Search for $t\bar{t}H$ in fully hadronic channel and new physics in multijet final state

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Contents

Introduction to $t\bar{t}H$ fully hadronic analysis

Top quark Yukawa coupling

$$\mathcal{L}_Y = -\frac{y_t}{\sqrt{2}}(v\bar{t}t + \bar{t}tH), \quad y_t \approx 1$$

- Coupling between H boson and top.
- Proportional to mass of top .
- Due to the large value of its mass the top-quark presents the strongest coupling.

- Fully hadronic $t\bar{t}H$

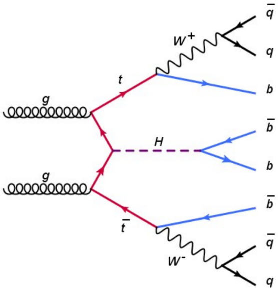
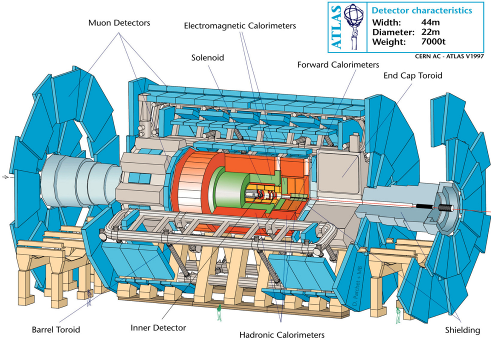


Diagram of fully hadronic ttH(H→bb)

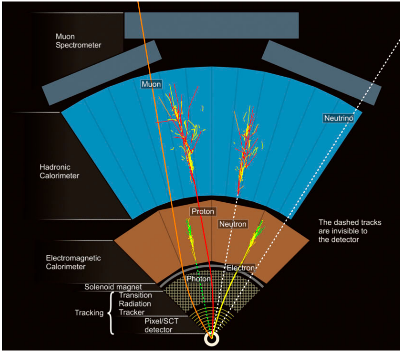
- Features:
  - Multi-jets multi-bjets signature.
  - Highest branching ratio.
  - Low purity after preselection.
- Run 1 result:
  - At signal rich region ($\geq 8j, \geq 4b$), S/B=1%
  - Signal strength:

$$\mu(m_H = 125\text{GeV}) = 1.6 \pm 2.6$$

ATLAS detector

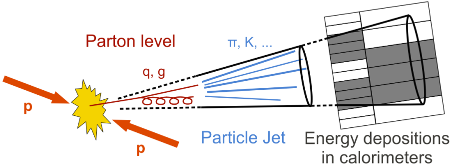


ATLAS detector

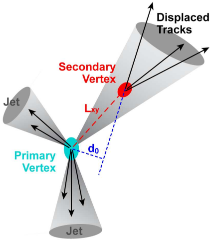


Overview of particles passage through ATLAS detector.

Jet reconstruction



Sketch of pp-collision and resulting collimated spray of particles, a jet.



Secondary Vertex reconstruction in b-jet.

Jet reconstruction

- Jets are reconstructed using anti-k_t algorithm with radius R=0.4.

b-jet identification

- b-hadrons travel $\sim 450\ \mu\text{m}$ before decaying.
- ATLAS has impact parameter track resolution of $\sim 10\ \mu\text{m}$
- High impact parameter track are used to reconstruct the Secondary Vertex (SV) to identify b-jet.

- $\Rightarrow$ b-jet triggers are built in order to select events containing b-jets.

b-jet trigger performance

- The ATLAS b-jet trigger uses MV2 algorithm to separate b-jet from light- and c-jet depends on
  - IP3D exploit 2D distribution of impact parameters.
  - SV1 exploits invariant mass of tracks, jet energy fraction associated to SV.
  - JetFitter exploits topological structure of weak b- and c- hadron decays inside jet.
- Expected performance of the ATLAS b-jet trigger in 2017.

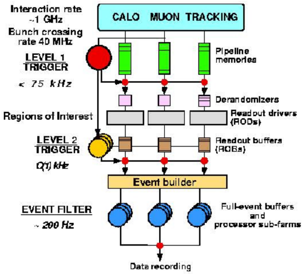


Figure: ATLAS trigger system consists of L1 and HLT, and MV2 algorithms work in HLT

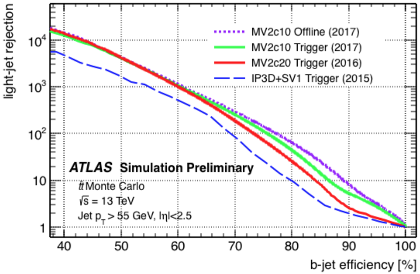


Figure: Expected performance of b-tagging algorithms in terms of light-jet rejection on $t\bar{t}$ simulation

Example of b-jet trigger chain.

- Example: HLT_j70_bmv2c2077_split_3j70_L14J15.0ETA25

How b-jet trigger select events

- At Level 1 trigger (L14J15.0ETA25)
  - Require $\geq$ 4 jets with $E_T > 15$ GeV and $|\eta| < 2.5$
- At High Level Trigger (HLT_j70_bmv2c2077_split_3j70)
  - Require $\geq$ 4 boffperf_split jets with $E_T > 70$ GeV and $|\eta| < 3.2$
  - Require $\geq$ 1 of the 4 jets above has b-tagging weight larger than mv2c20 cut at 77% working point (WP)

Trigger monitoring

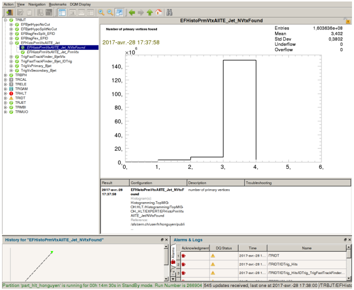
Trigger monitoring

- Ensure the the ATLAS triggers and data acquisition systems operate properly. Quickly recognize potential issues, check whether the trigger algorithm configuration runs without problems.
- Consists of online and offline monitorings.

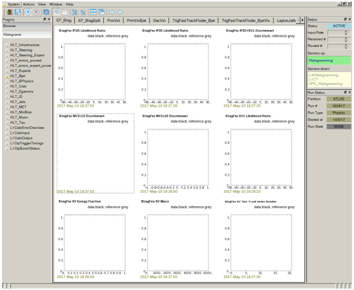
Online monitoring

- Assess the performance of specific histograms created and fillied during data taking using automated evaluations based on pre-defined tests run.
- Consists of two tools used to perform the online monitoring of the HLT:
  - DQMD: Data Quality Monitoring Display.
  - OHP: Online Histogram Presenter

DQMD and OHP



Interface of the DQMD.

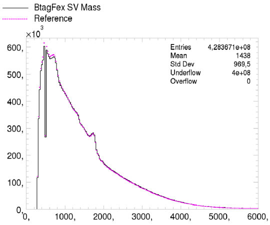


Interface of the OHP.

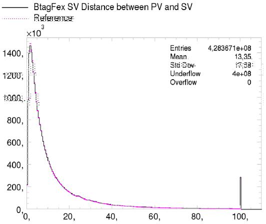
- DQMD in charge of surveying the trigger objects quality. In case of b-jet signature, the domains of variables are
  - tracks and vertex related variables.
  - variables used by b-tagging algorithm (d_0, etc).
  - weight used for event selection (IP3D, etc).

- OHP is a diagnostic tool used by shift crew to monitor the trigger behavior in ATLAS control room during data taking.
- Allow a fast checks on the histograms.

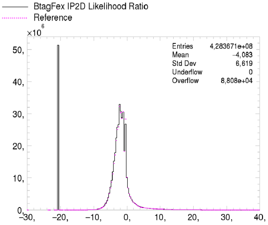
Distributions from trigger monitoring



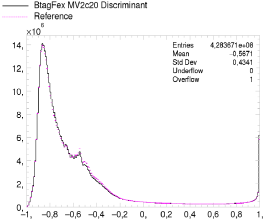
sv_mass



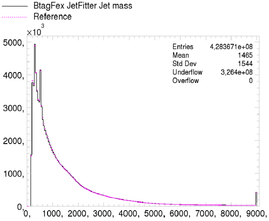
sv_L3d



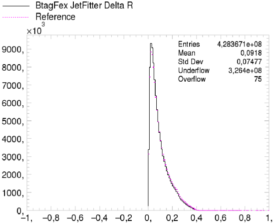
tag_IP2D



tag_Mv2c20



jf_mass



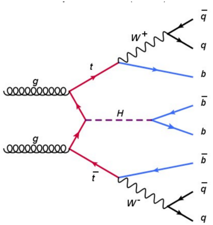
jf_dR

Trigger aware pre-selection in RUN 2

- Trigger dependent pre-selection.
  - offline confirmation of the online requirement.
- Example trigger: HLT_2j45_bmv2c2077_split_3j45

Event requirements

- Lepton number = 0.
- Trigger decision.
- HLT_2j45_bmv2c2077_split_3j45 Trigger offline confirmation:
  - ≥ 5 jets with $E_T > 45$ GeV.
  - ≥ 2 jets with $E_T > 45$ GeV and b-tagged with offline at 60% WP

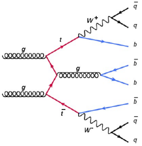


Signal region ($\geq 8j, \geq 4b$)

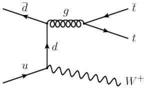
- ≥ 8 jets with $E_T > 25$ GeV
- ≥ 4 of which are b-tagged with offline at 60% WP

Number of events at $(\geq 8j, \geq 4b)$ at 60% WP

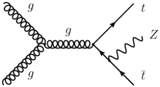
- MC samples processed with AnalysisTop 2.4.24
  - $t\bar{t}H$: aMC@NLO + Pythia8
  - $t\bar{t}$: PowhegPythia8 including
    - $t\bar{t}0l$
    - $t\bar{t}1l$



$t\bar{t}$+jets



$t\bar{t}W(W \to jj)$

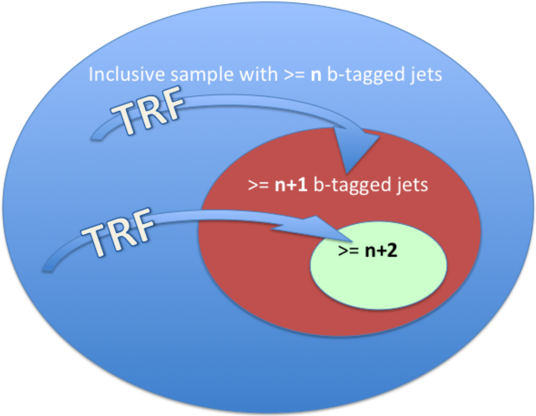


$t\bar{t}Z(Z \to jj)$

Trigger	$t\bar{t}H$ 0l	$t\bar{t}H$1l	$t\bar{t}H$2l	$t\bar{t}$0l	$t\bar{t}$1l	$t\bar{t}W$	$t\bar{t}Z$	data
HLT_j175_bmv2c2040_split	20.47	8.14	0.64	278.02	91.08	0.62	14.41	■
HLT_j225_bmv2c2060_split	13.01	5.08	0.37	187.71	62.5	0.43	9.25	■
HLT_j275_bmv2c2070_split	7.17	2.92	0.21	109.72	34.97	0.27	5.24	■
HLT_j300_bmv2c2077_split	5.19	2.17	0.16	82.17	26.56	0.16	3.99	■
HLT_j360_bmv2c2085_split	2.38	1.02	0.08	40.38	13.2	0.06	1.94	■
HLT_j150_bmv2c2060_split_j50_bmv2c2060_split	35.33	14.49	1.09	472.53	151.95	0.94	22.9	■
HLT_j175_bmv2c2060_split_j50_bmv2c2050_split	25.87	10.18	0.81	348.26	113.37	0.8	17.54	■
HLT_j75_bmv2c2070_split_3j75_L14J15.0ETA25	52.04	18.64	1.31	647.39	184.9	1.33	30.48	■
HLT_j100_2j55_bmv2c2060_split	69.06	27.49	1.98	915.35	273.8	1.73	40.25	■
HLT_2j70_bmv2c2060_split_j70	63.37	24.35	1.76	800.08	234.14	1.53	37.1	■
HLT_2j75_bmv2c2070_split_j75	58.74	22.44	1.62	741.16	214.63	1.34	34.46	■
HLT_2j35_bmv2c2050_split_2j35_L14J15	95.68	37.23	2.58	1335.29	387.06	2.12	55.03	■
HLT_2j35_bmv2c2060_split_2j35_L14J15.0ETA25	99.3	38.84	2.7	1423.76	409.52	2.29	57.07	■
HLT_2j45_bmv2c2077_split_3j45_L14J15.0ETA25	85.72	31.84	2.14	1156.23	321.1	2.16	48.97	■
HLT_2j45_bmv2c2077_split_3j45	81.66	30	1.97	1105.77	300.64	2.09	46.56	■
HLT_5j70_L14J15.0ETA25	49.57	16.46	1.12	606.88	161.94	1.4	28.32	■
HLT_4j100	30.78	10.8	0.76	361.88	107.31	1.07	17.2	■

- Cut flow validation with other analysis group is in progress.
- QCD background is missing $\Rightarrow$ Its estimation is under development using TRF_{MJ} method.

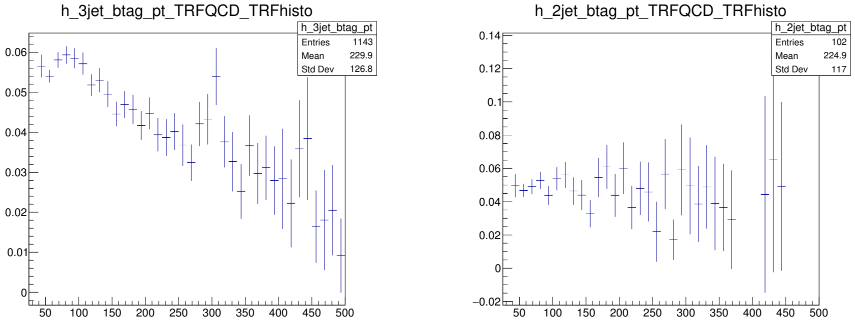
Tag Rate Function method for multijet events (TRF_{MJ})



- TRF_{MJ} method estimate the number of event with high b-tag multiplicity starting from an inclusive sample.

Definition of $\mathrm{TRF_{MJ}}$

- QCD background is estimated at low jet multiplicity.
- Given a sample with n_b, remove n_b with the highest mv2c10 scores, $\mathrm{TRF_{MJ}}$ is defined as a probability of b-tagging the extra jet.
- Example: $\mathrm{TRF_{MJ}}(P_T)$ is defined from 5-jet region with a given n_b(=2,3), trigger used HLT_2j45_bmv2c2077_split_3j45
  - MC $t\bar{t}$ is removed when estimating $\mathrm{TRF_{MJ}}$



$\mathrm{TRF_{MJ}}(P_T)$ with $n_b = 2$

$\mathrm{TRF_{MJ}}(P_T)$ with $n_b = 3$

Validation of $\mathrm{TRF_{MJ}}$ method in 5-jet data

Probabilities of having $n_b + N$ b-tag jets (N=0,1,2,3)

$$P_{N=0} = \prod_{i=1}(1-\epsilon_i),$$

$$P_{N=1} = \sum_{j=1}\left(\epsilon_j \prod_{i\neq j}(1-\epsilon_i)\right),$$

$$P_{N=2} = \sum_{j=1}\sum_{l=j+1}\left(\epsilon_j\epsilon_l \prod_{i\neq j,l}(1-\epsilon_i)\right),$$

$$P_{N=3} = \sum_{j=1}\sum_{l=j+1}\sum_{m=l+1}\left(\epsilon_j\epsilon_l\epsilon_m \prod_{i\neq j,l,m}(1-\epsilon_i)\right)$$

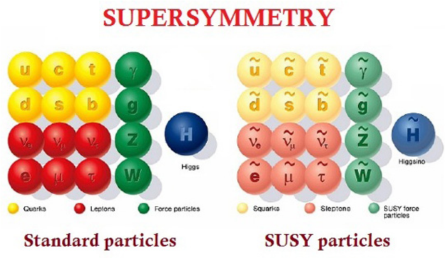
where $\epsilon_i = \mathrm{TRF_{MJ}}(P_T)$

Samples\\n_{btag}	2	3	4	5
$t\bar{t}0l$	44065.9	1302.3	11.8	0
$t\bar{t}1l$	23939.6	893.6	32.6	0.2
$t\bar{t}W$	64.3	1.8	0.01	0
$t\bar{t}Z$	74.9	13.2	1.7	0
Sum $t\bar{t}$	68145	2211	46	0.2
MCbkg + $\mathrm{TRF_{MJ}}(n_b = 2)$	124772.1	11521.1	556.7	9.5
MCbkg + $\mathrm{TRF_{MJ}}(n_b = 3)$		10781.9	906.8	21.9
data	125015	10764	911	19

Number of 5 jets events with respective number of b-tagged jets, work in progress.

Prospect of fully hadronic analysis channel

- What future for fully hadronic analysis? $\Rightarrow$ Super symmetry with R-parity violation scenario (SUSY RPV)



Motivation:

- Larger symmetry
- Provide candidate of DM
- Solve the Higgs mass correction problem
- Possible QT of gravity

New symmetry: R-parity

$$R = (-1)^{2S+3(B-L)}$$

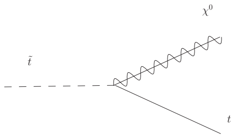
S: Spin
B: Baryonic number
L: Leptonic number

R-parity scenarios

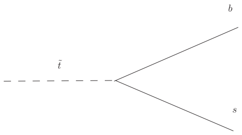
Superpotential of MSSM

$$W_{RpC} = U^c y_u Q H_u - D^c y_d Q H_d - E^c y_e L H_d + \mu H_u H_d,$$

$$W_{RpV} = \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \mu'_i L_i H_u + \lambda''_{ijk} U^c_i D^c_j D^c_k$$



RpC vertex



RpV vertex

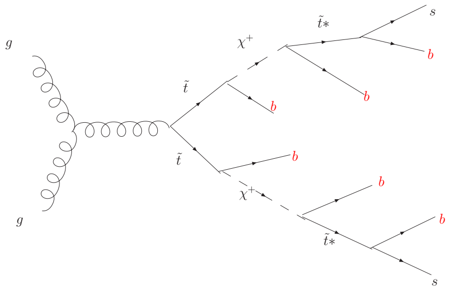
- Sparticles are in pair at vertex.
- Lightest supersymmetric particle (LSP) as dark matter candidate.
- Generate undetectable particle.
- Conserve B and L.

- Sparticles are single at vertex.
- Gravitino as dark matter candidate.
- Sparticles decay to SM particles.
- Violate B and L.

Signal generation

Samples are generated by

- MadGraph5 aMC@NLO v2.1.2 and CTEQ6L1 PDF to generate the matrix element.
- Partons are showered in PYTHIA 8 to simulate extra jets.
- Detector simulation is done by Delphes 3 using ATLAS setup.

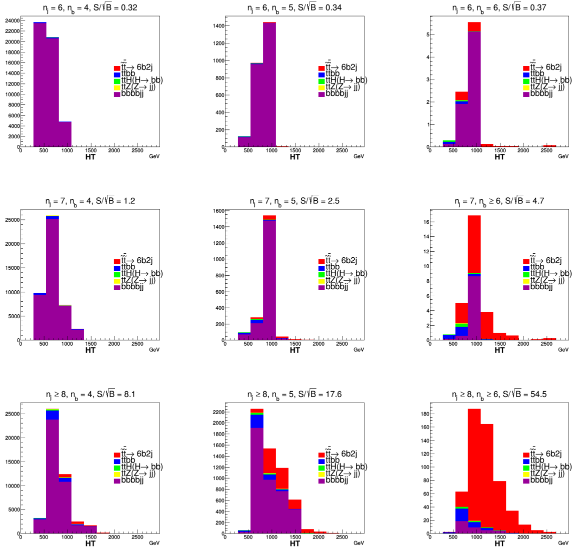


RpV signature ($\tilde{t}\bar{\tilde{t}} \to 6b2j$).

$\sigma(pp \to \tilde{t}\bar{\tilde{t}} \to 6b2j)$	0.072 pb
Stop mass $m_{\tilde{t}}$	600 GeV
Chargino mass $m_{\chi^\pm}$	500 GeV
Coupling λ''_{332}	10^{-3}
Number of entry N	10000

Table: Input parameters of the RpV signal.

Preliminary result of search for SUSY RPV



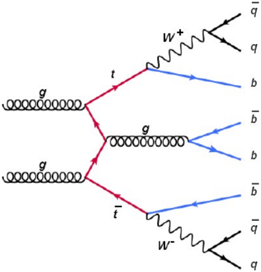
- HT: transverse hadronic energy.
- The region $(\geq 8j, \geq 6b)$ looks promising to distinguish signal and MC backgrounds.

Conclusion

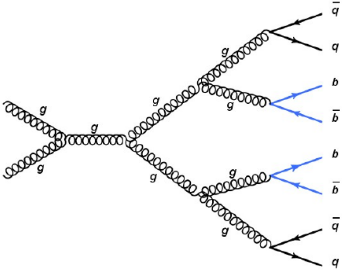
- Search for top quark pairs associated production in the fully hadronic final state just started.
- Very challenging analysis, large multi-jet background that has to be derived from data $\mathrm{TRF}_{\mathrm{MJ}}$
- The first version of $\mathrm{TRF}_{\mathrm{MJ}}$ is implemented in data and validated in 5-jet region.
- SUSY is a viable extension of SM because it provides candidate for dark matter and solution for Higgs mass hierarchy.
- RPC is constrained by LHC, RpV is becoming valid in SUSY if we still want to have $m_{\tilde{t}} < 1$ TeV
- Multi-jet multi-b-jet final state could be used to probe RPV stop production signal.

THANK YOU FOR LISTENING.

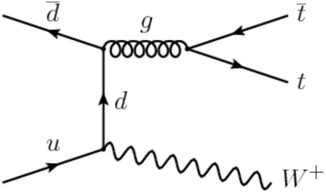
Main backgrounds



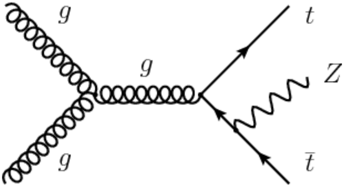
$t\bar{t}$+jets



QCD background



$t\bar{t}W(W \to jj)$



$t\bar{t}Z(Z \to jj)$

What we have been done in RUN 1?

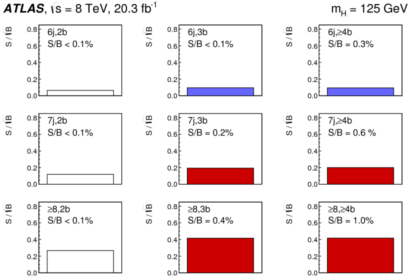


Figure: Trigger used HLT_5j55

Run 1 analysis:

- Used multi-jet triggers to select events.
- Applied a BDT in all regions for discrimination between signal and background.
- Performed a fit under the signal-plus-background hypothesis.

- Observed (expected) 95% CL upper limit of 6.4 (5.4) times the SM cross section is obtained.
- Signal strength in the all-hadronic t$\bar{t}H$ decay mode

$$\mu(m_H = 125\text{GeV}) = 1.6 \pm 2.6$$

⇒ Proceed to RUN 2 with a similar strategy and new techniques.

b-jet trigger performance

- The ATLAS b-jet trigger uses MV2 algorithm to separate $b$jet from light and c-jet depends on
  - IP3D exploit 2D distribution of impact parameters.
  - SV1 exploits invariant mass of tracks, jet energy fraction associated to SV.
  - JetFitter exploits topological structure of weak b- and c- hadron decays inside jet.
- Expected performance of the ATLAS b-jet trigger in 2017.

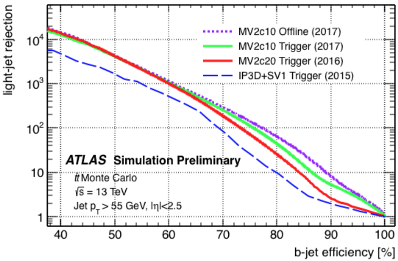


Figure: Expected performance of b-tagging algorithms in terms of light-jet rejection on $t\bar{t}$ simulation

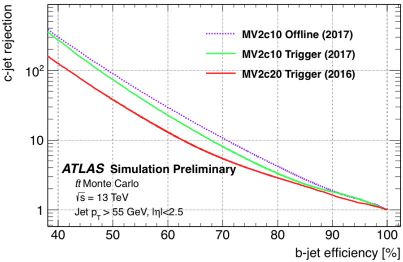
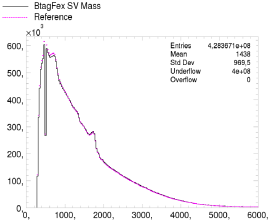
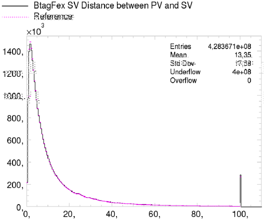


Figure: Expected performance of b-tagging algorithms in terms of c-jet rejection on $t\bar{t}$ simulation

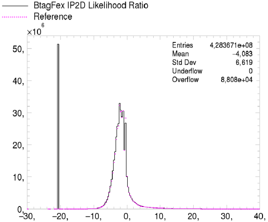
Distributions of some monitored variables



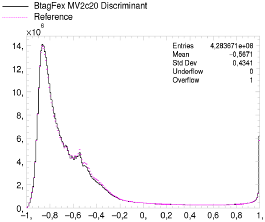
Invariant mass of tracks at the secondary vertex



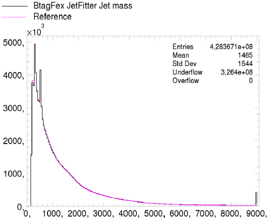
3D distance between SV and PV



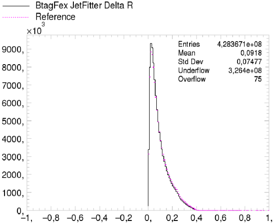
IP2D likelihood ratio



Mv2c20 discriminant



Invariant mass of tracks from displaced vertices



Delta R between the jet axis and the vectorial sum of the mo menta of all tracks attached to displaced vertices