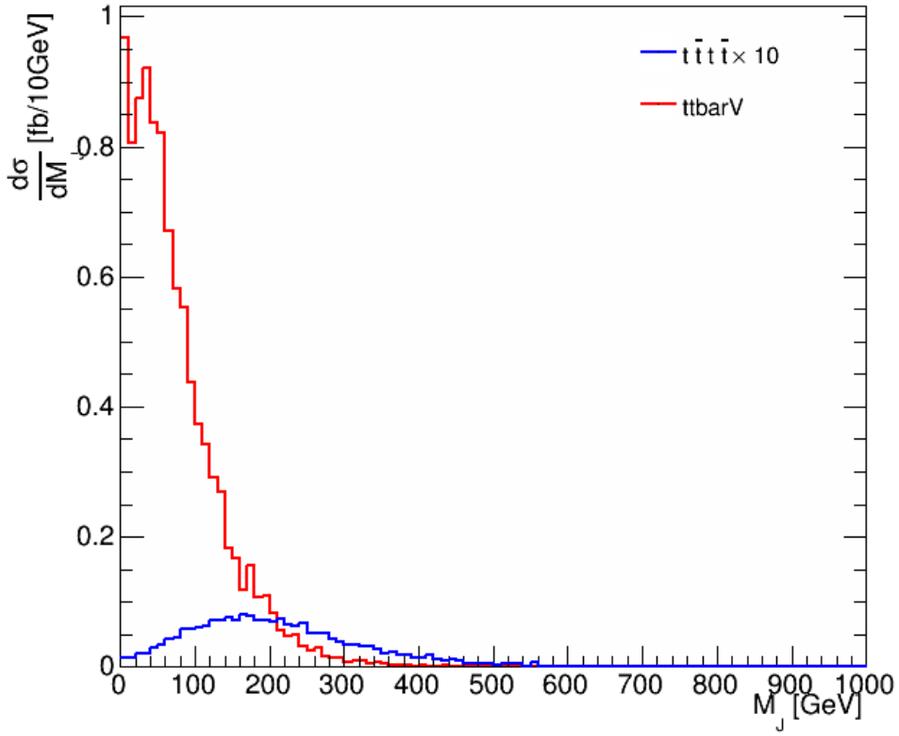
backgroud

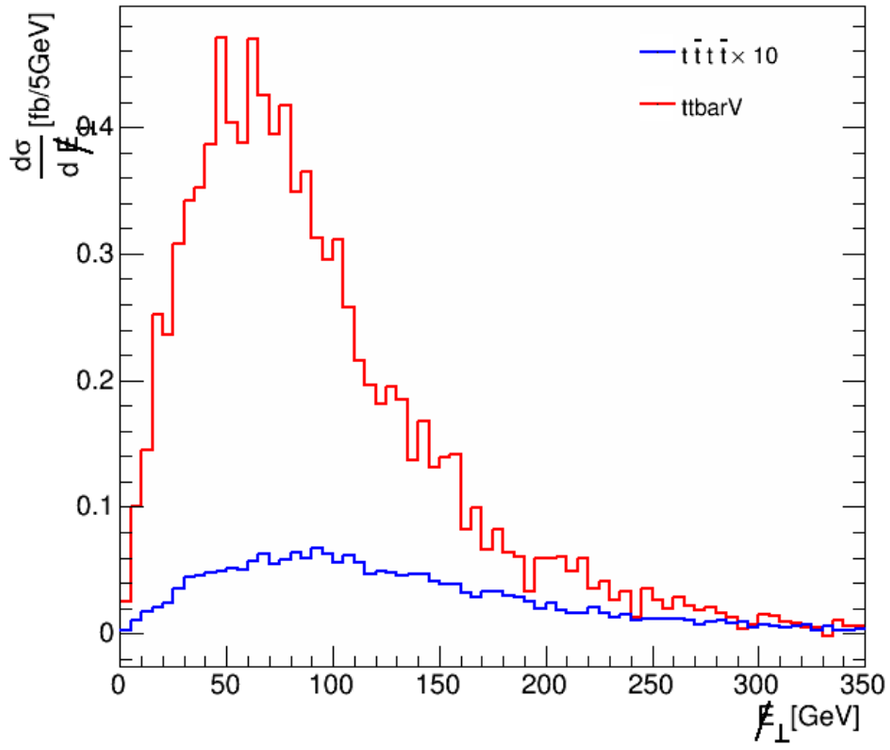




signal

Jet mass and missing $E_\perp$ spectra





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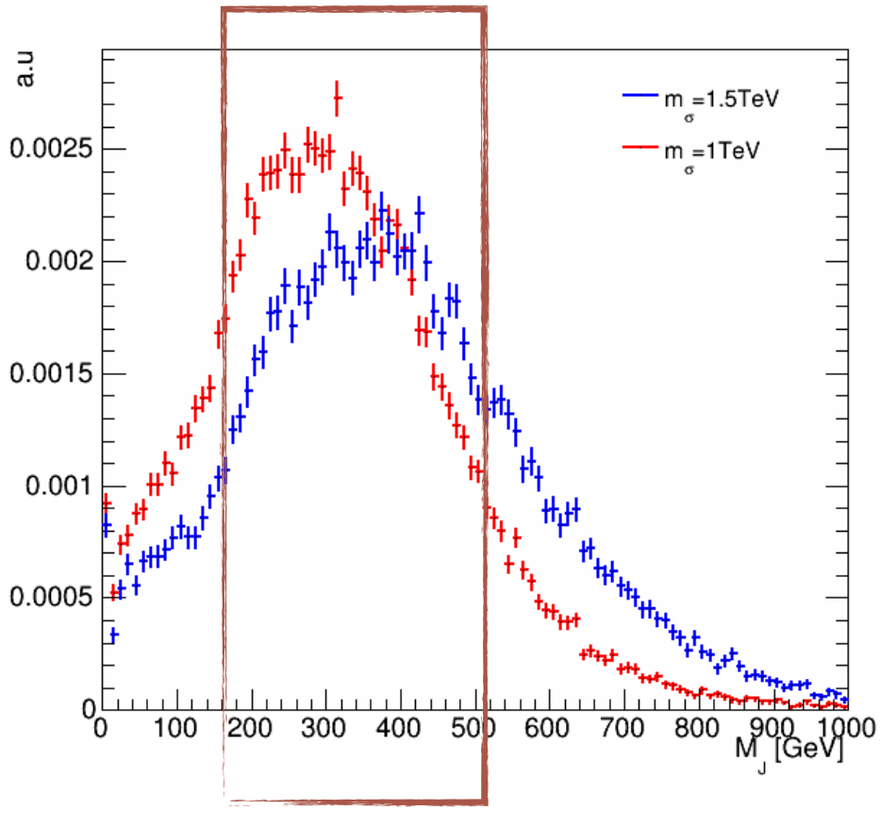

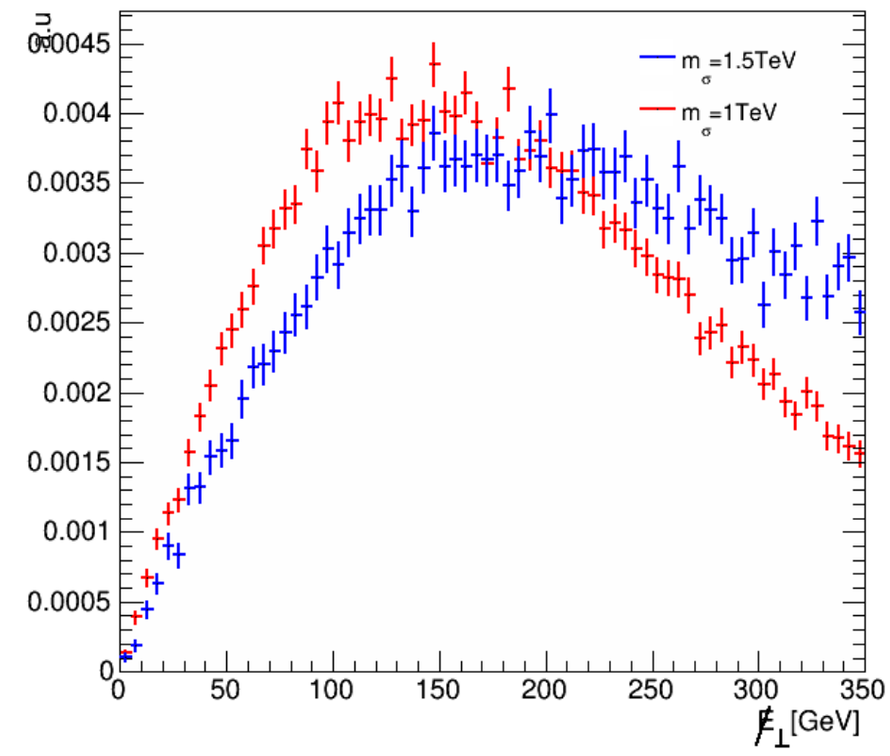

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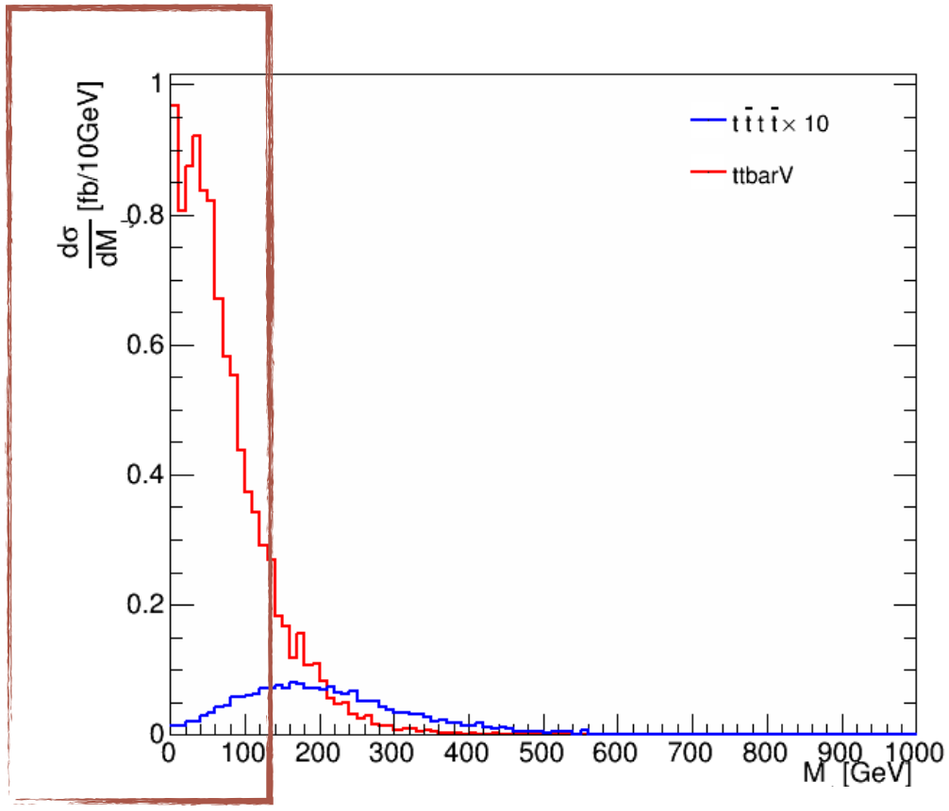

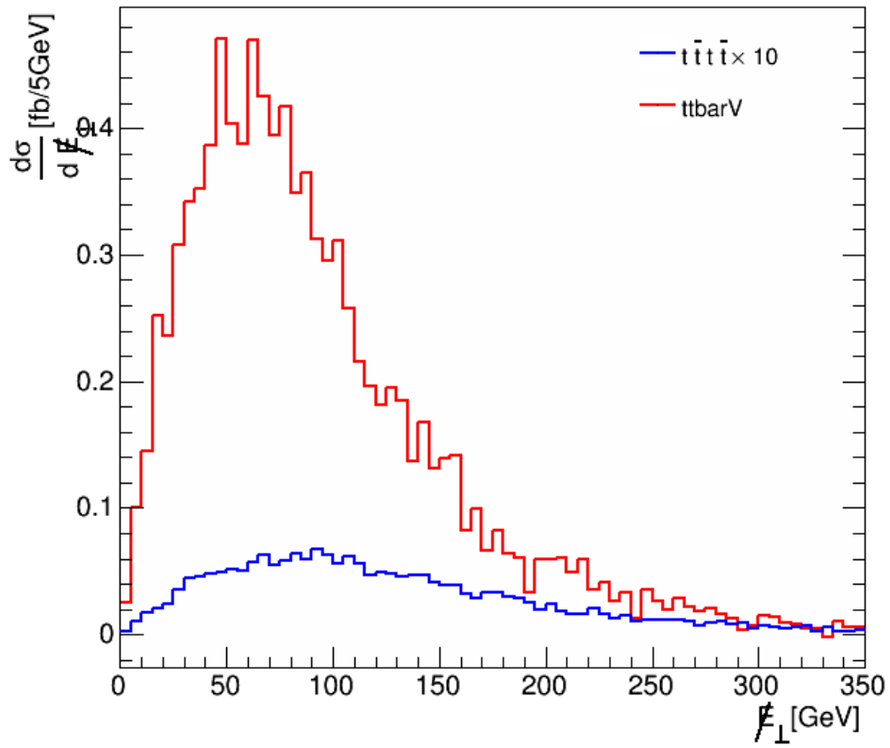

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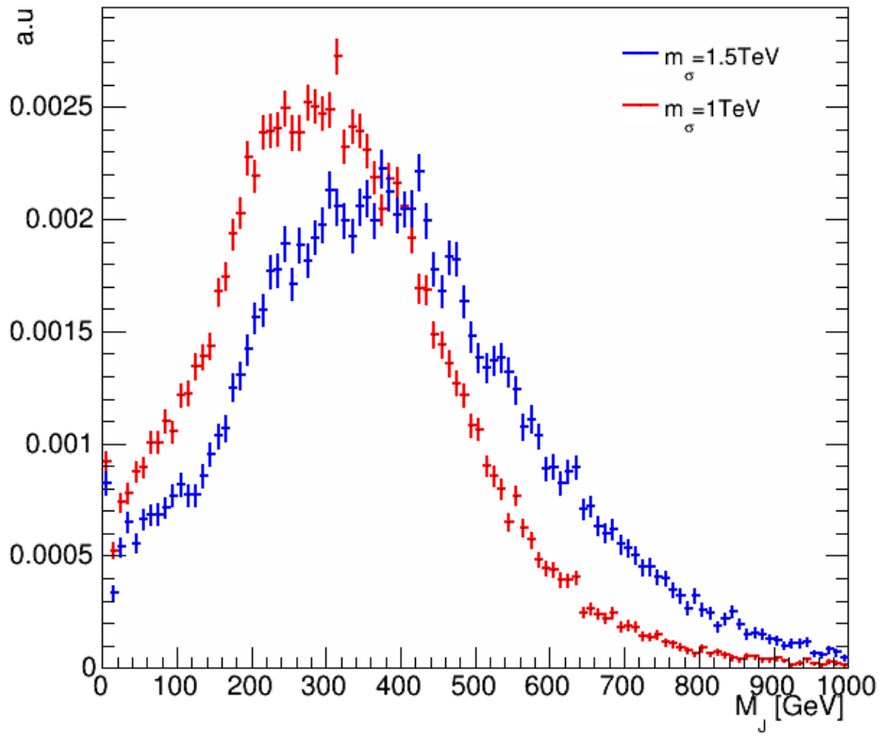
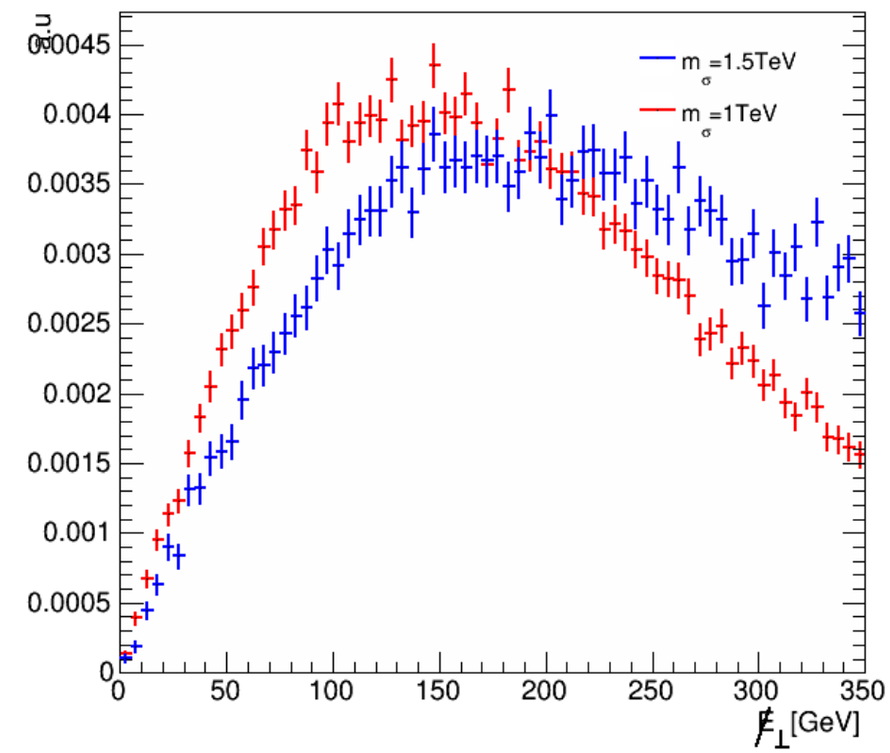
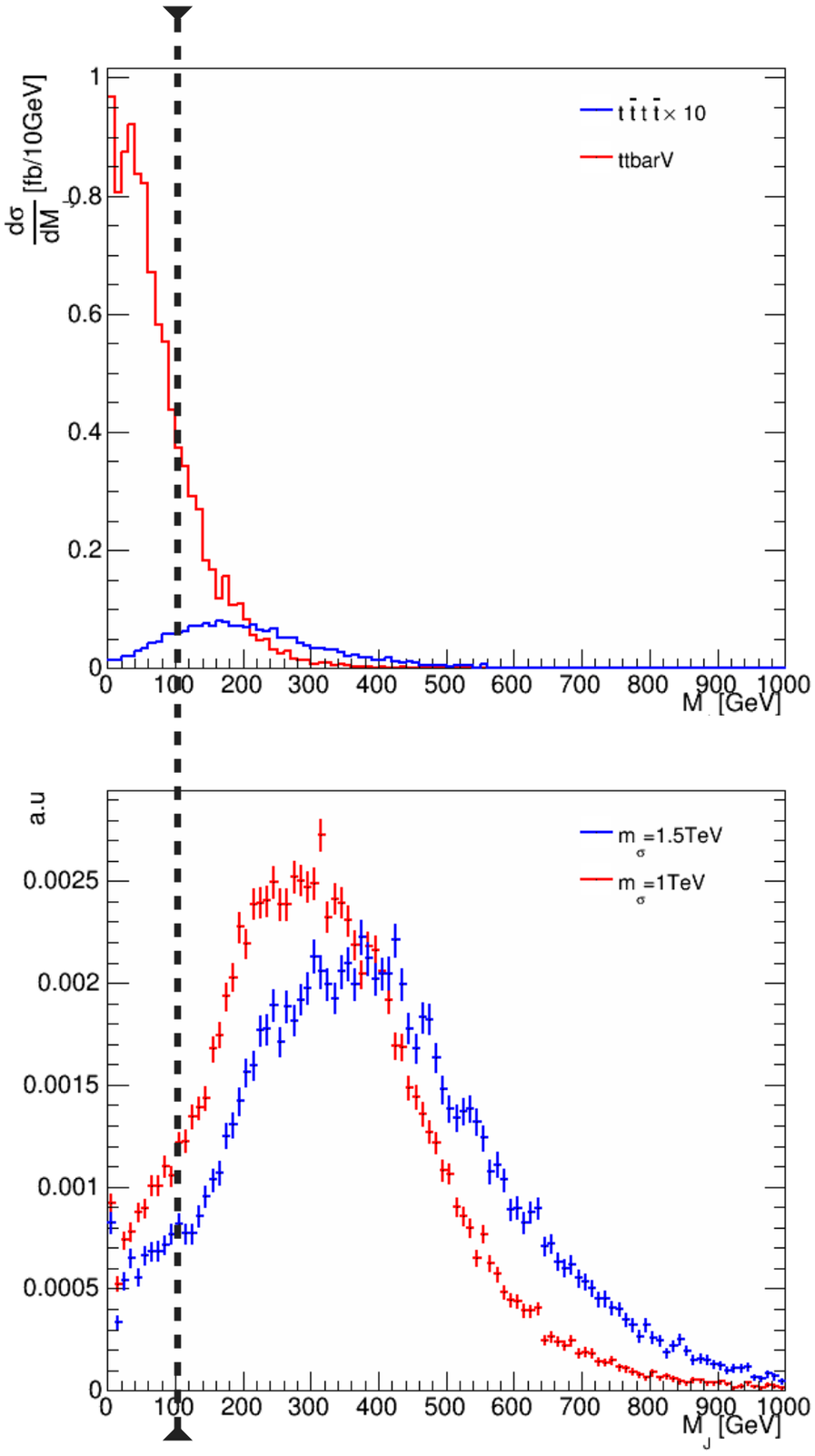
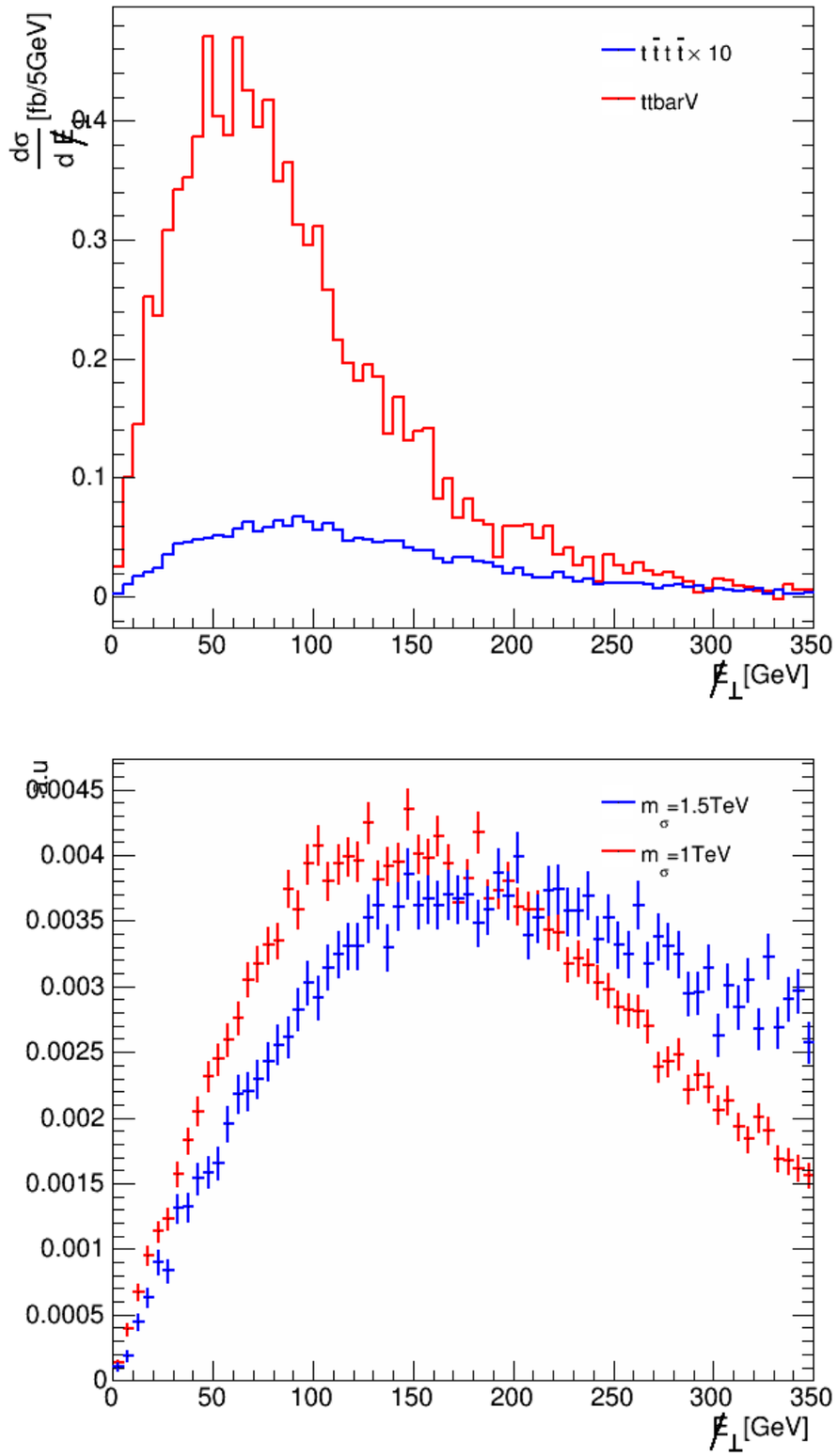




signal

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

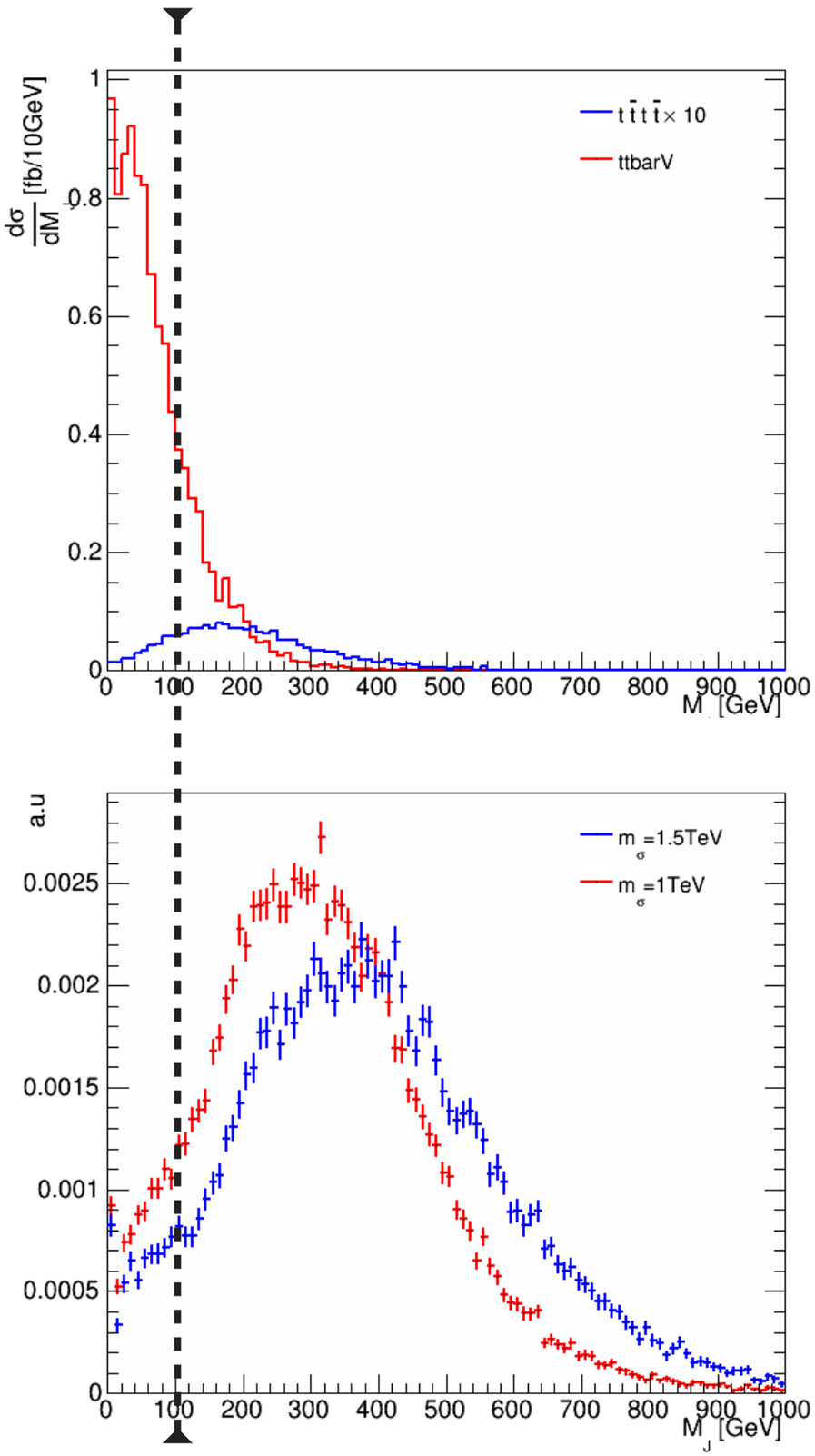


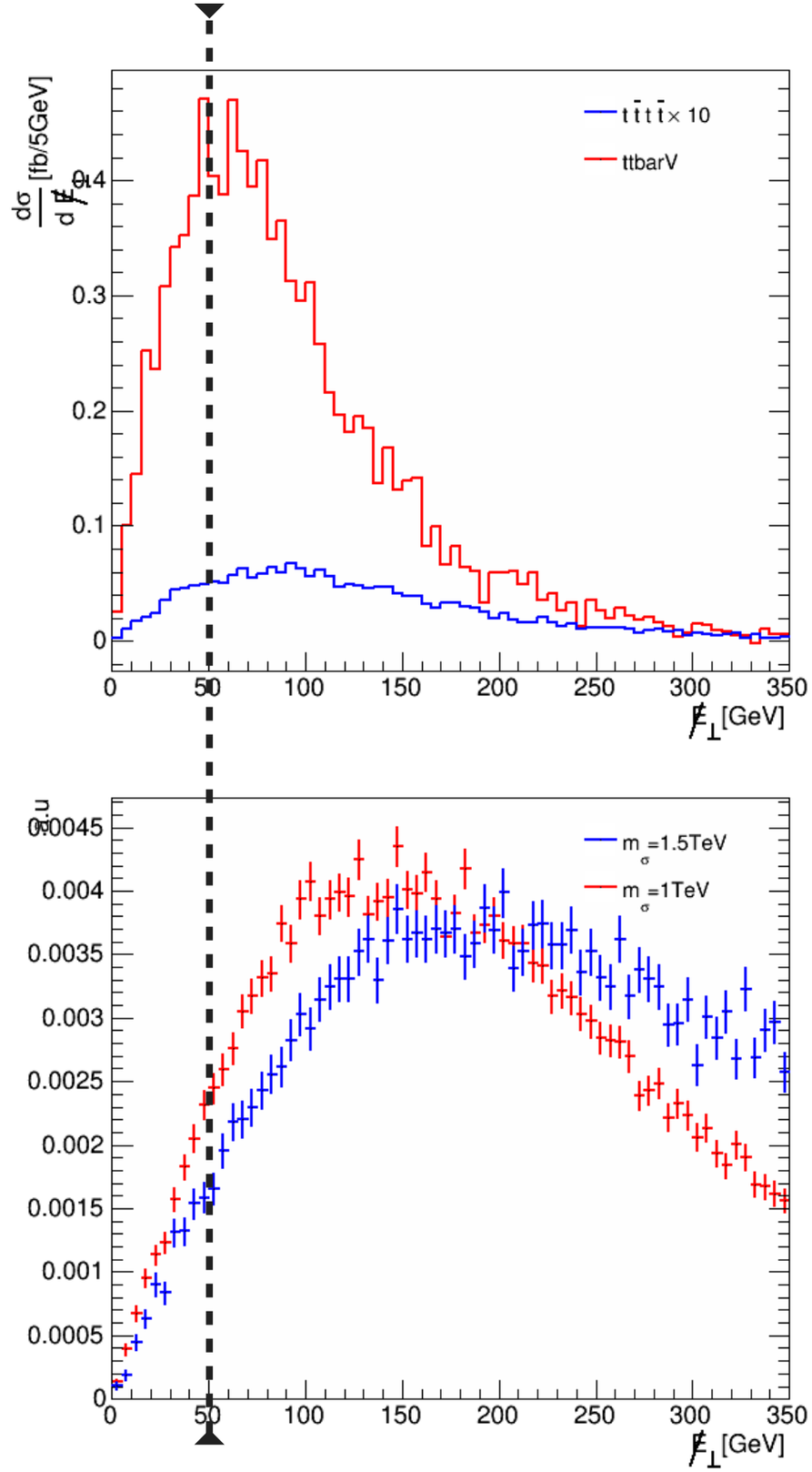


backgroud

signal

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

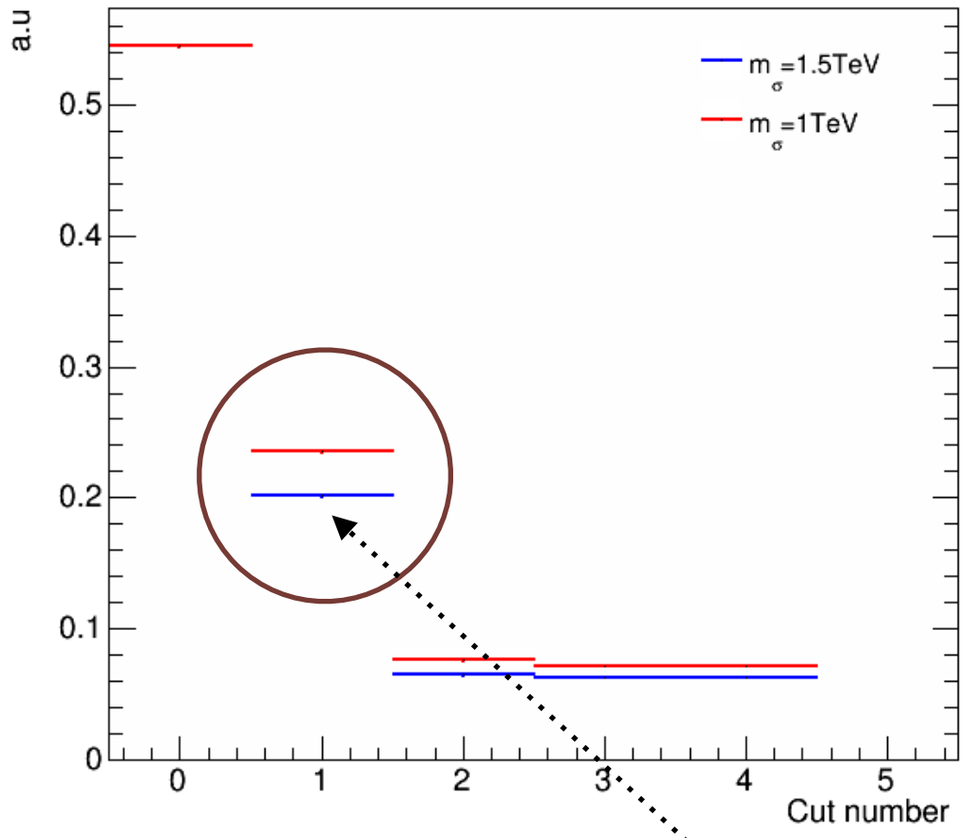


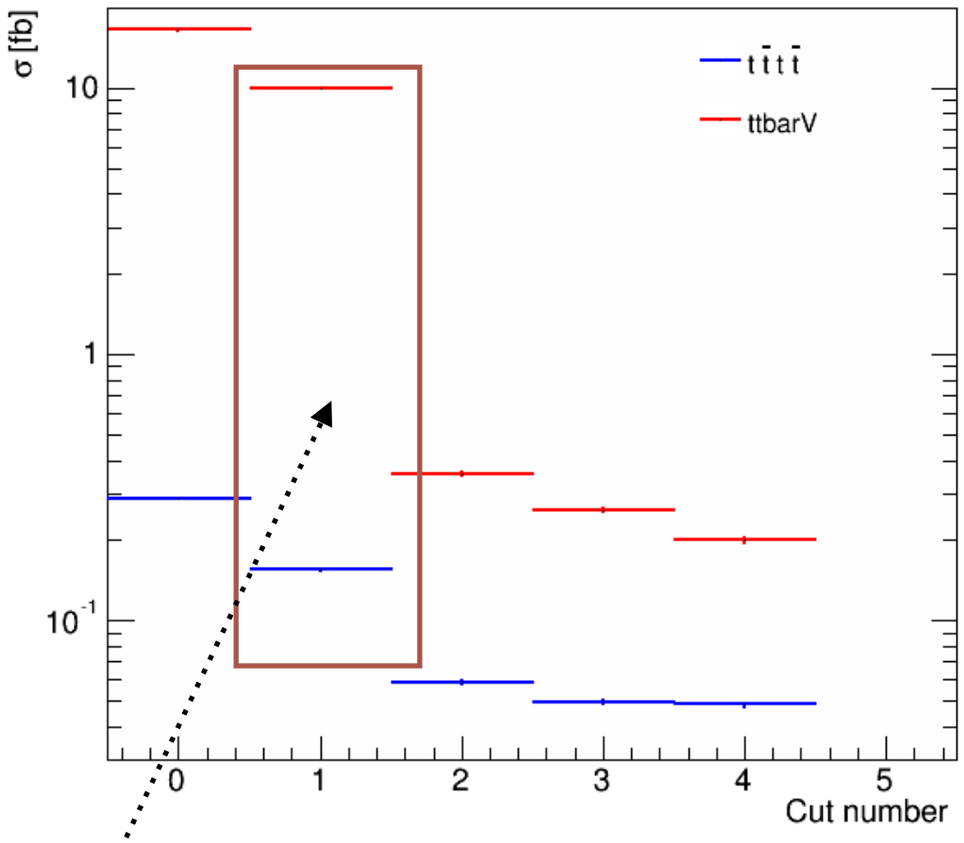


backgroud

signal

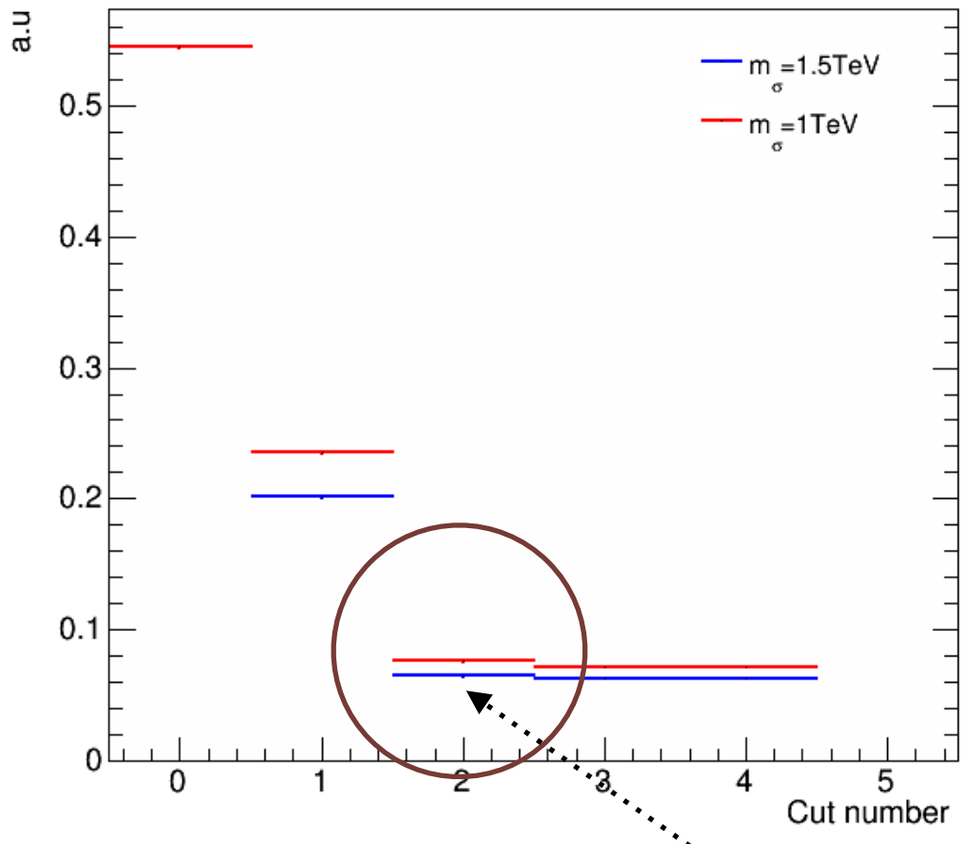
Final result

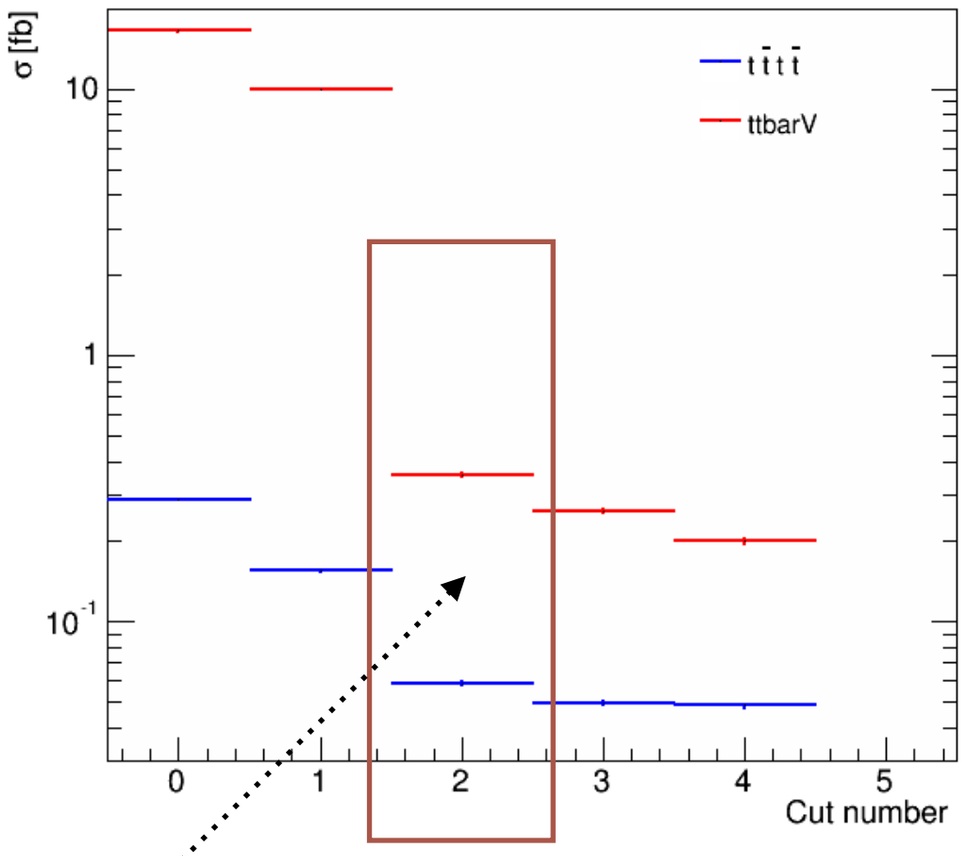




two same-sign isolated muons

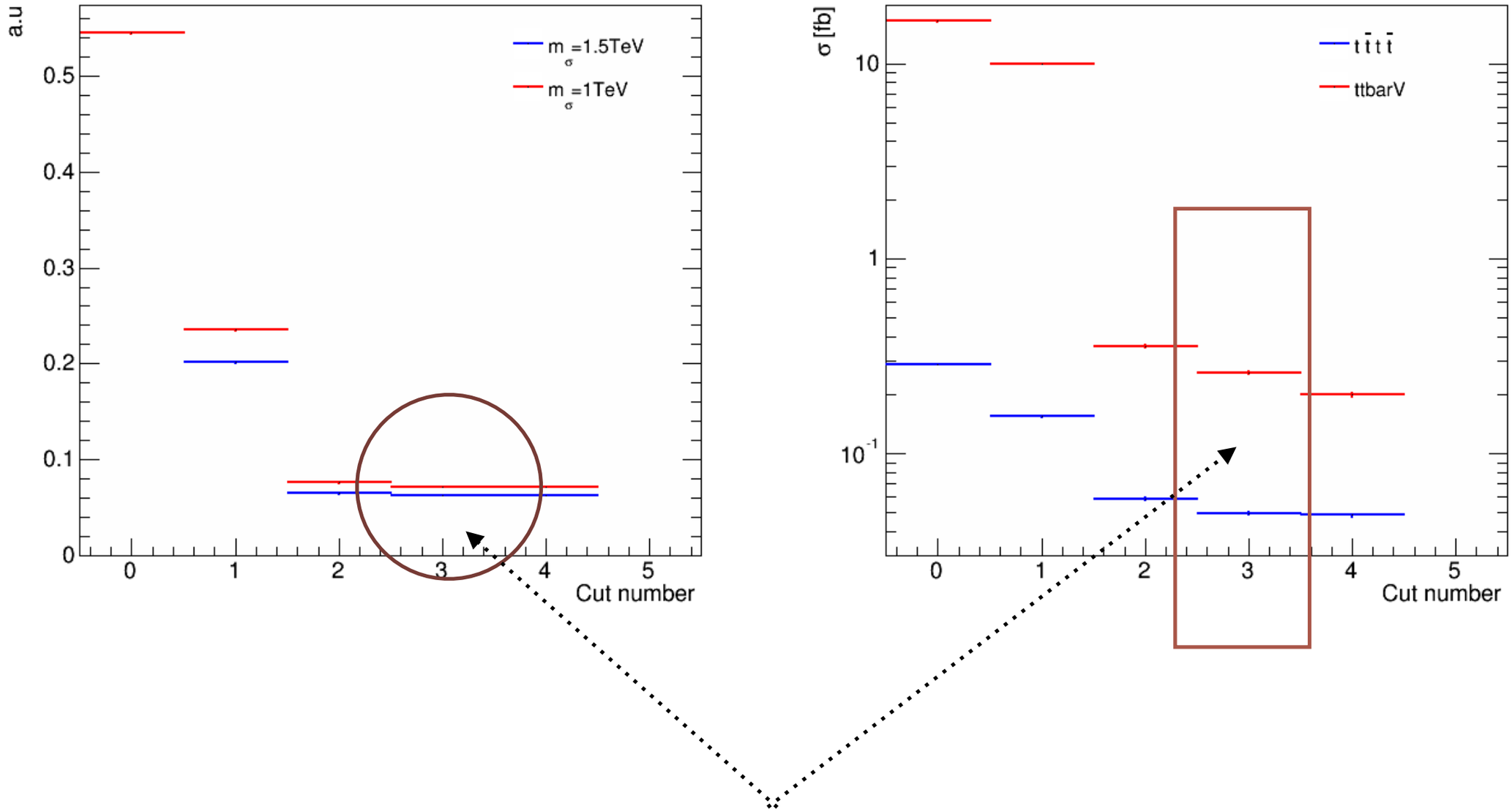
Final result





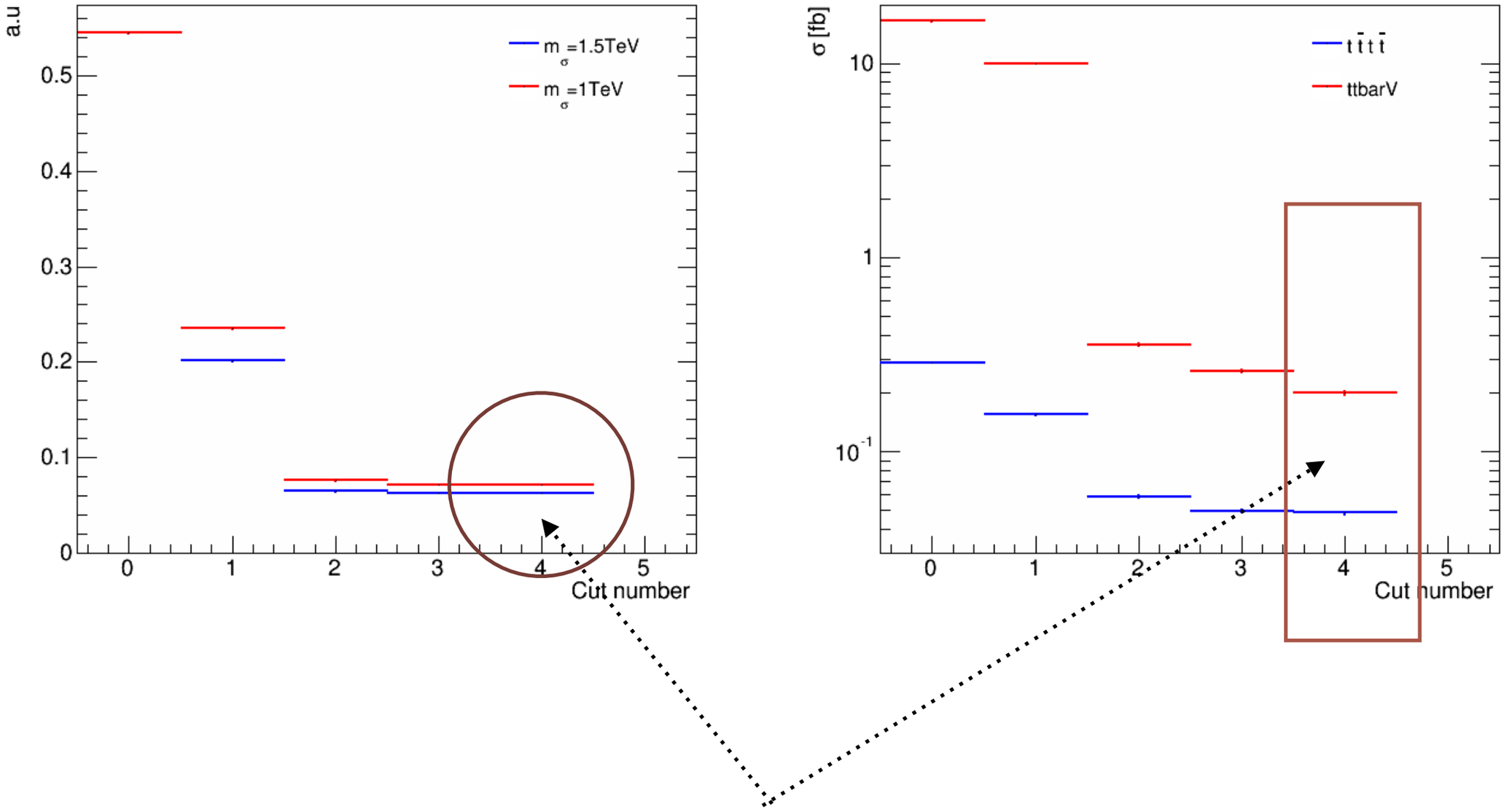
at least 1 b-jet and 2 light jets

Final result



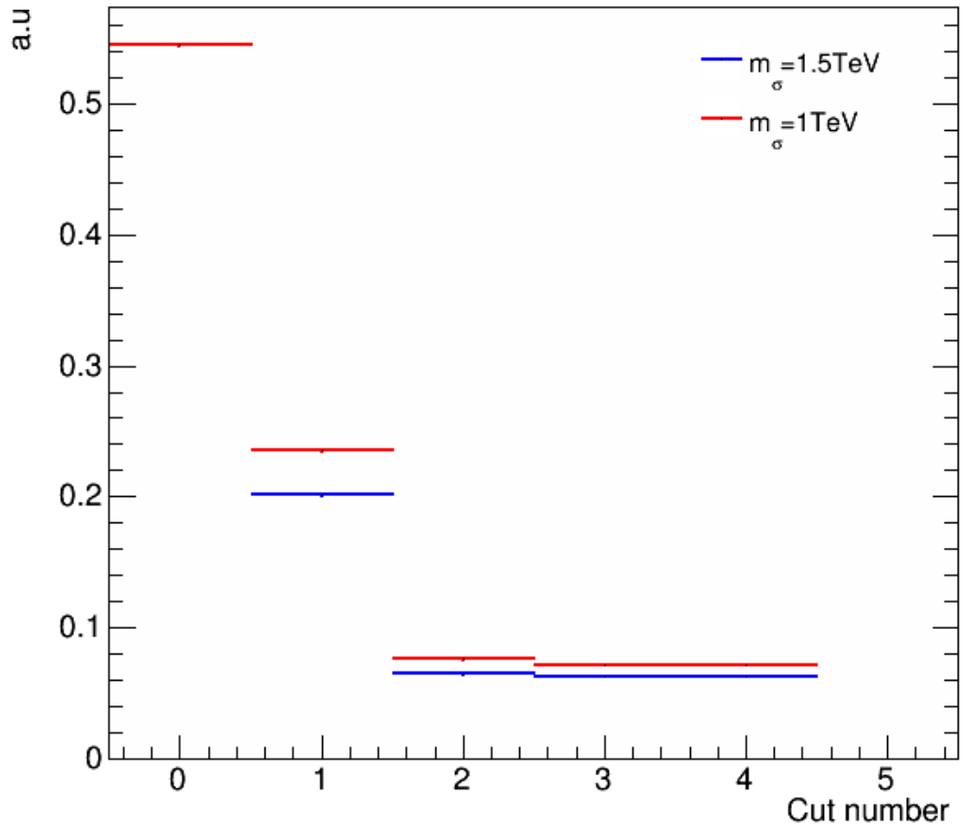
MET > 50 GeV

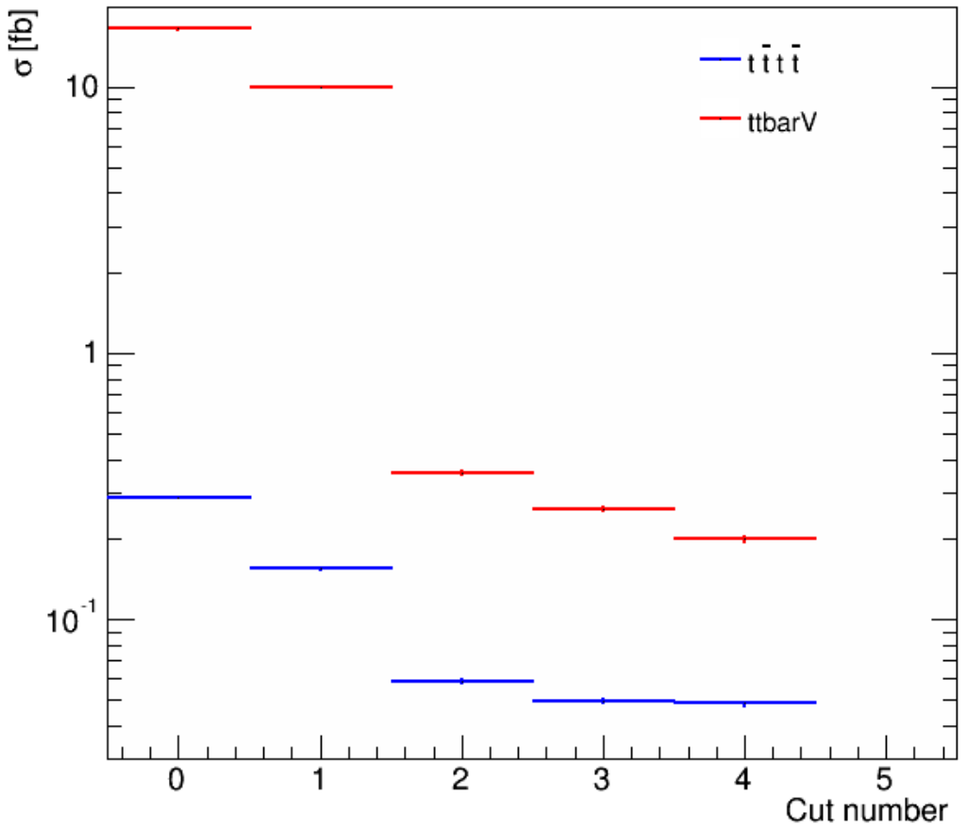
Final result



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 cross-section for signal production

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