XXIV International Scientific Conference of Young Scientists and Specialists (AYSS-2020)

$pp \rightarrow tH$

Monte-Carlo study of Higgs boson production in association with a single top quark at 13 TeV

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pp→tH: Analysis stages

1. Parton level
- MadGraph vs ATLAS MC Data
- MadGraph SM vs BSM
- MadGraph Signal tHbq vs Bkg tt, ttH
2. Jet truth level
- Efficiency and quality of MadGraph SM truth jet matching

AYSS-2019 Conference

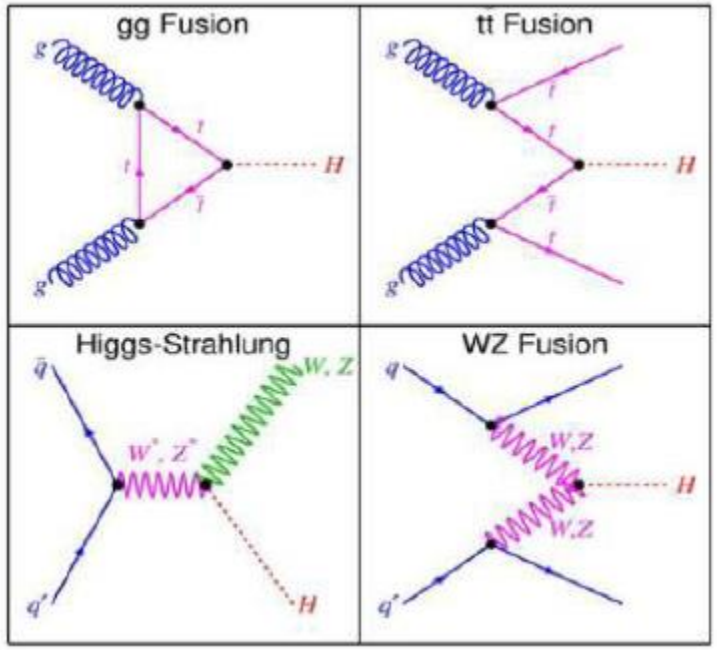
- Event selection cuts at jet level
- Backgrounds ttbb, ttZ, tZbq
- Variation of cuts for optimization of Signal to Bkg ratio
- New variables for optimization of Signal to Bkg ratio

this presentation

3. BDT/NN Analysis
4. Full simulation/reconstruction level, real data analysis (next step)

Higgs production and decay modes

- gg→H (87%)
- pp → VVqq → Hqq (7%)
- qq → V* → VH (4%)
- gg → tttt → ttH (1%)



Purity

Observed

- H → γγ (0.23%)
- H → ZZ* (2.6%)
  → ℓℓℓℓ
- H → WW* (21.4%)
  → ℓνℓν
- H →ττ (6.3%)
- H → bb (58%)

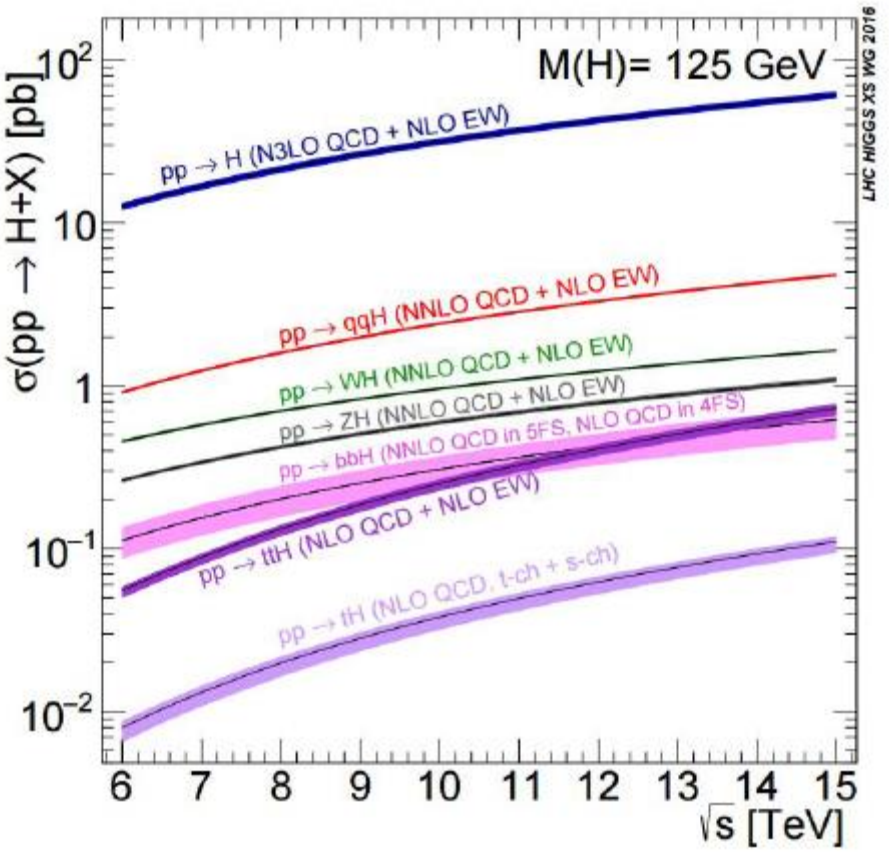
Can be observed later at LHC:

- H → Zγ (0.15%)
- H →μμ (0.02%)

Can be observed only at future colliders:

- H → cc (2.9%)
- H → gg (8.2%)

ttH vs tH



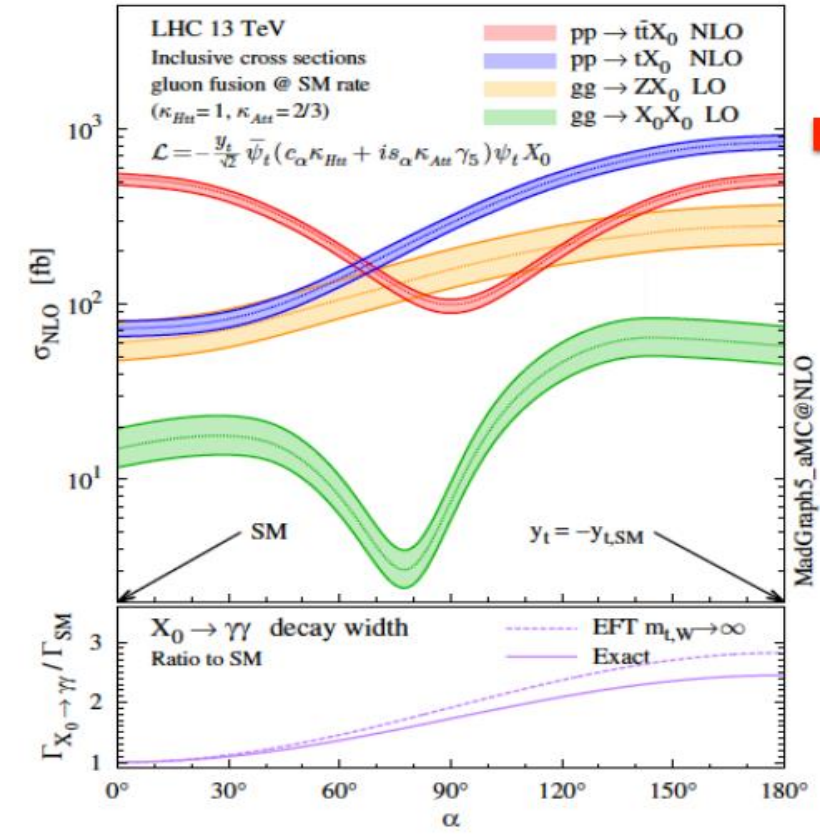
- pp → tH cross-section is 5-7 times smaller than that of pp → ttH
- …mostly because of the destructive interference between ttH and WWH vertices, both contributing to pp → tH

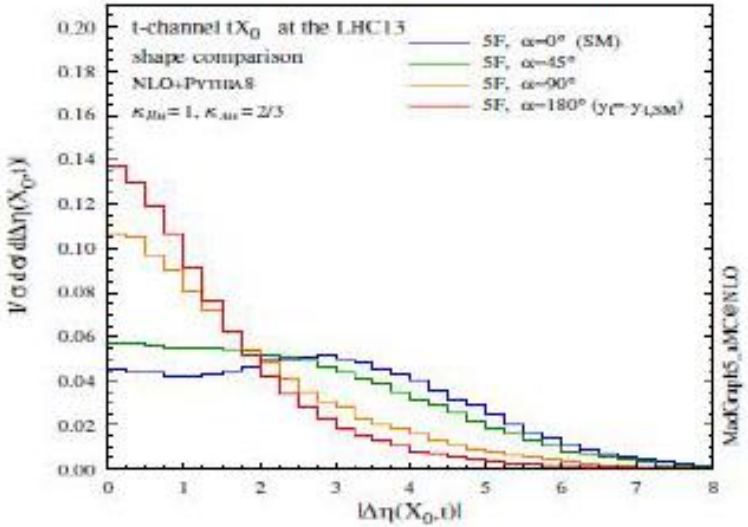
tH

- Top Yukawa coupling is directly measured in pp → ttH events
- However, ttH is only sensitive to **square** (i.e. absolute value) of y_t
- tH is the only channel sensitive to sign of y_t (or more generally to its complex phase)

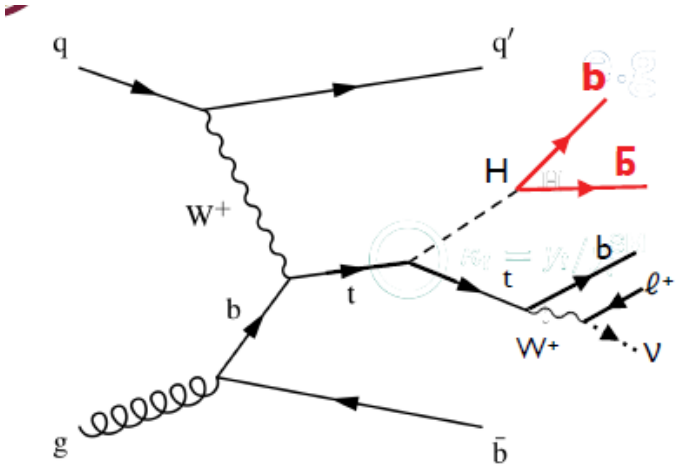
- More generally, it is sensitive to the phase between ttH and WWH

- The ratio tH/ttH may vary between 0.2 (SM) to 2.5 (ITC scenario y_t=-y_t,SM)





How to select tHbq events



- A hard lepton and large missing E_T from semileptonic top decays
- Very energetic, very forward jet, with large rapidity gap from the rest of the event
- b-tagging: 3 or 4 b-jets (for H→bb), 1 or 2 b-jets for other channels
- Need NN to exploit all available information

Signal and background generation

- We generate Signal and Background using **MadGraph MG5_aMC_v2_6_3_2 at 13 TeV.**
  Private **Monte-Carlo truth level** data (**LO, 4-fl**) is produced for

PDF set: CT10;
m(b): 4.2 GeV;
m(t): 172.5 GeV
m(H): 125 GeV;
Y_b **:** +1;
Y_t **: (+1) (SM)**
and **(-1) (BSM)**

Signal:

- **$pp \rightarrow tHbq(H \rightarrow bb)$, BSM ($Y_t$ = -1)**
- **$pp \rightarrow tHbq(H \rightarrow bb)$, SM ($Y_t$ = +1)**

SM Background:

- **$pp \rightarrow tt$ – main source of Bkg**
- **$pp \rightarrow ttbb$**
- **$pp \rightarrow ttH(H \rightarrow bb)$**
- **$pp \rightarrow ttZ(Z \rightarrow bb)$**
- **$pp \rightarrow tZ(Z \rightarrow bb)$**

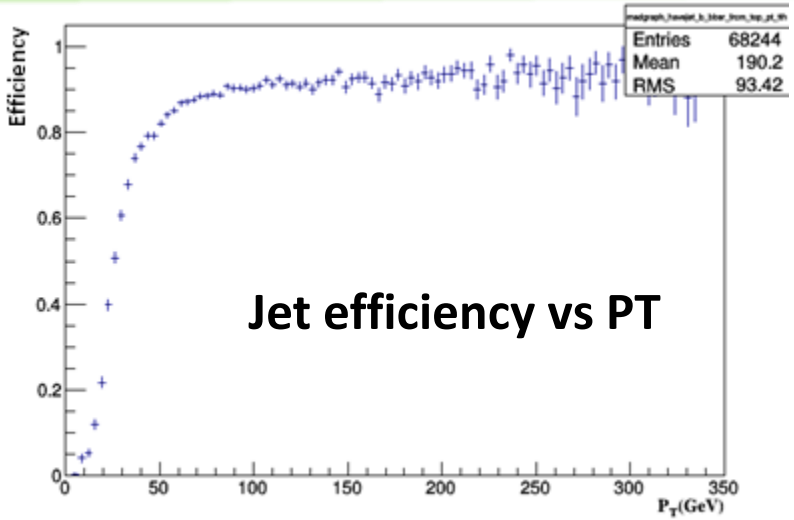
	tHbq(BSM)	tHbq(SM)	tt	ttbb	ttH	tZ	ttZ
Cross Section MadGraph, pb^{-1}	0.4829	0.0355	746	8.917	0.1963	0.0635	0.0885
Generated Number of Events	100K	100K	1M	100K	100K	100K	100K

Cross section of SM tH is very small, so we can't detect this signal at LHC RUN II.
However, there is a chance to observe BSM signal in RUNII data.

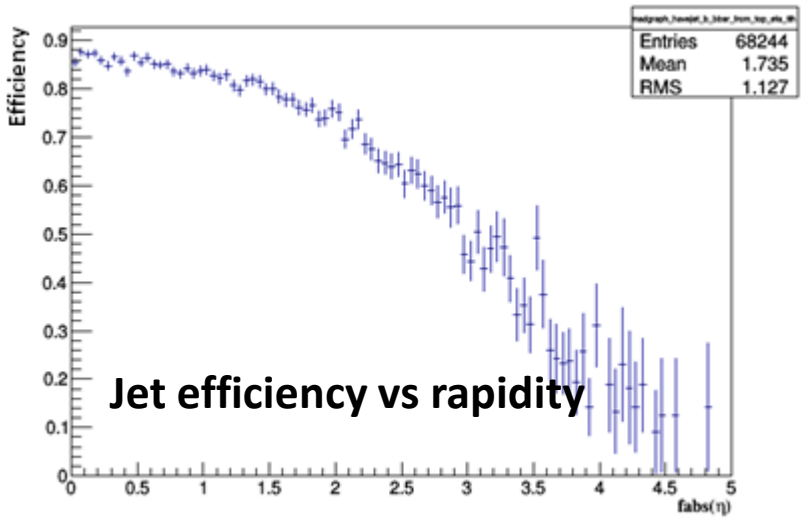
Reconstruction of analysis objects

- Pythia is used for showering and hadronization.
- Delphes is used for truth jet reconstruction and missing E_T calculation.
- We take leptons at truth level, no attempt to introduce an artificial smearing
- Jets are reconstructed from the truth final-state particles after hadronization.
- Neutrino is reconstructed from the MET of the reconstructed jets
- Neutrino P_T reconstructed as jet missing E_T using Delphes Algorithm, P_Z reconstructed from m_W constraint.
- Top is reconstructed from b-jet, lepton and MET (W mass constraint, 2 solutions)
- Higgs is reconstructed from 2 b-jets
- A forward ("tagging") jet is also required

Efficiency and quality of jet reconstruction for Bkg ttH (jet from b quark from top)



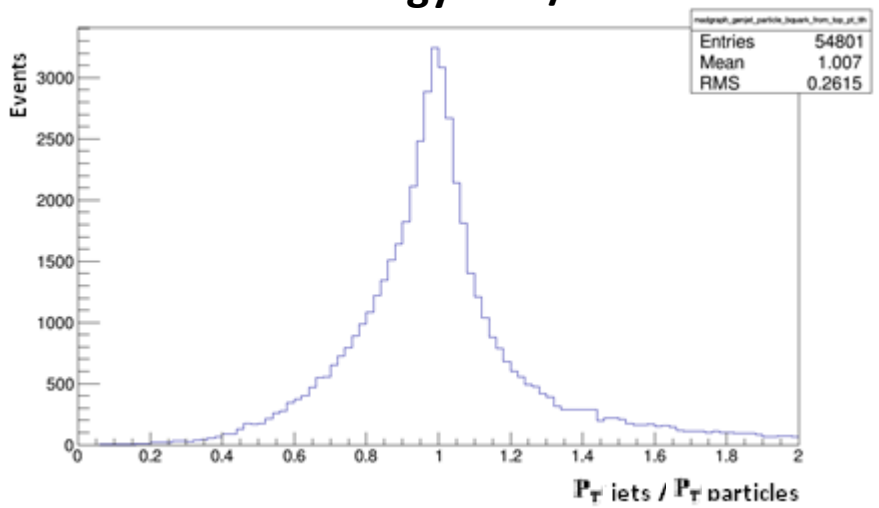
Jet efficiency vs PT



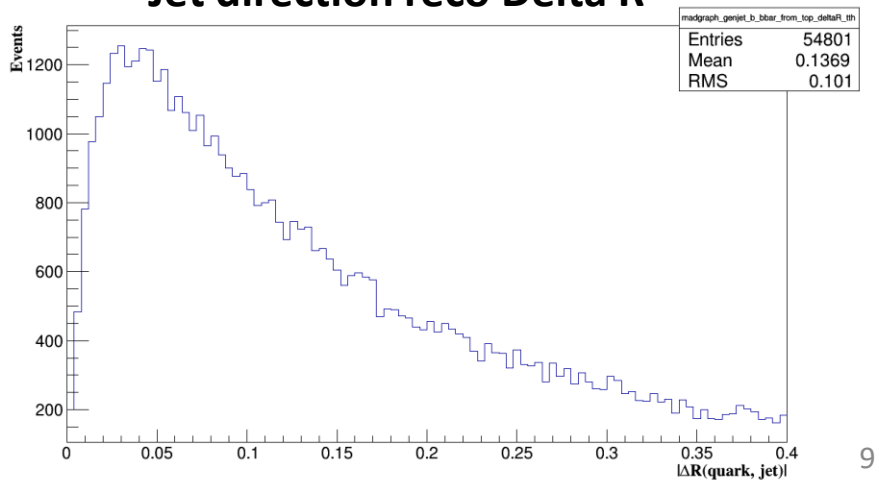
Jet efficiency vs rapidity

JetAlgorithm: antikt
JetPTMin: 20.0

Jet energy reco/truth



Jet direction reco Delta R



Event Selection (before cut optimization)

- Find leading lepton, veto sub-leading lepton:
  $|\eta^{\text{Lead lep}}| < 2.5$, $P_T^{\text{Lead lep}} > 25$ GeV, $P_T^{\text{Sublead lep}} < 15$ GeV, $|\eta^{\text{Sublead lep}}| < 2.75$
- E_T^{miss}: $E_T^{\text{miss}} > 40$ GeV
- Definition of any jet: $P_T > 25$ GeV
- Number of b-jets: $3 \leq N_{\text{b-jets}} \leq 4$
- Forward light jet: Jet with highest P_T among all jets $|\eta| > 2$
- P_T of forward light jet: $P_T^{\text{FWD}} > 30$ GeV
- Rapidity gap: $\Delta\eta = |\eta_{\text{FWD}} - \eta_{\text{b-jet}}| > 1.5$
- Mt, MH are loose&tight cut

Cut-flow (events normalized to 140 fb^{-1})

	Signal BSM tHbq		Bkg SM tHbq		Bkg SM tt		Bkg SM ttbb		Bkg SM ttH		Bkg SM tZbq		Bkg SM ttZ	
Cross section, pb^{-1}	0.4829		0.0355		746		8.917		0.1963		0.0885		0.0635	
Generated number of events	20549		19213		410707		40472		37366		20312		37060	
Generated number of events, normalized to 140 fb^{-1}	13892	100%	956	100%	14M	100%	0,51M	100%	10269	100%	2516	100%	3295	100%
Leading lepton, veto sub-leading lepton: $\|Eta^{Lead\ lep}\| < 2.5$, $P_T^{Lead\ lep} > 25$ GeV, $P_T^{Sublead\ lep} < 15$ GeV, $\|Eta^{Sublead\ lep}\| < 2.75$	8083	58.2%	536	56.1%	7.4M	51.8%	0.24M	48.1%	4801	46.8%	1422	56.5%	1536	46.6%
E_T^{miss}: $E_T^{miss} > 40$ GeV	4926	35.5%	315	32.9%	4.7M	32.8%	0.16M	31%	3270	31.8%	872	34.7%	1041	31.6%
Number of b-jets: $3 \leq N_{b\text{-}jets} \leq 4$	2988	21.5%	192	20.1%	260K	1.8%	40K	7.9%	2237	21.8%	459	18.3%	705	21.4%
P_T of forward light jet: $P_T^{FWD} > 30$ GeV	1985	14.3%	126	13.2%	91K	0.6%	17K	3.4%	916	8.9%	311	12.4%	296	9%
Rapidity gap: $\Delta Eta = \|Eta_{FWD} - Eta_{b\text{-}jet}\| > 1.5$	1383	9.9%	62	6.5%	42K	0.2%	7.8K	1.5%	428	4.2%	151	6%	128	3.9%
Higgs and Top mass	856	6.2%	36	3.8%	31K	0.2%	2K	0.4%	99	0.9%	84	3.3%	30	0.9%

tt(SM) vs ttbb(SM) at LO

- Signal: at least 3 b-jets expected
  (1 from top, 2 from Higgs).

- Background tt: only 2 b-jets from tops.
  3rd b-jet: either from ttbb, or fake b-tagging
  (from c in W $\rightarrow$ cs, or from light jets).

Typical ATLAS/CMS fake b-tagging rate:

From c-quarks we have in 12% cases fake b-jets and

From light quarks we have in 0.2% cases fake b-jets.

For 140 fb^{-1}, N_{tt}=31K (SM), N_{ttbb}=2K (SM)

So, ttbb less than tt by 15 times!

Optimization of selection cuts

Selection cuts were varied and optimal value was found from maximum $S/\sqrt{B}$ significance

№ cut	Cut	Starting value	Variations
1	Pt of lead lepton >	25 GeV	27 GeV
2	Pt of definition of jets >	25 GeV	30, 35 GeV
3	Et_miss >	40 GeV	20, 30 GeV
4	Eta of definition of forward light jet >	2.0	1.5, 2.25, 2.5
5	Pt of definition of forward light jet >	30 GeV	20, 25 GeV
6	Rapidity Gap >	1.5	1, 1.25
7	Cuts of m_top & m_Higgs	1Loose, 1Tight	both loose, both tight

New nominal cuts

Event Selection (after cut optimization)

- Find leading lepton, veto sub-leading lepton:
  $|\eta^{\text{Lead lep}}| < 2.5$, $P_T^{\text{Lead lep}} > 27$ GeV, $P_T^{\text{Sublead lep}} < 15$ GeV, $|\eta^{\text{Sublead lep}}| < 2.75$
- E_T^{miss}: $E_T^{\text{miss}} > 20$ GeV
- Definition of any jet: $P_T > 25$ GeV
- Number of b-jets: $3 \leq N_{\text{b-jets}} \leq 4$
- Forward light jet: Jet with highest P_T among all jets $|\eta| > 2$
- P_T of forward light jet: $P_T^{\text{FWD}} > 30$ GeV
- Rapidity gap: $\Delta\eta = |\eta_{\text{FWD}} - \eta_{\text{b-jet}}| > 1$
- Mt, MH are loose&loose cut

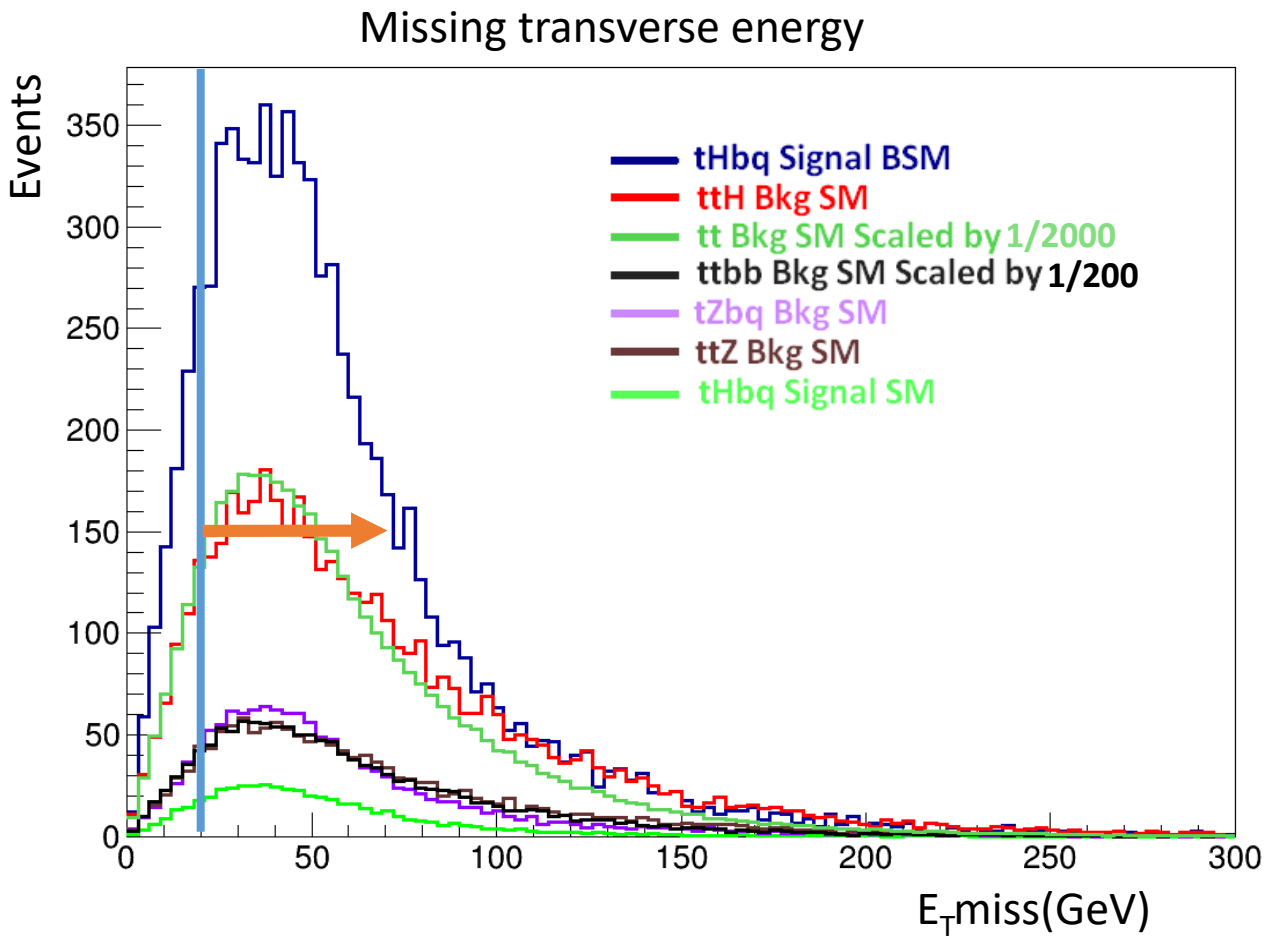
Missing Transverse Energy

Signal BSM&SM tHbq vs Bkg SM ttH, tt, ttbb, tZbq, ttZ

Leading lepton, veto sub-leading lepton:

$|\eta^{\text{Lead lep}}| < 2.5$, $P_T^{\text{Lead lep}} > 27$ GeV, $P_T^{\text{Sublead lep}} > 15$ GeV, $|\eta^{\text{Sublead lep}}| < 2.75$

We normalized histograms to 140 fb^{-1}

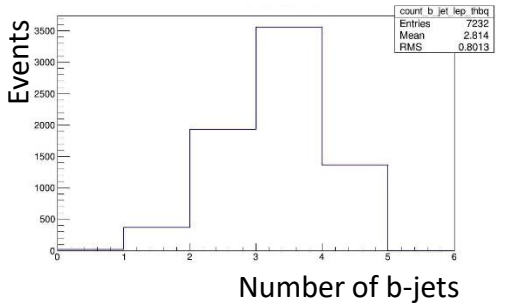


Number of b-jets (fake including)

Signal BSM&SM tHbq vs Bkg SM ttH, tt, ttbb, tZbq, ttZ

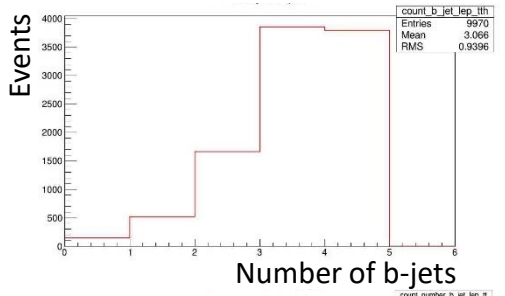
Signal BSM tHbq

Expect 4 b-jets:
1 from top
2 from Higgs
1 from spectator soft b-quark



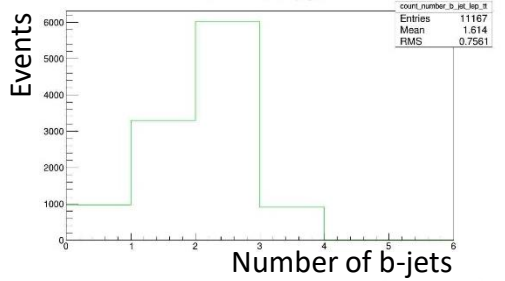
Bkg SM ttH

Expect 4 b-jets:
2 from top
2 from Higgs



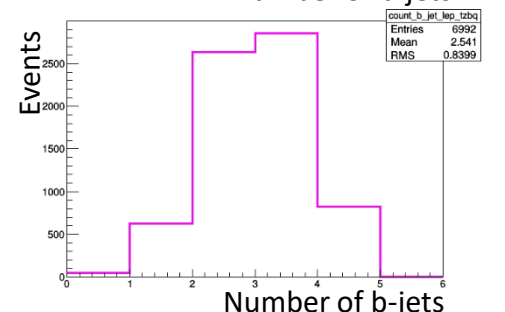
Bkg SM tt

Expect 3 b-jets:
2 from top
1 fake b-jet



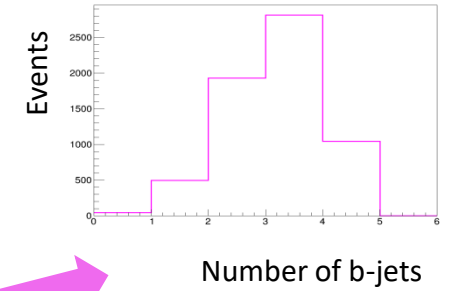
Bkg SM tZbq

Expect 4 b-jets:
2 from top
2 from Z-boson



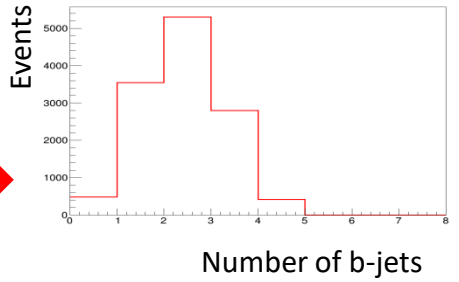
SM tHbq

Expect 4 b-jets:
1 from top
2 from Higgs
1 from spectator soft b-quark



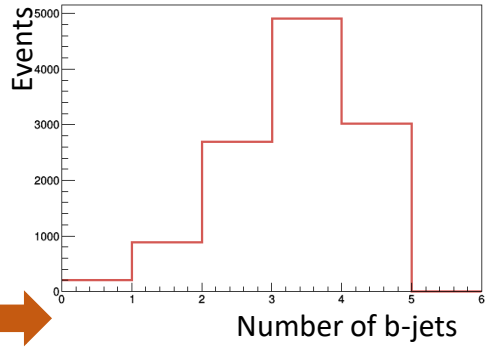
Bkg SM ttbb

Expect 4 b-jets:
2 from gluon splitting
2 from Higgs



Bkg SM ttZ

Expect 4 b-jets:
2 from top
2 from Z-boson



Jet association with forward light jet tHbq BSM

Finding of forward light jet:

We study different cut for P_T, P_{Total} and $|\eta|$.

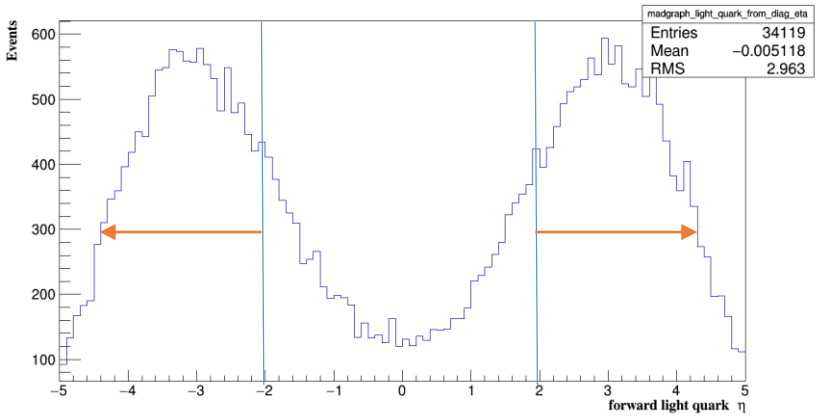
Final optimum for all jets:

Jet with highest P_T among all jets $|\eta| > 2.0$

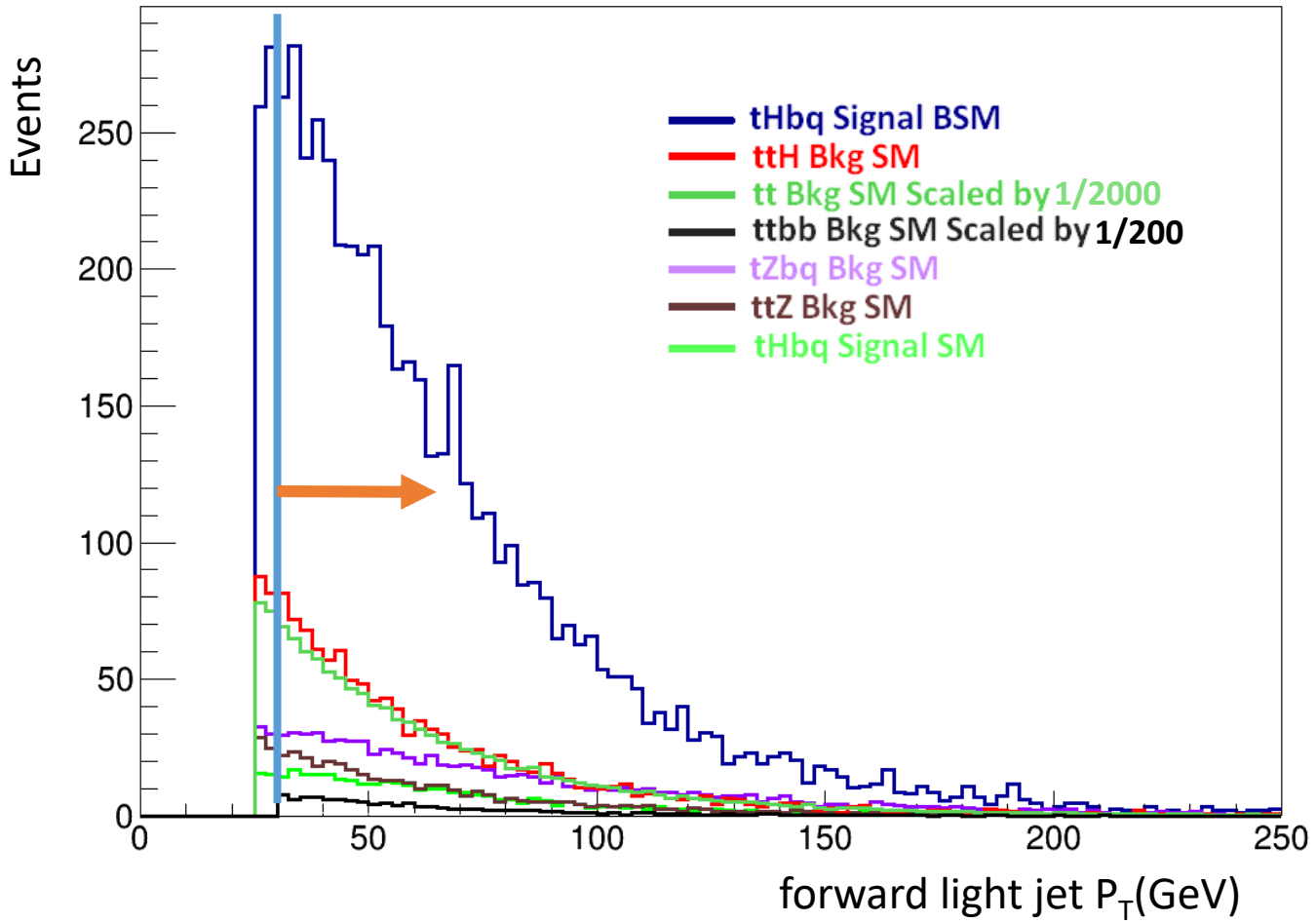
Correctly identified jets are found in ~90% cases.

Forward Light Jet
Signal BSM tHbq vs Bkg SM ttH, tt, ttbb, tZbq, ttZ

We normalized histograms to 140 fb^{-1}



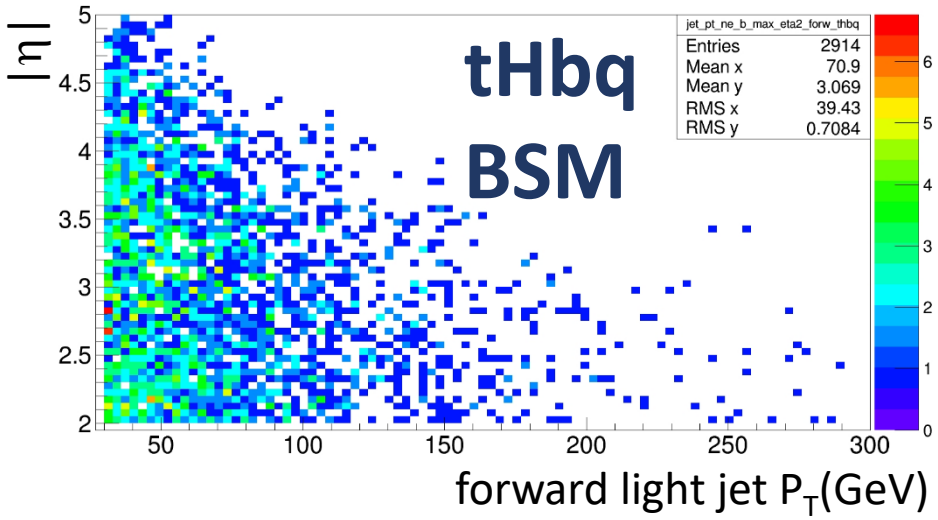
Transverse momentum of forward light jet

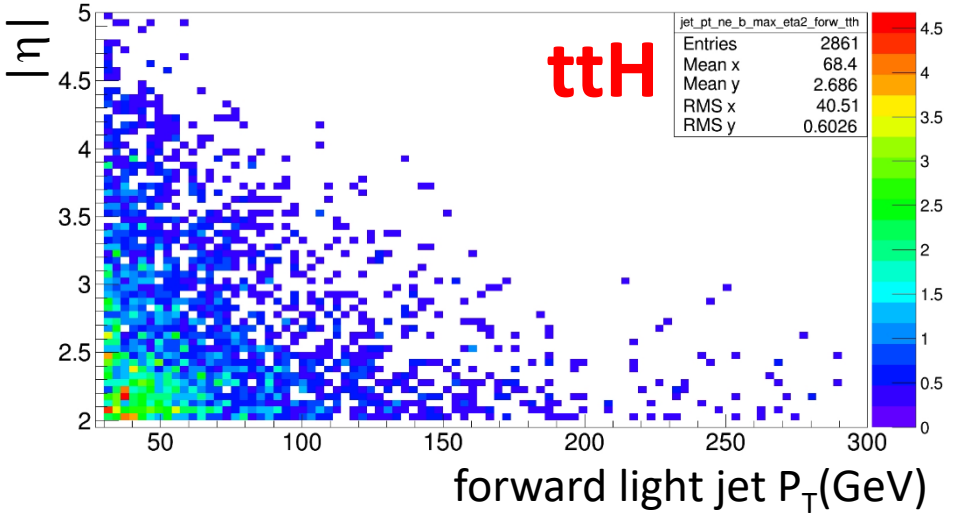


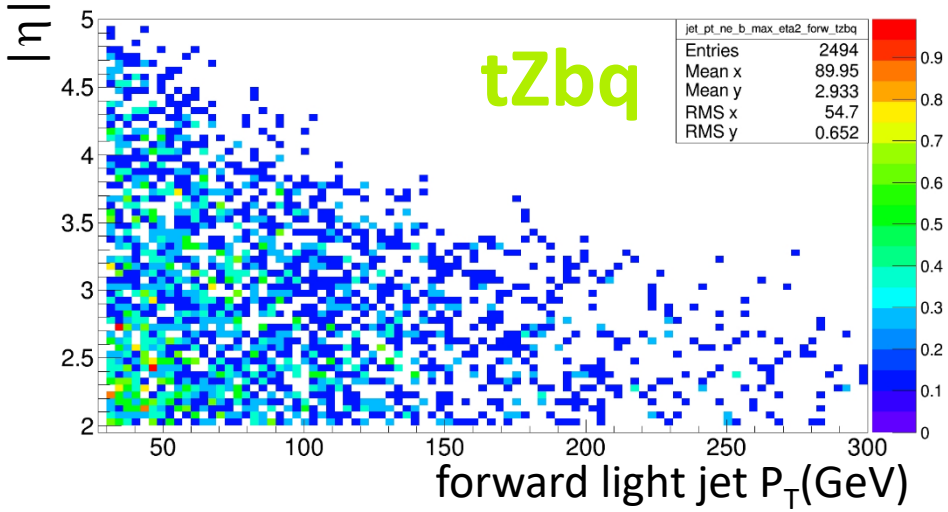
Pseudorapidity vs Transverse momentum of forward light jet

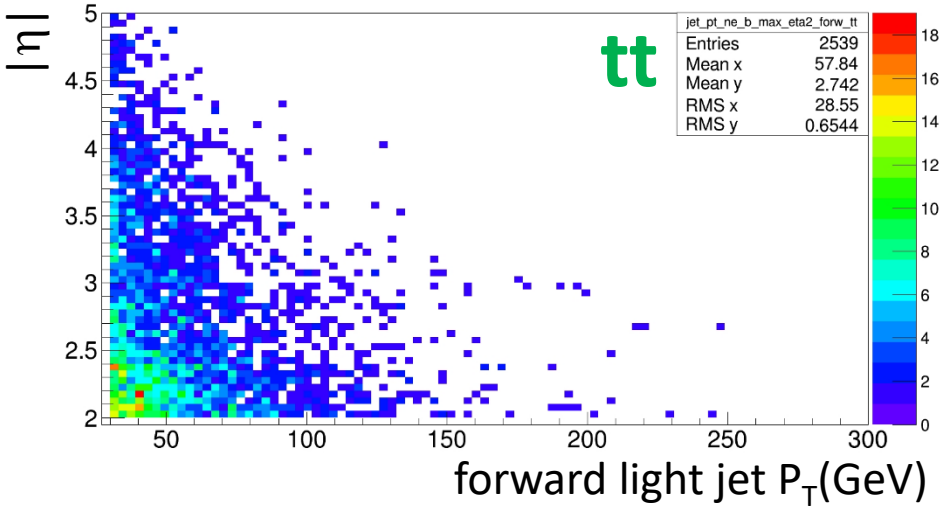
Signal BSM tHbq vs Bkg SM ttH, tt, tZbq

Normalized histograms to 140 fb^{-1}







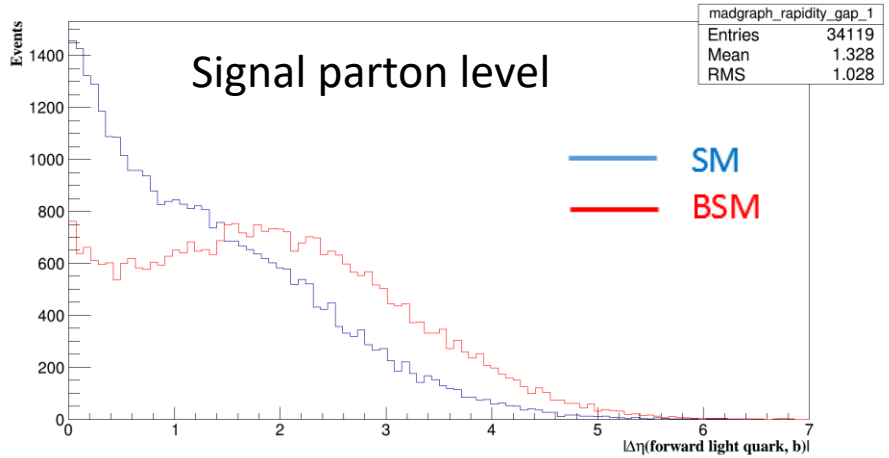


Rapidity Gap

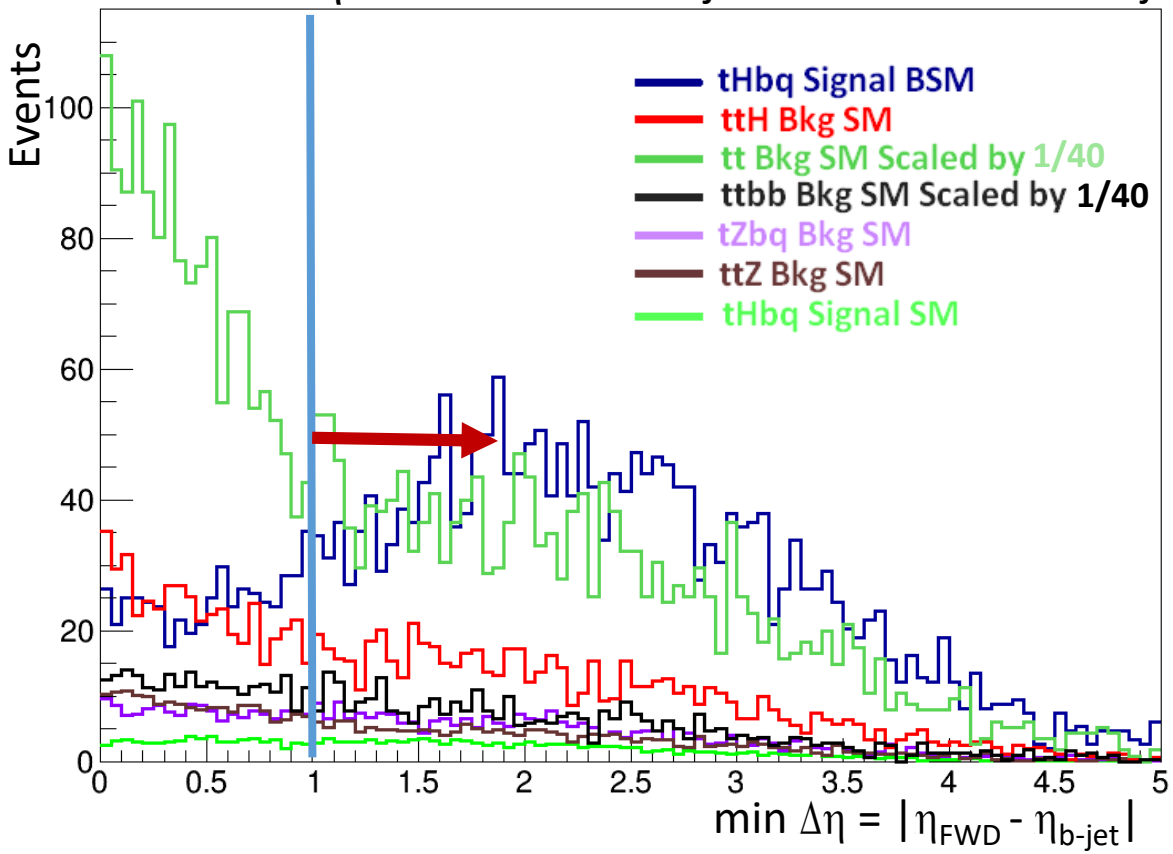
Signal BSM tHbq vs Bkg SM ttH, tt, ttbb, tZbq, ttZ

Number of b-jets: $3 \leq N_{\text{b-jets}} \leq 4$

P_T of forward light jet: $P_T^{FWD} > 30$ GeV



Distance in η between forward jet and closest central jet



We normalized histograms to 140 fb^{-1}

Jet-parton association

tHbq BSM, SM vs Bkg SM ttH, tt, ttbb, tZbq, ttZ

Number of b-jets: $3 \leq N_{\text{b-jets}} \leq 4$

- In event we have 3 b-jets.
- Need to associate each jet with its parton.
- We have 3 combinations: 1 correct and 2 wrong.
- We find correct combination using reconstruction of masses of top-quark and Higgs (chose the one with best χ^2).

$$\chi^2 = \left(\frac{M - M_H}{\sigma_H}\right)^2 + \left(\frac{M - M_t}{\sigma_t}\right)^2$$

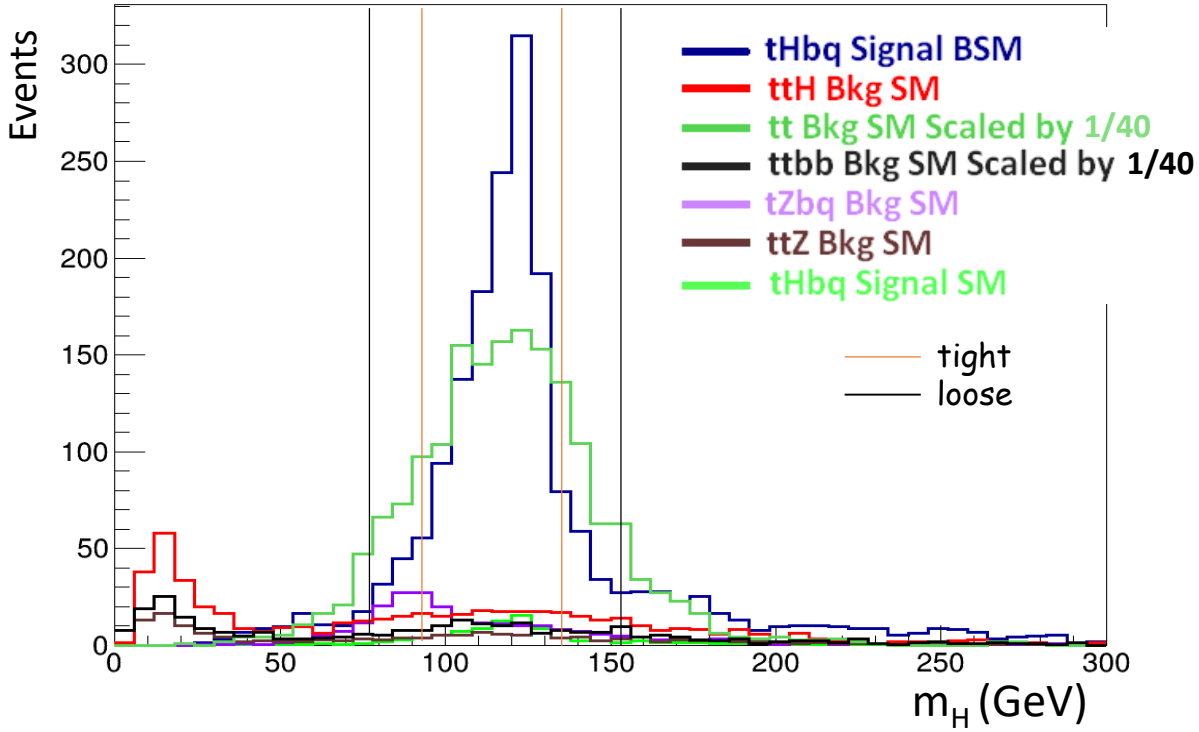
Reconstruction of top and Higgs masses

Number of b-jets: $3 \leq N_{\text{b-jets}} \leq 4$

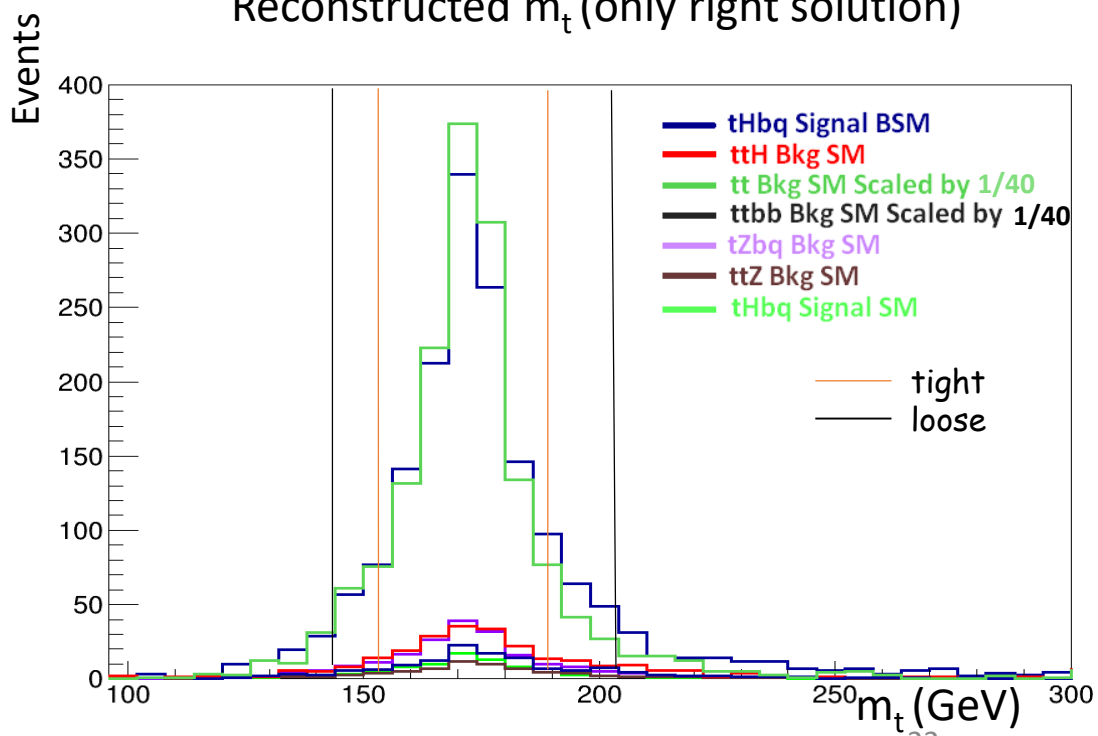
Loose cuts:
$75 < m_H < 155$
$140 < m_t < 210$

Tight cuts:
$90 < m_H < 135$
$155 < m_t < 180$

Reconstructed mass of Higgs if $140 < m_t < 210$



Reconstructed m_t (only right solution)



Cut-flow (events normalized to 140 fb^{-1})

	Signal BSM tHbq		Bkg SM tHbq		Bkg SM tt		Bkg SM ttbb		Bkg SM ttH		Bkg SM tZbq		Bkg SM ttZ	
Cross section, pb^{-1}	0.4829		0.0355		746		8.917		0.1963		0.0885		0.0635	
Generated number of events	20549		19213		410707		40472		37366		20312		37060	
Generated number of events, normalized to 140 fb^{-1}	13892	100%	956	100%	14M	100%	0,51M	100%	10269	100%	2516	100%	3295	100%
Leading lepton, veto sub-leading lepton: $\|Eta^{Lead\ lep}\| < 2.5$, $P_T^{Lead\ lep} > 27$ GeV, $P_T^{Sublead\ lep} < 15$ GeV, $\|Eta^{Sublead\ lep}\| < 2.75$	7756	55.8%	508	53.1%	7.1M	49.8%	0.23M	46.2%	4623	45.0%	1346	53.5%	1473	44.7%
E_T^{miss}: $E_T^{miss} > 20$ GeV	6857	49.4%	450	47.1%	6.3M	44.4%	0.21M	41.3%	4171	40.6%	1205	47.9%	1335	40.5%
Number of b-jets: $3 \leq N_{b\text{-}jets} \leq 4$	4150	29.9%	276	28.9%	380K	2.7%	55K	10.9%	2889	28.1%	644	25.6%	907	27.5%
P_T of forward light jet: $P_T^{FWD} > 30$ GeV	2760	19.9%	183	19.1%	130K	0.9%	24K	4.7%	1168	11.4%	435	17.3%	381	11.6%
Rapidity gap: $\Delta Eta = \|Eta_{FWD} - Eta_{b\text{-}jet}\| > 1$	2264	16.3%	121	12.6%	75K	0.5%	14K	2.9%	703	6.8%	282	11.2%	211	6.4%
Higgs and Top mass	1519	10.9%	77	8.0%	59K	0.4%	4.4K	0.9%	206	2.0%	182	7.2%	58	1.8%

Statistical signal significance

$$S = Nsig/\sqrt{N_{bkg}}$$

Starting cut values –

Signal significance:

0.2σ (SM), 4.7σ (BSM)

Optimized cut values –

Signal significance:

0.3σ (SM), 6.0σ (BSM)

	Yields	Cross section, pb
tHbq BSM	1519 ± 32	0.4829
tHbq SM	77 ± 2	0.0355
tt	51217 ± 1436	746
ttbb	$4\,407 \pm 235$	8.917
ttH	206 ± 8	0.1963
tZbq	182 ± 5	0.0885
ttZ	58 ± 2	0.0635
Total Bkg	56070 ± 1455	

Cut-and-count analysis finished.
Next step: MVA analysis.
We prepare additional variables
with signal/background separation power.

List of MVA input variables

- We concentrate on variables inspired by CMS paper:
  CMS Collaboration // Phys. Rev. D 99 , 9 (2019) 092005

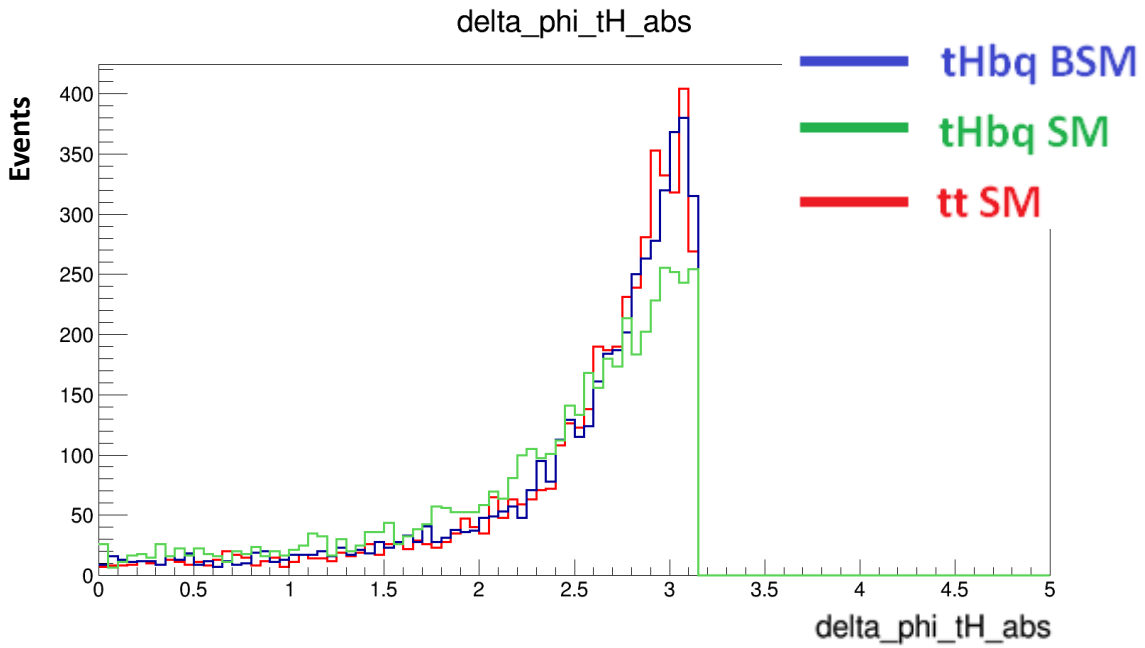
Number of all variables: 110

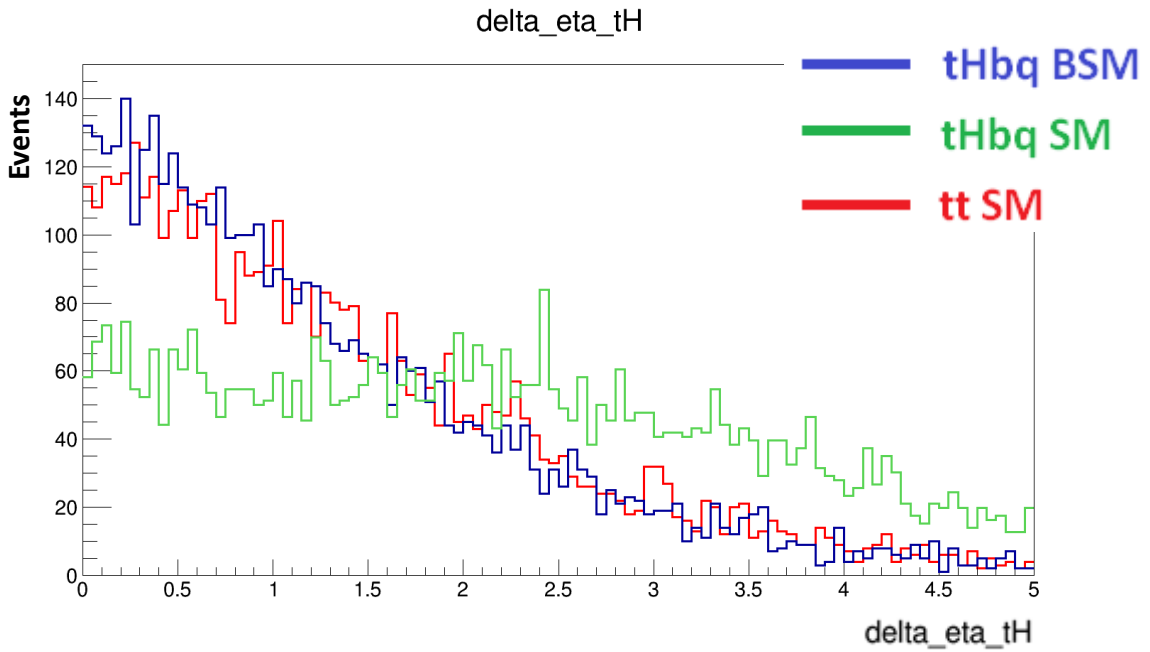
- Invariant mass of 3 jets with max PT
- Fox-Wolfram Moment (0-4 states) of all jets
- Fox-Wolfram Moment (0-4 states) of l+ν+all jets
- Aplanarity
- ΔR between 2 nonb-jets with max PT
- $Cos\theta(b_{\nu},l)$
- $Cos\theta(b_{\nu},l)^*$ (in top quark rest frame)

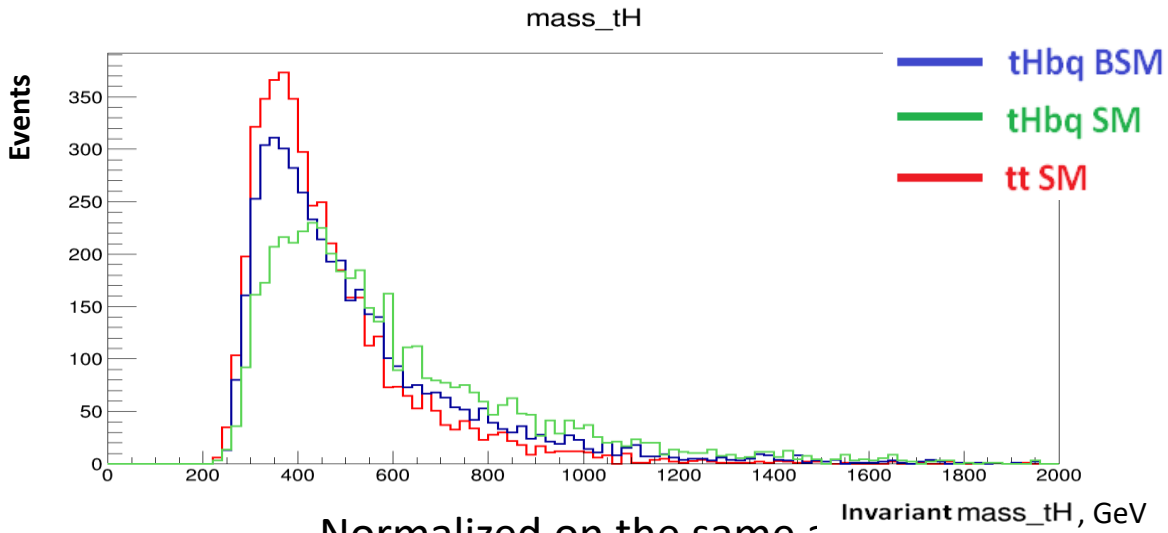
- Also we investigate new variables:

- $|\Delta\varphi|$(t-H),$|\Delta\eta|$(t-H), M(t+H)
- Rapidity gap: $|\Delta\eta|$(FWD,H) $|\Delta\eta|$(FWD,top)
- Central non-b with max P_T: M(H+jet)
- Forward non-b with max P_T: M(H+jet)

Comparison of signal tHbq SM&BSM and Bkg tt

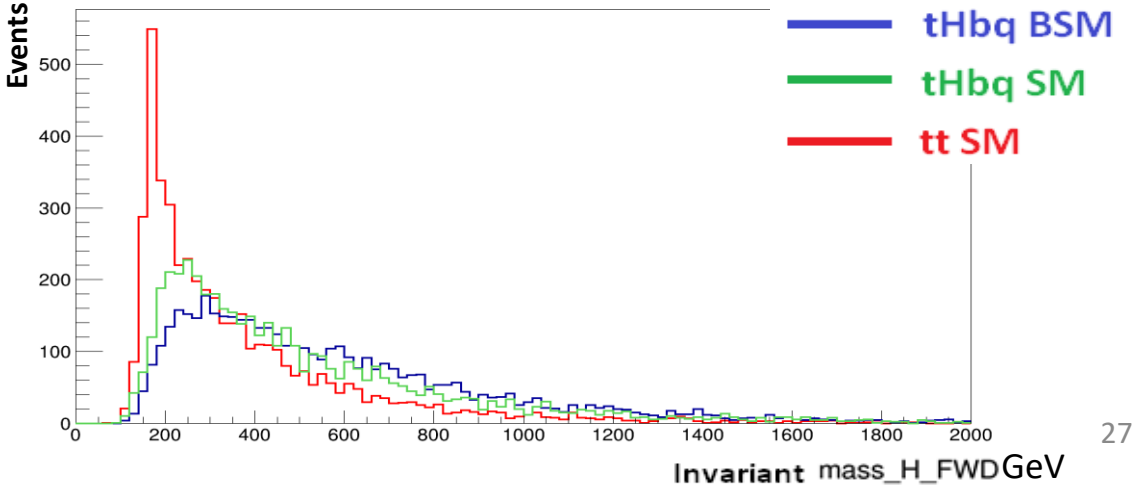






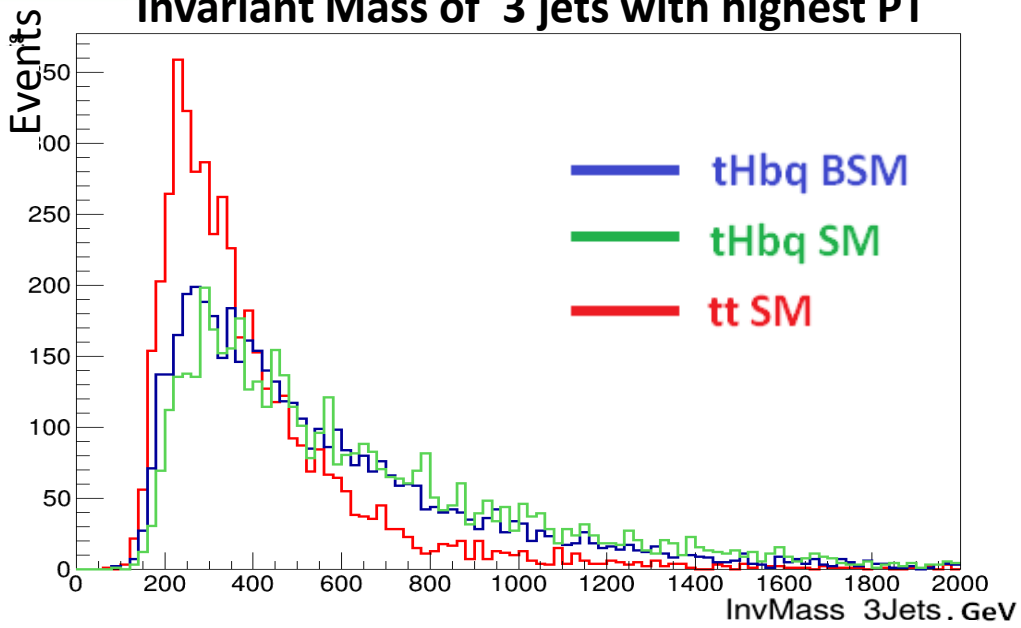
Normalized on the same area

Invariant mass of Higgs and Forward Jet

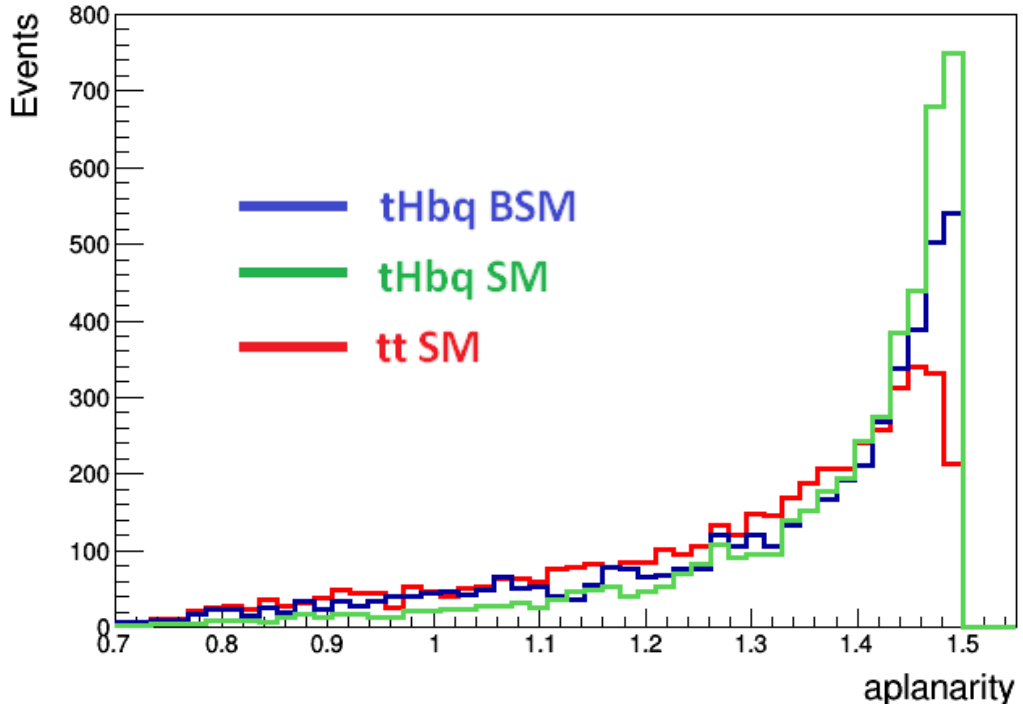


Comparison of signal tHbq SM&BSM and Bkg tt

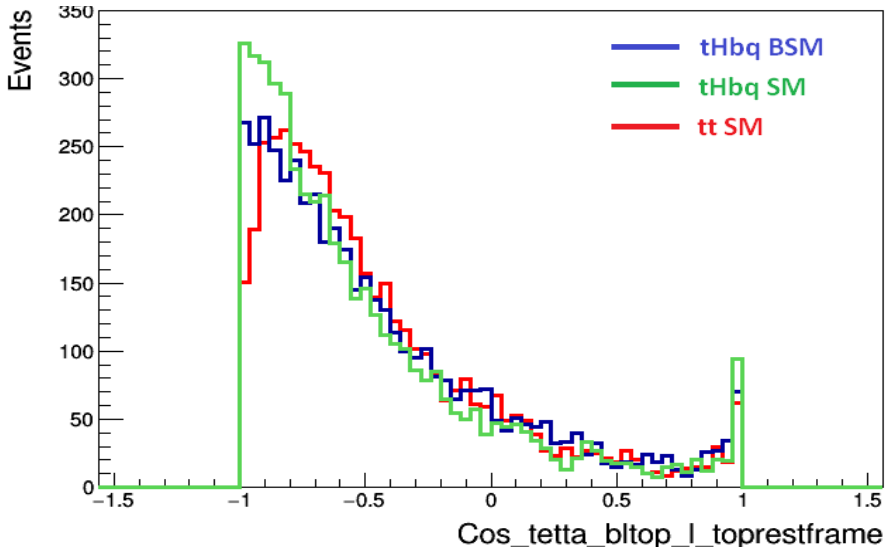
Invariant Mass of 3 jets with highest PT



Aplanarity

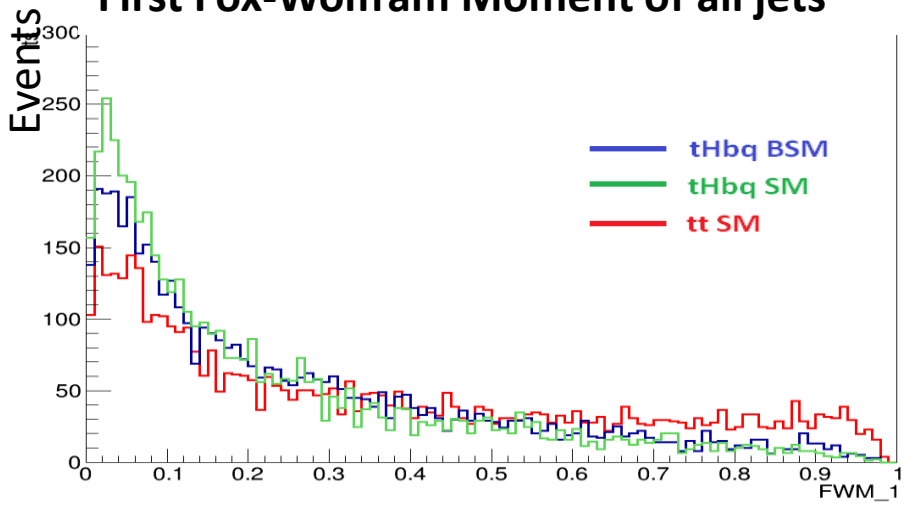


Cosine theta of b and lepton (from lepton decay of top) in top rest frame



Normalized on the same area

First Fox-Wolfram Moment of all jets

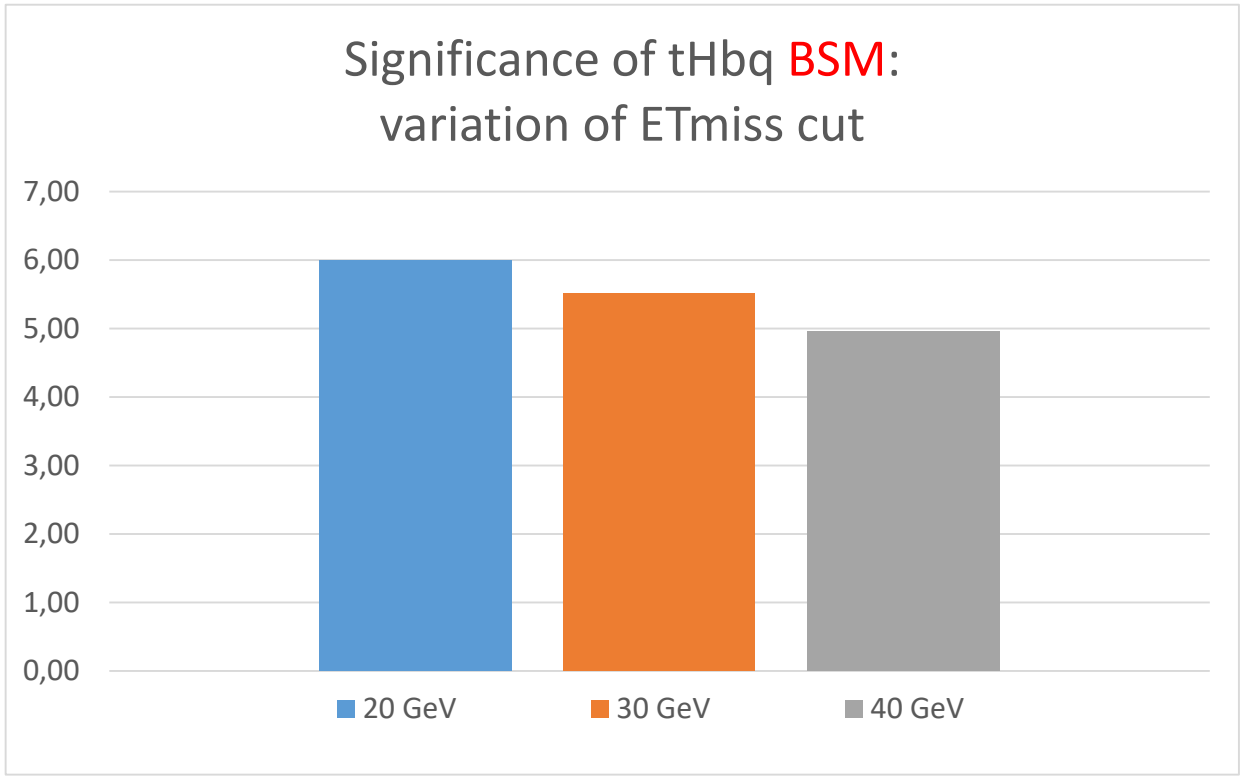


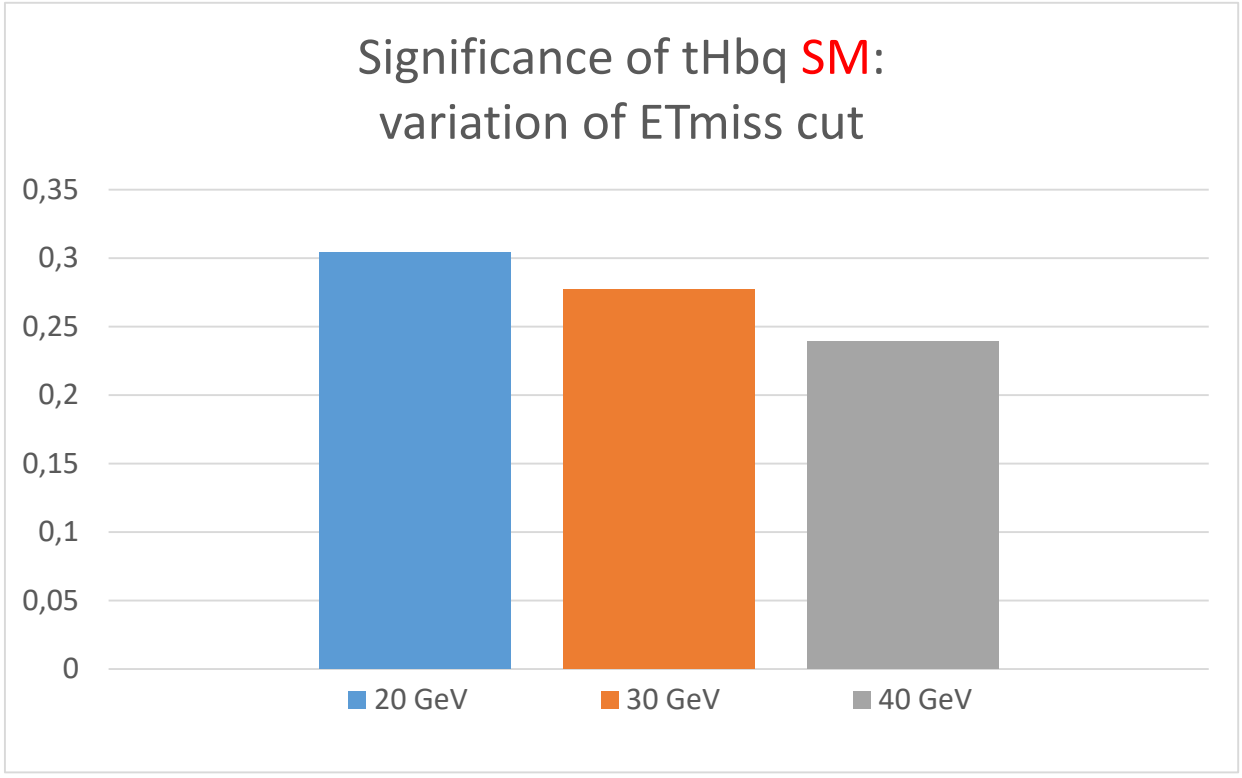
Summary and plans

- ✓ **AYSS-2019 Conference:**
  - **Studied preselection cuts at the parton level (Signal only)**
  - **Added background simulation ttH, tt**
  - **Performed analyses on simulated jet level**
- ✓ **Presented at this meeting:**
  - **Added Signal simulation tHbq (SM)**
  - **Added background simulation ttbb, , tZbq, ttZ, tHbq (SM)**
  - **Performed analyses on simulated jet level with new backgrounds**
- ✓ **Event selection cuts optimized**
- ✓ **With 140 fb^{-1} signal significance is 6.0 (BSM) and 0.30 (SM)**
- ✓ **Event yields: 56070 $\pm$ 1455 (background), 77 $\pm$ 2 (SM signal), 1519 $\pm$ 32 (BSM signal)**
- ✓ **Results of this study**
  - **1) Determination of neutrino P_z**
  - **2) Discovered that dominant background is not ttbb, but tt with W$\rightarrow$cs, and c mistagged as b**
  - **3) b-jet association with top or Higgs decays using best χ^2 of M_t and M_H**
- ✓ **As a separate study, we plan to use the selected events as input for a MVA to improve the significance**

Thank you for your attention!

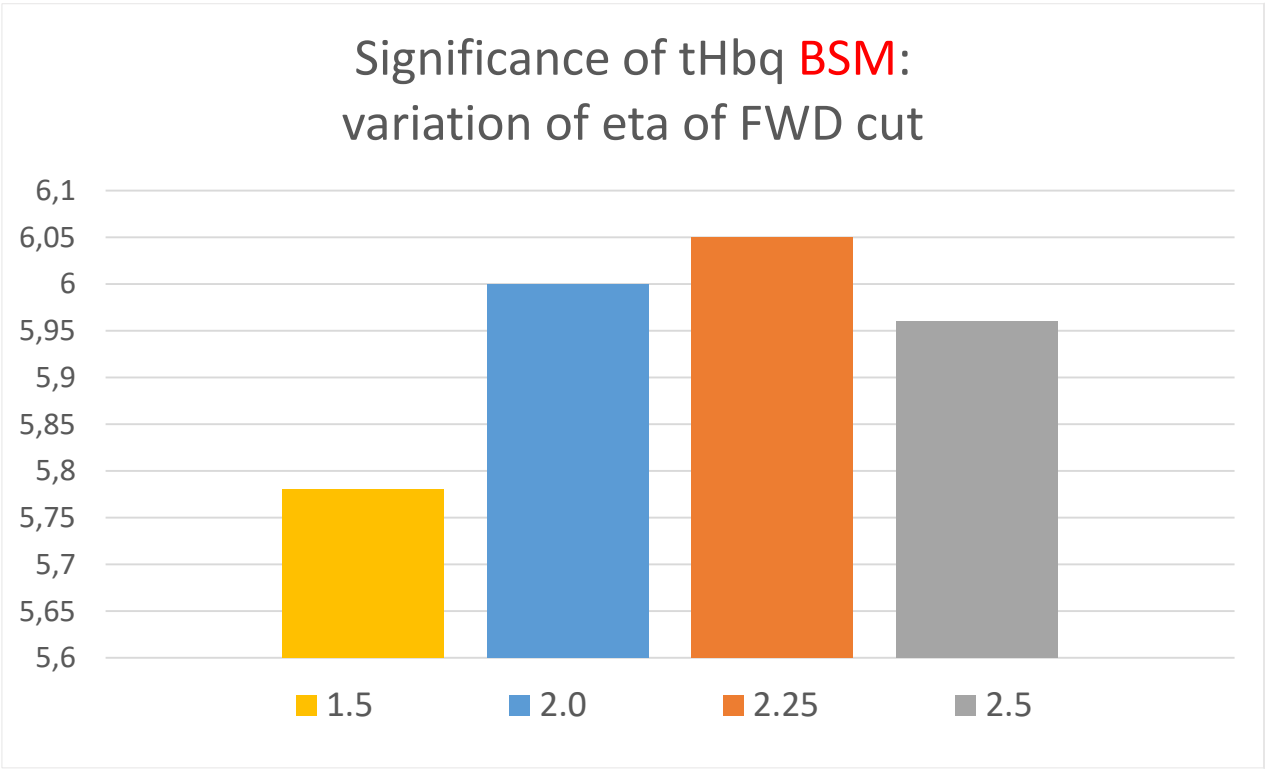
Statistical signal significance

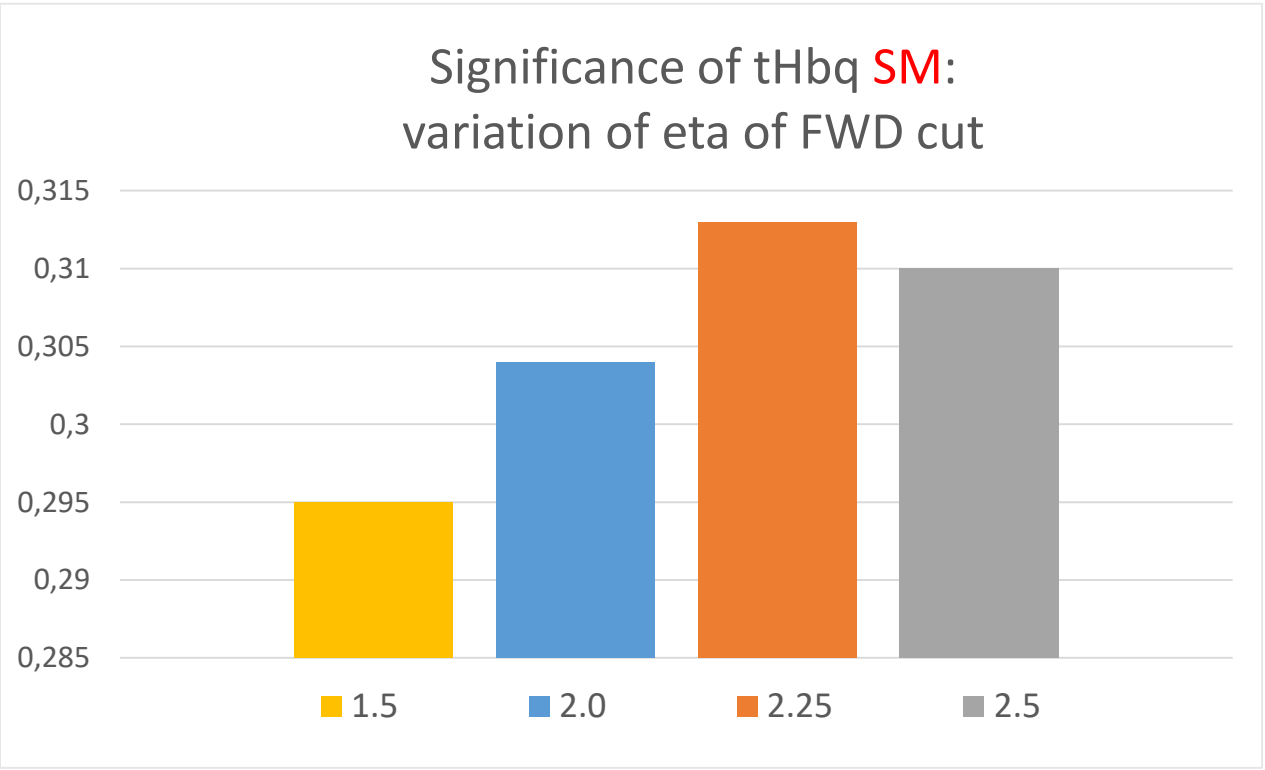




New nominal cuts

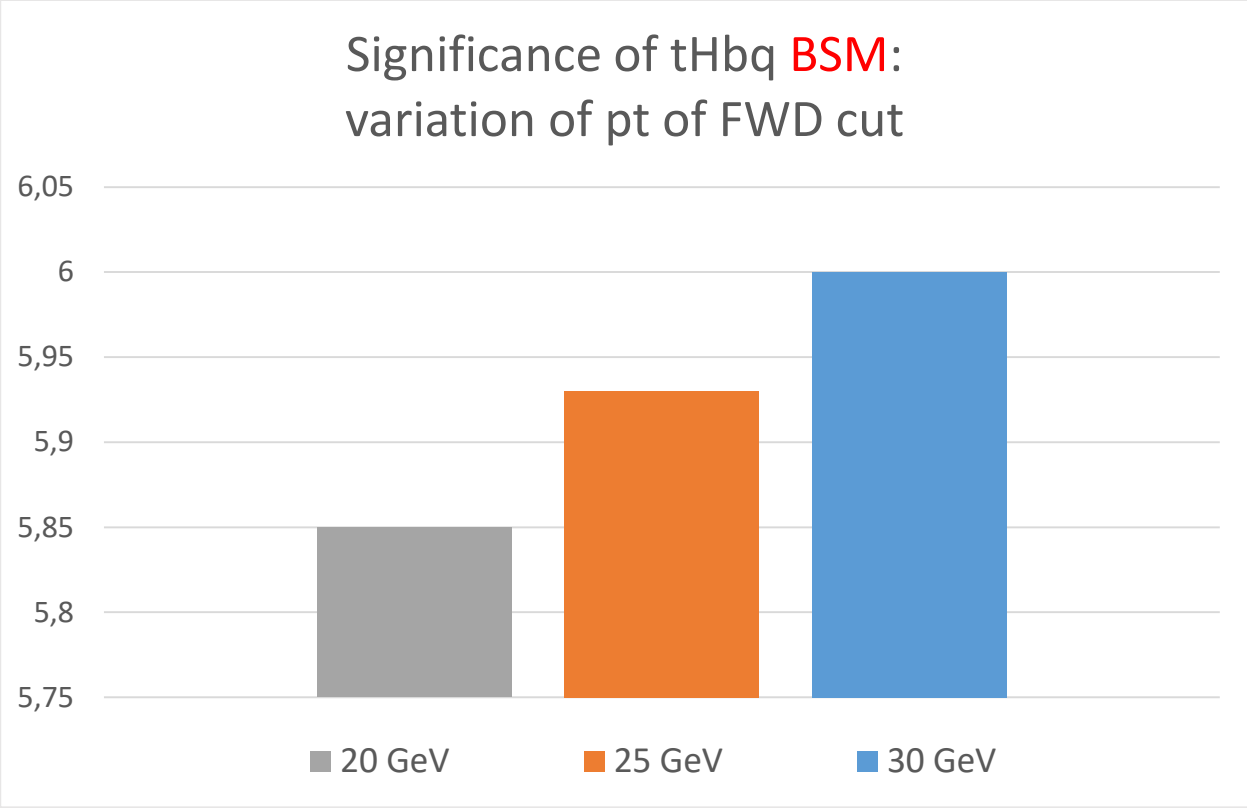
Statistical signal significance

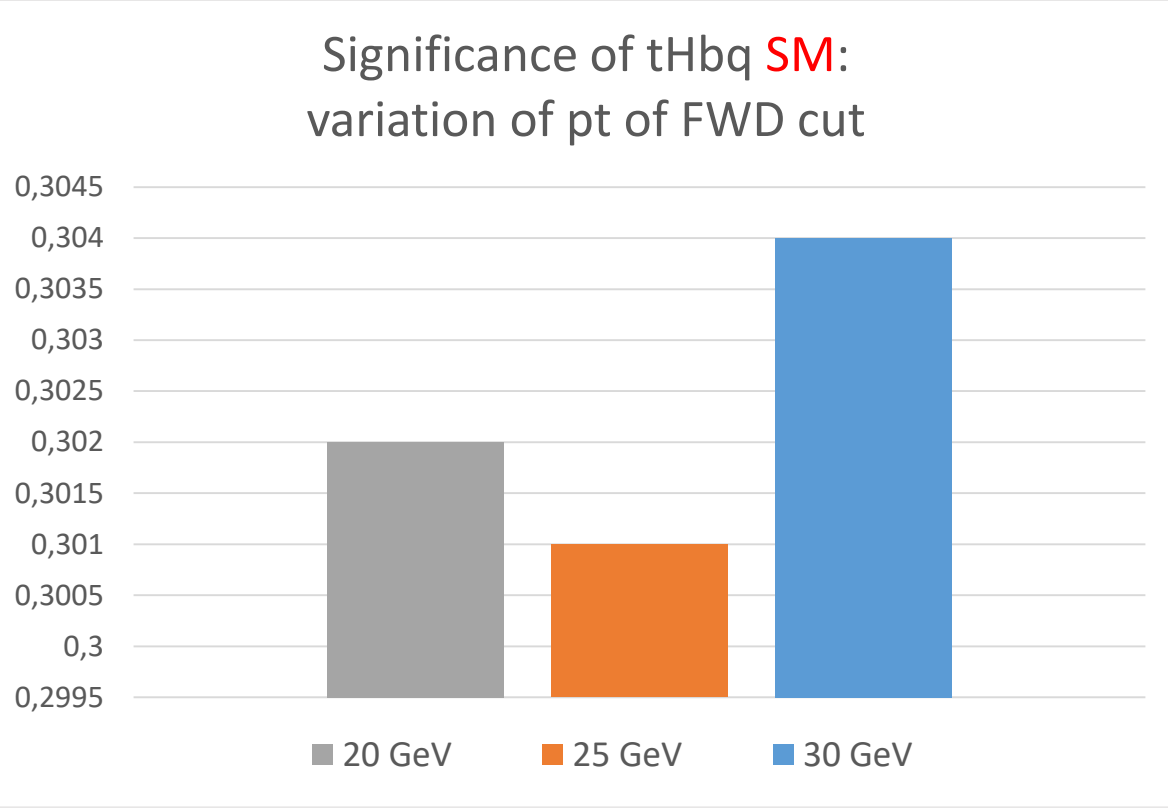




New nominal cuts

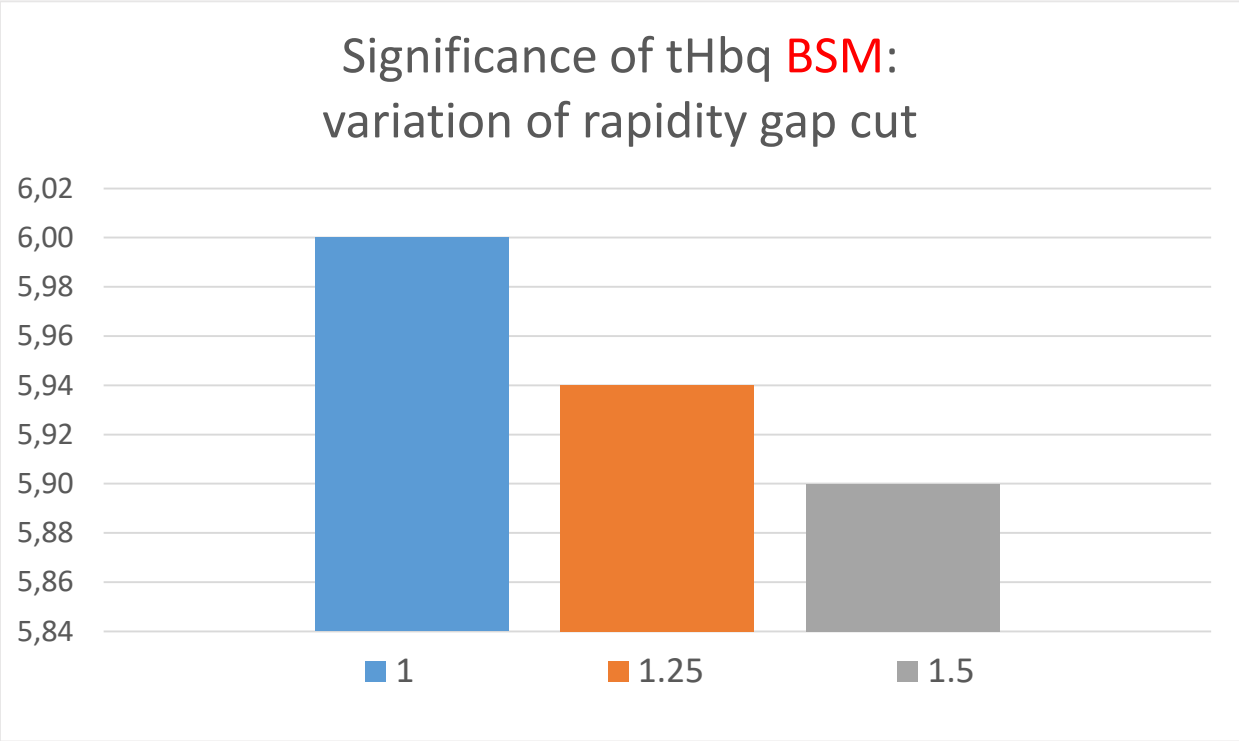
Statistical signal significance

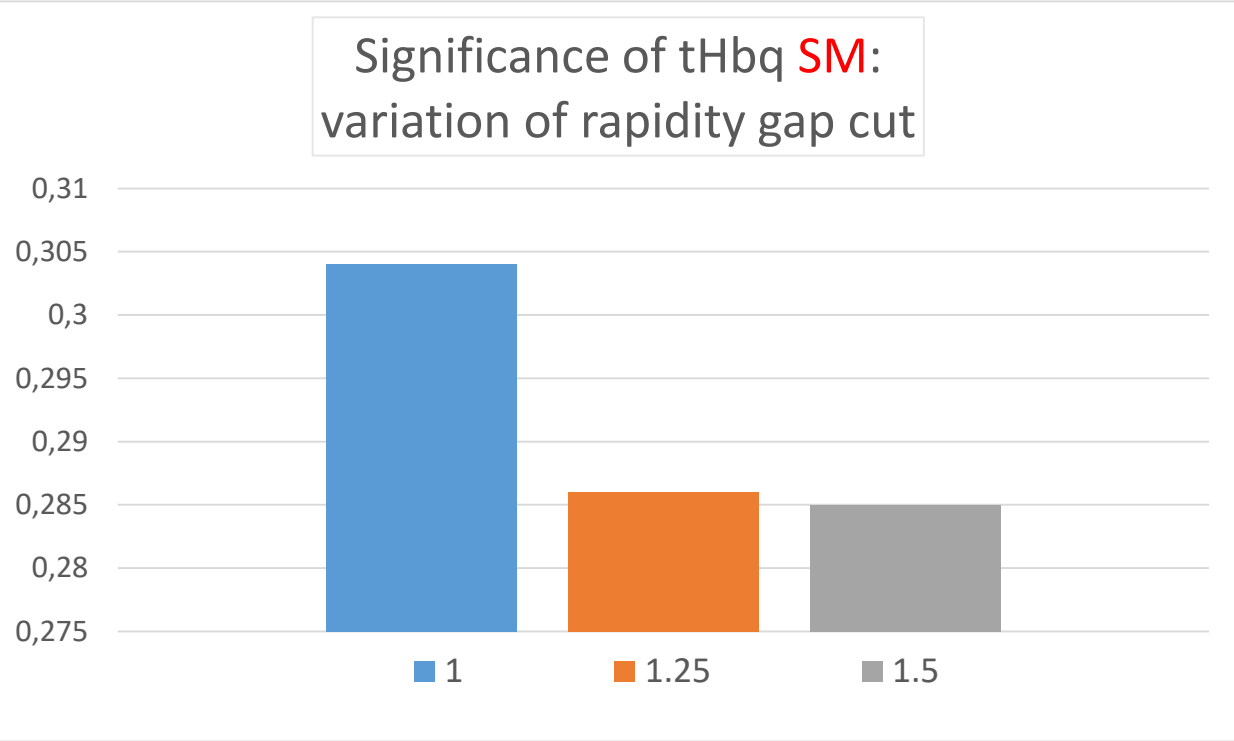




New nominal cuts

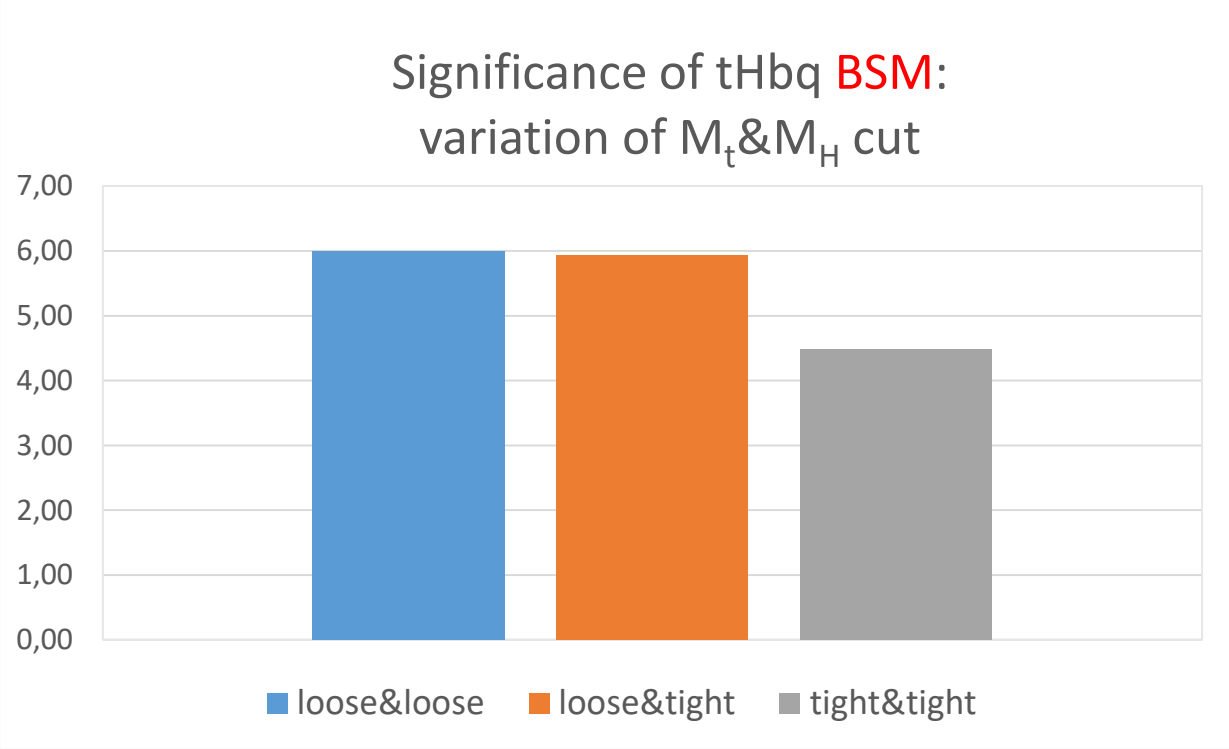
Statistical signal significance

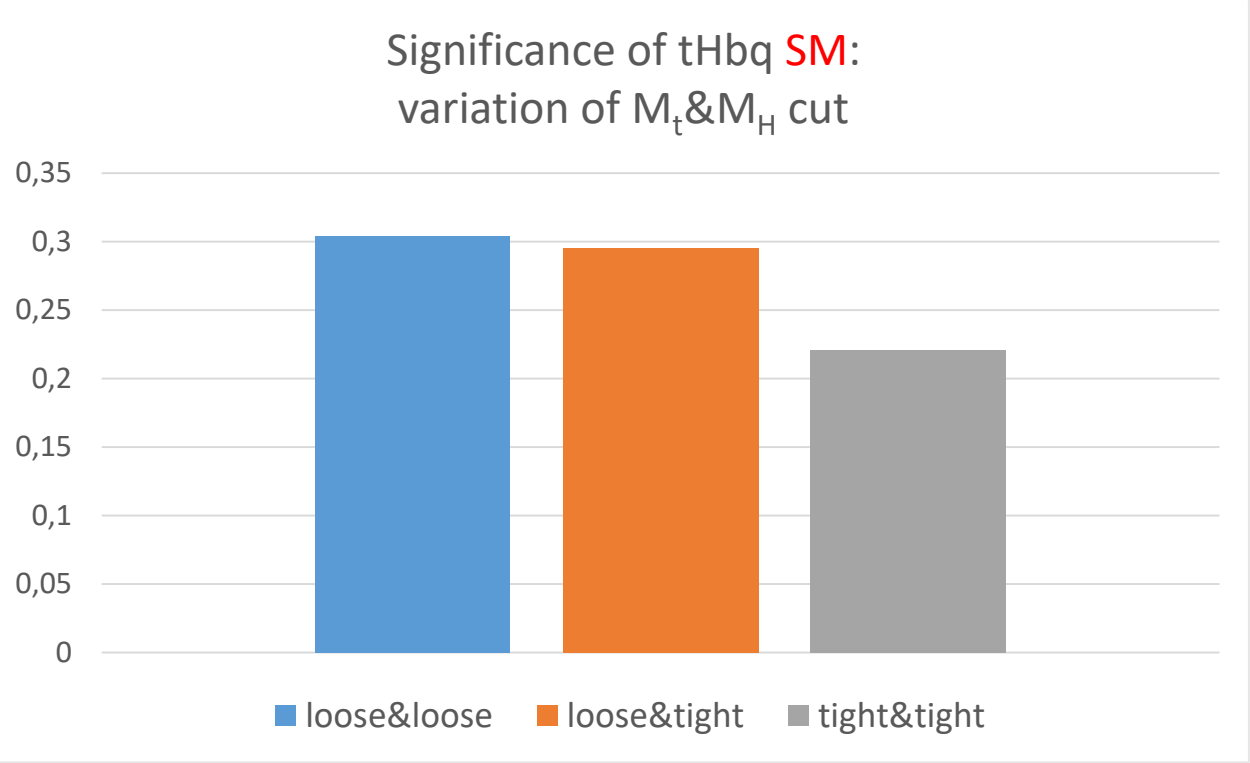




New nominal cuts

Statistical signal significance



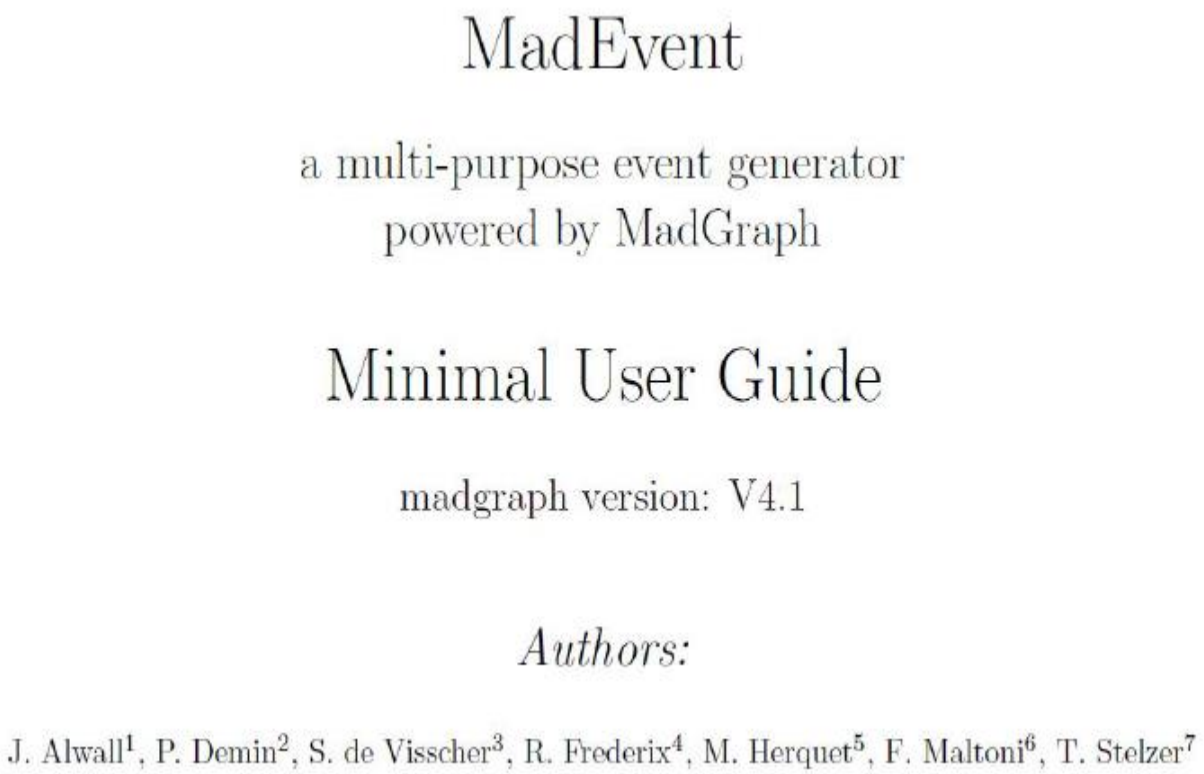


New nominal cuts

MC generator MadGraph

- **MadGraph MG5_aMC_v2_6_3_2**

- **LHAPDF-6.1.6** (last version)
- **ExRootAnalysis:** A package to convert the various output (LHE) in a ROOT format.
- **Pythia 8.2:** A package containing Pythia8. Pythia8 is able to shower and to hadronize your events and is able to perform the matching for multi-jet production.
- **Delphes:** A package allowing to have a fast detector simulation, in replacement of PGS.



MadEvent

a multi-purpose event generator
powered by MadGraph

Minimal User Guide

madgraph version: V4.1

Authors:

J. Alwall[1], P. Demin[2], S. de Visscher[3], R. Frederix[4], M. Herquet[5], F. Maltoni[6], T. Stelzer[7]

Reconstructed mass of top-quark in leptonic decay mode $t \rightarrow b l\nu$: choose right sign of neutrino P_z

Reconstruction of m_W

- For reconstructed W-boson's mass:

$$m_W^2 = \left(E_l + \sqrt{\left(E_{miss}^T \right)^2 + P_{L,\nu}^2} \right)^2 - \left(P_{T,l} + E_{miss}^T \right)^2 - \left(P_{L,l} + P_{L,\nu} \right)^2 ,$$

E_l is the energy of lepton and P_l denote longitudinal momenta of the lepton and neutrino.$P_{T,l}$ is the transverse of the lepton.

- we need to choose solution with right sign of P_Z from two solutions:

$$P_{Z,\nu}^{\pm} = \frac{1}{P_{T,l}^2} \left(\mu P_{Z,l} \pm E_l \sqrt{\mu^2 - P_{T,l}^2 \left(E_{miss}^T \right)^2} \right)^2$$

$$P_{T,l} = \sqrt{E_l^2 - P_{Z,l}^2}; \quad \mu = \frac{m_W^2}{2} + P_{X,l} E_{miss}^{T,X} + P_{Y,l} E_{miss}^{T,Y}; \quad m_W = 80.35\text{GeV}$$

Dubna group's choice of right sign of P_z

- In our choice we consider the differences:

$$\Delta m^{\pm} = \left| m_t^{\pm} - 172.5 \right|$$

We choose the solution, which provides the smallest Δm=> correct $|\eta_C|$ and another solution gives the wrong $|\eta_{WR}|$

So we note the sign of the P_Z as correct, if reconstructed mass of top-quark is closest to right $m_t = 172.5 GeV$.

And we calculate $|\eta_C|$ and $|\eta_{WR}|$ for correct and wrong sign of solution of P_Z, if the solution is real.

Comparison choice with P_z at parton level

- From truth information of $|\eta_{TR}|$ of neutrino at parton level we know which solution is correct

Correct choice $|\eta_C| = \min \big| |\eta_\pm| - |\eta_{TR}| \big|$

Wrong choice $|\eta_{WR}|$ is second solution, which is not minimum of $\big| |\eta_\pm| - |\eta_{TR}| \big|$

We compared two existing top quark mass reconstruction methods:

"Single-Top Group" and "Dubna group" methods

In what percent of cases each of these methods do correct choice of sign P_z ? $|\eta_C| - |\eta_{WR}|$

	Single-Top Group	Dubna group
percent of cases each of these methods select correct solution	63%	73.9%

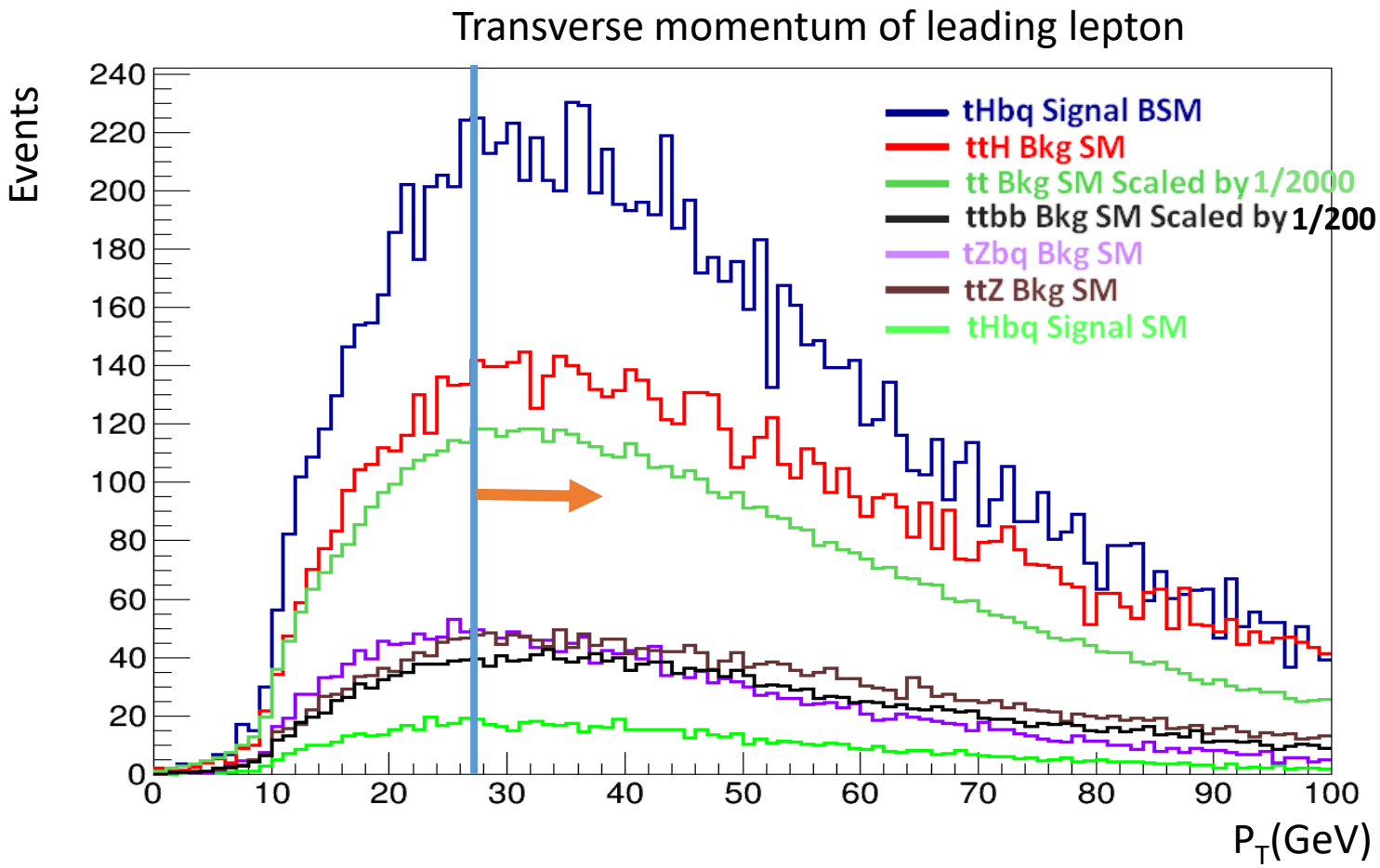
PT of Leading Lepton

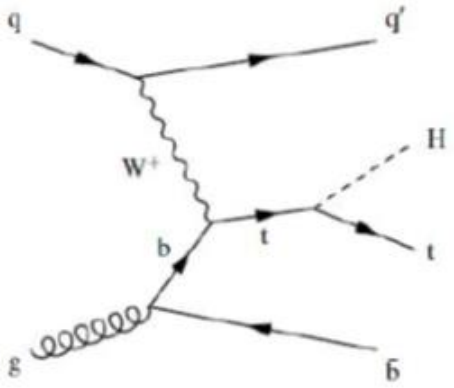
Signal BSM & SM tHbq vs Bkg SM ttH, tt, ttbb, tZbq, ttZ

Leading lepton, veto sub-leading lepton:

$|\eta^{\text{Lead lep}}| < 2.5$, $P_T^{\text{Lead lep}} > 27$ GeV, $P_T^{\text{Sublead lep}} > 15$ GeV, $|\eta^{\text{Sublead lep}}| < 2.75$

We normalized histograms to 140 fb^{-1}





Reconstructed jets

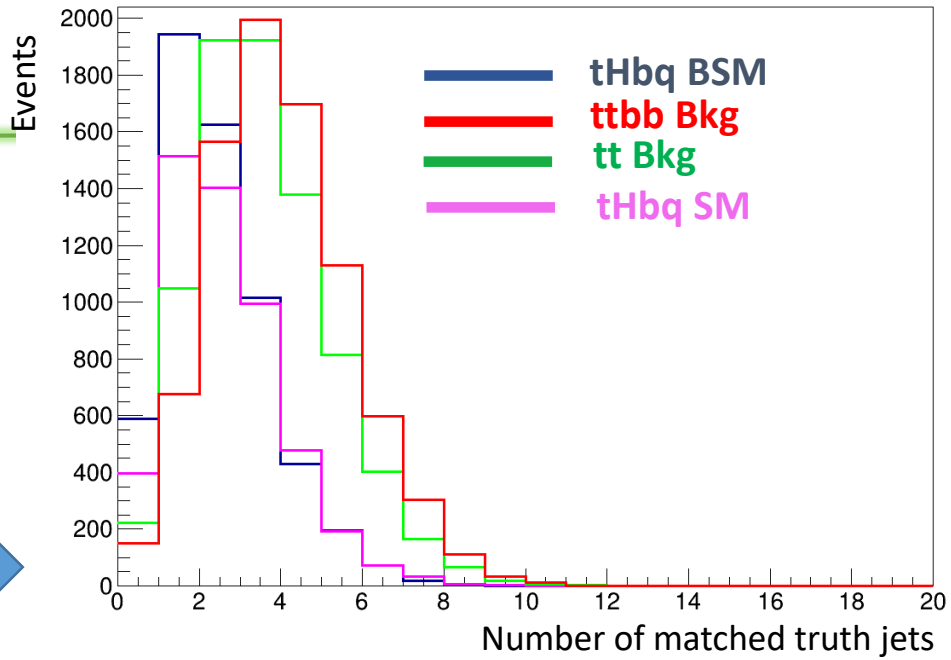
E_T^{miss}: $E_T^{miss} > 20$ GeV

Definition of any jet: $P_T > 25$ GeV

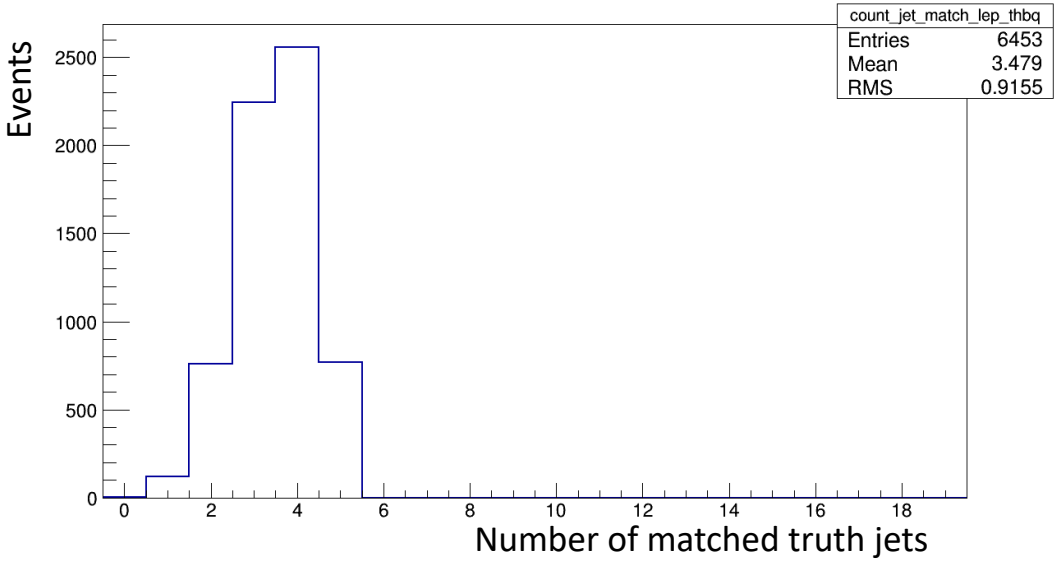
b-jet from top, 2 b-jets from Higgs,b-jet from spectator
soft b-quark and FWD-jet from forward light quark
So, we expect 5 matched jets

All jets without b-jets and tagged forward jet

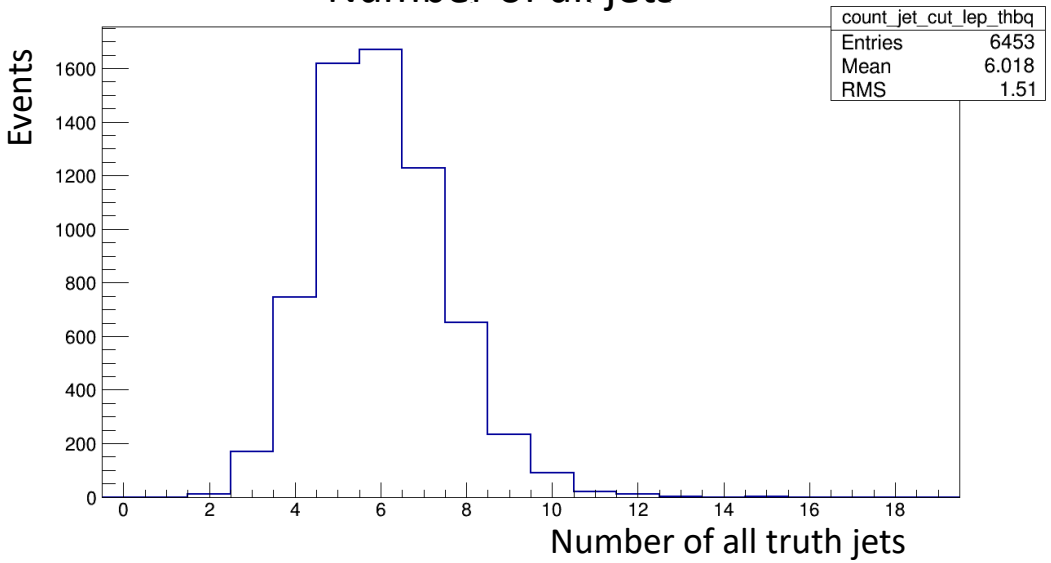
Number of jets matched



Number of jets matched with truth quarks



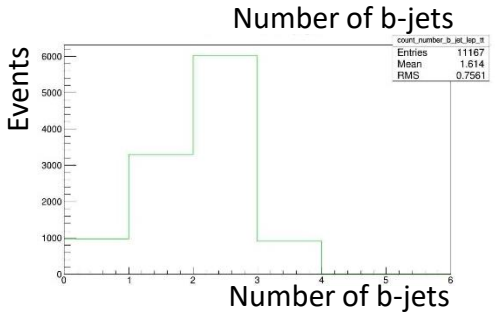
Number of all jets



Fake b-jets Bkg SM tt

Bkg SM tt

Expect 3 b-jets:
2 from top
1 fake b-jet



We take fake b-jets from c-quark and light quarks, which come from hadronic decay of top-quark.

From c-quarks we have in 12% cases fake b-jets and

From light quarks we have in 0.2% cases fake b-jets.

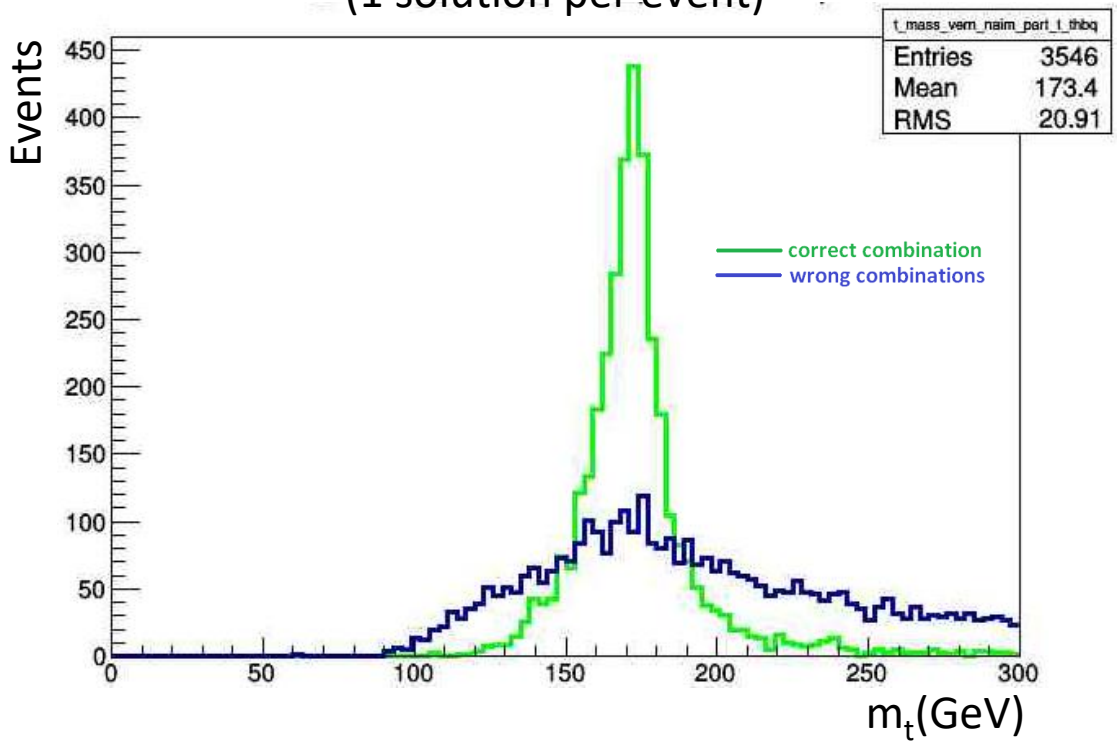
Jet-parton association tHbq BSM

Number of b-jets: $3 \leq N_{b\text{-jets}} \leq 4$

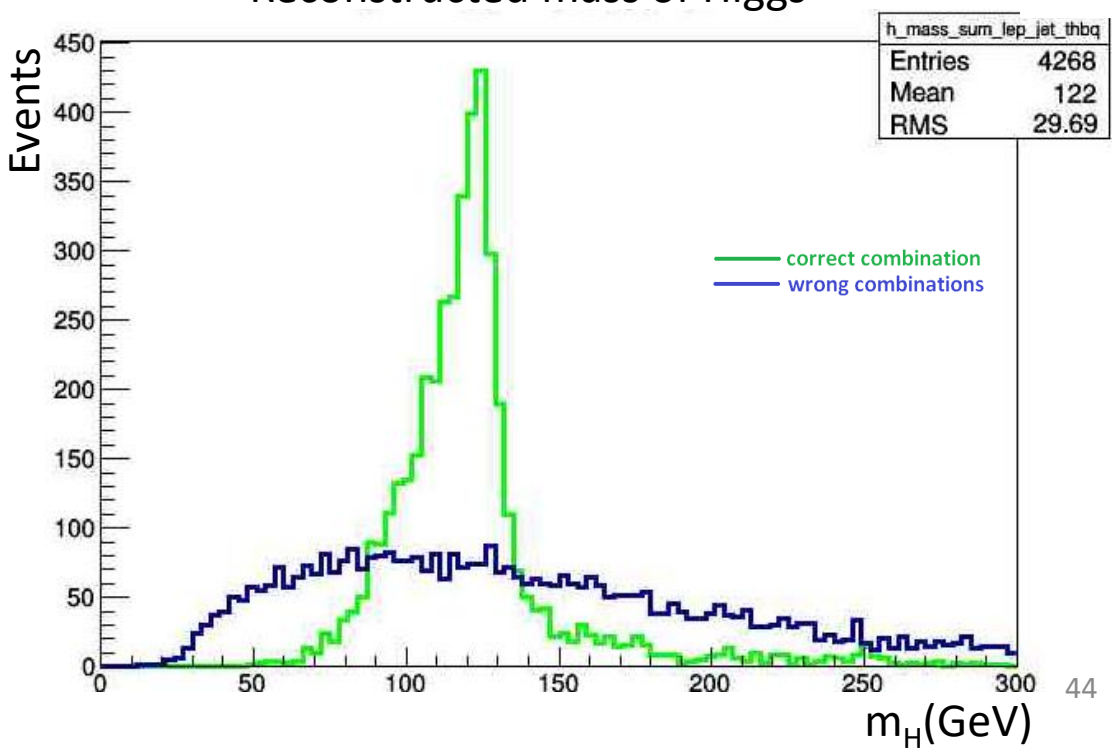
In event we have 3 b-jets.
We have 3 combinations: 1 correct and 2 wrong

Normalized histograms
to the same area

Reconstructed mass of top-quark
(1 solution per event)



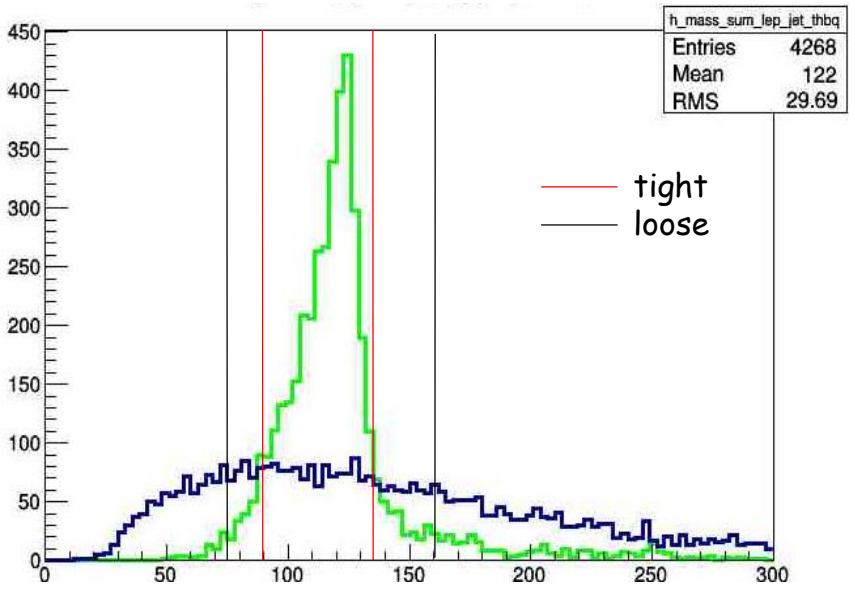
Reconstructed mass of Higgs



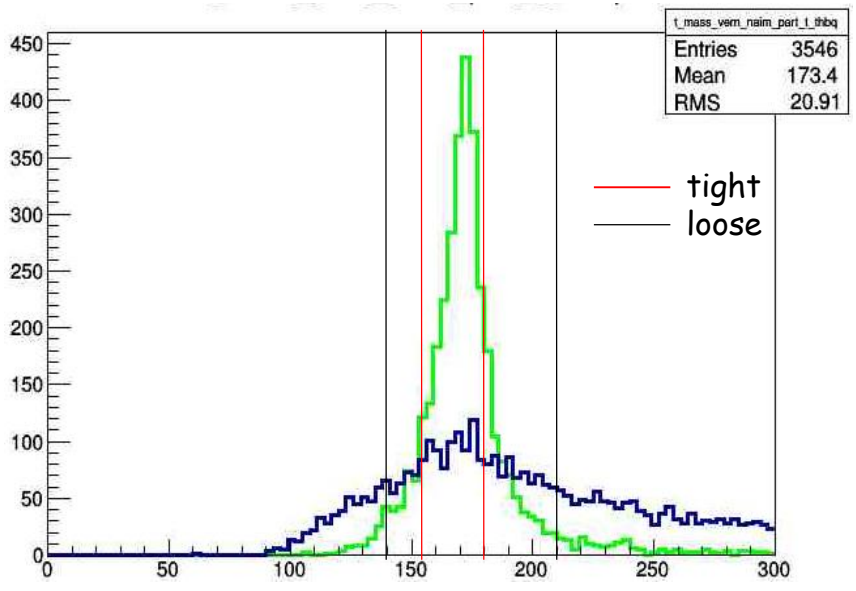
Jet-parton association tHbq BSM

Loose cuts:	Tight cuts:
$75 < m_H < 155$	$90 < m_H < 135$
$140 < m_t < 210$	$155 < m_t < 180$

Higgs inv. mass



Top inv. mass



Ambiguity of Pz sign
Take solution closest to 172.5

Reconstruction of top and Higgs masses

Both top and Higgs masses must satisfy loose criteria, and at least one of them must satisfy tight criterium.

Three possible combinations

1. Loose cut & Loose cut :
   (75 GeV < m_H < 155 GeV) & (140 GeV< m_t < 210 GeV)

2. Loose cut & 1 Tight cut :
   (75 GeV < m_H < 155 GeV) & (155 GeV< m_t < 180 GeV)
   or
   (140 GeV< m_t < 210 GeV) & (90 GeV < m_H < 135 GeV)

3. Tight cut & Tight cut :
   (90 GeV < m_H < 135 GeV) & (155 GeV< m_t < 180 GeV)

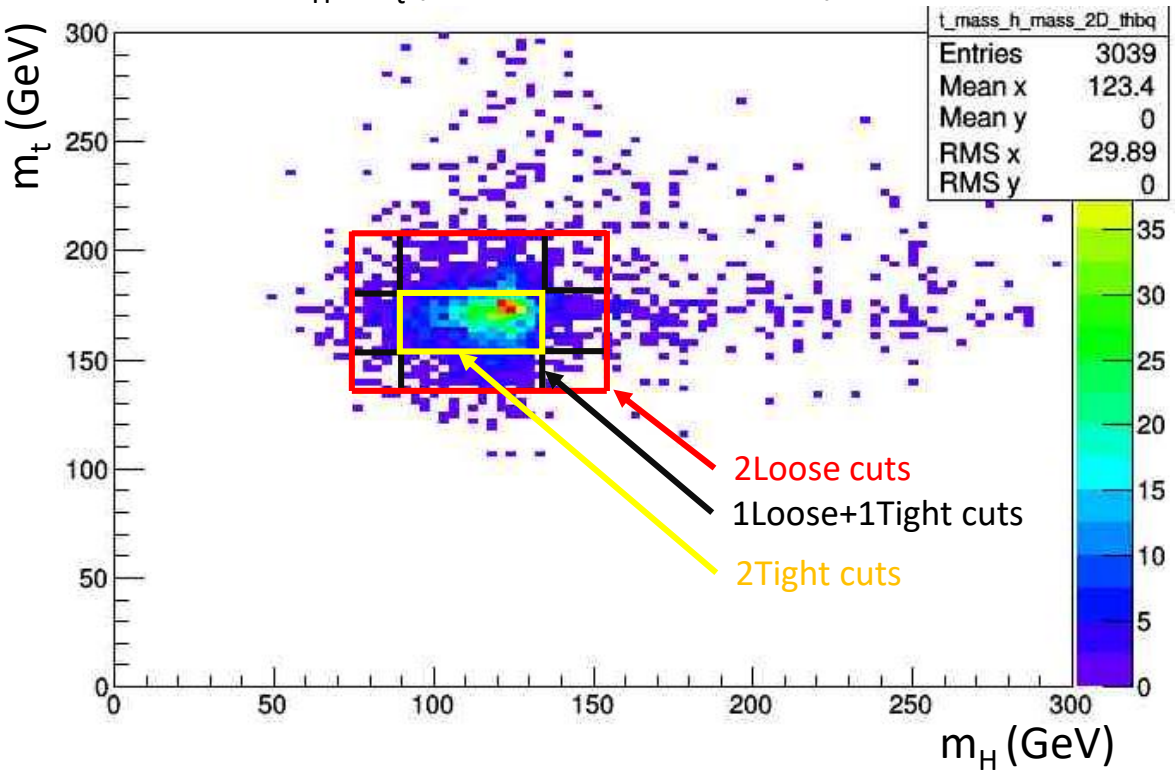
Reconstruction of top and Higgs masses

Number of b-jets: $3 \leq N_{\text{b-jets}} \leq 4$

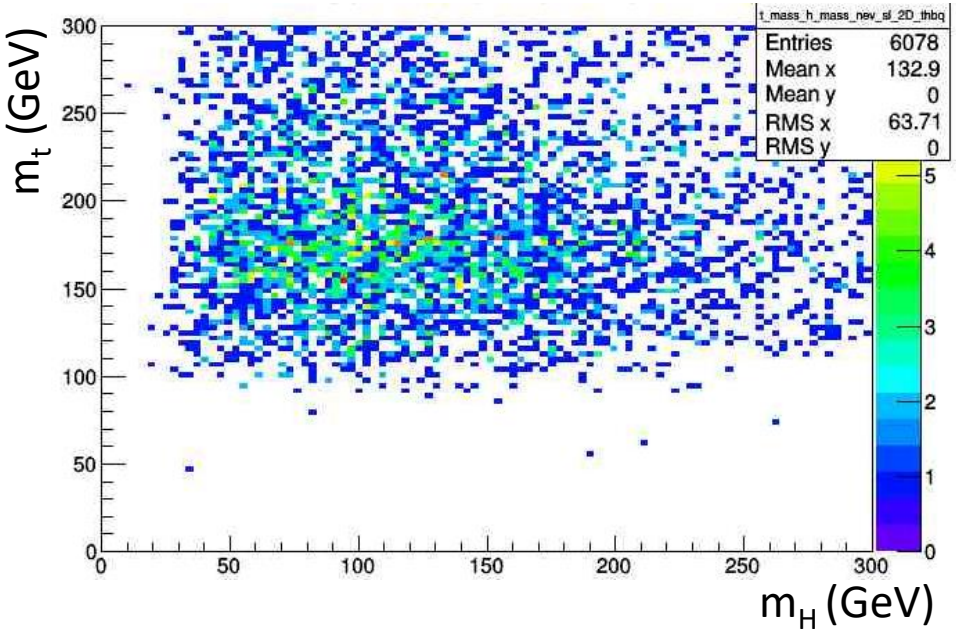
Loose cuts:
$75 < m_H < 155$
$140 < m_t < 210$

Tight cuts:
$90 < m_H < 135$
$155 < m_t < 180$

m_H / m_t (correct combination)



m_H / m_t (wrong combinations)



Selection of top and Higgs masses
Jet-parton association tHbq BSM

Number of b-jets: $3 \leq N_{\text{b-jets}} \leq 4$

	Efficiency of correct combination	Impurity (selection of wrong combination)
Number of events before cuts	3039 100%	6078 100%
2 Loose cuts	82%	17%
1Loose+1Tight cuts	66%	9%
2 Tight cuts	53%	5%

tt(SM) vs ttbb(SM) at LO

Bkg SM tt

Expect 3 b-jets:
2 from top
1 fake b-jet

From c-quarks we have in 12% cases fake b-jets and

From light quarks we have in 0.2% cases fake b-jets.

We take fake b-jets from c-quark and light quarks, which come from hadronic decay of top-quark.

For 140 fb^{-1}, N_{tt}=59K (SM), N_{ttbb}=4.4K (SM)

So, ttbb 13 times less than tt.

Cut variation for optimization of Signal to Bkg ratio

Pt of lead lepton > 25 GeV, Pt of definition of jets > 25 Gev, Et_miss > 40 Gev, Rapidity Gap > 1.5,
Pt of definition of forward light jet > 30 GeV, Eta of definition of forward light jet >2, m_top & m_Higgs – loose&tight cuts

№ cut	Cut	New nominal cut	Variants
1	Et_miss >	20 GeV	30, 40 GeV
2	Eta of definition of forward light jet >	2.0	1.5, 2.25, 2.5
3	Pt of definition of forward light jet >	30 GeV	20,25 GeV
4	Rapidity Gap >	1.0	1.25, 1.5
5	Cuts of m_top & m_Higgs are	Loose&loose	Loose&tight, Tight&tight

■ New nominal cuts

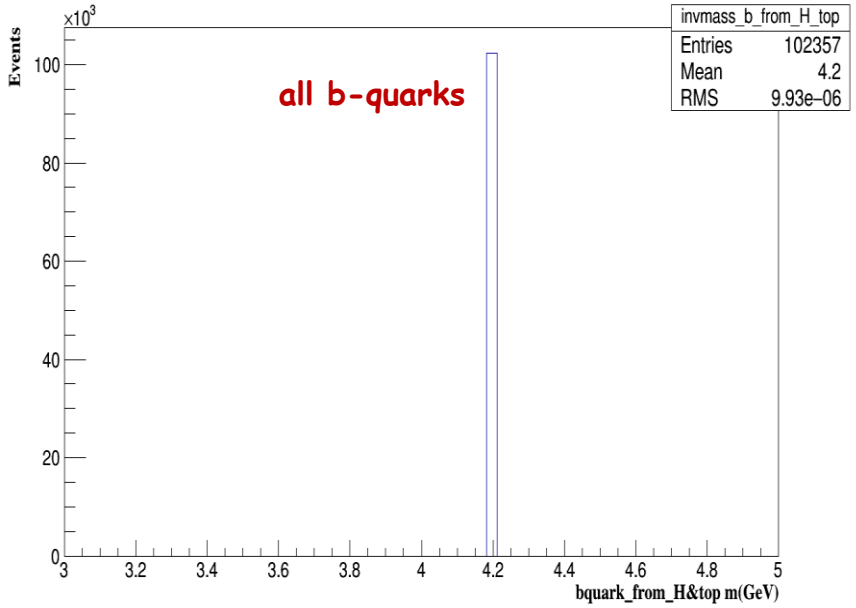
Preselection cuts for pp → tHqb → (bℓν)(bb)qb

- $P^T_{lead} > 27$ GeV/c, $|\eta_{lead}| < 2.5$
  - A high-PT lepton must exist to ensure leptonic trigger
- $P^T_{sublead} < 15$ GeV/c, $|\eta_{sublead}| < 2.75$
  - Other leptons (if any) must have low PT, to ensure single-lepton event topology
- $E^T_{miss} > 10$ GeV
  - Missing neutrino to reconstruct the top decay
- Nbjets = 3 or 4
- $P^T_{FWD} > 25$ GeV/c, $|\eta_{FWD}| > 2.0$
  - At least 1 good jet in the forward region

Truth mass of b quarks

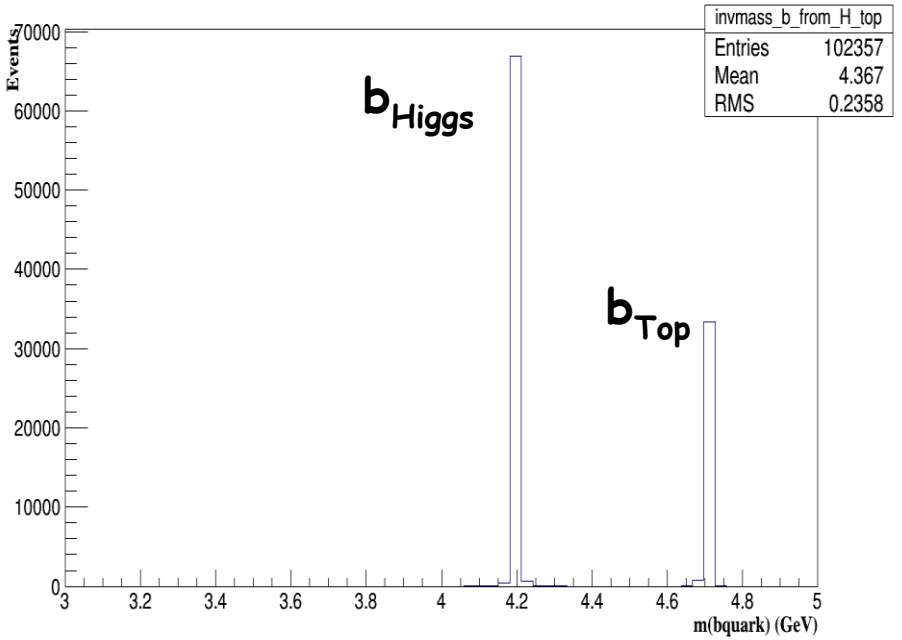
MadGraph SM/BSM (Parton level)

MadGraph



We generated all b-quarks 4.2 GeV

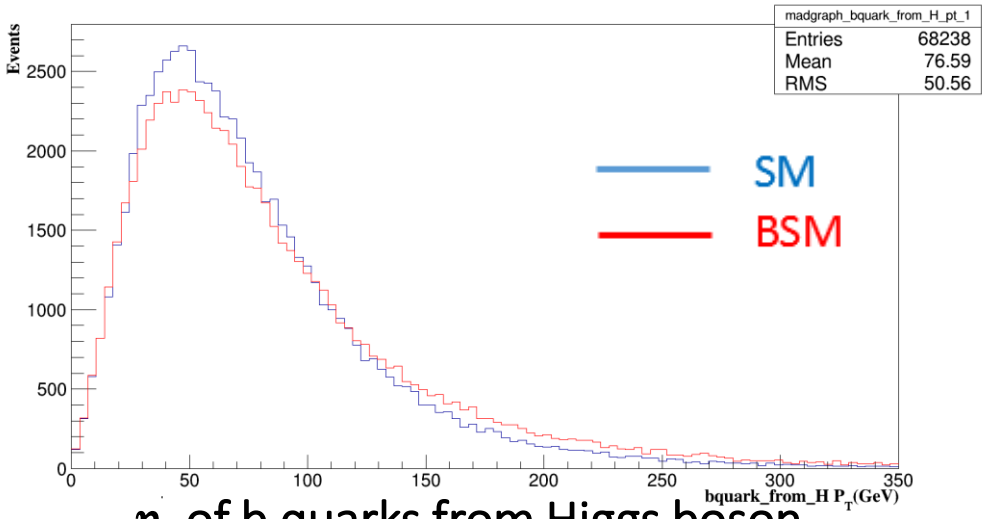
MC Atlas



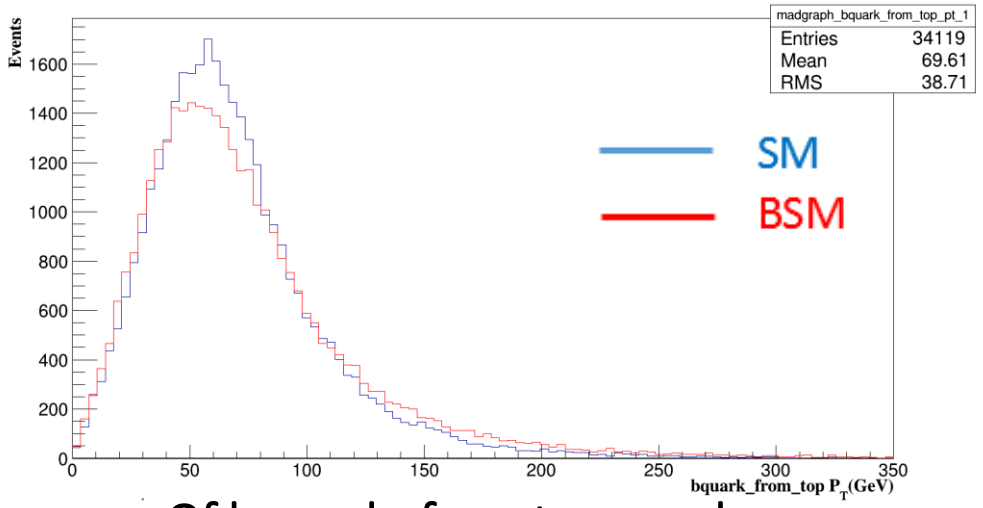
Difference between
mass of b from H (4.2 GeV) and
mass of b from top (4.7 GeV)

Comparison MadGraph SM/BSM (Parton level)

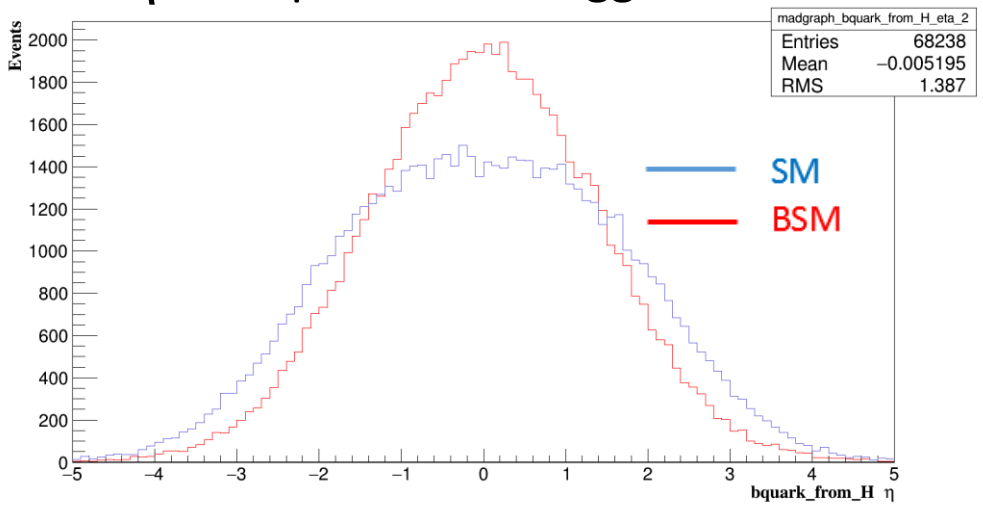
P_T of b quarks from Higgs boson



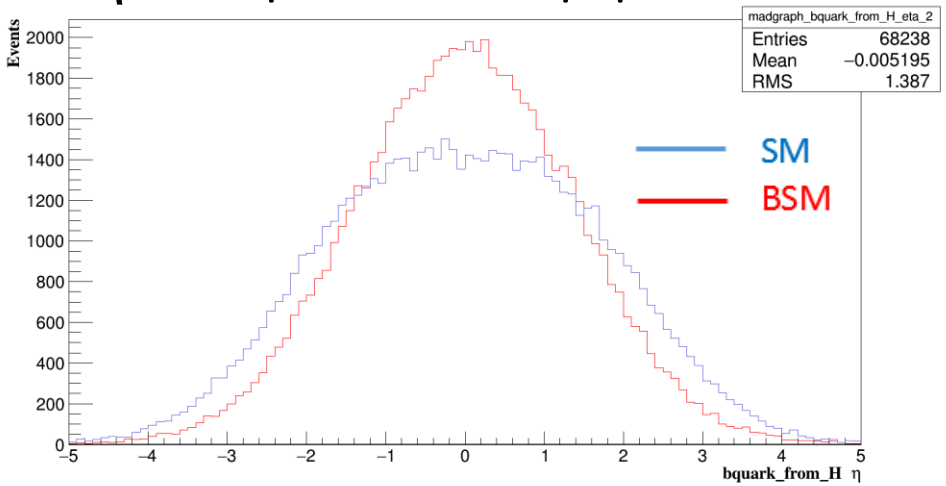
P_T of b quarks from top quark



η of b quarks from Higgs boson

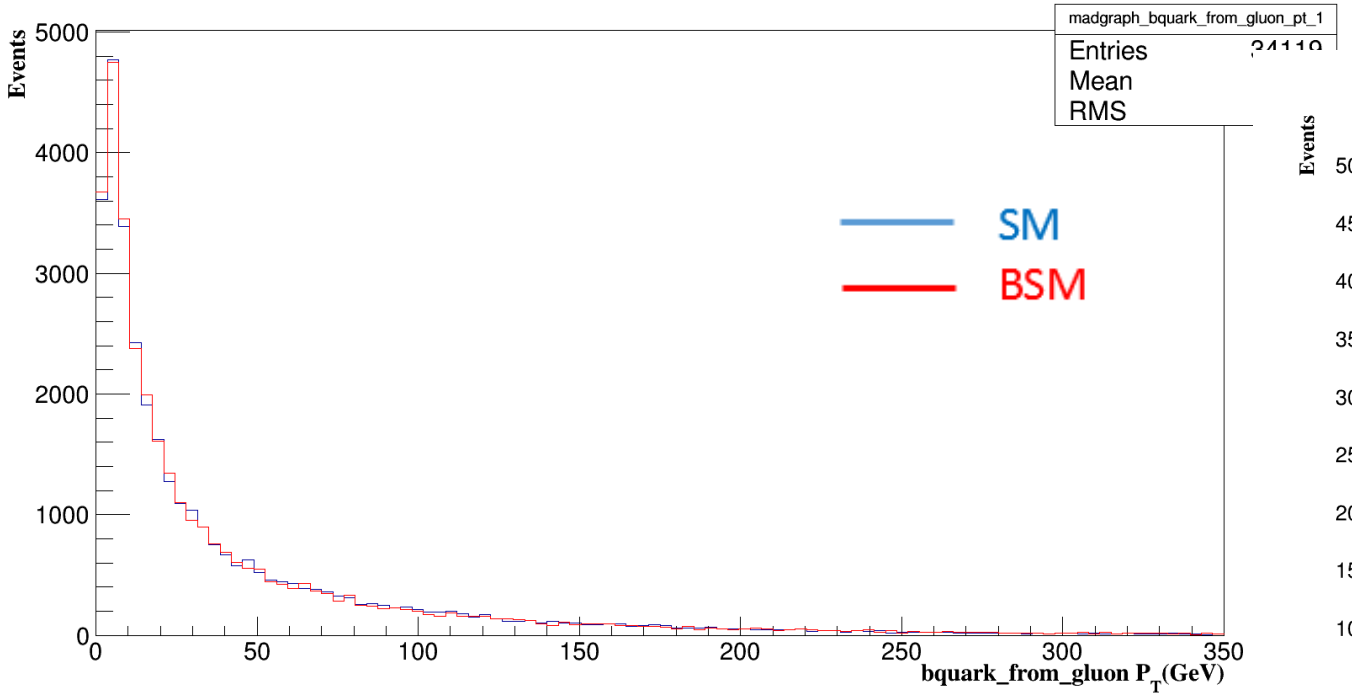


η Of b quarks from top quark

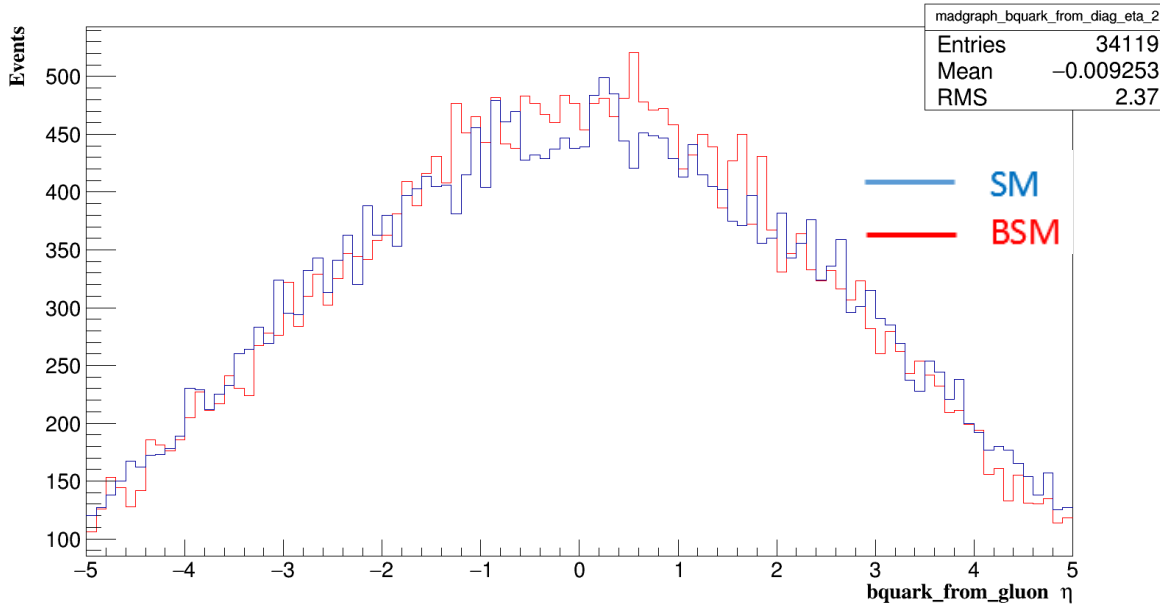


Comparison MadGraph SM/BSM (Parton level)

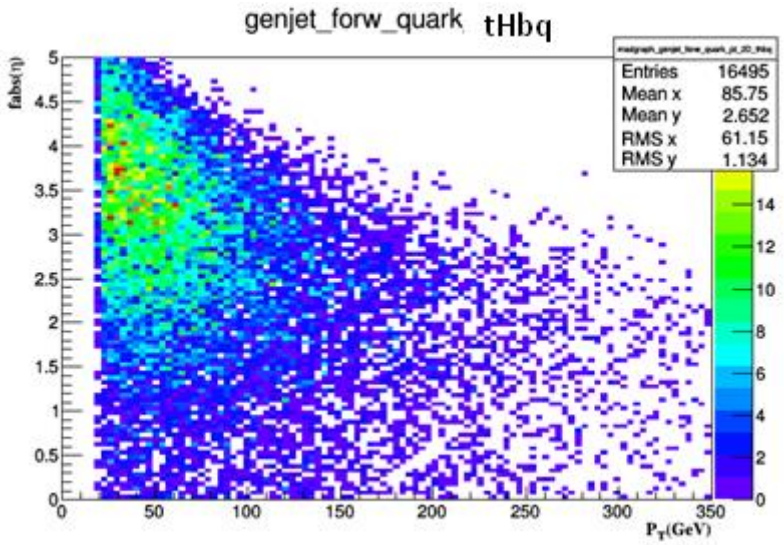
P_T of b quark from gluon

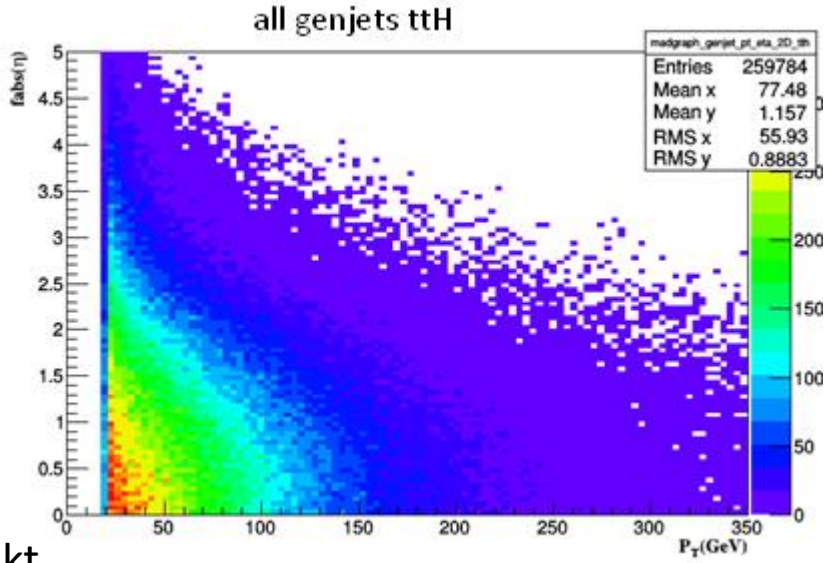


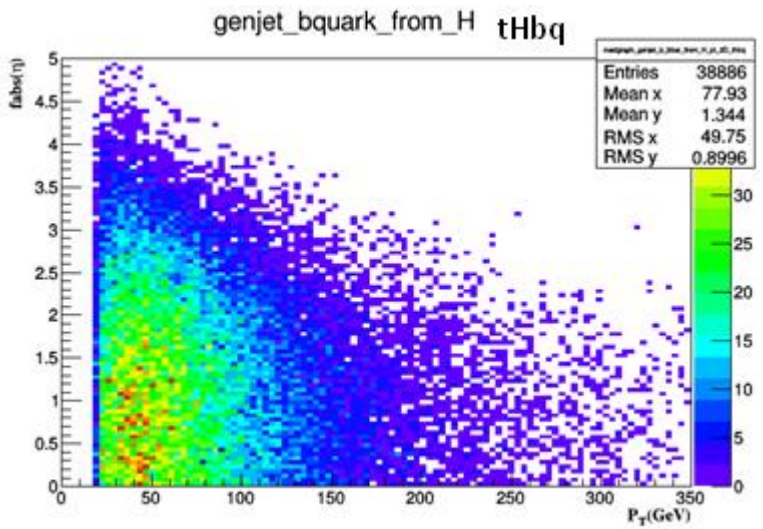
η of b quark from gluon



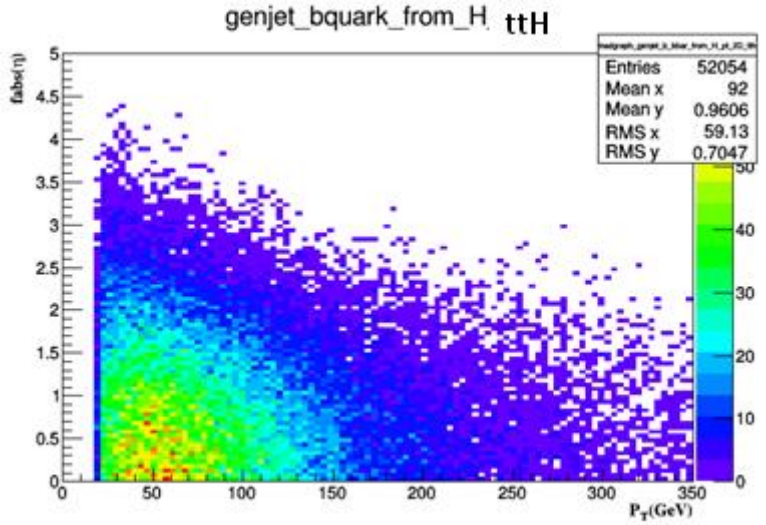
Distribution of P_T and $|\eta|$ of jets for Signal(tHbq) and Bkg(ttH)



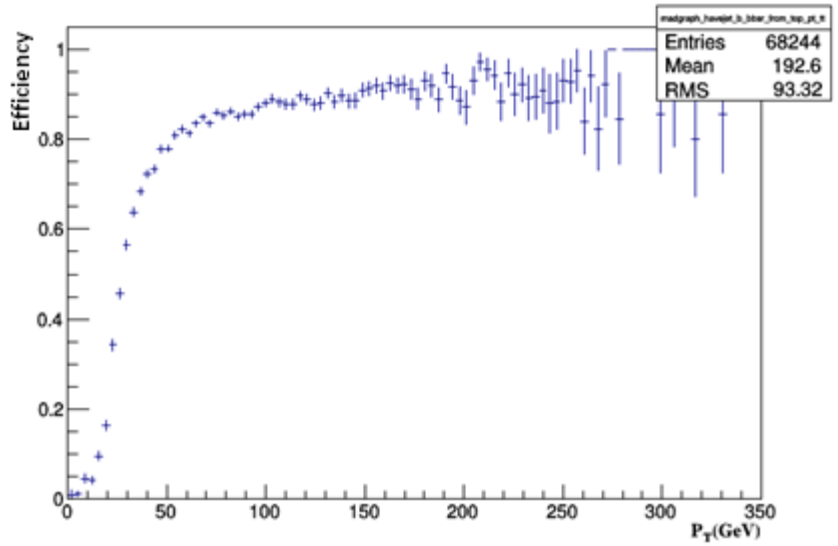


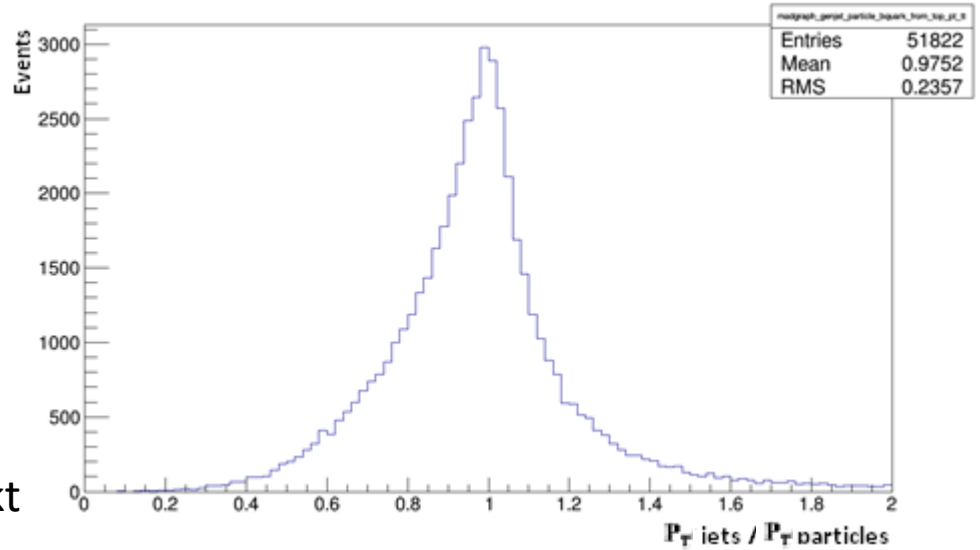


JetAlgorithm: antikt
Parameter R: 0.5
JetPTMin: 20.0

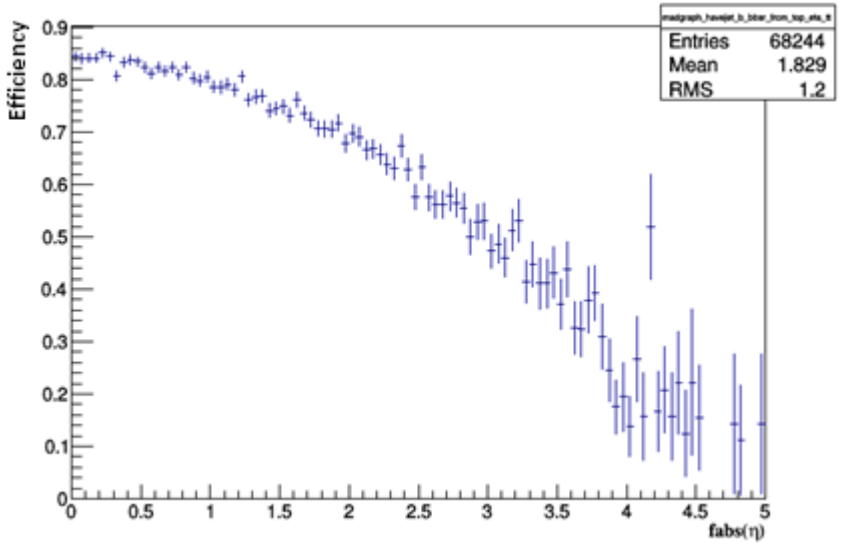


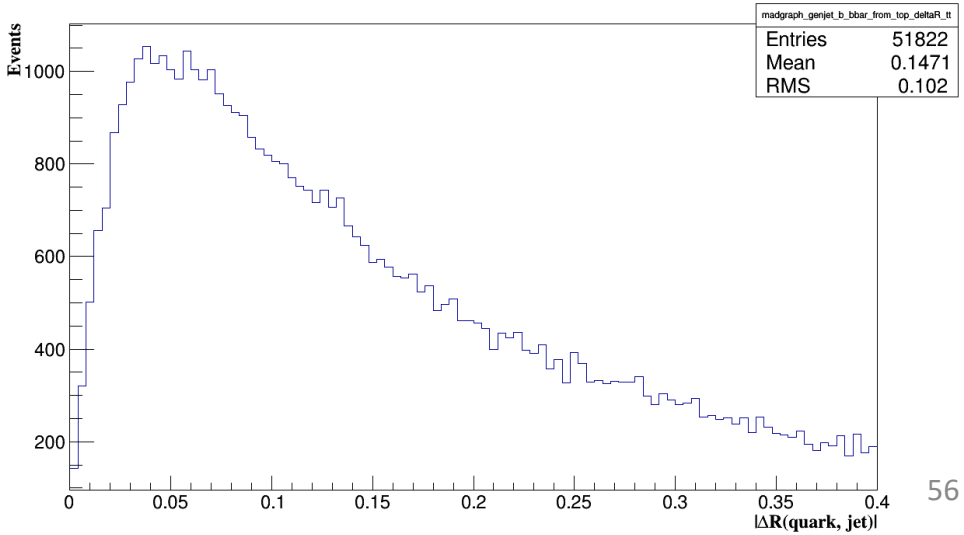
Efficiency and quality of jet reconstruction for Bkg tt (jet from b quark from top)





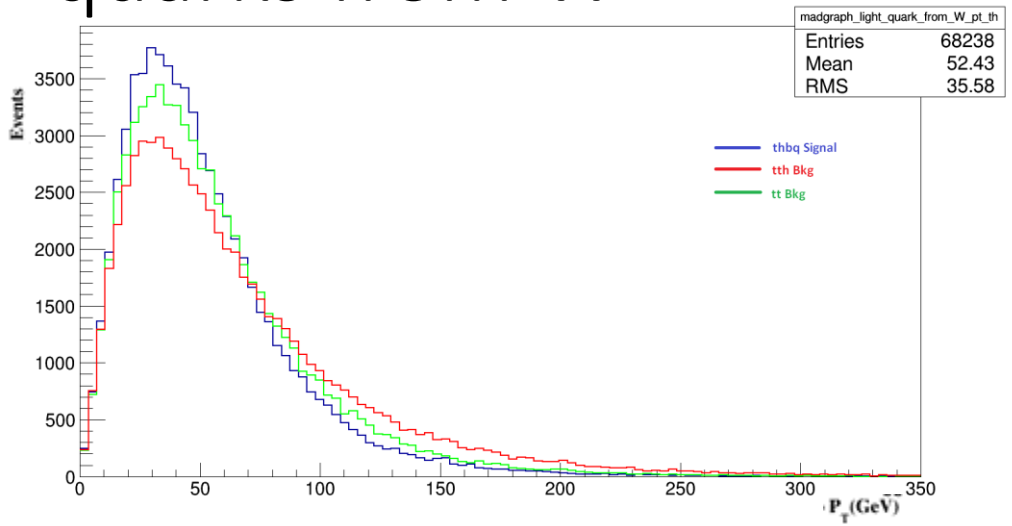
JetAlgorithm: antikt
JetPTMin: 20.0

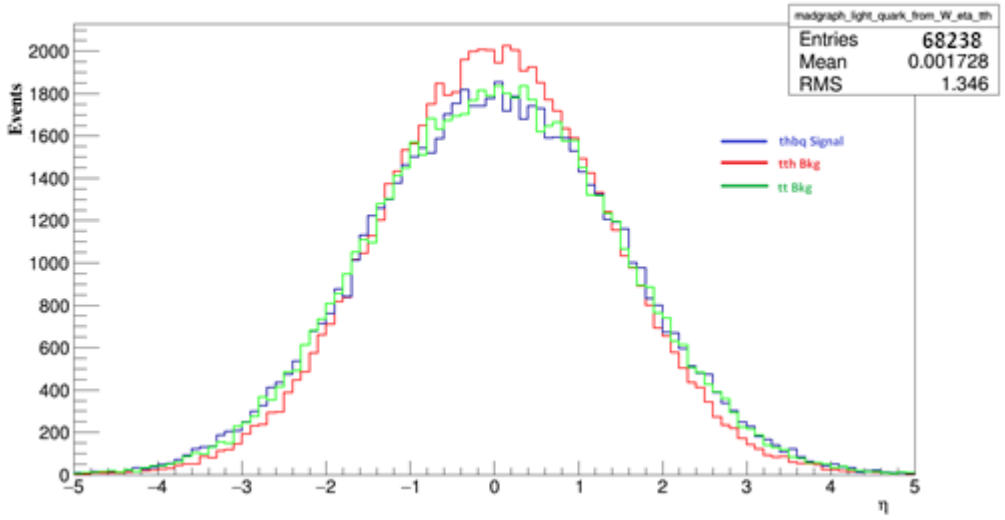




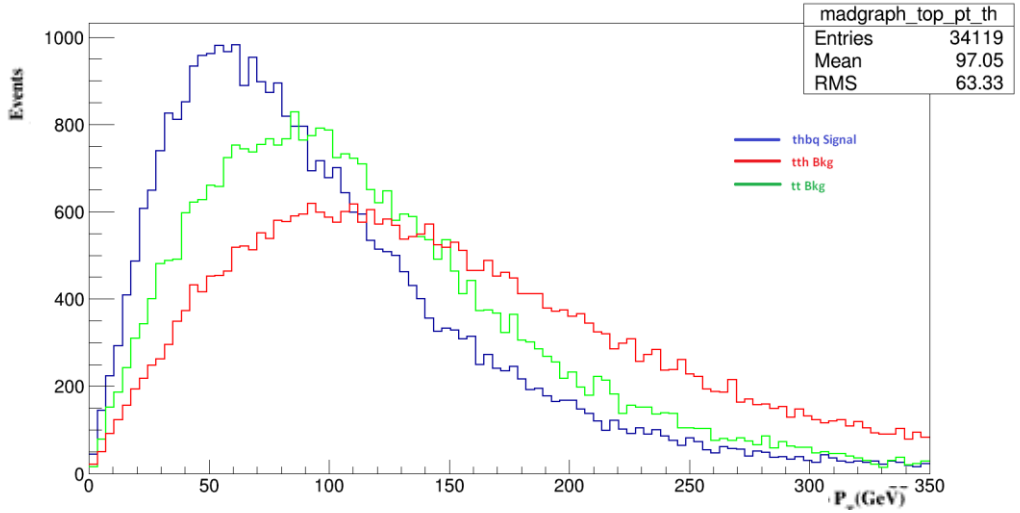
Comparison MadGraph Signal (tHbq) /Bkg (tt,ttH)

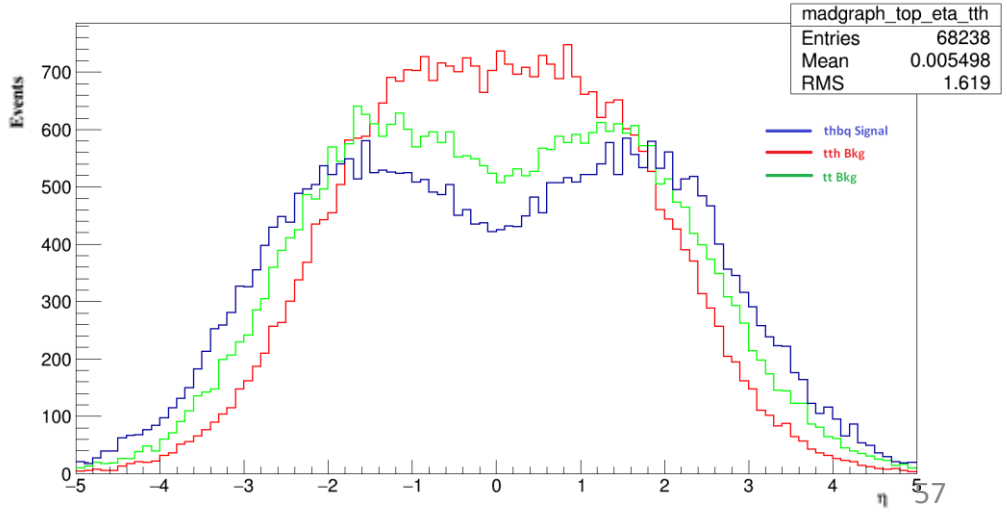
quarks from W





top quarks

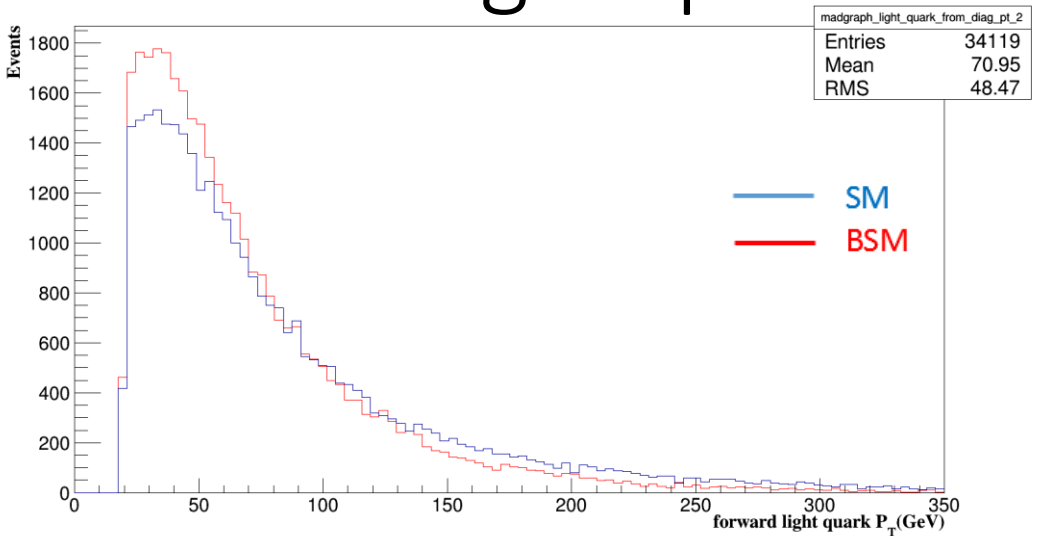


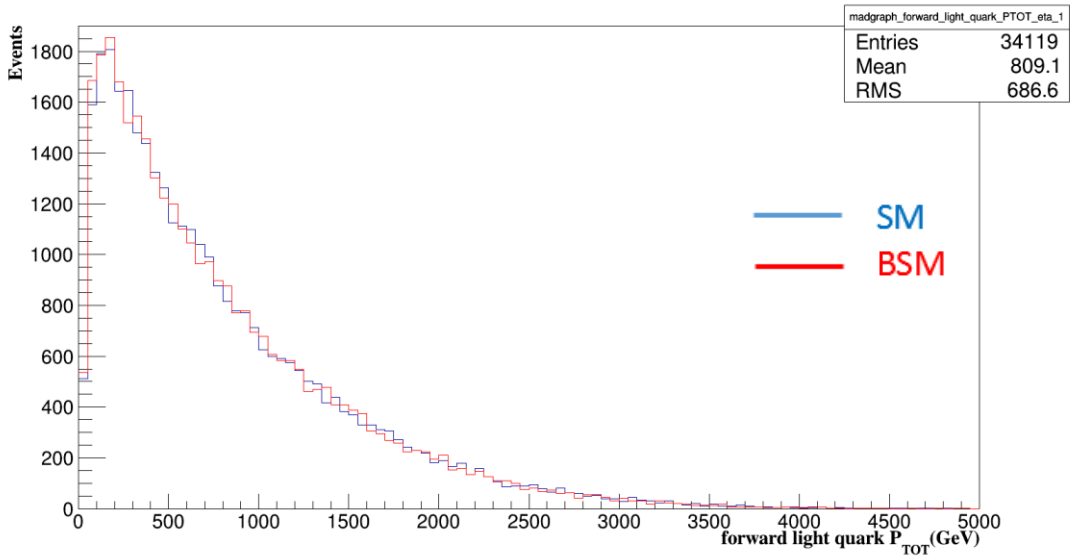


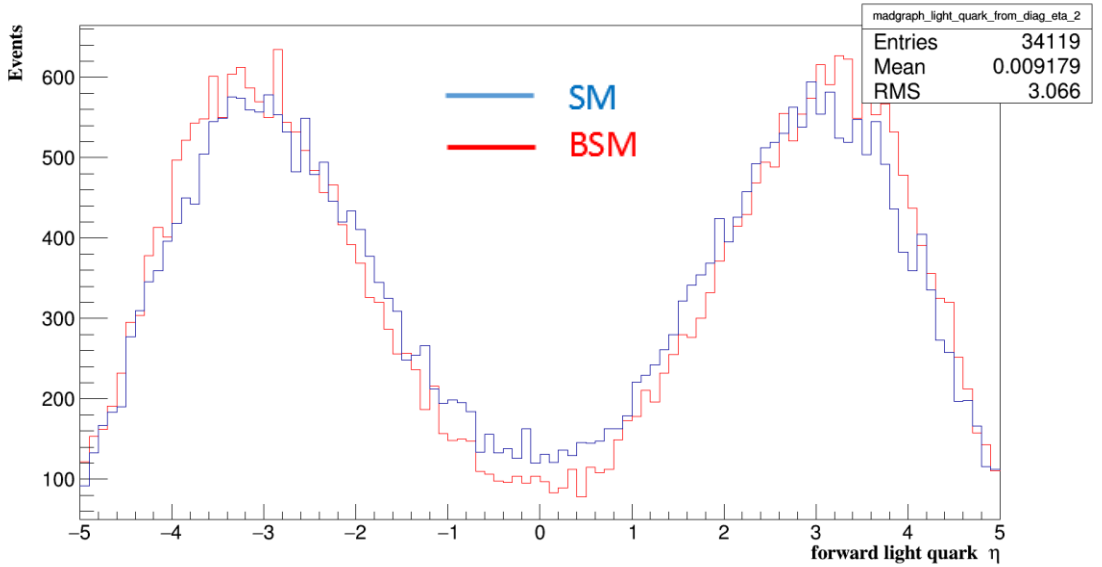
Comparison MadGraph SM results with BSM results

Comparison MadGraph SM Signal pp->tHbq results with Bkg results pp->tt, pp->ttH

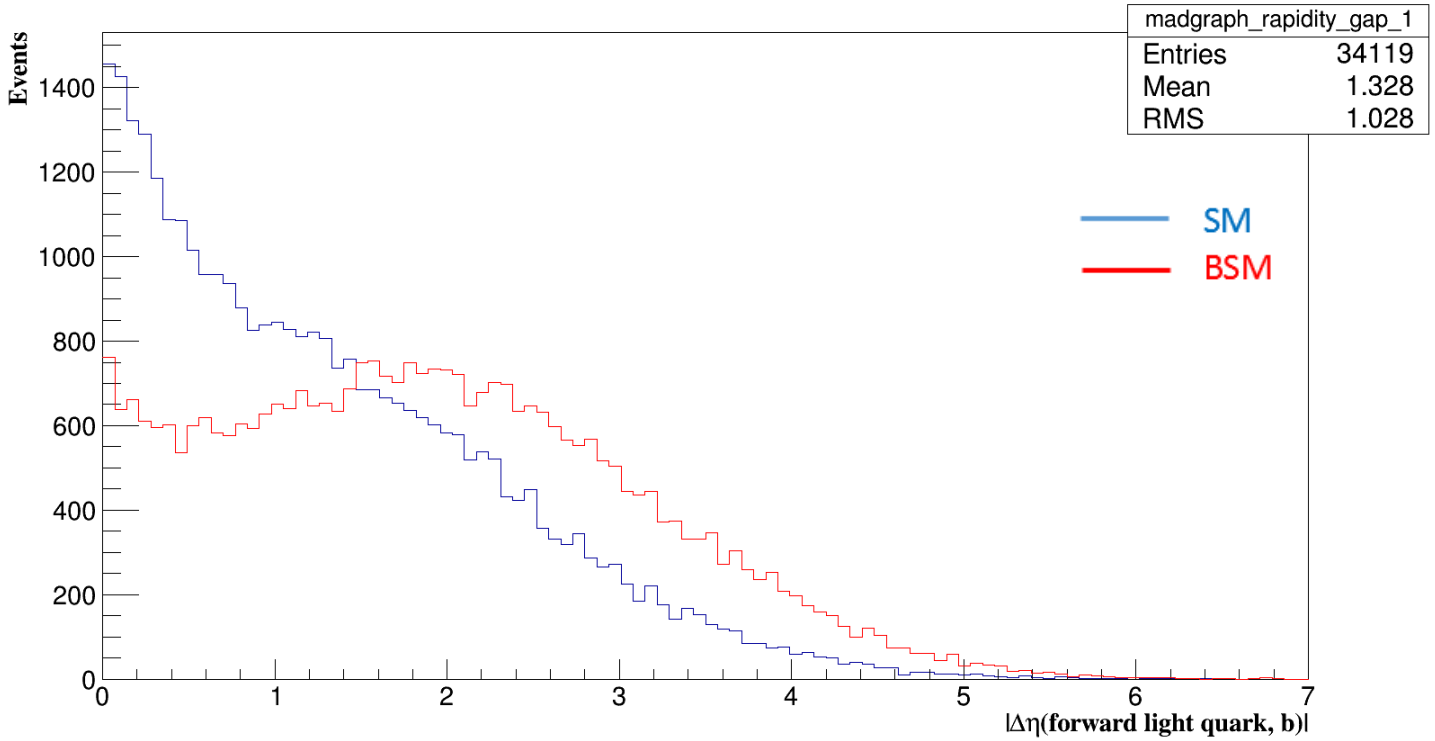
Comparison MadGraph SM/BSM (Parton level)
Forward light quark in tHbq-process



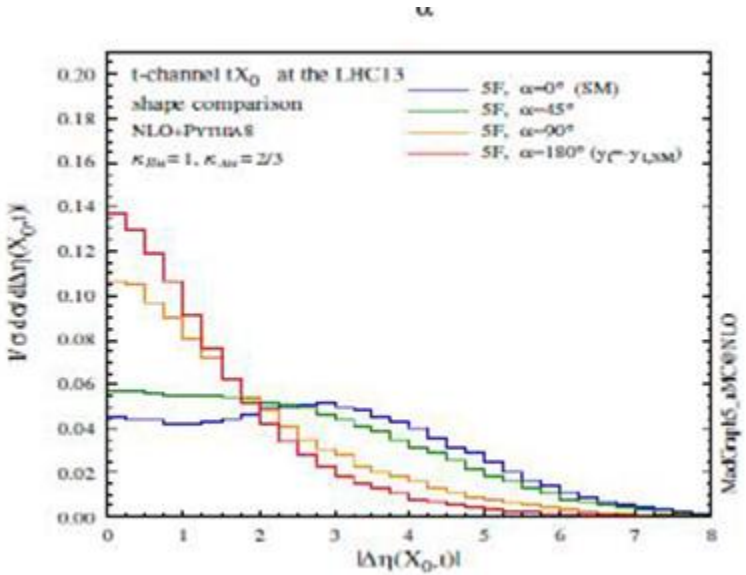




Comparison MadGraph SM/BSM (Parton level)
Rapidity gap: Forward light quark, b quarks



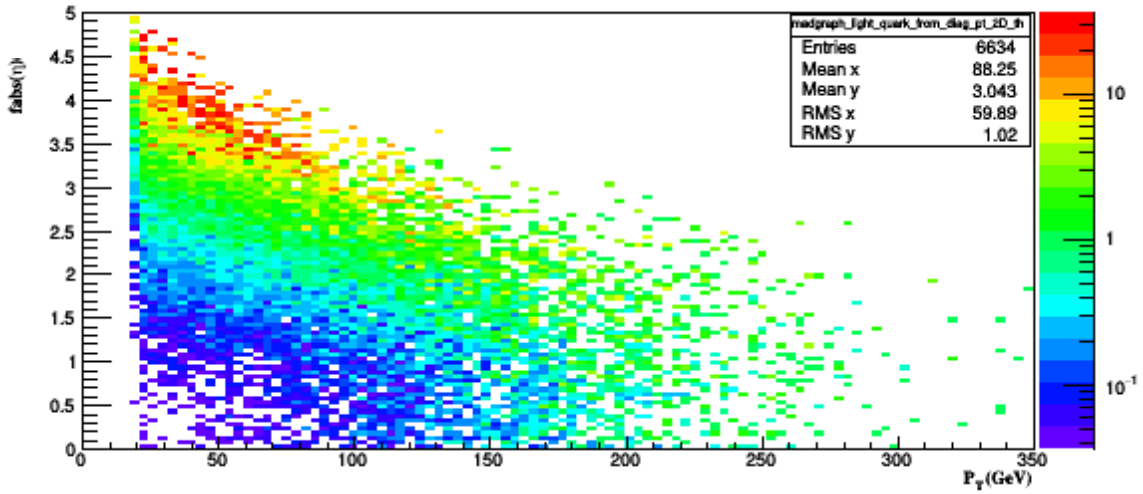
CMS Results



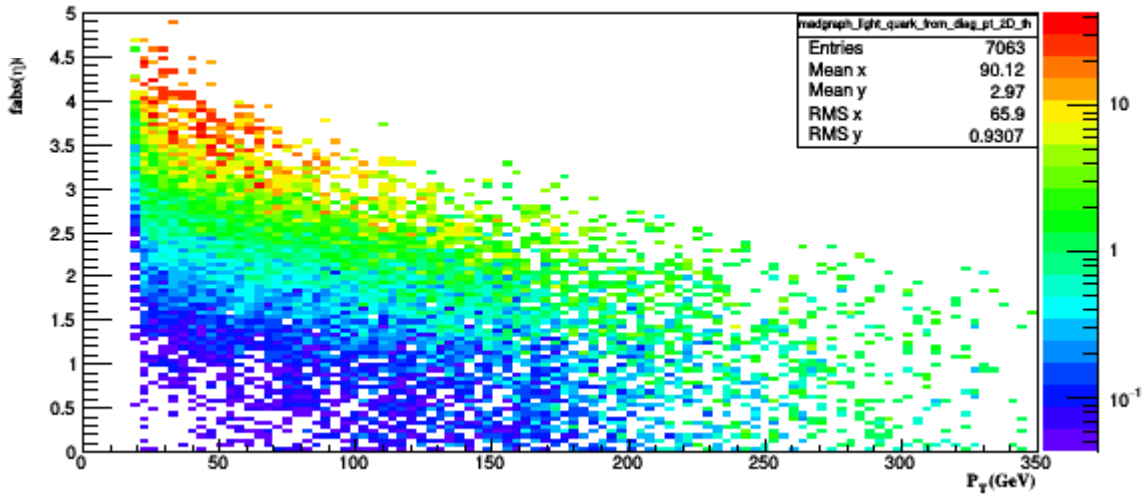
Comparison MadGraph Signal (tHbq) /Bkg (tt,ttH)

Ratio of quark distributions:
(forward light quark from tHbq) / (background quarks)

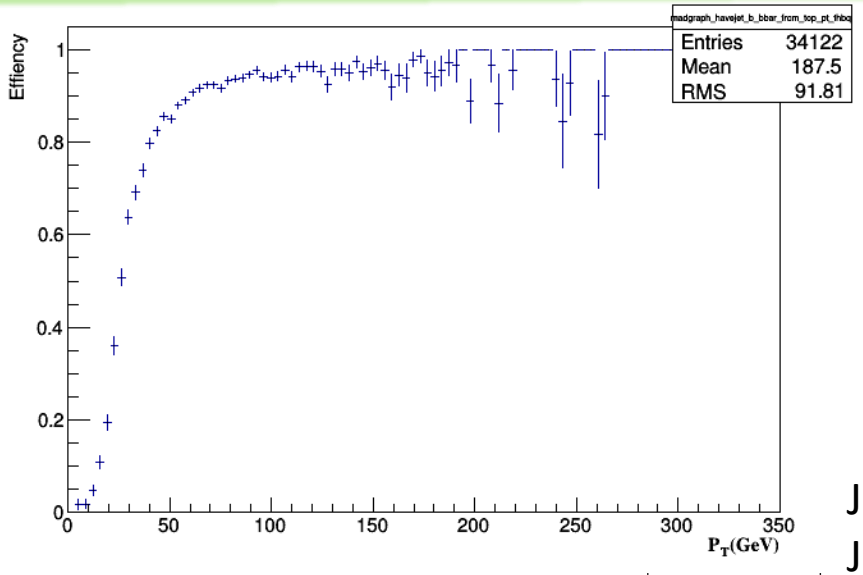
Ratio Signal and Bkg
Forward light quark in tHbq-process /
quarks from W in tt processes

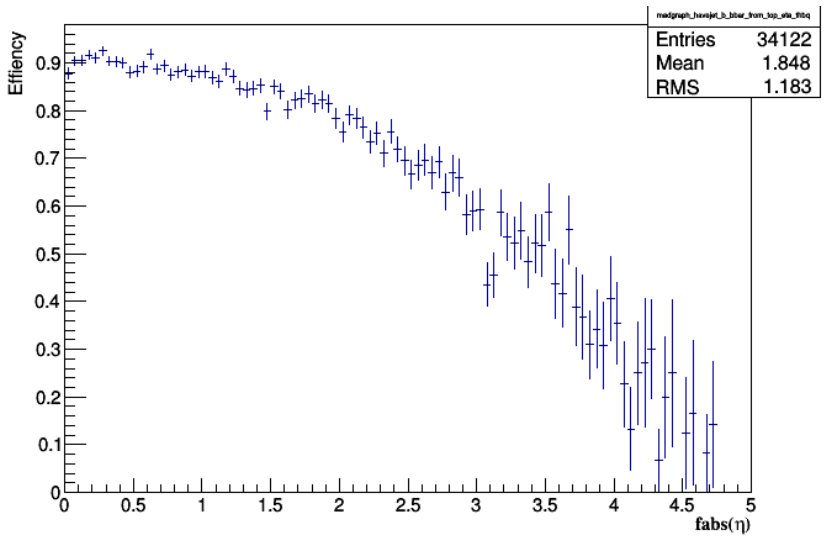


Ratio Signal and Bkg
Forward light quark in tHbq-process /
quarks from W in ttH processes

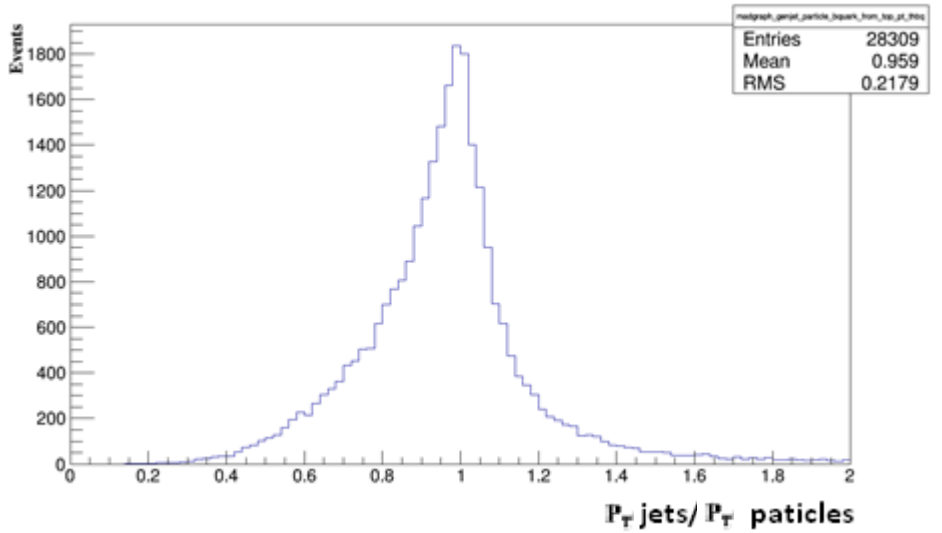


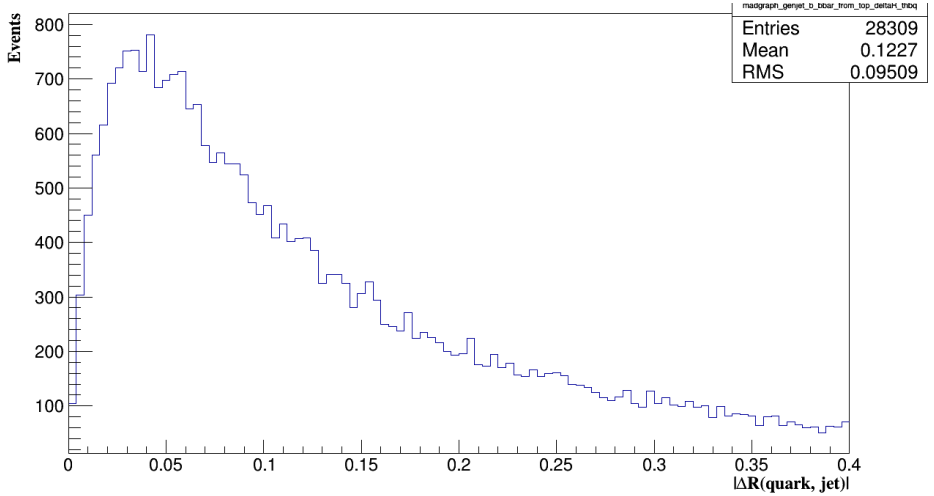
Efficiency and quality of jet reconstruction for Signal tHbq (jet from b quark from top)



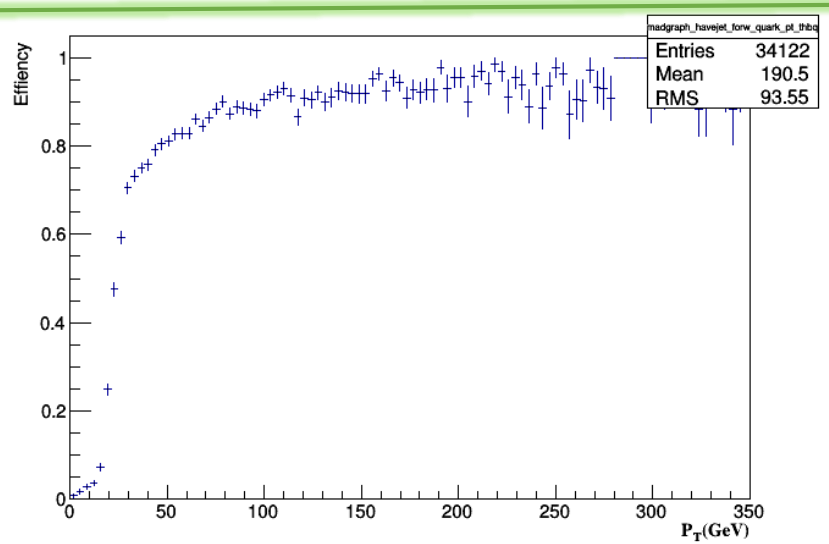


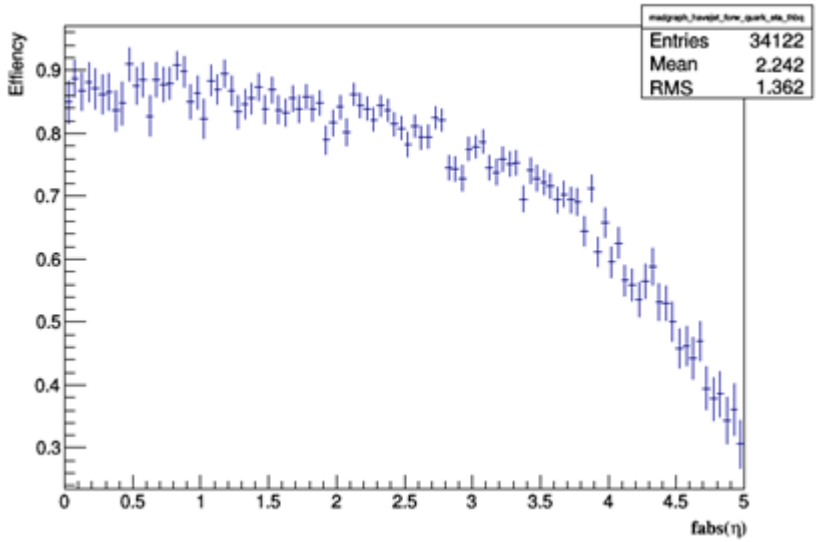
JetAlgorithm: antikt
JetPTMin: 20.0



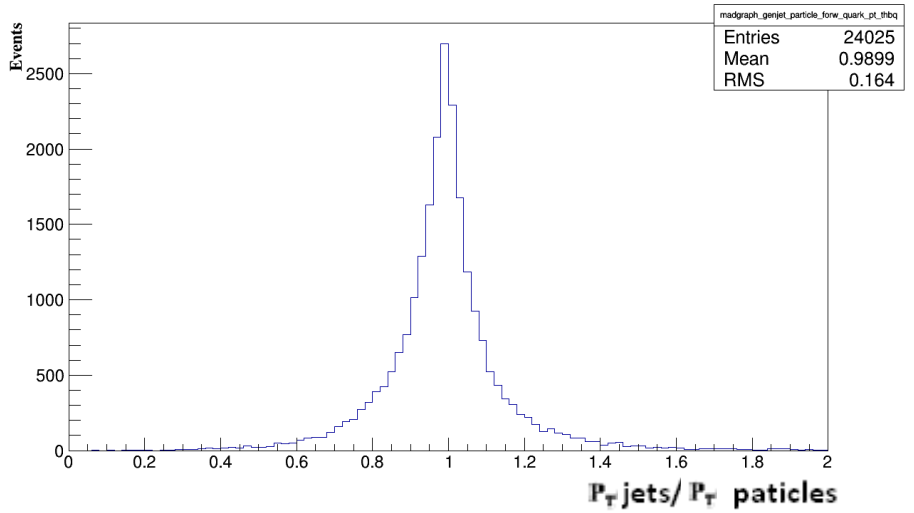


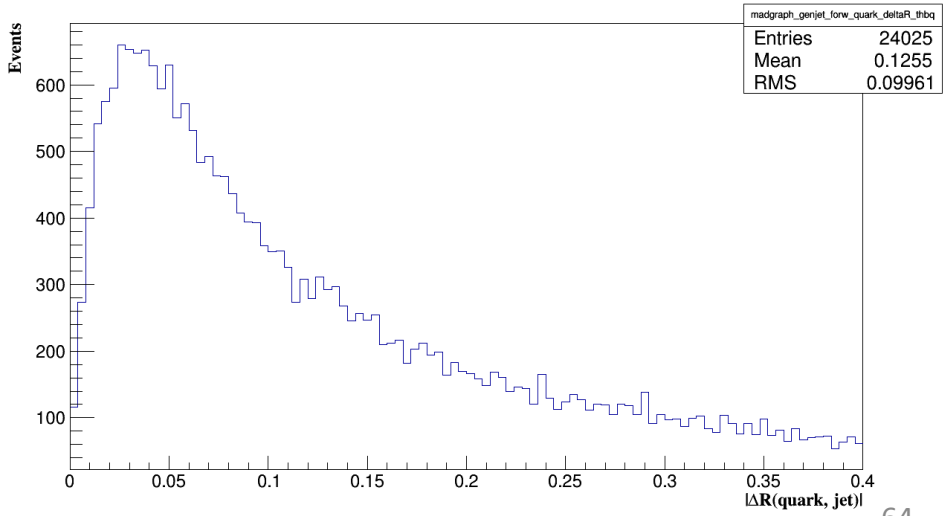
Efficiency and quality of jet reconstruction for Signal tHbq (jet from forward light quark)





JetAlgorithm: antikt
Parameter R: 0.5
JetPTMin: 20.0

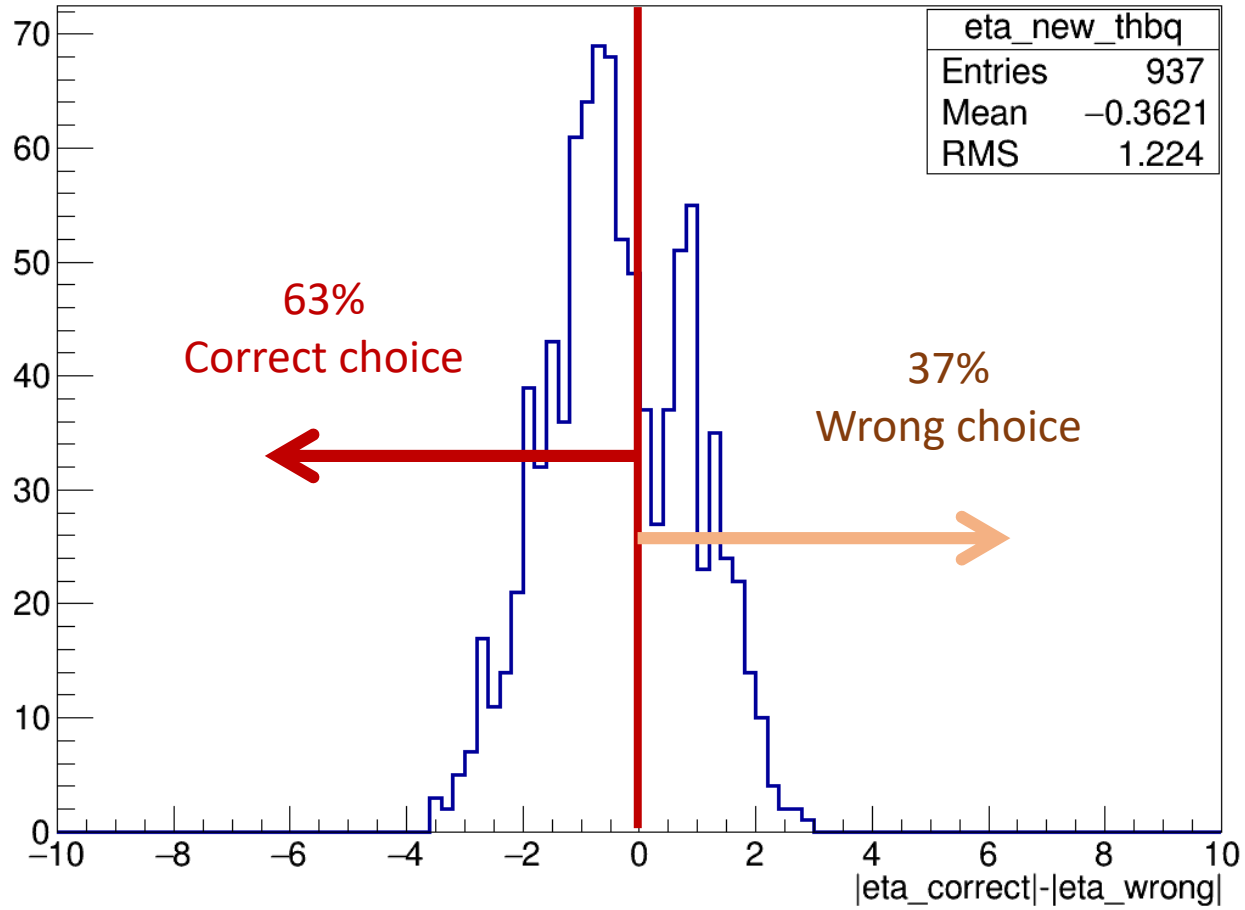




Comparison choice with P_z on parton level

Method of “Single-Top Group” :

$r = |\eta_C| - |\eta_{WR}|$ choice is correct, than $\eta_C < \eta_{WR}$, i.e. $r < 0$



Comparison choice with P_z on parton level

- Our method: **In what percent of cases we have correct choice of sign P_z ?**

1 is assigned when our solution is closer to $|\eta_{TR}|$, than the other solution

0 is assigned in opposite case