# Single top in the CSC framework

Arnaud Lucotte
(LPSC, IN2P3/CNRS, UJF, INPG )

## Outline

**Introduction**
- a) Motivations & Context
- b) Lessons from the TeVatron

**Preselection of single-top**
- a) Triggers
- b) Tagging Rate Function
- c) Preselected sample

**CSC and cross-section measurements**
- a) t-channel
- b) Wt-channel
- c) S-channel
- d) Systematics

**Conclusion & perspectives**

# Contributors to single-top CSC analyses

1. Introduction
   - S. Rolli , AL
2. Phenomenology
   - R. Schwienhorst, AL
3. Reconstruction & trigger performance
   - A. Shibata, M. Kajkhad, C. Cojocaru, P. Ryan
4. Preselection of single top events
   - S. Rolli, all
5. Single-top evidence with the early data
   - R. Schwienhorst, Jenny, P. Ryan
6. t-channel cross-section measurement
   - A. Shibata, N. Triplett
7. s-channel cross-section measurement
   - A.L
8. Wt-channel cross-section measurement
   - B. Clement
9. Common systematics
   - M. Cristinziani, G. Khoriauli, A. Shibata,
   - D. Shouten, J. Cochran


**ATLAS NOTE**

ATL-PHYS-PUB-2007-XXX

August 29, 2007


**Prospect for single top cross-section measurements in ATLAS**

The ATLAS Collaboration

**Abstract**

At the LHC, the production of single top quarks accounts for a third of the top pairs production. With more than two millions of single top events produced every year during a low luminosity run, a precise determination of all contributions to the total single-top cross-section seems achievable. These measurements will constitute the first direct measurement of $V_{tb}$ [illegible] fraction, and constitute a powerful probe for new physics, via the search for evidence of anomalous couplings to the top quark or the measurements of additional bosonic contributions to the single top production.

The single top production mechanisms proceeds through three different sub-processes leading in distinct final states, topologies, and backgrounds. This report establishes the ATLAS potential for the cross-sections measurements of all three contributions. A common preselection, including triggers, is described and it addresses lepton identification issues, [illegible] b-tagging performance. Specific selections are detailed extensively and the expected performance are assessed in terms of statistical sensitivity and systematic uncertainties. A special emphasis is put on the strategies for an early evidence of single top production, including triggers issues as well as methods which will be used to estimate Standard Model backgrounds from data when possible.

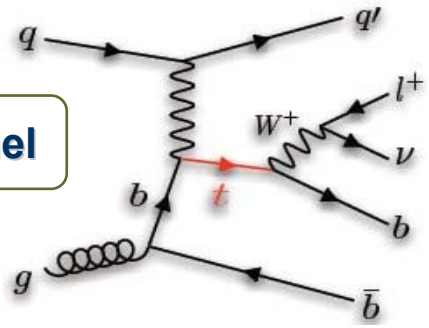
# Motivations & Context

# Single Top Production @ LHC

## Production at the LHC

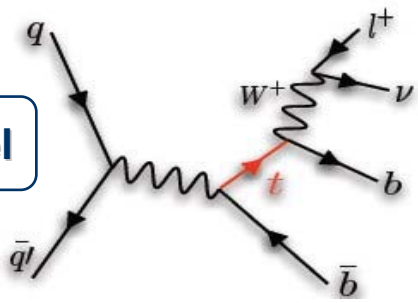
### All 3 contributing mechanisms in SM

**t-channel**



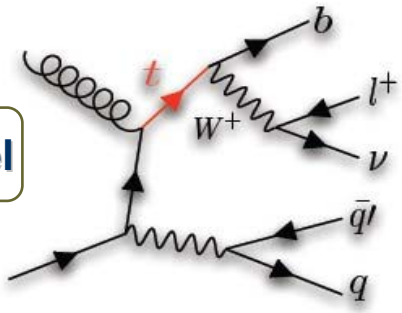

σ = 246.6±10 pb (NLO) (1)
- dominant source of single top
- N(1 fb$^{-1}$) ~ 80,000 in W→ e/μ,ν

**s-channel**




σ = 10.65±0.65 pb (NLO) (1)
- smallest source of single top
- N(1 fb$^{-1}$) ~ 3,000 in W→ e/μ ν

**W+t channel**




σ = 62.10±0.03 pb (NLO) (2)
- source of single top
- N(1 fb$^{-1}$) ~ 18,000 in W→ e/μ ν

## Phenomenology

### Cross-section uncertainties

$\Delta\sigma/\sigma_{theo}$ ~ 4 to 6% (renorm. scale, pdf, input $m_{top}$)

### Main backgrounds @ LHC

Top pair events (was W+jets @ TeVatron)

(1) Z. Sullivan, Phys. Rev D70 (2004) 114012
(2)Campbell et al., hep-ph/0506289

# Motivation : why single-top ?

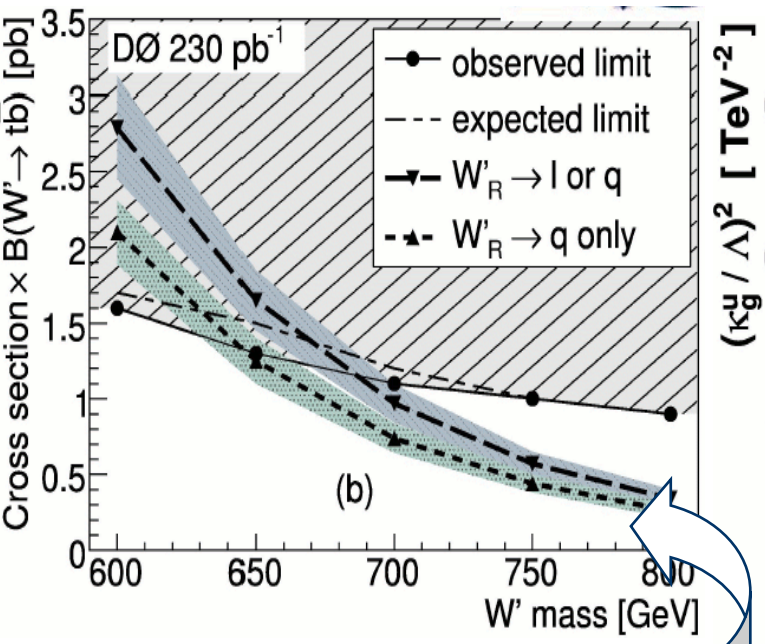
## Precise tests of SM

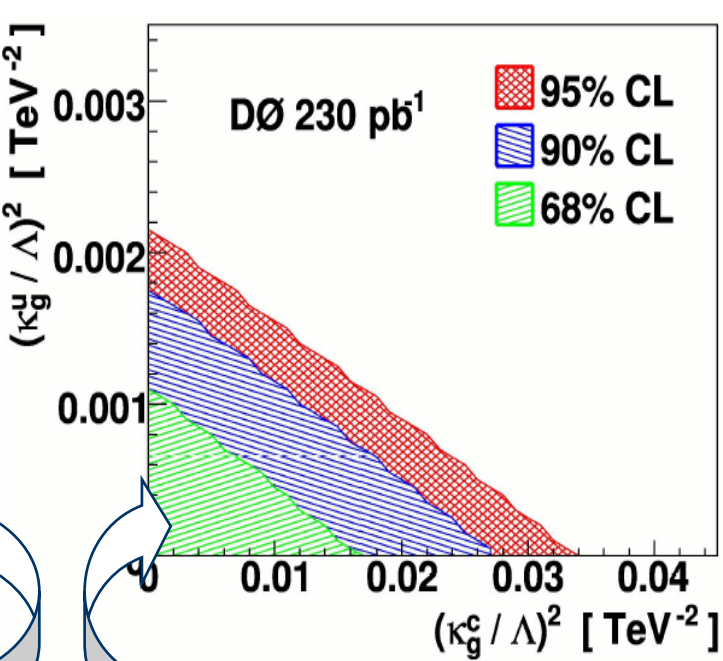
### Precise measurement of cross-section :

- Direct determination of $V_{tb}$
- Measurement of Top width

### Polarized top :

- Top polarization measurement




## Probe for New Physics

### Sensitivity to new boson

- Charged W' (GUT, KK …)
- Charged Higgs (2HDM)

### Anomalous Couplings

- FCNC qq/gg → tq …

# Single Top production at the TeVatron…

## Evidence for single-top

**First evidence (3σ) in DØ :**

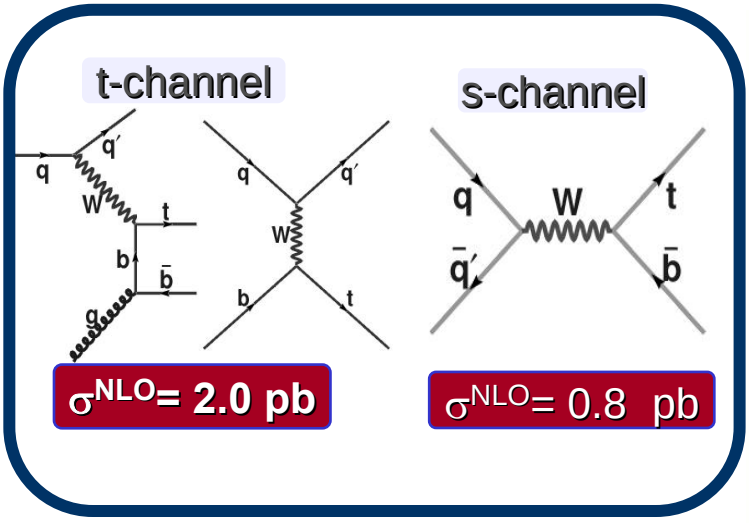
→ (s+t) combined

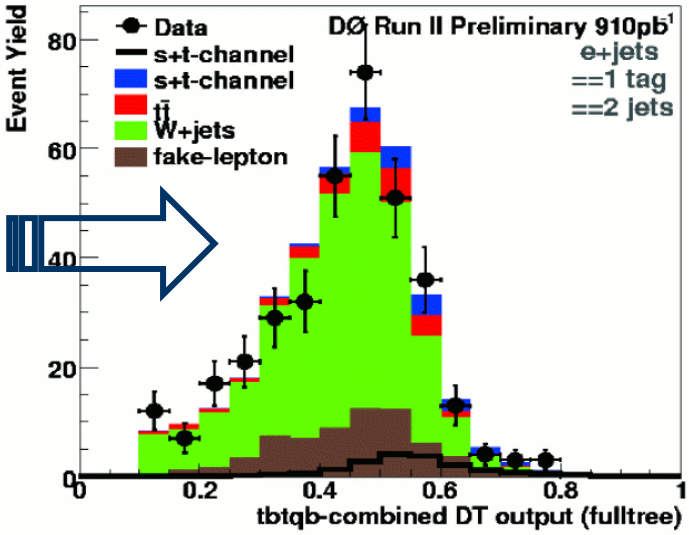
**High level of background :**

Low S/B, B mainly from W+(b) jets + Top pairs

**Development of statistical methods :**

Boosted Decision+ Trees Neural Net +Likelihoods …




## Lessons from the TeVatron

**Performance need in :**

b-tagging efficiency & mistag rates

Jet energy scale (to a lesser extend)

**Main background (W+jets) poorly understood :**

Considerable tuning of MC to data required

**Use of refined techniques :**

Several MultiVariate analyses confronted

→ Need to use DATA to normalize backgds

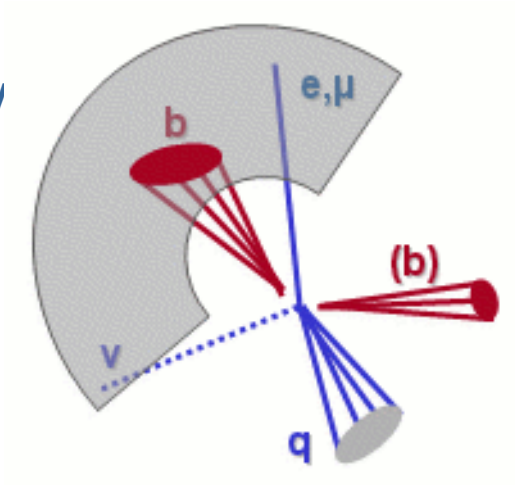
# Strategies :
# Trigger, Tools and event preselection

# Strategies for Single-top at the LHC

## Common Pre-selection

**Triggers for single-top events**

- Inclusive leptons
- Lepton+jet combined under study




**Selection of a leptonic W decay:**

- One high $p_T$ lepton
- High missing Energy

**Rejection of top pair events:**

- Jet Multiplicity : $2 \leq Njet \leq 4$ with $p_T^{jet} \geq 30$ GeV/c

**Rejection of dilepton (top) pair:**

- 2ndary isolated lepton Veto
- Define orthogonal e/μ analyses

**Selection of a leptonic top:**

- at least 1 b-tagged jet

## Individual selections

**Selection of specific topologies**

Three channels have (very) distinct features

**Analyses in bin of jet as function of N(b-tag)**

Cut-based analyses

Complemented by MultiVariate techniques

**Systematic uncertainties**

Same order of stat. errors (will be dominating)

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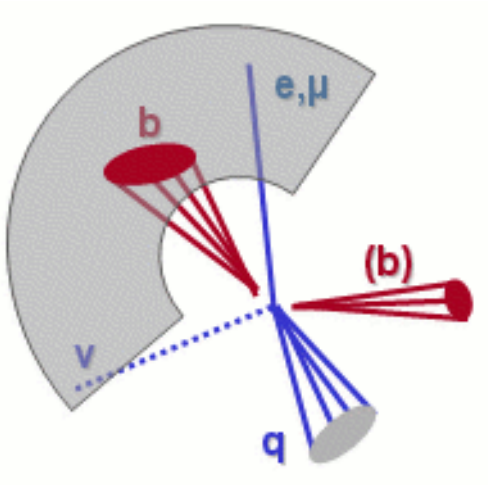


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Cut-based analyses

Complemented by MultiVariate techniques

**Systematic uncertainties**

Dominate early the stat. errors

# Single-top Preselection : triggers

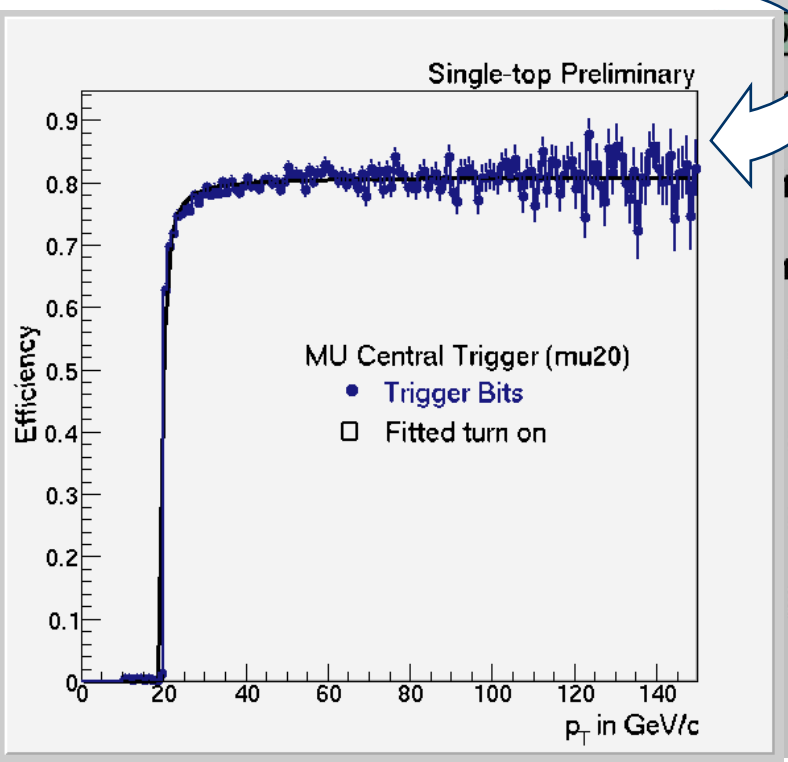
## Muon Trigger for single-top

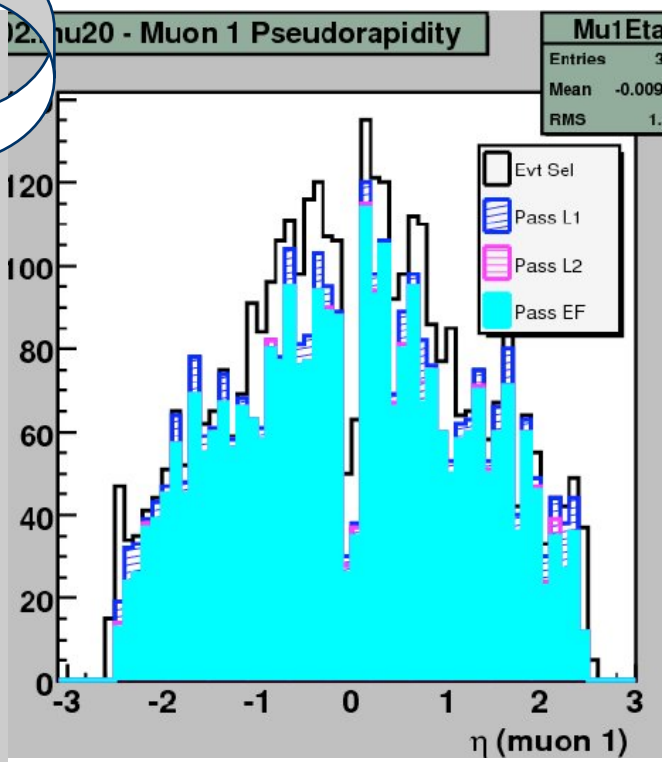
### Muon trigger MU20 :

L1+L2+EF combined

### Performance on MC top samples :

turn-on : $\varepsilon_{trig}$~80-90%




## Electron Trigger

### Inclusive electron : (e25i OR e60)

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Gain of 2-3% by adding e60 (no isolation)

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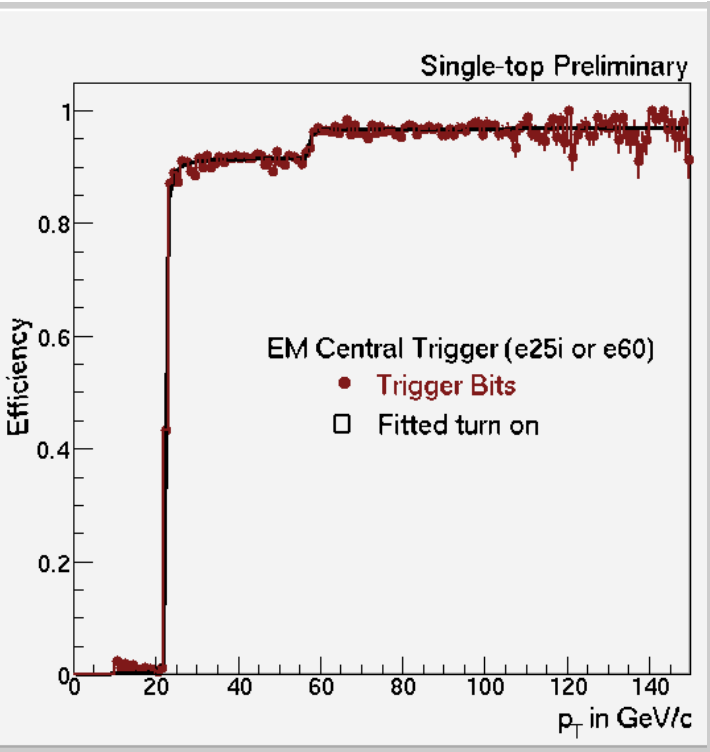


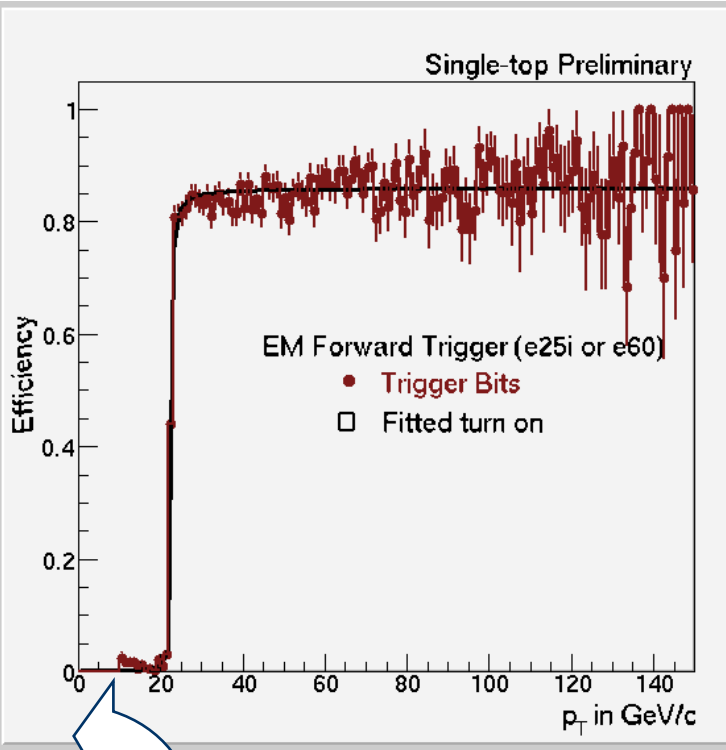


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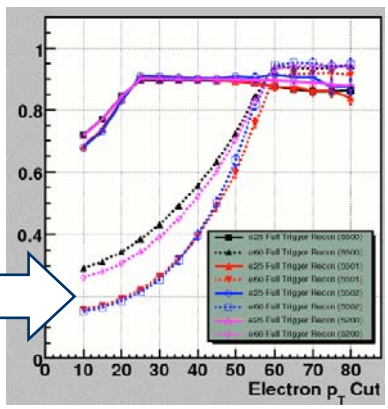


# Tools for Single-top : TRF tag

## Tagging Rate Function (TRF)

### Tagging Rate Function :

Light jet may be mistagged as b-jet :

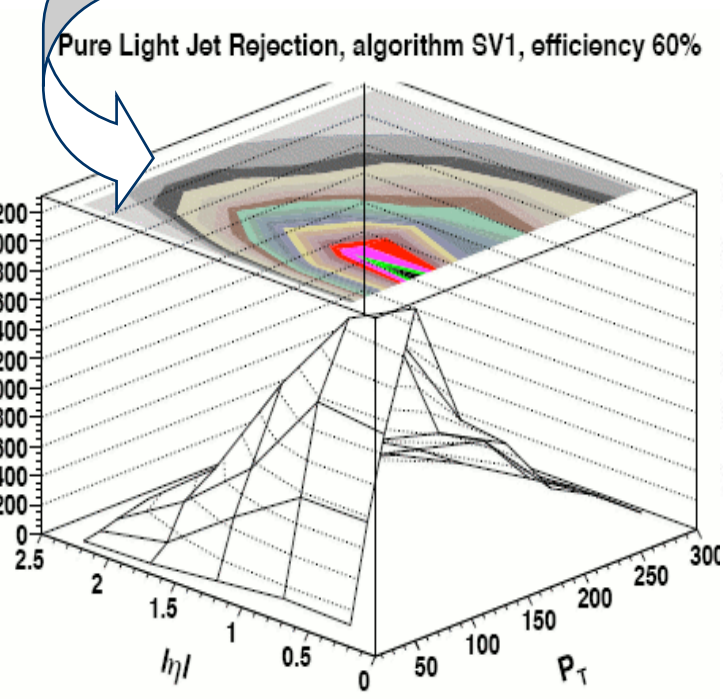
→ Use of parametrization as $f(p_T, \eta)$ from ATLFAST

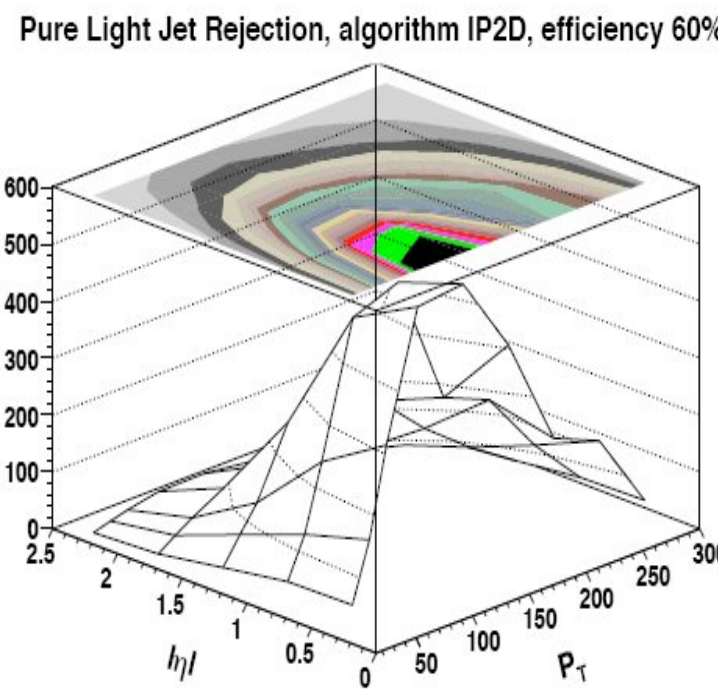
### Parametrization used to affect a weight to:

a b-jet to be seen as a b-jet

a c-jet to be seen as a c-jet, b-jet

a light jet to be seen as a b-jet




### Use combinations of jet's TRF weights to compute

the event probability (weight) for an evt to be seen as :

→ 1 b inclusive, 1-b exclusive,

→ 2-b inclusive etc…

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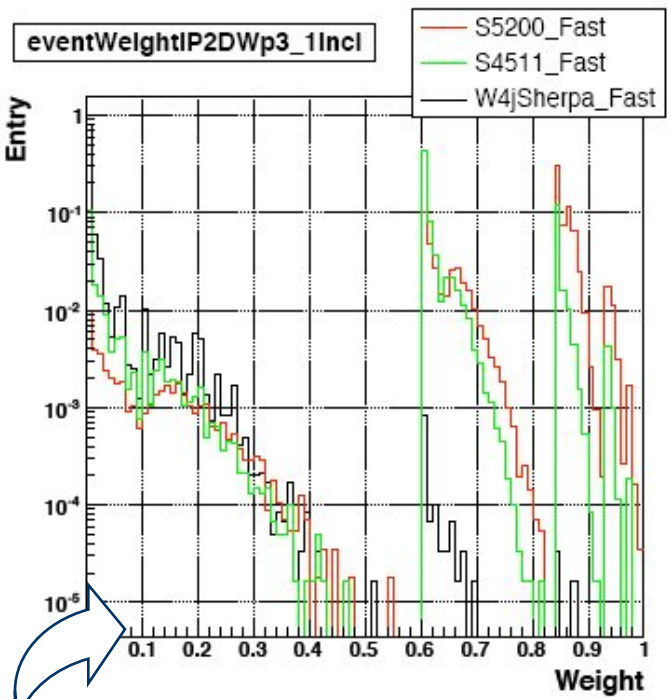


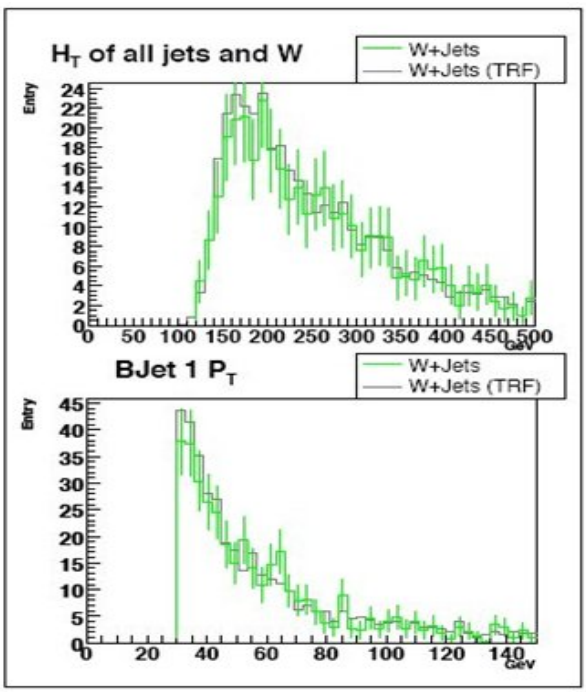


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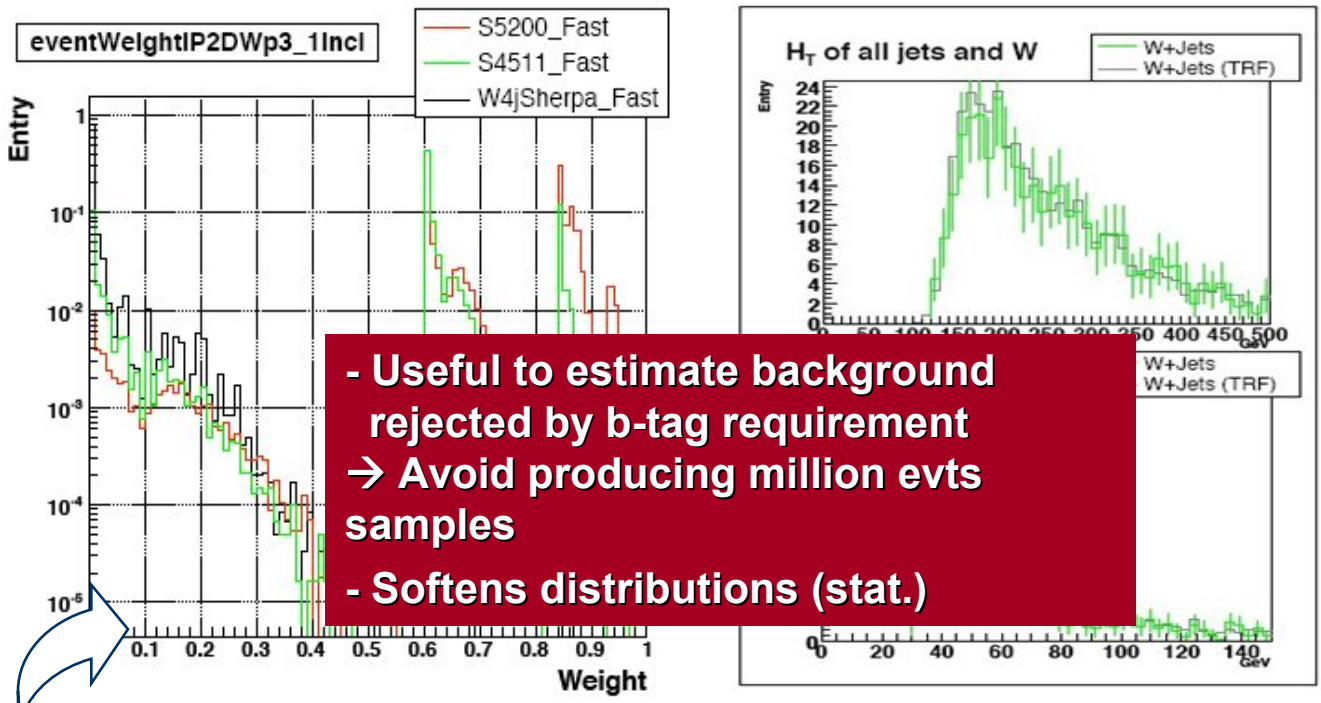


- Useful to estimate background rejected by b-tag requirement
→ Avoid producing million evts samples
- Softens distributions (stat.)

Use combinations of jet's TRF weights to compute the probability (weight) for an evt to be seen as :

→ 1 b inclusive, 1-b exclusive,

→ 2-b inclusive etc…

# Individual single-top Analyses

# Single-top Pre-selection

## Common Pre-selection

### Triggers for single-top events

- Inclusive electron (E25i or e60)
- Inclusive muon (Mu20)
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### Selection of a leptonic W decay:

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### Selection of low multiplicity jets

- – Jet Multiplicity : $2 \leq Njet \leq 4$ with $pTjet \geq 30$ GeV/c
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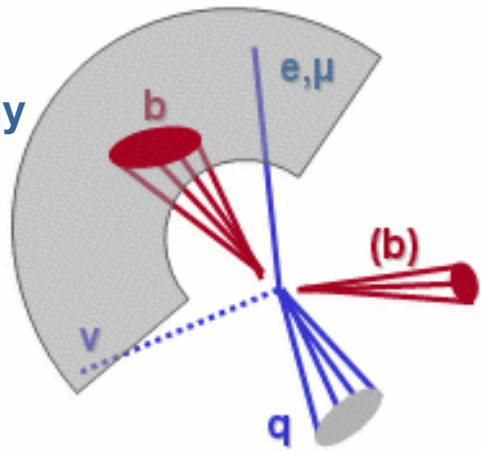


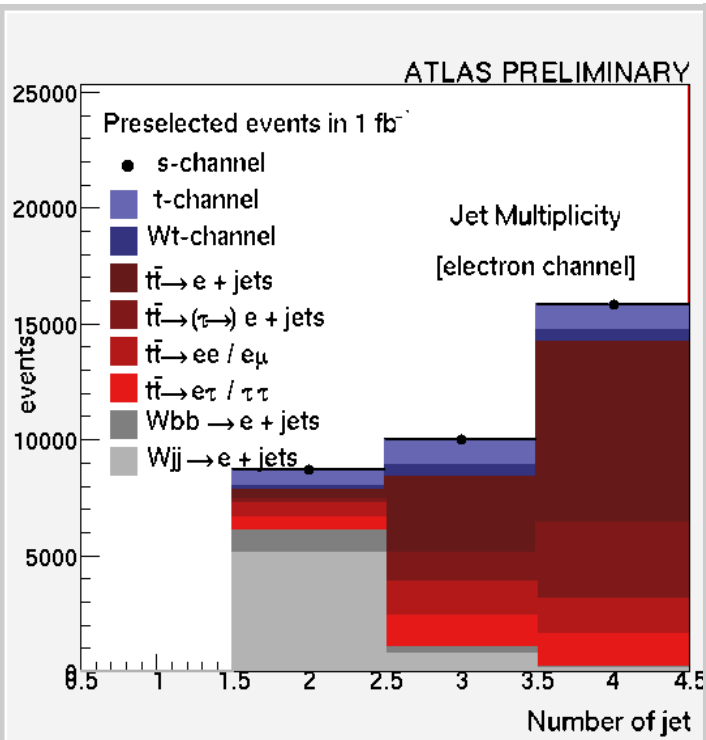


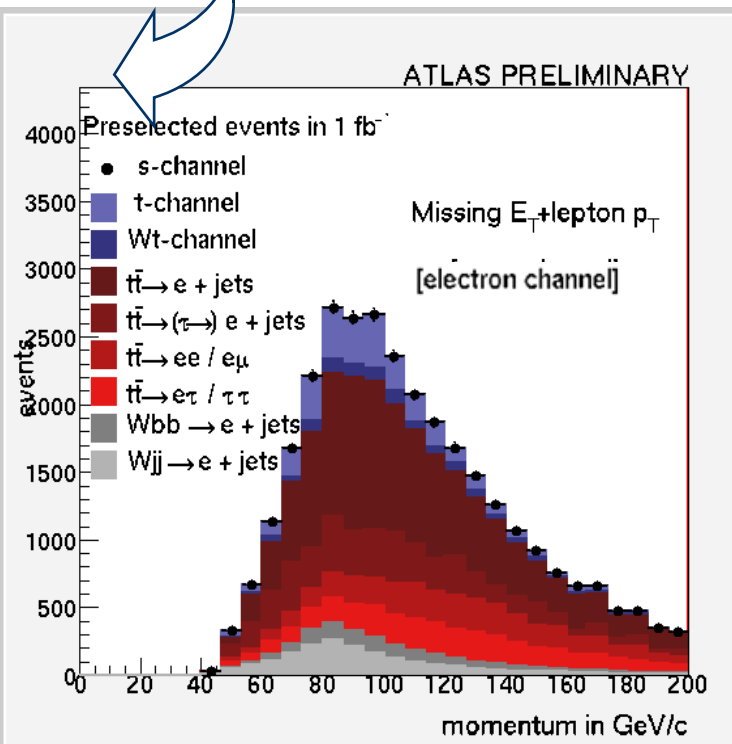

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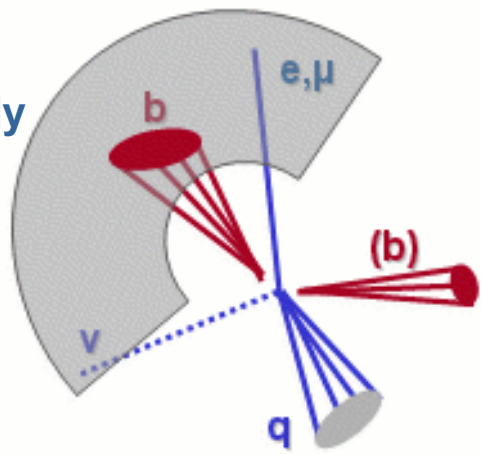
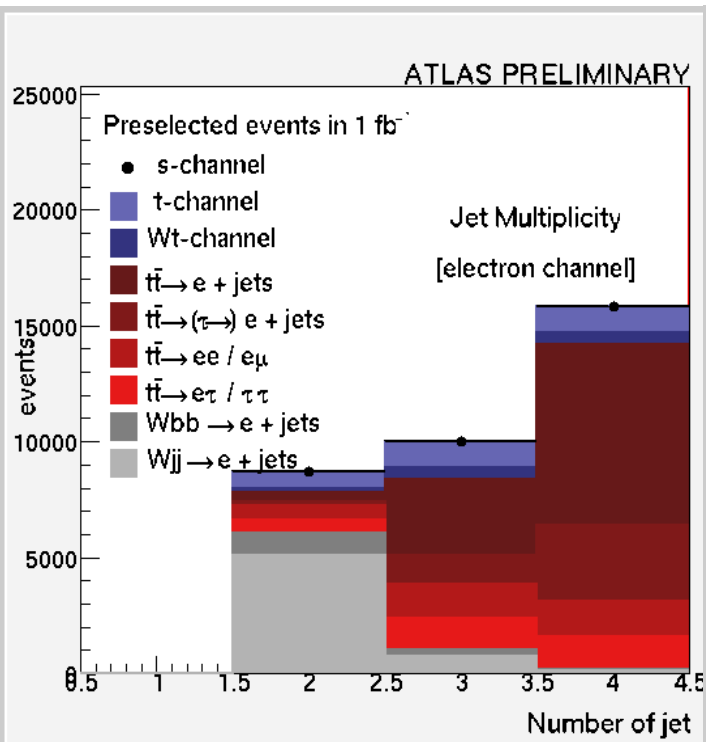
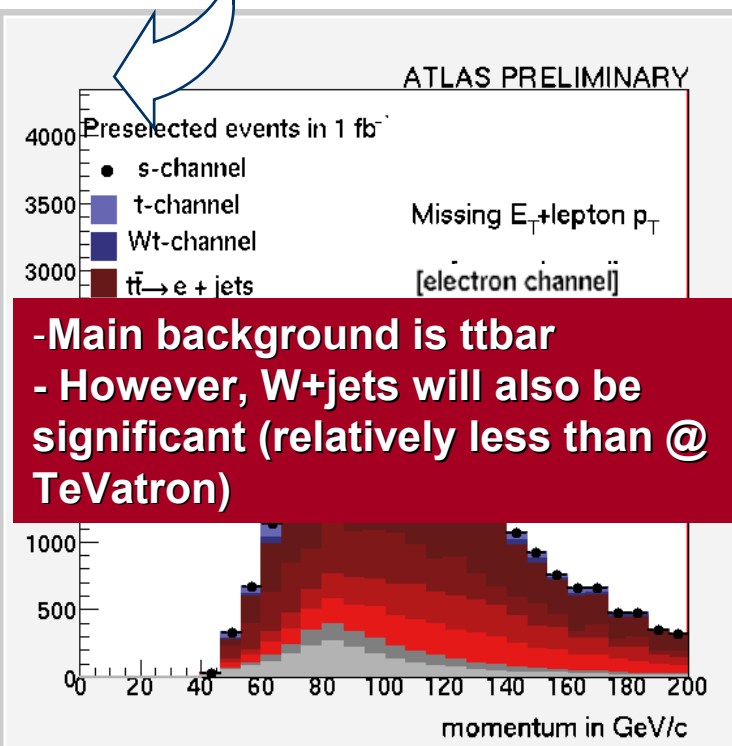


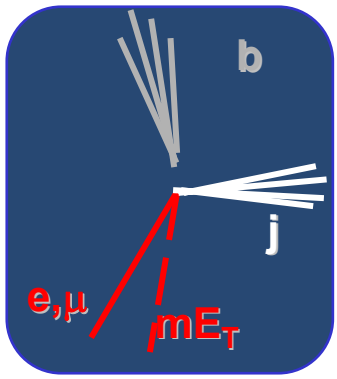



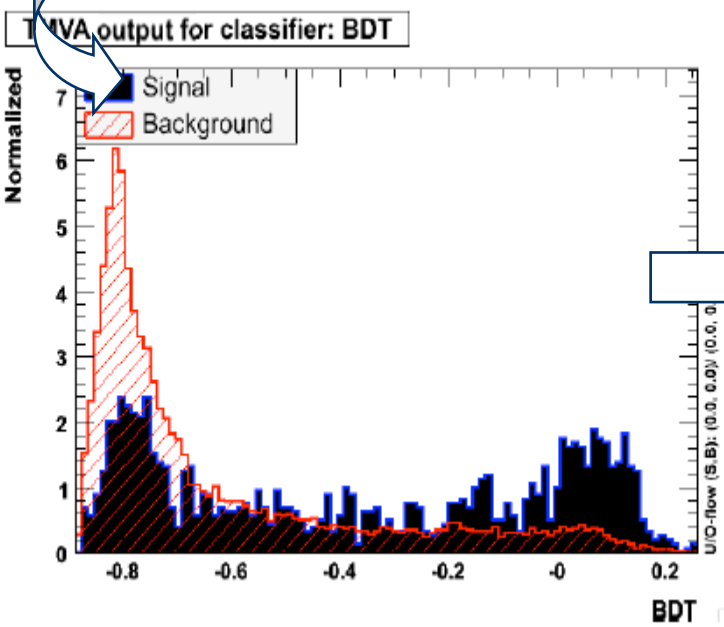

**-Main background is ttbar**
**- However, W+jets will also be significant (relatively less than @ TeVatron)**

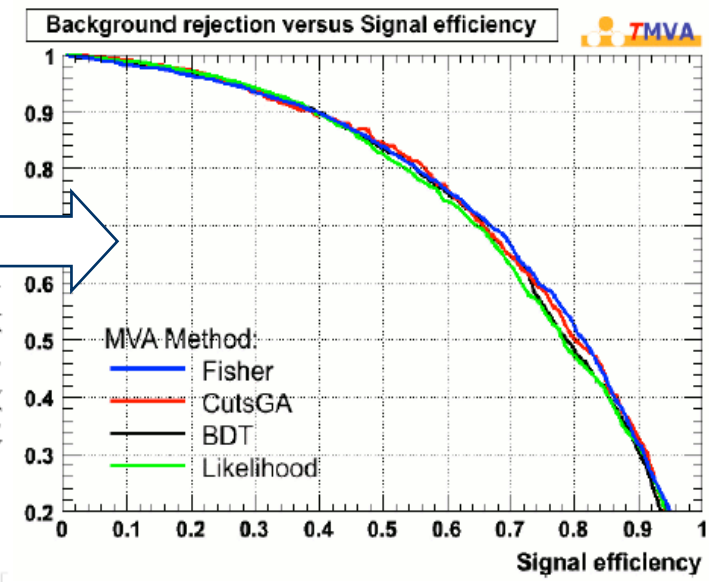
# Single-top t-channel

## Event Selection




- **Exactly 2 high-$p_T$ jets:**
  - 1 central high $p_T$ b-jet
  - 1 forward light jet $|\eta|>2.5$
  - → Limit combinatorial ambiguities
- **Use of topological variables**
  - Optimization via MVA

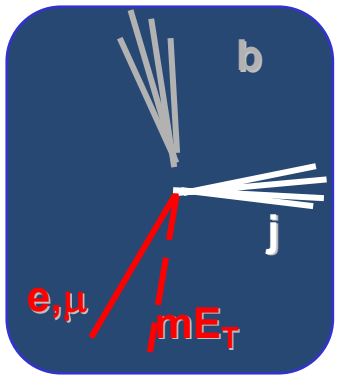



## Performance

- **Signal yields**
  - $\varepsilon \approx$ 1-2% and N(1fb$^{-1}$) ~ 7,000 events
- **S/B ~ 47%, S/√B ~ 12.4σ and √(S+B)/S ~ 8.4% at 1fb$^{-1}$**
- **Measurement systematically limited**

# Single-top t-channel

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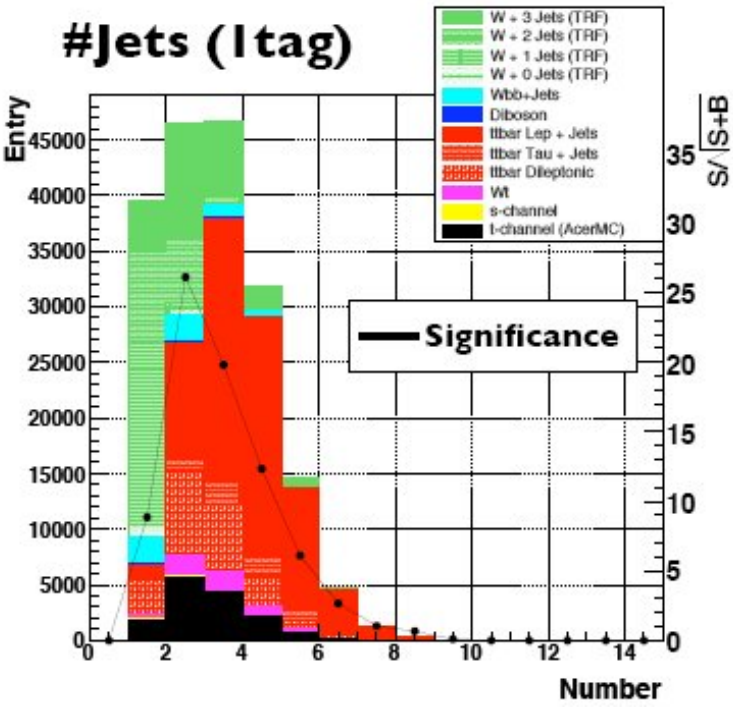
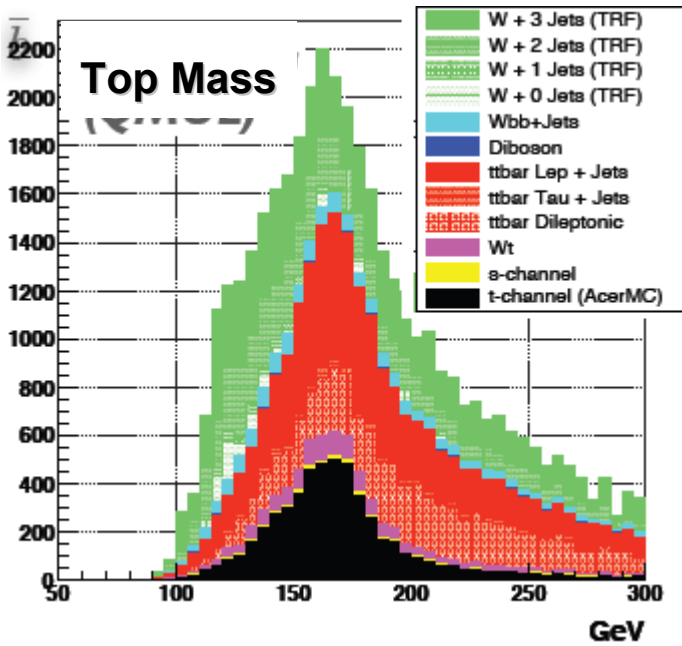


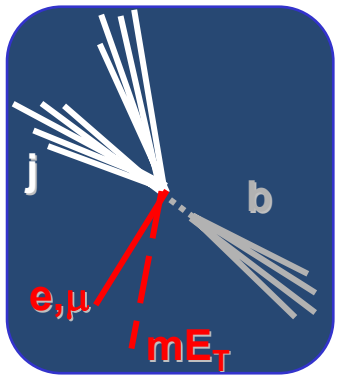




## Performance

- **Signal yields**
  - $\varepsilon \approx$ 1-2% and N(1fb$^{-1}$) ~ 7,000 events
- **S/B ~ 47%, S/√B ~ 21σ and √(S+B)/S ~ 5.6% at 1fb$^{-1}$**
- **Measurement systematically limited**

# W+t channel cross-section

## Strategy




**Reconstruct the hadronic W→jj**

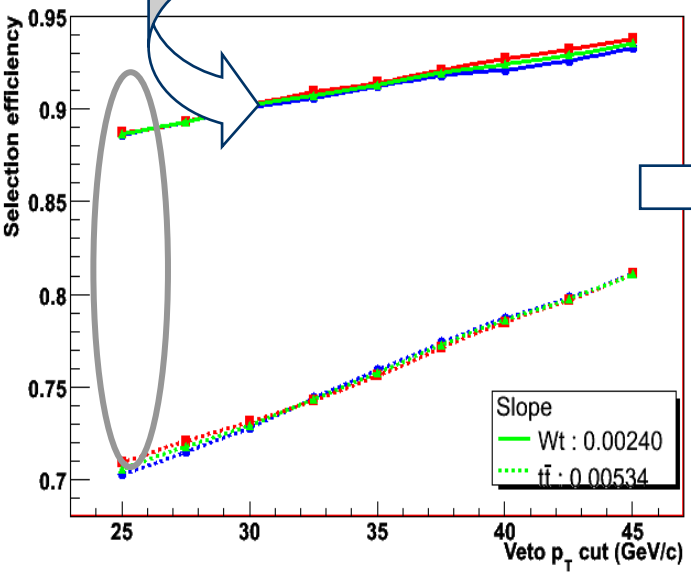
Untagged jets (if $N_{jet} \geq 3$ jets):

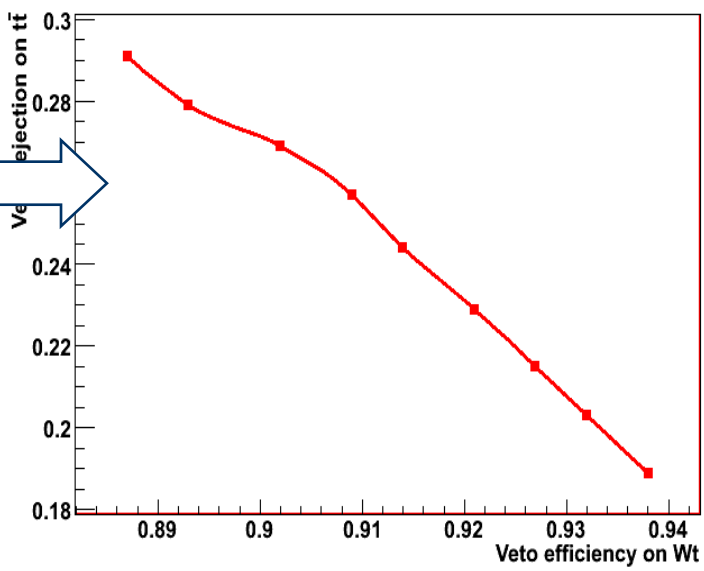
Require $55 \leq M_{jj} \leq 85$ GeV/$c^2$

**Require only one b-tag jet**

Exactly 1 btag above 30 GeV/c

Veto on extra b-tags




## Performance

**Analysis in bins of N(jet) and N(b-tag)**

Develop an MVA in each multiplicity bin:

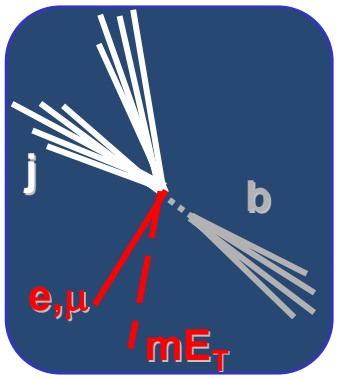
2 jets : S/B ~ 7.1%
3 jets : S/B ~ 8.8%
4 jets : S/B ~ 4.8%

} overall : S/B ~ 7.2%

→ $S/\sqrt{B} \sim 12.4\sigma$ and $\sqrt{(S+B)/S} \sim 8.4\%$ at 1fb$^{-1}$

# W+t channel cross-section

## Strategy

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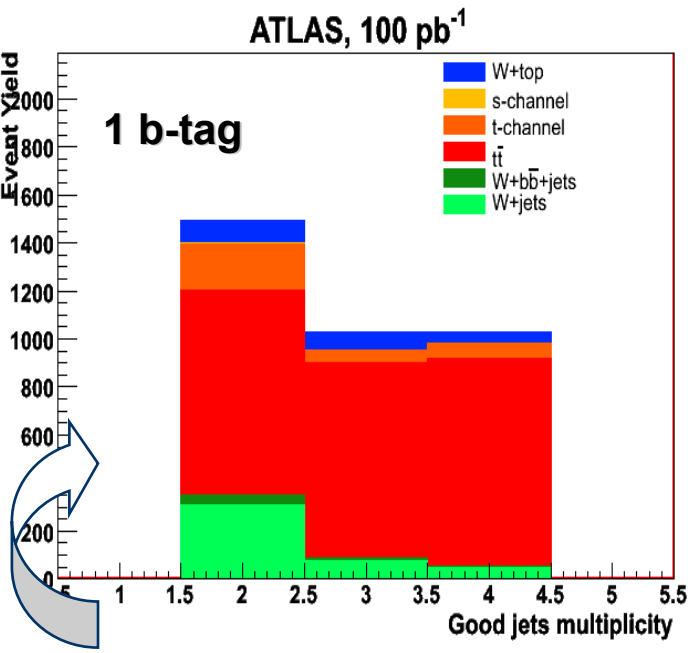
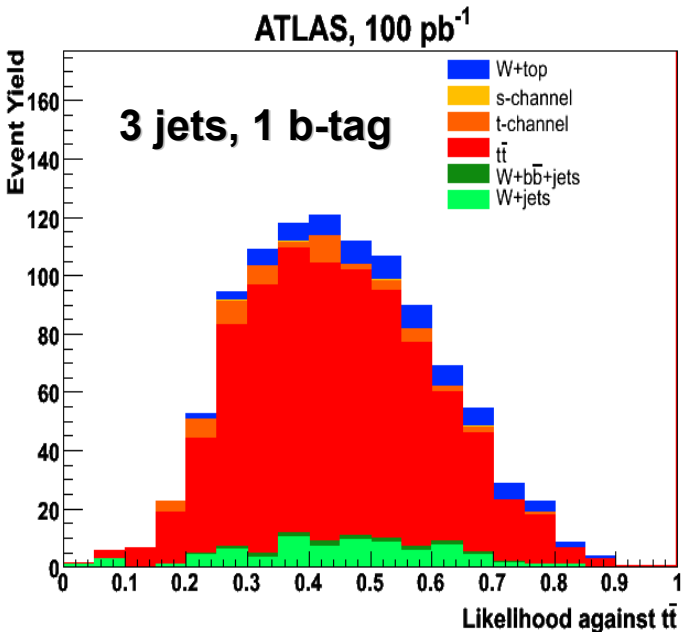
Exactly 1 btag above 30 GeV/c

Veto on extra b-tags




## Performance

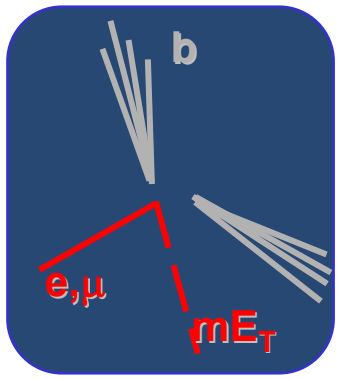
**Analysis in bins of N(jet) and N(b-tag)**

Develop an MVA in each multiplicity bin:

2 jets : S/B ~ 7.1%
3 jets : S/B ~ 8.8%
4 jets : S/B ~ 4.8%
} overall : S/B ~ 7.2%

→ $S/\sqrt{B} \sim 12.4\sigma$ and $\sqrt{(S+B)/S} \sim 8.4\%$ at 1fb$^{-1}$

# s-channel cross-section




## Strategy

**Select "2b0j" final state:**

- **2 b-tagged jets**
- **3rd jet veto**

**Develop specific likelihoods against:**

- **Top pair "di-lepton" , "τ+lepton"**
- **Top pair "lepton+jets"**
- **W+(b)jets and W+jets**

**Using specific sets of discriminant variables**

| | |
|---|---|
| *b-tagged jets* | *: $\Delta R(b_1,b_2)$, $\eta_{b1}$ , $\eta_{b2}$, $p_T^{b1}$ , $p_T^{b2}$* |
| *b-jets and lepton* | *: $\Delta R(lep,b_2)$, $\Delta R(lep,b_1)$* |
| *b-jets and W(lν) mass:* | *$M(W,b_1)$, $M(W, b_2)$* |
| *Total energy* | *: $H_T(jets)$, $mE_T+p_T^{lep}$, $M_{TOT}(jets)$* |
| *Event shape* | *: Sphericity, Aplanarity* |

**Select only the variables with a power > threshold**

**→ Form L(tt→l+jets), L(tt→τ+jets), L(Wjet) etc…**

**Combine likelihoods into one discriminant**

## Performance

**Event yields: ε ≈ 1-2%, S/B~12-18%**

**$S/\sqrt{B} \sim 7\sigma$ and $\sqrt{(S+B)/S} \sim 19\%$ at 10 $fb^{-1}$**

**Stat. and systematics limited**

# s-channel cross-section

## Strategy

**Select "2b0j" final state:**

- 2 b-tagged jets
- 3rd jet veto

**Develop specific likelihoods against:**

- Top pair "di-lepton" , "τ+lepton"
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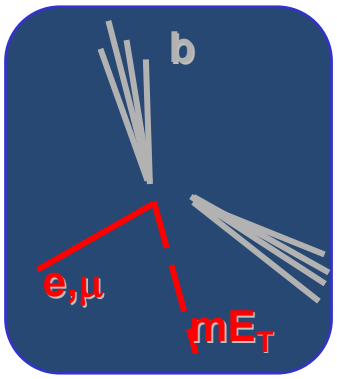
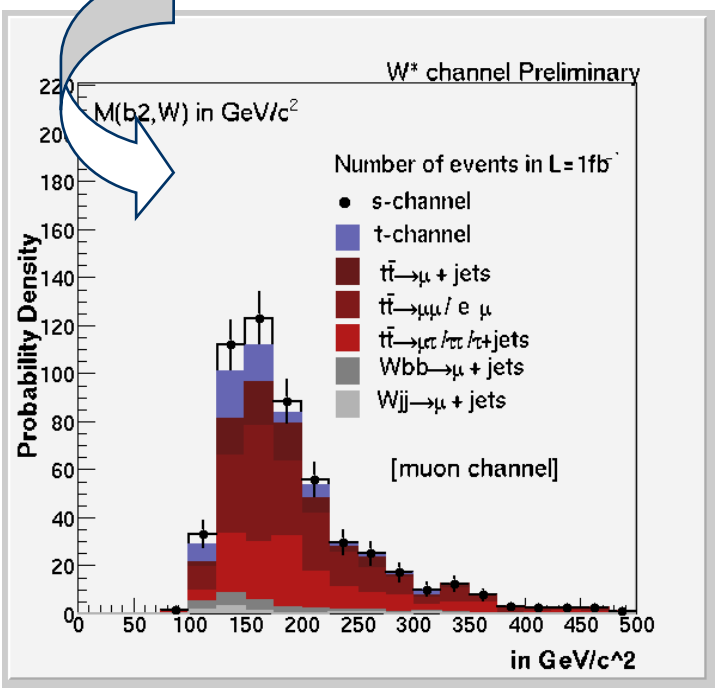
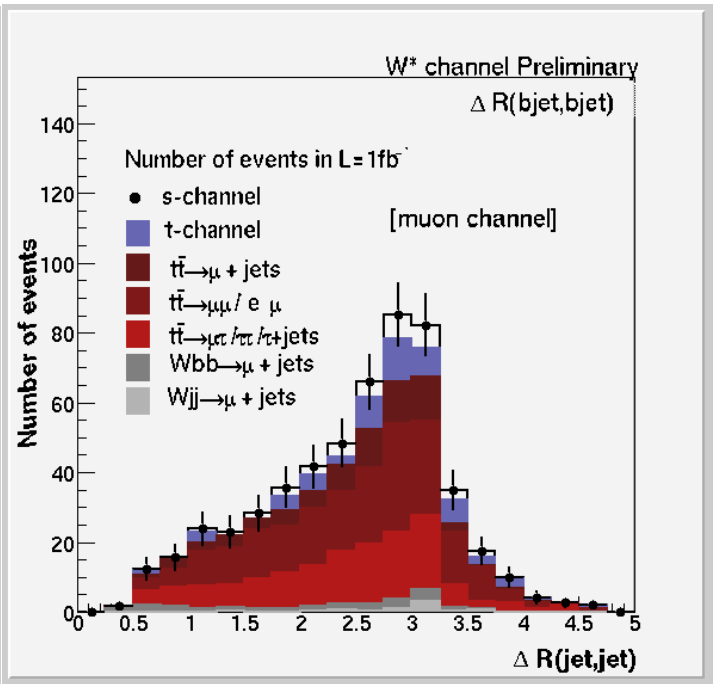
**Using specific sets of discriminant variables**




## Performance

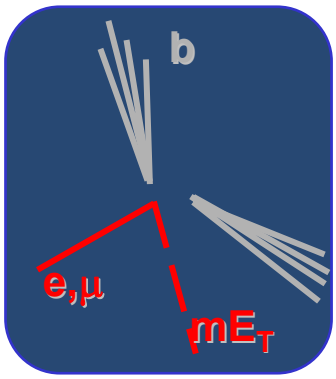
**Event yields: ε ≈ 1-2%, S/B~12-18%**

**S/√B ~ 7σ and √(S+B)/S ~ 19% at 10 fb$^{-1}$**

**Stat. and systematics limited**

# s-channel cross-section

## Strategy

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**Develop specific likelihoods against:**

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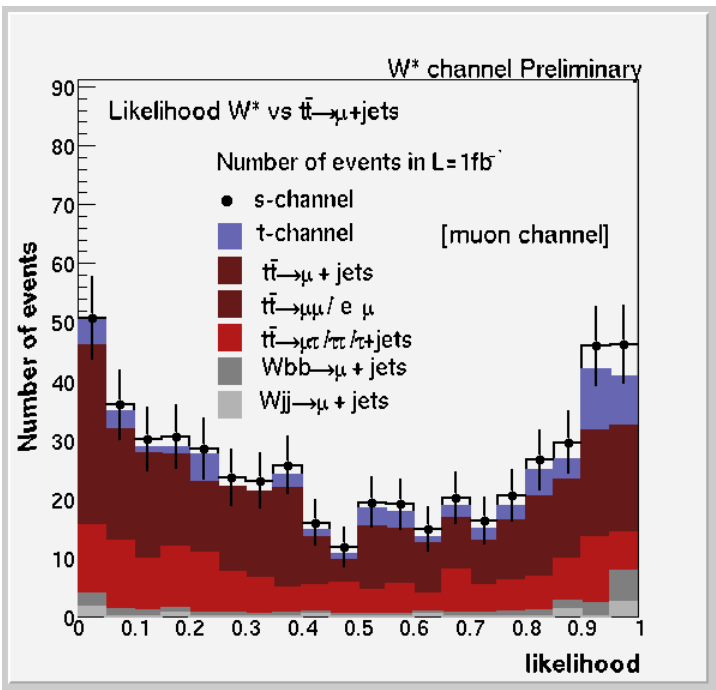
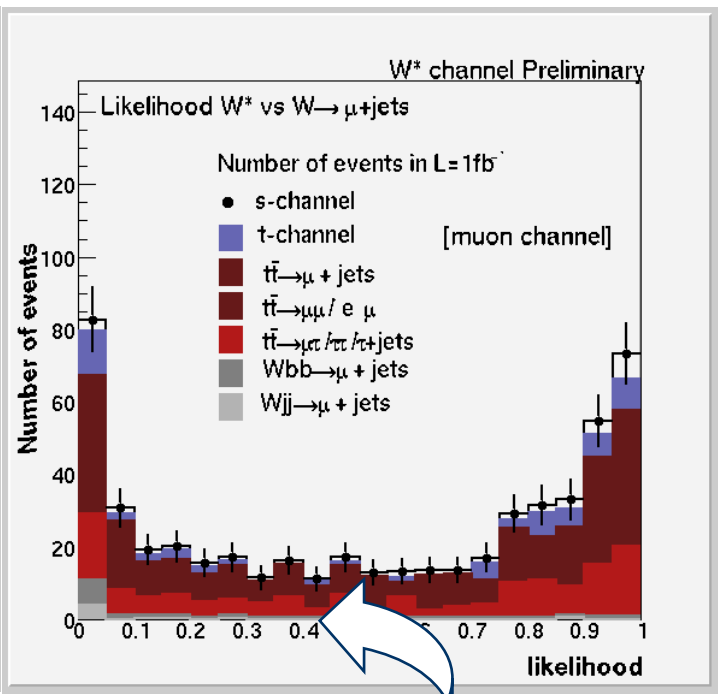
- Top pair "lepton+jets"
- W+(b)jets and W+jets

**Using specific sets of discriminant variables**




## Performance

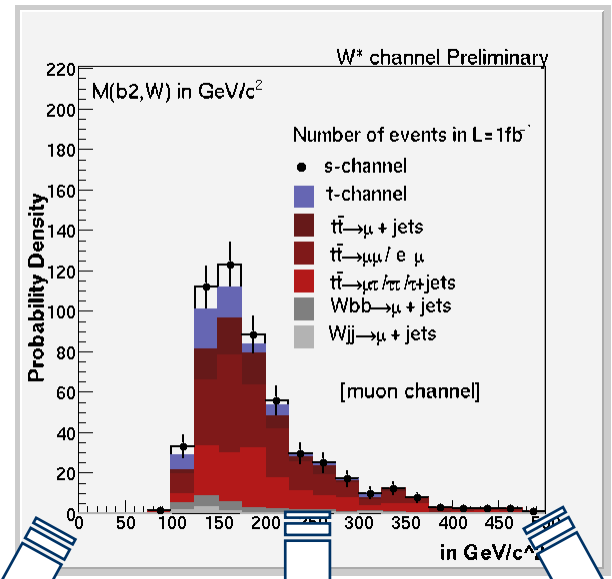
**Event yields: ε ≈ 1-2%, S/B~12-18%**

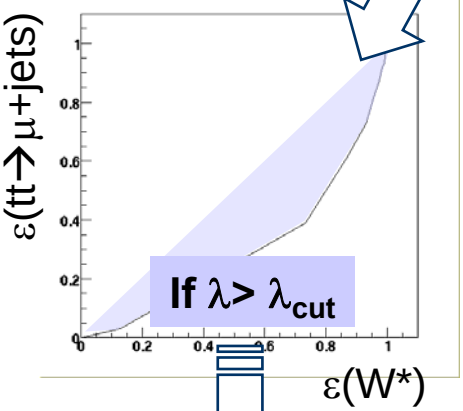
**S/√B ~ 7σ and √(S+B)/S ~ 19% at 10 fb$^{-1}$**

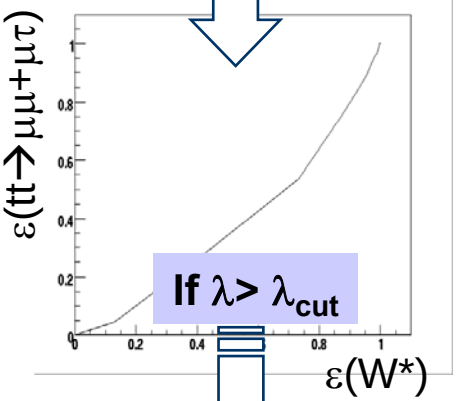
**Stat. and systematics limited**

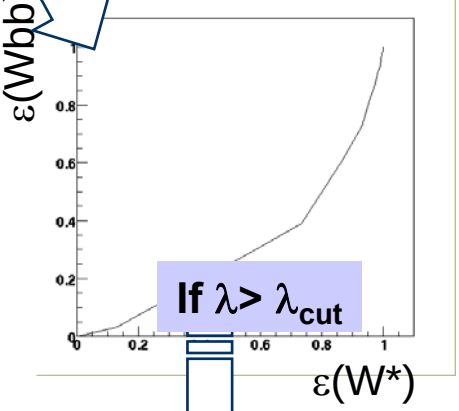
# Methods used for the s- and Wt- channels

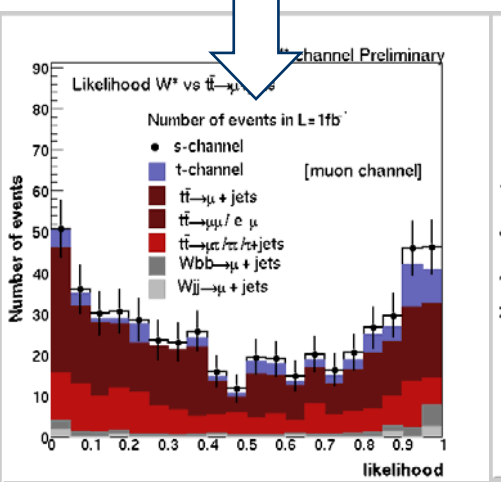
B. clement

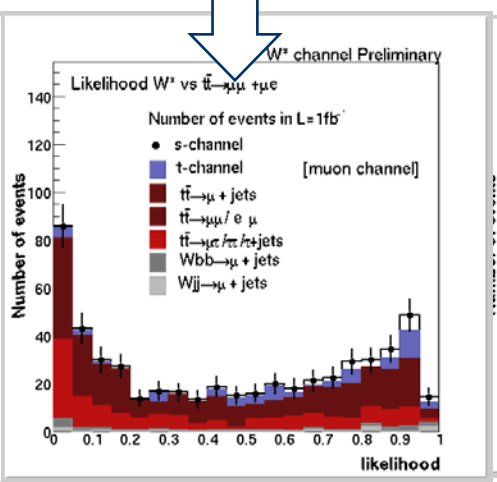


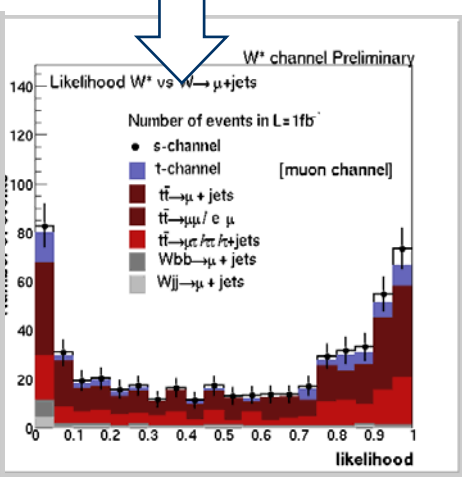



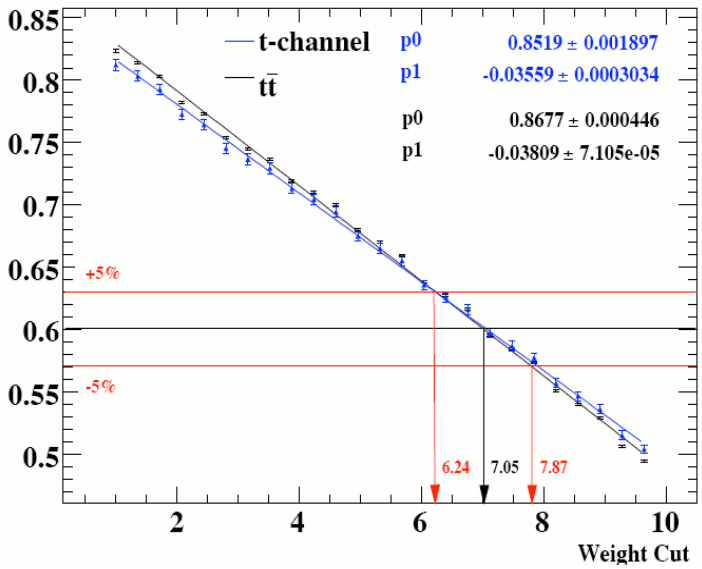



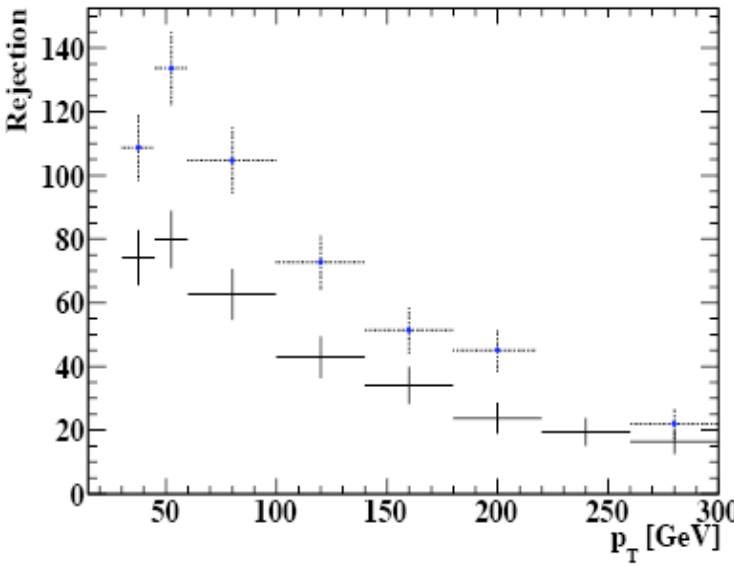
# Systematic uncertainties studies for single-top

## b-tagging performance uncertainties

### Use SV1 and IP2D weight variations :

→ vary b-tag efficiency with corresponding mistag rates




**Expect an effect of : 5% (t-) to 9% (s-channel)**

# Systematic uncertainties studies for single-top

## b-tagging performance uncertainties

Use SV1 and IP2D weight variations :

Vary b-tag efficiency with corresponding mistag rates

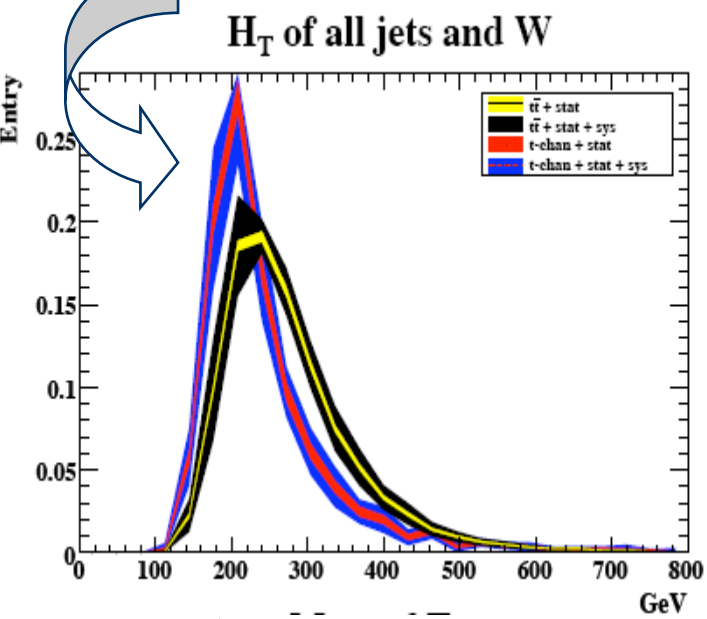
→ Expected effects ~8% (s-chan) and ~5% (t-)

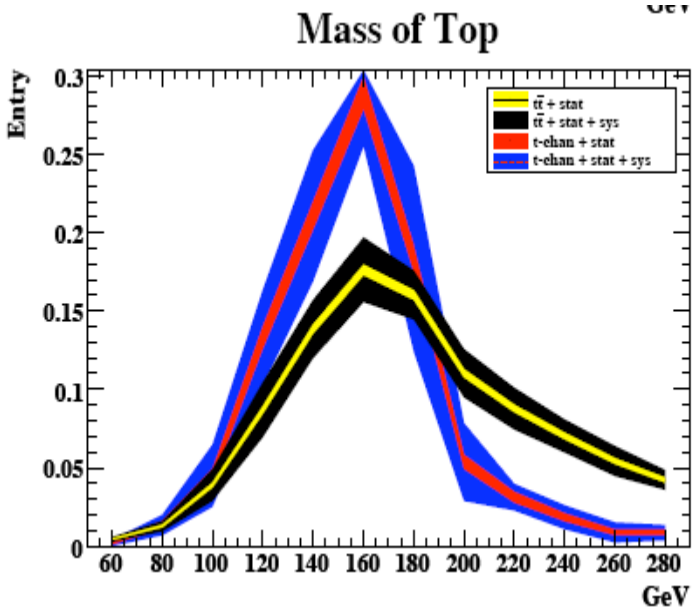
## Jet Energy scale

Produce distributions for +/-10% variation

Compute difference in efficiency (cut-based A.)

Apply MVA to new distributions (trained on 0-bias evts)




Expect an effect of :4-5%

# Systematic uncertainties studies for single-top

## b-tagging performance uncertainties

**Use SV1 and IP2D weight variations :**

→ vary b-tag efficiency with corresponding mistag rates

Vary b-tag efficiency with corresponding mistag rates

→ Expected effects ~8% (s-chan) and ~5% (t-)

## Jet Energy scale

**Produce distributions for +/-10% variation**

Compute difference in efficiency (cut-based A.)

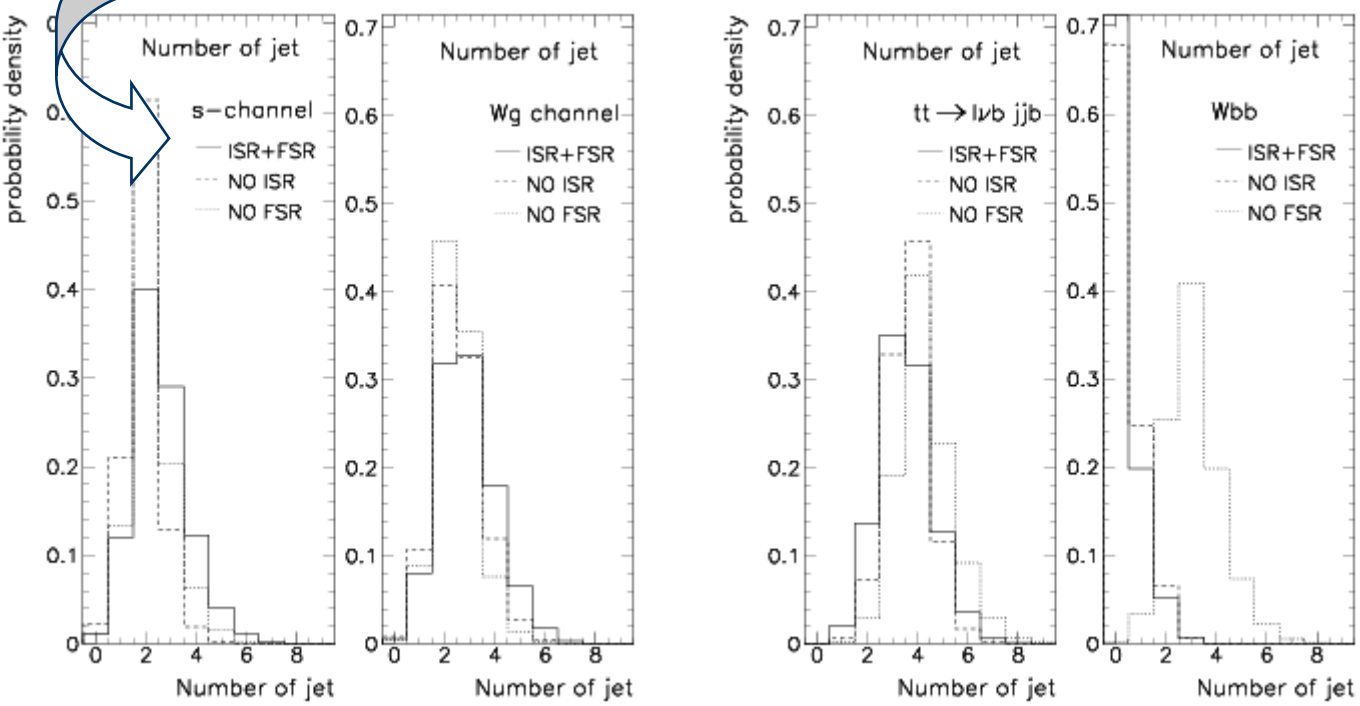
Apply MVA to new distributions (trained on 0-bias evts)

→ Expected effects ~4-5%

## IS/FS Radiation Modeling

**Select low jet multiplicity events**

Very sensitive to gluon radiation modeling



# Systematic uncertainties studies for single-top

## b-tagging performance uncertainties

**Use SV1 and IP2D weight variations :**

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**Produce distributions for +/-10% variation**

Compute difference in efficiency (cut-based A.)

Apply MVA to new distributions (trained on 0-bias evts)

→ Expected effects ~4-5%

## IS/FS Radiation Modeling

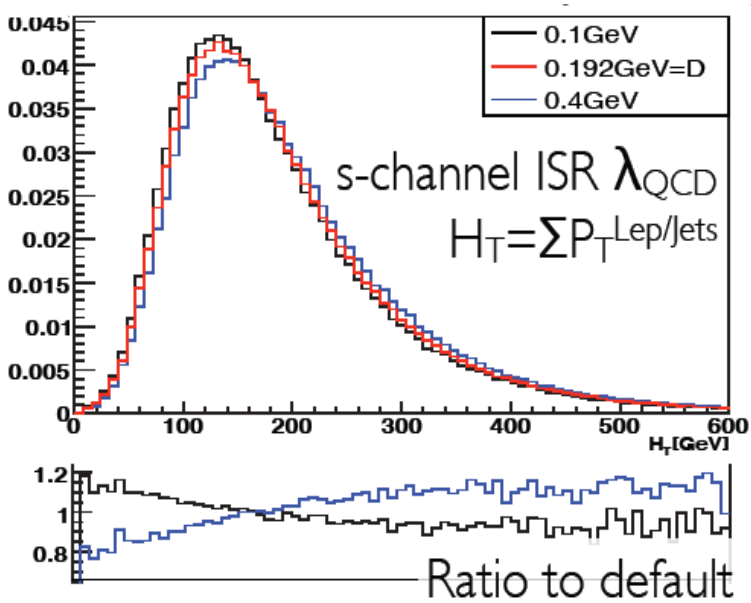
**Select low jet multiplicity events**

Very sensitive to gluon radiation modeling

Now defining samples varying the parameters relevant to ISR/FSR description in PYTHIA

…

**- ISR/FSR MC production undergoing**



# Systematic uncertainties studies for single-top

## b-tagging performance uncertainties

- Use SV1 and IP2D weight variations :
  - → vary b-tag efficiency with corresponding mistag rates
  - Vary b-tag efficiency with corresponding mistag rates
    - → Expected effects ~8% (s-chan) and ~5% (t-)

## Jet Energy scale

- Produce distributions for +/-10% variation
  - Compute difference in efficiency (cut-based A.)
  - Apply MVA to new distributions (trained on 0-bias evts)
    - → Expected effects ~4-5%

## IS/FS Radiation Modeling

- Select low jet multiplicity events
  - Very sensitive to gluon radiation modeling
    - → Under study (Switch ON/OFF ~ $\Delta\sigma/\sigma$~10%!)

## Background Estimates

- W+jets MC production : : $\Delta\sigma/\sigma$ ~ 15-20% ?
  - Studies using AlpGen (rescaled to NLO/MCFM)
- Top pair : $\Delta\sigma_{tt}/\sigma_{tt}$~ 12%
  - Tests AcerMC vs MC@NLO
- ➔ Expected effects of 8-10% on sgtop cross-section
- ➔ Will need to use measurement from data

## Event with plle-up

- Samples being produced

# Conclusion & perspectives

## SingleTop at the LHC

- More than 80k recorded events a year
  - Systematics limited measurements ~ 10-14%
- Cross-section measurements :
  - Should lead to $V_{tb}$ at a few % level
  - Will be sensitive to anomalous couplings, FCNC
  - Will probe models with extra boson W', $H^{\pm}$ (2HDM)

## SingleTop within the CSC framework

- Reconstruction Performance :
  - Object reco perf. Estimated (dependence upon release #)
  - Set of Triggers designed
- Strategies for early data established:
  - Will be early stat+systematics limited measurements
    - → b-tagged jet performance crucial
    - → JES determination
    - → Modeling of backgrounds
  - Cut-based complemented by multiVariate analyses
    - → signal extraction delicate (s- and Wt-)
- Will require important MC important tuning to data:
  - Top pair, the main background
  - W+jets will still be there…

# BACKUP

# RecoPerformance on Single-top : Jets

## Ntuple Versions

v1212 : 1 mm bug

v1213 : bugFixed (AOD)

## Resolution in $p_T$

~8.6%-9.3%

## Reconstruction efficiency

$p_T^{jet} \geq 15$ GeV/c

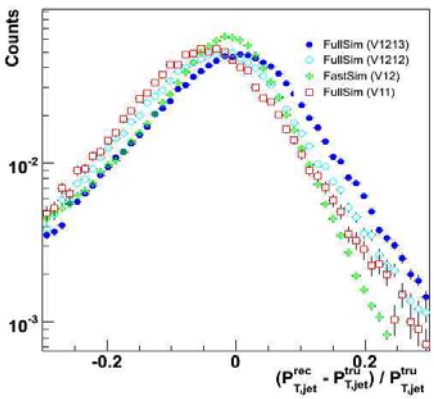
$|\eta^{jet}| \leq 5.0$

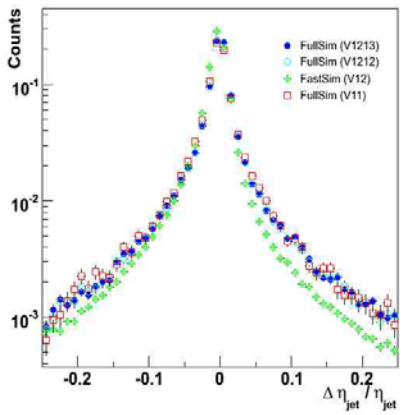
[t channel] : 94.2%

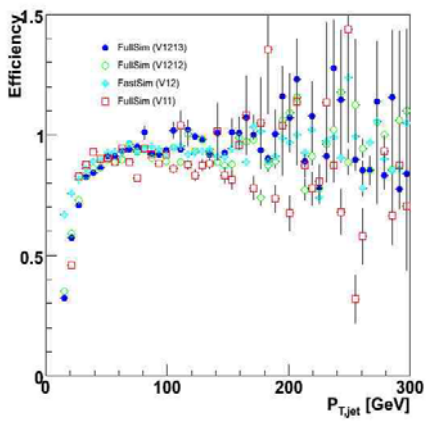
[s channel] : 94.4%

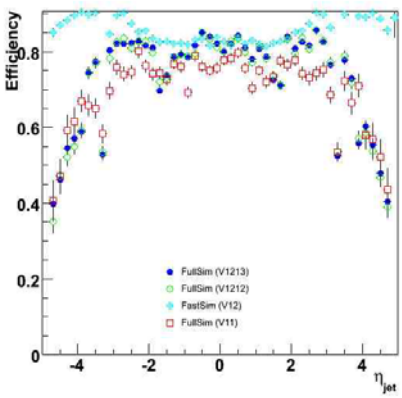
[Wt channel] : 90.4%

[ttbar] : 94.3%




$p_T$ cut=15 GeV/c
DeltaRcutoff=0.3

# Single Top : Event Selection

## Procedure

**(1) Select and tag event**

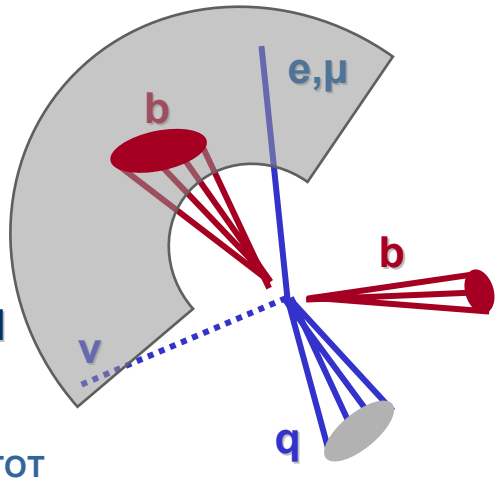
- 1 high-$p_T$ lepton
- high missing Energy
- at least 2 high-$p_T$ jets
- at least 1 high-$p_T$ b-tagged jet

**(2) Discriminate vs non-top background**

- Reconstruct a Top mass $M_{lvb}$
- Use event shape & high $H_T$ or $M_{TOT}$

**(3) Discriminate vs top backgrounds**

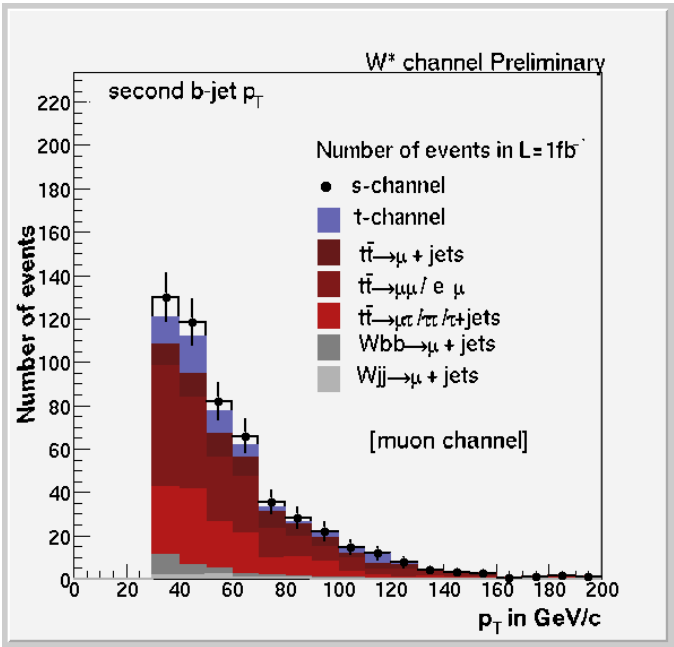
- Number of b-jets
- Event topology

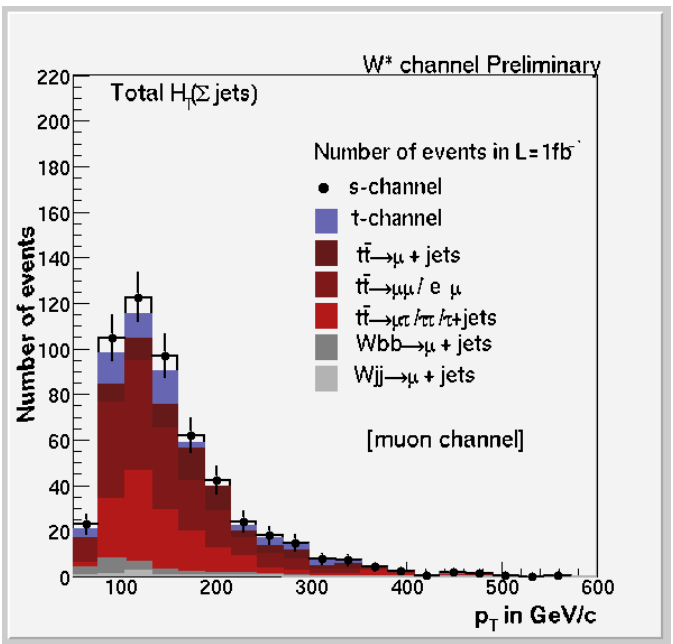


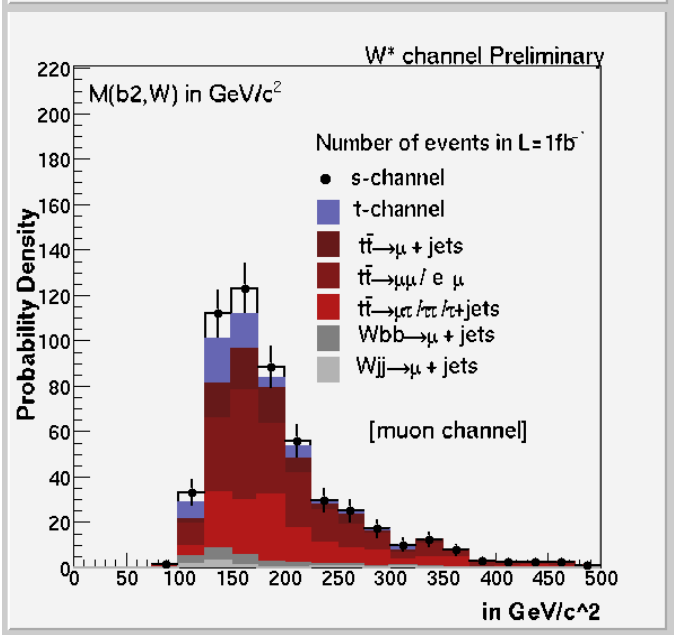

| | σ x BR (pb) |
|---|---|
| Wg →(lν)b qb | 54.2 |
| Wt → (jj) (lν)b | 17.8 |
| W* → (lν)b b | 2.2 |
| W+jets→ lν+jets | 3,850 |
| W+QQ→ lν+QQ | 66.7 |
| WZ →lν+jets | 3.4 |
| WW → lν + jets | 17.1 |
| tt → (lν)b (lν)b | 38.2 |
| tt → (lν)b (jj)b | 242.8 |

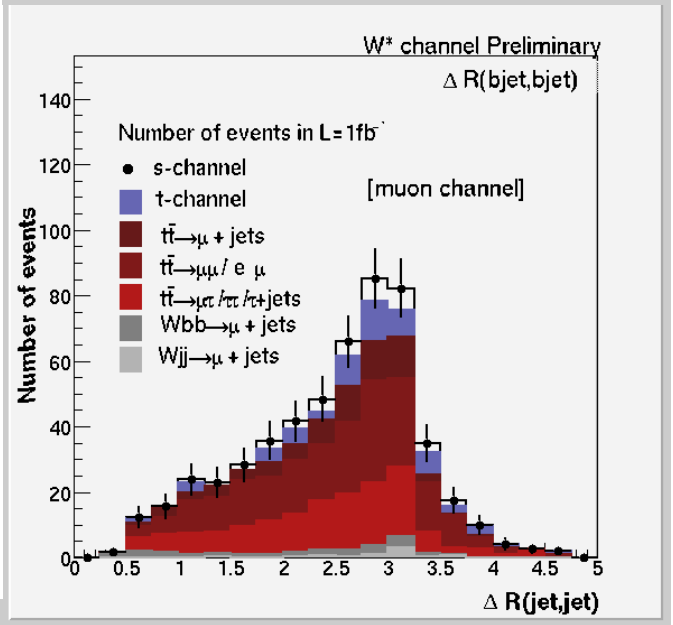
**Main backgrounds :**
**– ttbar : ~ 1/100 , Δtheo~10%**
**– W+jets : ~ 1/2000**

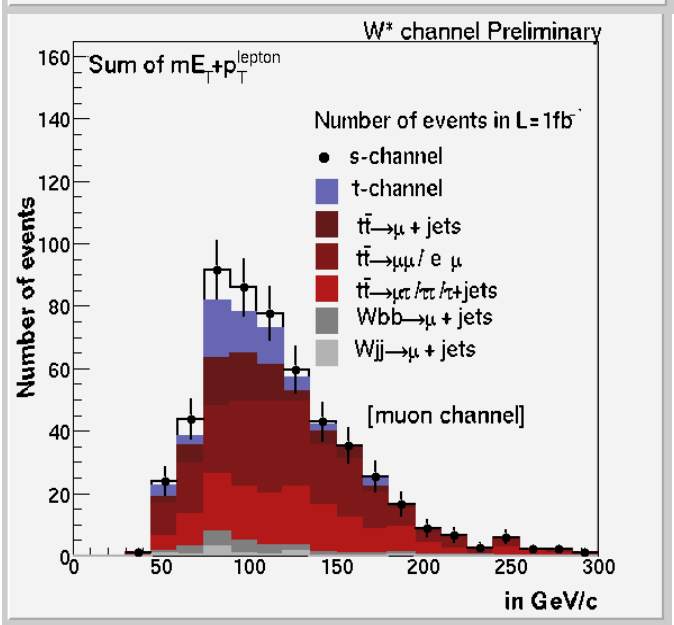
**→ Use of DATA !**

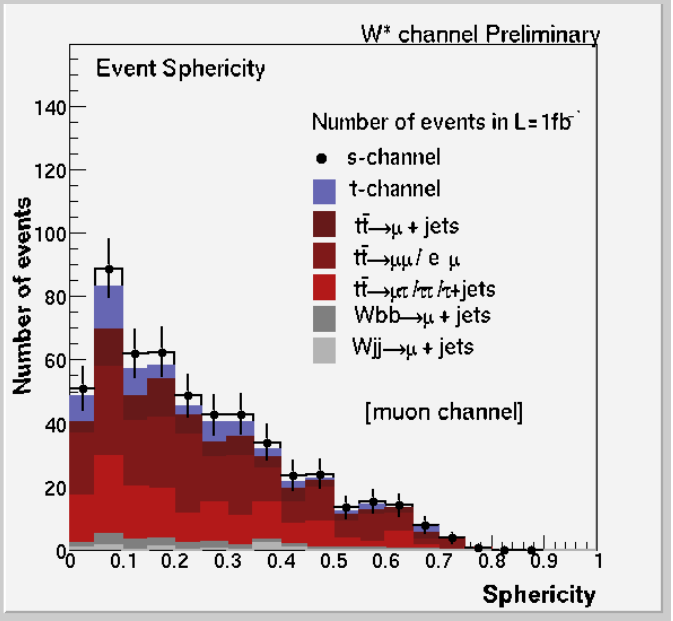

W* channel Preliminary
second b-jet $p_T$
Number of events in L=1fb$^{-1}$
s-channel
t-channel
$t\bar{t}\to\mu$ + jets
$t\bar{t}\to\mu\mu$ / e $\mu$
$t\bar{t}\to\mu\tau$ /$\tau\tau$ /$\tau$+jets
Wbb$\to\mu$ + jets
Wjj$\to\mu$ + jets
[muon channel]
Number of events
$p_T$ in GeV/c


W* channel Preliminary
Total $H_T$(Σ jets)
Number of events in L=1fb$^{-1}$
s-channel
t-channel
$t\bar{t}\to\mu$ + jets
$t\bar{t}\to\mu\mu$ / e $\mu$
$t\bar{t}\to\mu\tau$ /$\tau\tau$ /$\tau$+jets
Wbb$\to\mu$ + jets
Wjj$\to\mu$ + jets
[muon channel]
Number of events
$p_T$ in GeV/c


W* channel Preliminary
M(b2,W) in GeV/c$^2$
Number of events in L=1fb$^{-1}$
s-channel
t-channel
$t\bar{t}\to\mu$ + jets
$t\bar{t}\to\mu\mu$ / e $\mu$
$t\bar{t}\to\mu\tau$ /$\tau\tau$ /$\tau$+jets
Wbb$\to\mu$ + jets
Wjj$\to\mu$ + jets
[muon channel]
Probability Density
in GeV/c^2


W* channel Preliminary
Δ R(bjet,bjet)
Number of events in L=1fb$^{-1}$
s-channel
t-channel
$t\bar{t}\to\mu$ + jets
$t\bar{t}\to\mu\mu$ / e $\mu$
$t\bar{t}\to\mu\tau$ /$\tau\tau$ /$\tau$+jets
Wbb$\to\mu$ + jets
Wjj$\to\mu$ + jets
[muon channel]
Number of events
Δ R(jet,jet)


W* channel Preliminary
Sum of $mE_T$+$p_T^{lepton}$
Number of events in L=1fb$^{-1}$
s-channel
t-channel
$t\bar{t}\to\mu$ + jets
$t\bar{t}\to\mu\mu$ / e $\mu$
$t\bar{t}\to\mu\tau$ /$\tau\tau$ /$\tau$+jets
Wbb$\to\mu$ + jets
Wjj$\to\mu$ + jets
[muon channel]
Number of events
in GeV/c


W* channel Preliminary
Event Sphericity
Number of events in L=1fb$^{-1}$
s-channel
t-channel
$t\bar{t}\to\mu$ + jets
$t\bar{t}\to\mu\mu$ / e $\mu$
$t\bar{t}\to\mu\tau$ /$\tau\tau$ /$\tau$+jets
Wbb$\to\mu$ + jets
Wjj$\to\mu$ + jets
[muon channel]
Number of events
Sphericity

# Uncertainties on PDF's

## PDF Uncertainty estimates

- Affects the cross-section
- May affect also the shapes and efficiency
  - → Assess effects on selection efficiencies / channel
  - → MC production (evgen, FastSim) undergoing for PDF's sets