Prospects for single-top cross-section measurements in ATLAS

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OUTLINE

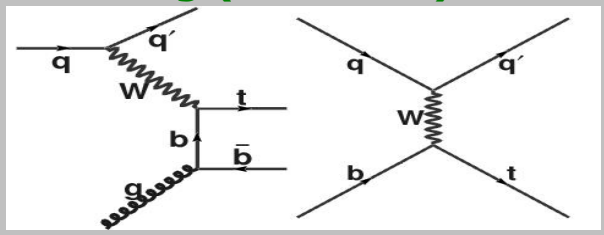
- **Introduction**
  - **Motivation**
  - **Production @ LHC**
- **Single-top Characterization :**
  - **Relevant Variables**
- **Individual Selection**
  - **t-channel & W+t channel (reminder)**
  - **s-channel (**improved**)**
- **Conclusion**

Single Top cross-section : context & motivation

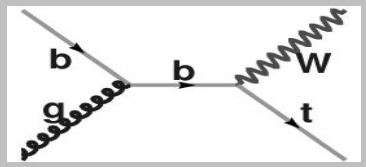
Single-top in the SM

- *3 production mechanisms*

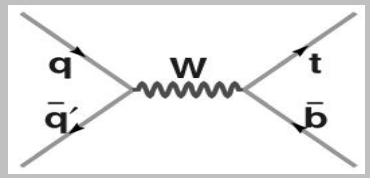
W-g (t-channel)



W+t (Associated)



W* (s-channel)



→ Two of them could be seen at the TeVatron (W*,Wg)

→ All will be measured *precisely* at the LHC

Motivations

- *Properties of the Wtb vertex :*

  Determination of σ(pp→tX), Γ(t→Wb)

  Direct determination of $|V_{tb}|$

  W, Top polarizations

- *Precision measurements → probe to new physics*

  Anomalous couplings, FCNC → t-channel,W+t

  Extra gauge-bosons W' (GUT, KK)

  Extra Higgs boson (2HDM)

  } → s-channel

- *Single-top is one of the main background to …*

  … Higgs physics with jets…

Single Top : Decay modes & backgrounds

Single-Top signal

- *Decay modes:*
  - s-channel (W*) : W* → t b → (lνb) b (l=e, μ)
  - t-channel (Wg) : q'g → tq b → (lνb) q b (l=e, μ)
  - Associated (W+t) : b+g → t W → (lνb) qq' (l=e, μ)

1 lepton + mE_T
+ ≥2 jets
+ 1 (2) b-tags

Main backgrounds

- *Non Top events :*
  - QCD multi-jets (fake l, b…)
  - W+n(jets) → (lν) n(jets)
  - WZ, W+QQ → (lν) QQ
- *Top pair production :*
  - tt → dileptons (l=e, μ)
  - tt → l+jets (l=e, μ)
  - tt → di-taus
  - tt → τ+jets

– NLO cross-sections (W*,Wg)
– Theor. Uncertainty: 4% - 8%
(pdf, μ, Δm_{top})

Channel	σ x BR (pb)
W-g	54.2
W+t	17.8
W*	2.2
ttbar	246
Wbb	66.7
W+jets	3,850

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

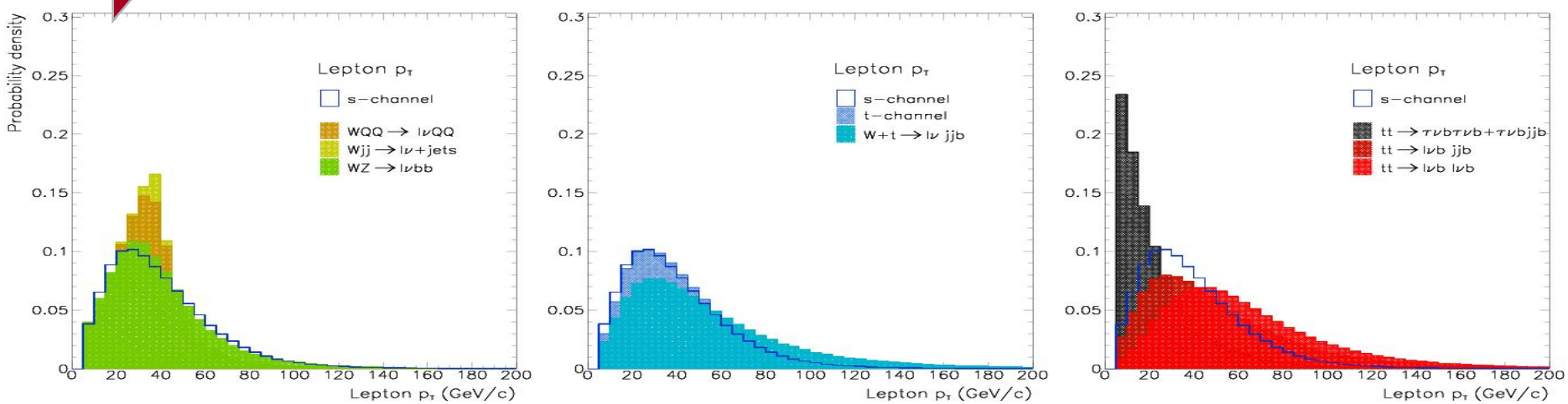
➔ Use of DATA !

Single-top Event Selection

High p_T lepton and mE_T

Lepton

- *Characteristics*
  - Isolated lepton ($\Delta R>0.4$)
  - Acceptance ($|\eta|<2.5$)
  - High-p_T trigger ($p_T>25$ GeV/c)
  - Veto on a secondary high-p_T lepton (>10 GeV/c)



Missing E_T

- *Characteristics*
  - High mE_T

Reproduce trigger & help discriminate against non-W and dilepton events

High p_T lepton and mE_T

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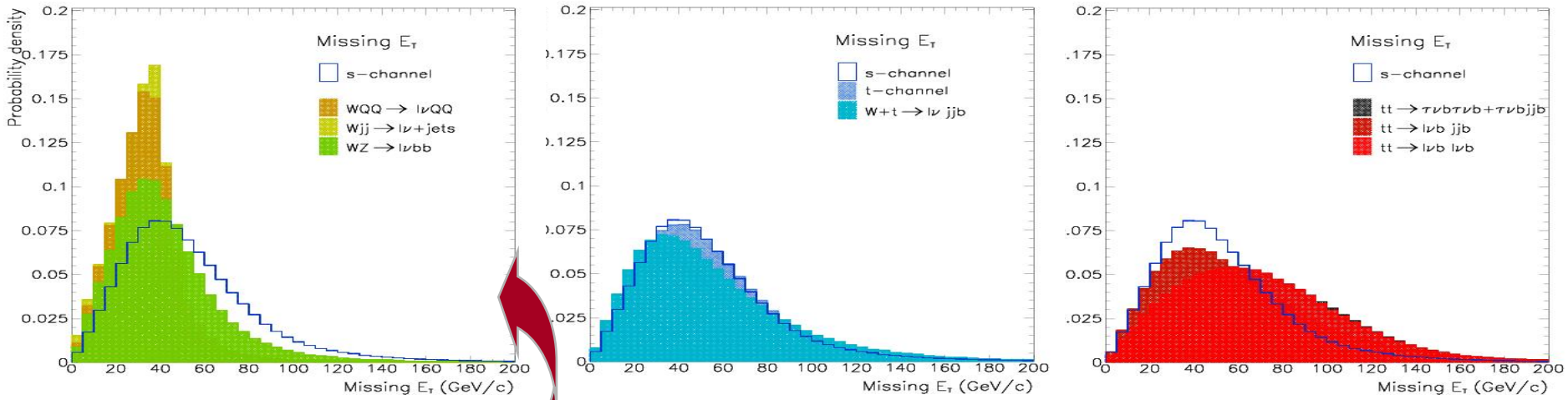


Missing E_T

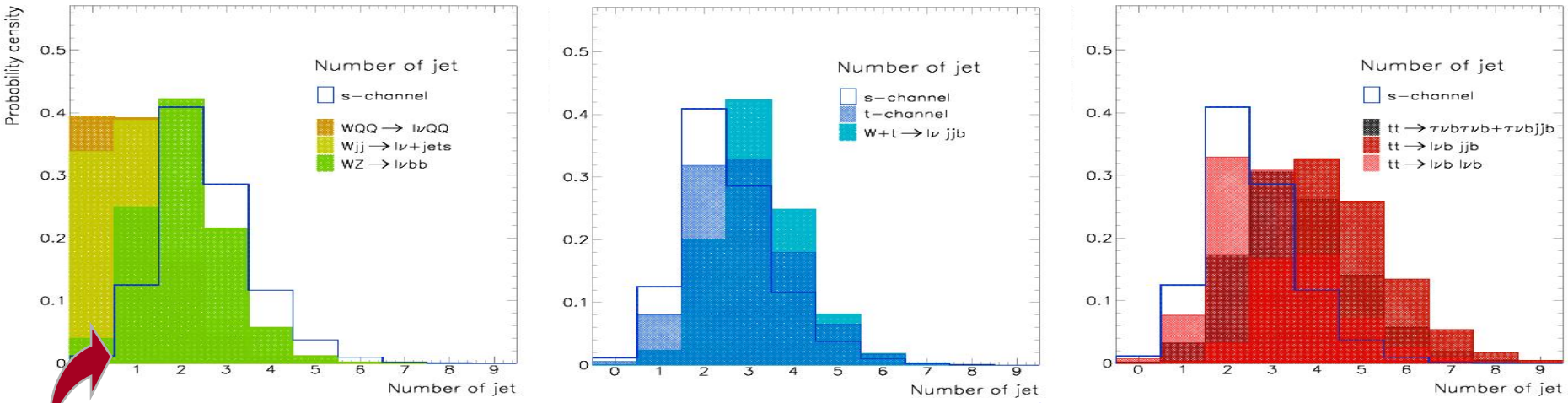
- *Characteristics*
  - High mE_T

Reproduce trigger & help discriminate against non-W and dilepton events

High pT jets and N(jet)

Jet Definition

- *Characteristics*
  - Cone size R = 0.4
  - Acceptance : $|\eta| < 5.0$
  - High-pT jets ($\geq$ 25 GeV/c)
  - Jet energy resolution ($|\eta| < 3$) : $\sigma(E)/E \sim 0.5/\sqrt{E}$ (GeV)
  - Third Jet Veto against tt → as f(pT)



Number of jets :

- *Discriminating power :*
  - N(jet) $\leq$ 3 → reduce ttbar
  - N(jet) $\geq$ 2 will reduce WQQ, Wjets
  - N(jet) = 2 → used for s-channel, t-channel
  - N(jet) = 3 will favor W+t

Multiplicity is a very important criterium
Jet veto is a key issue

High p_T b-tagged jet : p_T

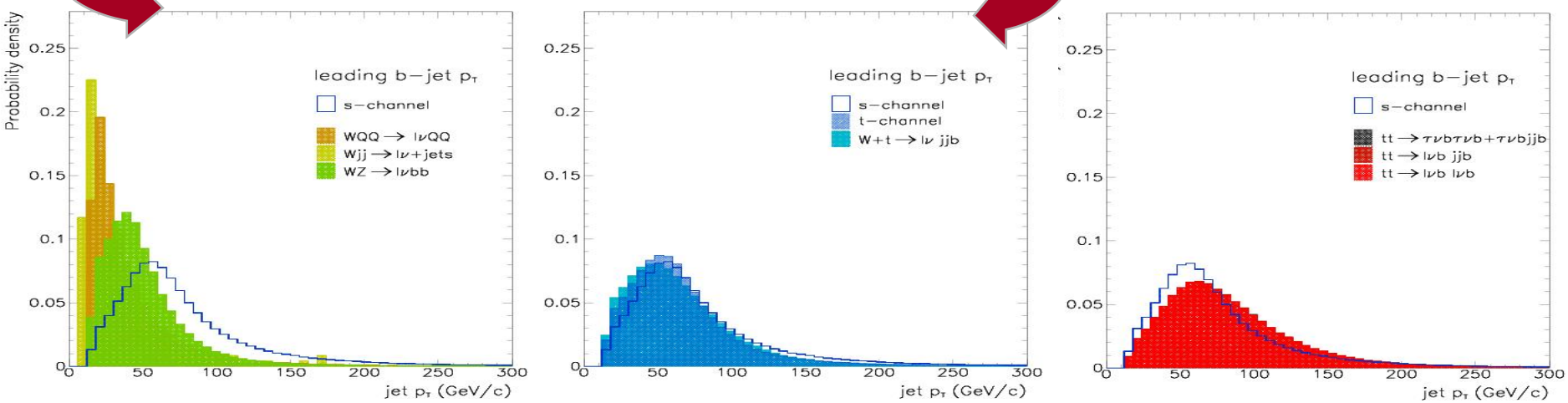
Characteristics

- ***Jet b-tagging***

  Jet Cone ΔR= 0.4

  $|\eta_{b\text{-jet}}| \leq 2.5$

  $p_T > 30$ GeV/c



- ***Discriminating power :***

  Leading b-jet spectra is harder for top events than for WQQ/W+nj events.

High p_T b-tagged jet : N(b-jet)

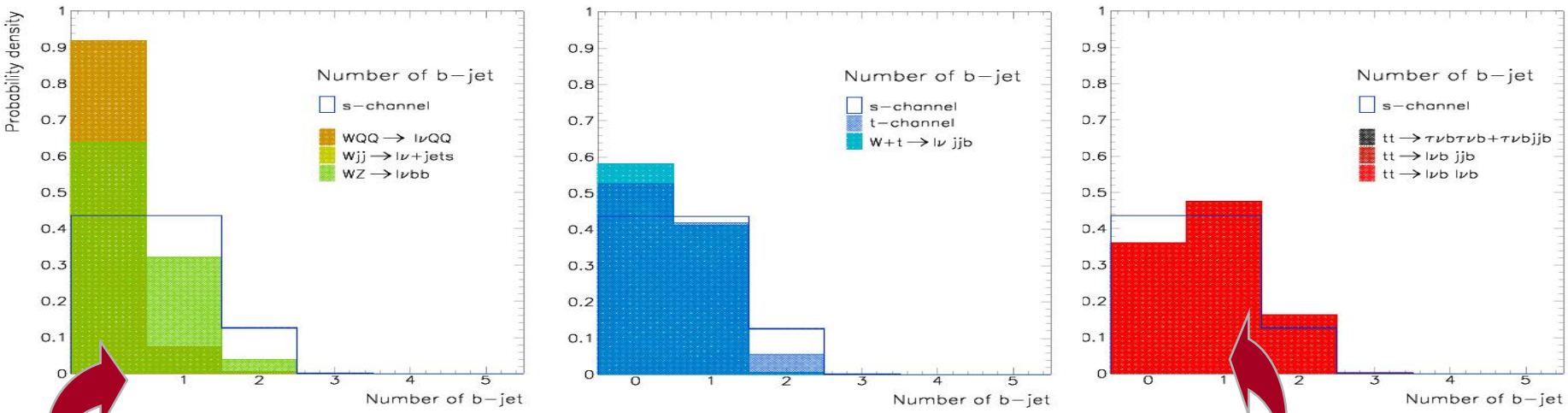
Characteristics

- ***Jet b-tagging :***

  Jet Cone $\Delta R = 0.4$

  $|\eta_{b\text{-jet}}| \leq 2.5$

  $p_T > 30$ GeV/c



- ***Discriminating power :***

  N(b-tag) = 1 exactly for W+t and Wg analyses

  N(b-tag) = 2 exactly for W* analysis

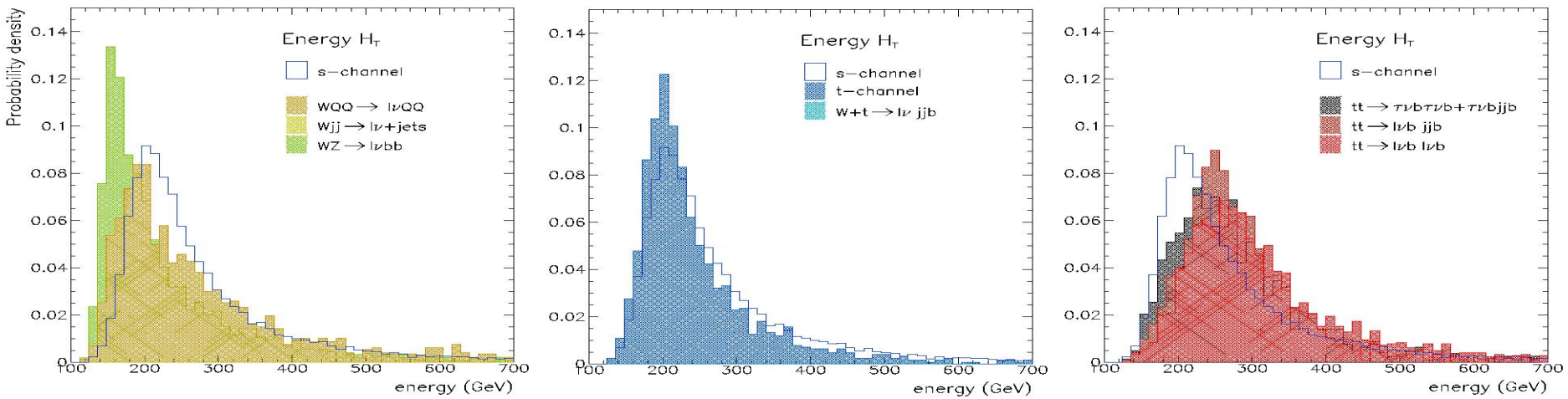
Discriminant Variable : H_T

Characteristics

- ***Sum of all objects E_T in the event***

  $H_T = \Sigma p_T(jet) + p_T(l) + mE_T$

  Note : can also use M_{tot}, P_{tot}..



- ***Discriminating power :***

  WQQ, W+jets : H_T lower than top events

  ttbar events : H_T higher than single-top

Discriminant Variable : $M_{l\nu b}$

Determination of M(lνb)

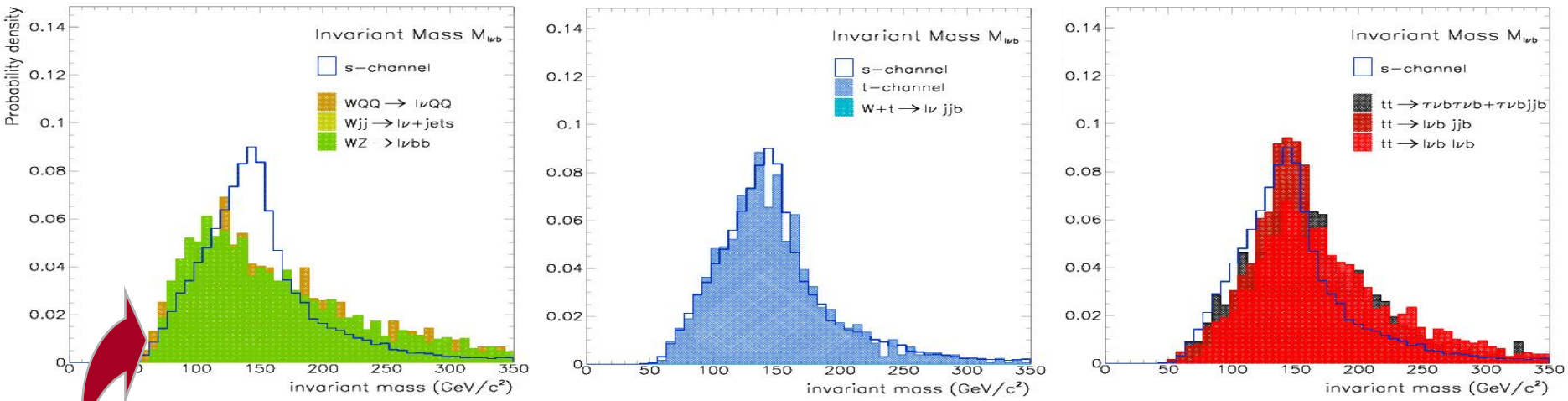
(1) Determination of $p_l(\nu)$

Interpret missing E_T as $p_T(\nu)$

Compute $p_l(\nu)$ using the W-mass constraint

→ $p_l(\nu)$ solutions : 2-fold ambiguity

→ no solution : $M^W_T > M_W$ → use real part for $p_l(\nu)$



(2) Detemination of M(lνb)

Take $p_L(\nu)$ and b-jet giving the highest p_T(top)

Selection :
preliminary results

W-g channel : reminder

Sequential analysis

- *Selection criteria*

  N(jets) = 2

  only 1 high-p_T b-tagged jets (p_T>50GeV/c)
  Wg evts have 1 b-jet escaping the acceptance

  Presence of a high-p_T forward jet
  → 1 jet with $|\eta|>2.5$ and $p_T \geq 50$GeV/c

  Window in H_T and top mass

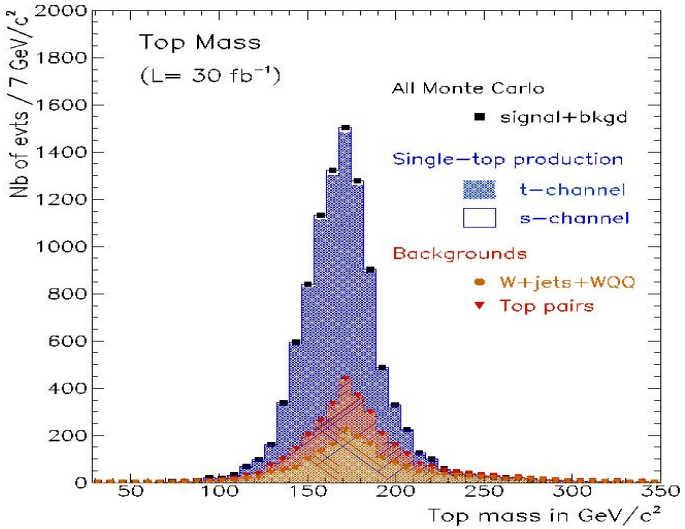
Performance

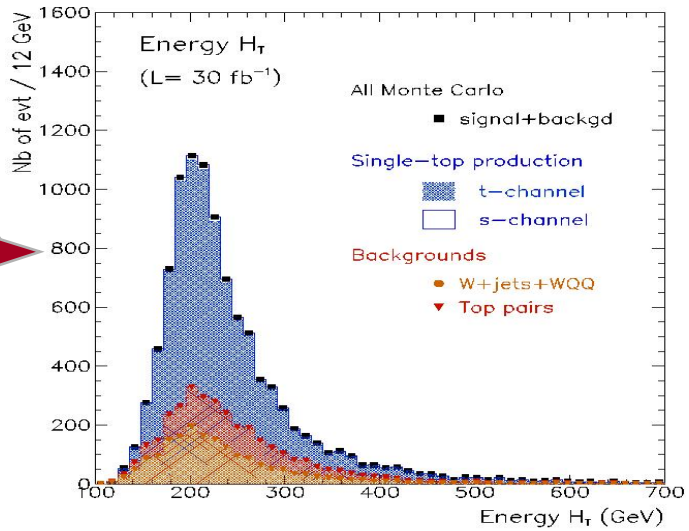
- *Signal efficiency*

  $\varepsilon \sim 0.4$ %

- *Main Backgrounds*

  top pair
  W+jets





30 fb^{-1}

S/B ~ 3
S/√B ~ 140
√(S+B)/S ~ 1.4% (stat)

W+t channel : reminder

Analysis Strategy

- *Selection*

  N(jets) = 3

  Only **one** b-jet in W+t events

  Presence of a W-boson mass peak
  → requires 60 < M(j,j) < 95 GeV/c²

  Reconstruct $M_{l\nu b}$ within ±25 GeV/c²
  Window in H_T

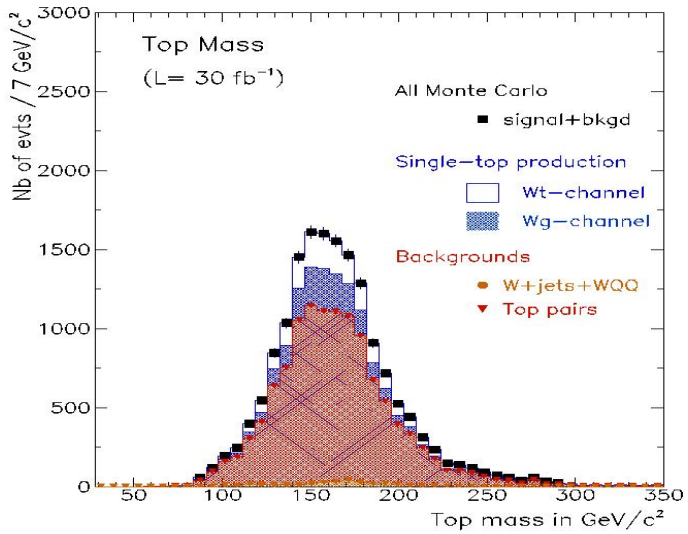
Performance

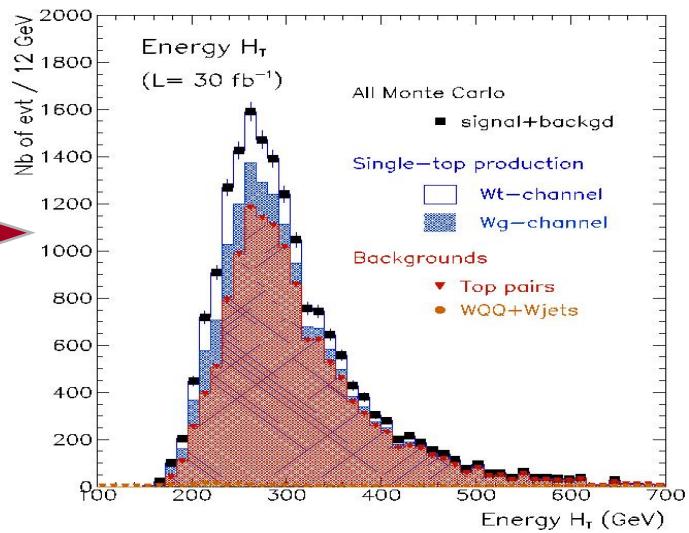
- *Signal efficiency*

  ε ~ 0.9 %

- *Main Backgrounds*

  top pair
  t-channel





30 fb⁻¹

S/B ~ 15%
S/√B ~ 22
√(S+B)/S ~ 4% (stat)

s-channel : strategy

Strategy

- *Selection*
  - N(jets) = 2
  - **exactly** 2 b-tagged jets
  - Window in H_T and top mass
- *Specific selection to reduce top pair*
  - Jet veto (delicate issue – f(pT))
  - Secondary high-pT lepton veto
  - Separate tb and $\bar{t}b$ final states
    - → high-p_T e-/μ- vs e+/μ+

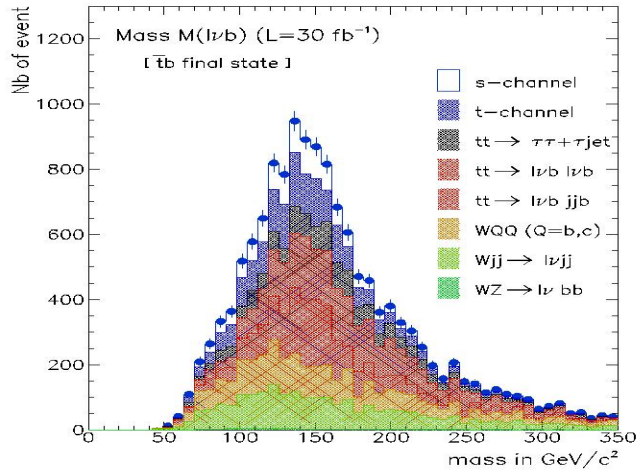
Matt Bowen

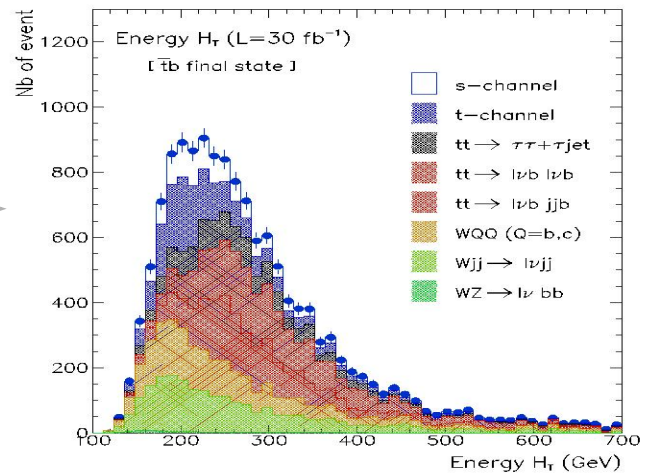
Performance

- *Signal efficiency*
  - ε ~ 2 %
- *Main Backgrounds*
  - top pair
  - t-channel

30 fb^{-1}

S/B ~ 12%
S/√B ~ 15
√(S+B)/S ~ 7% (stat)





Systematic uncertainties

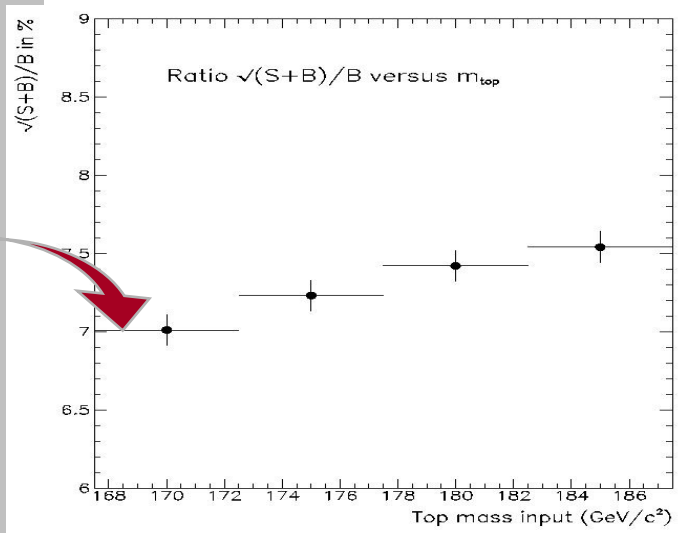
Systematics

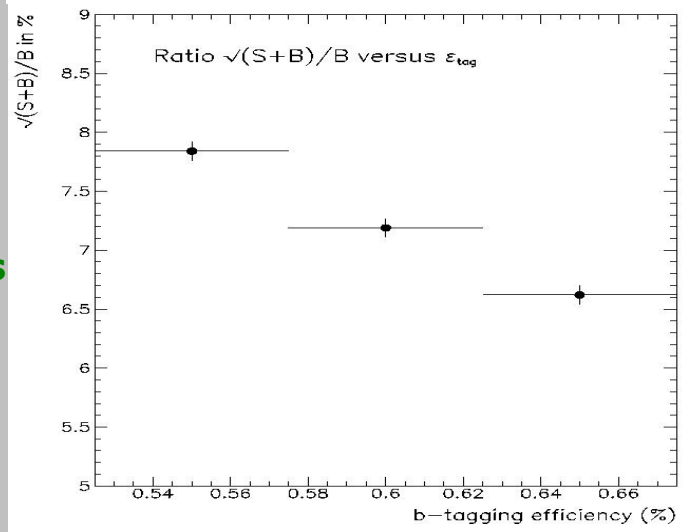
- *Experimental systematics*
  - Light jet & b-jet Energy Scale (p_T, H_T, m_t cuts)
  - Background estimation (normalization, shapes of distributions)
  - b-tagging efficiency & mistag rates
  - Input Top mass (affects selection efficiency)
  - Absolute σ(W*) : luminosity ΔL/L ~ ±5%
    - → Normalization with W→lν production could help

>>> All systematics are being estimated with full simulation

Theoretical uncertainty

- ISR/FSR uncertainty (5/10% on S and ΣB)
- Shape of the distribution of kinematic variables hence P_T,H_T,m_t, …
- M_{top}, μ_F, μ_R, PDF ~ 6-8% of sg-top xsections
- Background cross-sections :
  - $(\Delta\sigma/\sigma)_{tt}$ = 12% (NLO)
  - $(\Delta\sigma/\sigma)_{WQQ}$ = 30% ?
  - $(\Delta\sigma/\sigma)_{Wjets}$ = 50% ?





Use of data is mandatory

Conclusion

Single-top cross-section measurements

- ***Precision measurements are possible @ LHC***
  - **s-channel**
    - **tt , WQQ, W+jets, W+g major backgrounds**
    - **Statistical precision ~ few % with 30 fb^{-1}**
  - **W-g channel**
    - **Higher signal cross-section (cont. by tt & W+jets)**
    - **Expect statistical precision of ~1-2%**
  - **W+t channel**
    - **top pair is the major background**
    - **Expect statistical precision of ~ few %**
- ***All measurements are systematics limited***
  - **Background knowledge is important (need NLO generators)**
  - **Jet Energy Scale (H_T, reconstructed mass, …)**
  - **ISR/FSR uncertainty (nb of jets, jet energy)**
  - **b-tagging efficiency & rejection, mistag knowledge**
  - **➔ ➔ Use of data is mandatory ($t\bar{t}$, WQQ, W+jets)**

Full Simulation vs Fast Simulation

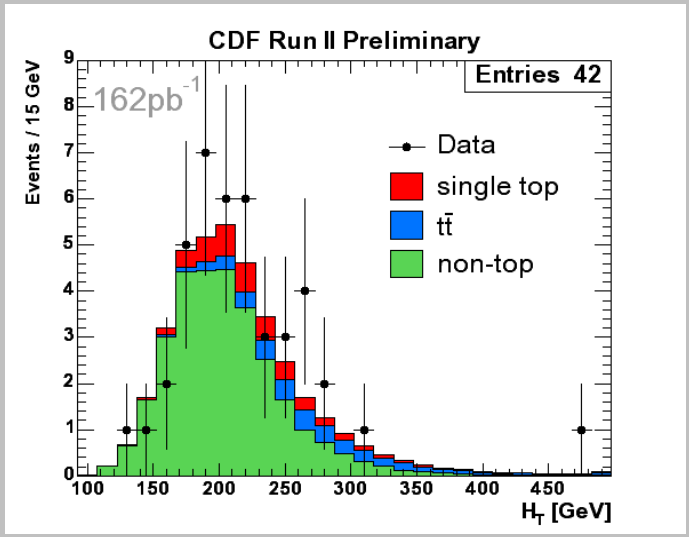
- ***Thorough full simulation study in progress (stat. limited so far)***
- ***First comparisons to fast simulation are promising***
- ***Systematics are being estimated using full simulation***

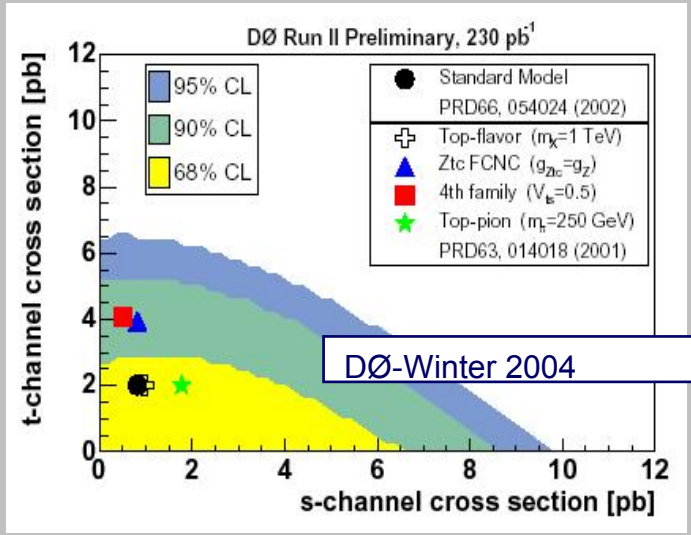
BACKUP SLIDES

Single Top as of Today …

TeVatron

- ***Single-top never seen so far !***
  - **Sensitivity to W-g and W* only**
  - **Low S/B and S/√B : statistically limited**
  - **Main Backgrounds : WQQ , W+jets, and ttbar**





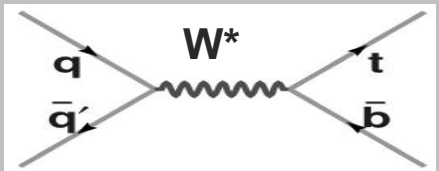
- ***Systematics (DØ)***
  - **Jet E-scale (~8%), b-tag, trigger modeling (~5%)**
  - **Jet fragmentation modeling (5%), Luminosity (~ 6.5%)**
  - **Backgrounds (Uncertainty Wbb,ttb normalization (18%))**
- ***Expectations @ Run II (2- 4 fb^{-1})***

S-channel with 30 fb-1 : Why ?

Charged Higgs and single-top

- *Production mode in 2 HDM*
  - 5 higgs: 3 neutral (A,h,H) + 2 charged ($H^{\pm}$)
  - Mass spectrum predicted
  - Decay modes : depends on $m_{H\pm}$ and tan β

- *tb final state rate can be modified by an extra boson H+*



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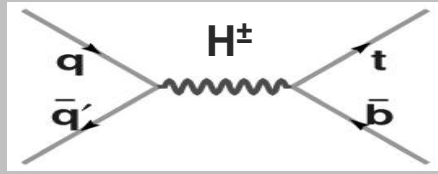
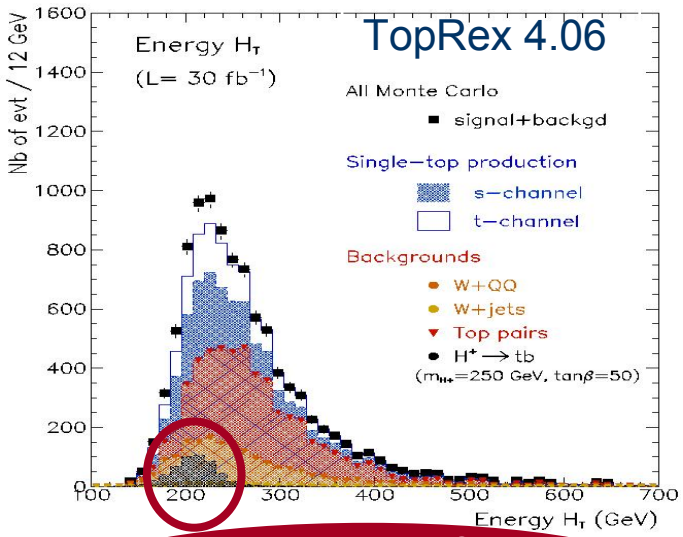
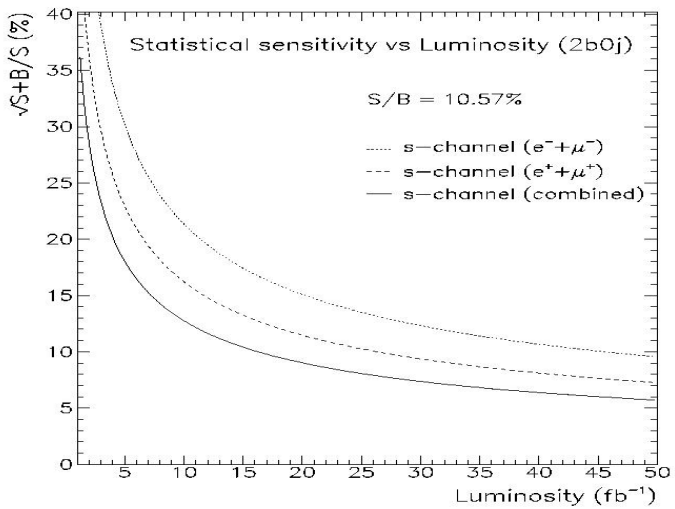


- *Results*
  - Sensitivity on some ($m_{H\pm}$, tan β) regions



$m_{H\pm}$= 250 tanβ=50
N~ 365 ± 10

S/√B~ 4.8 σ



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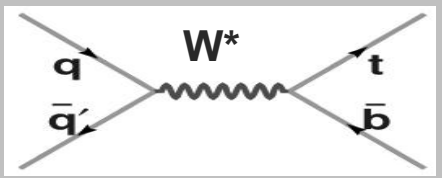

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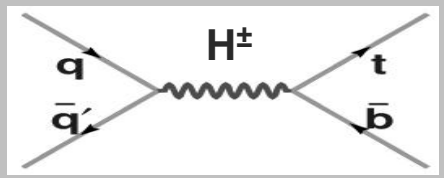

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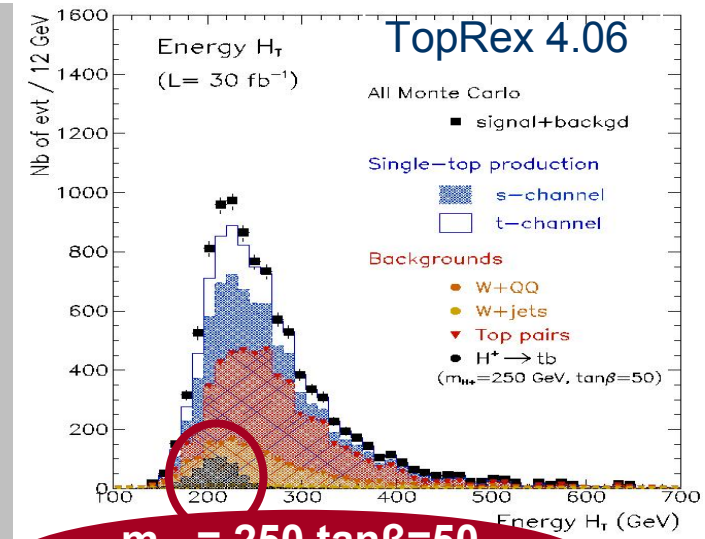

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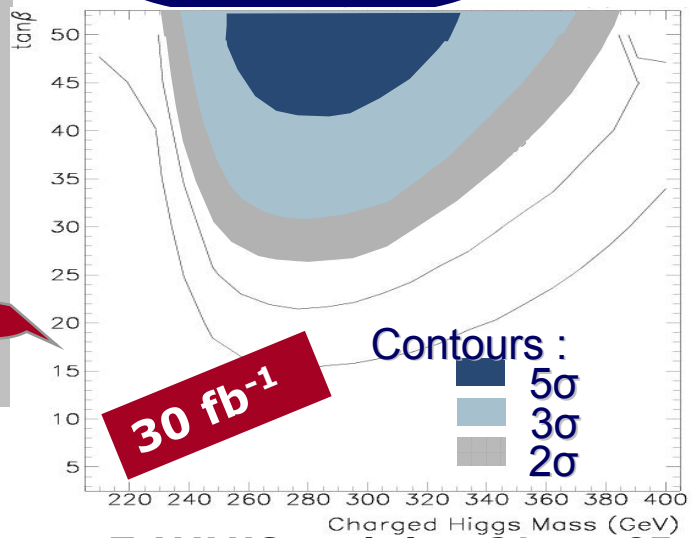
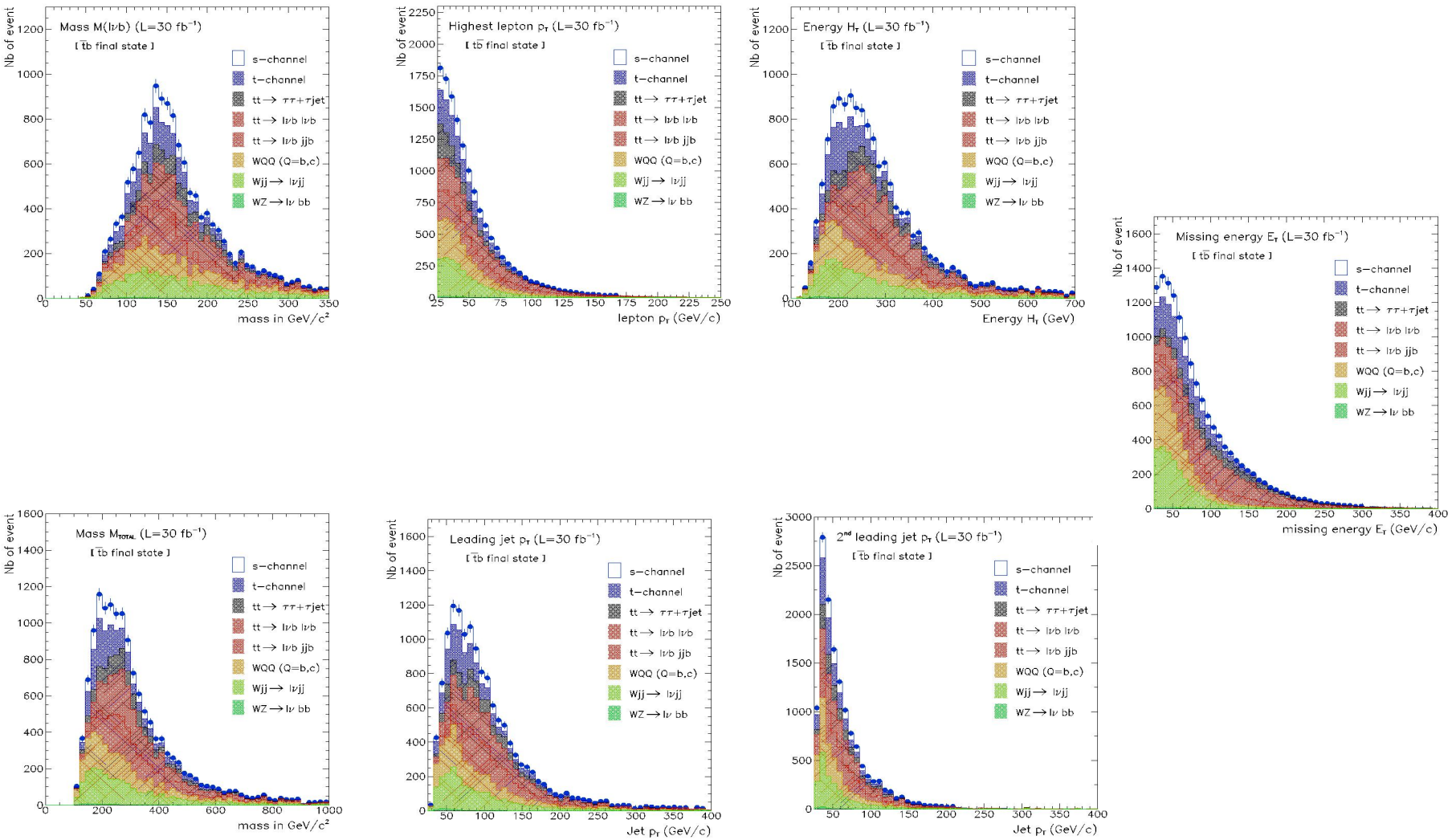


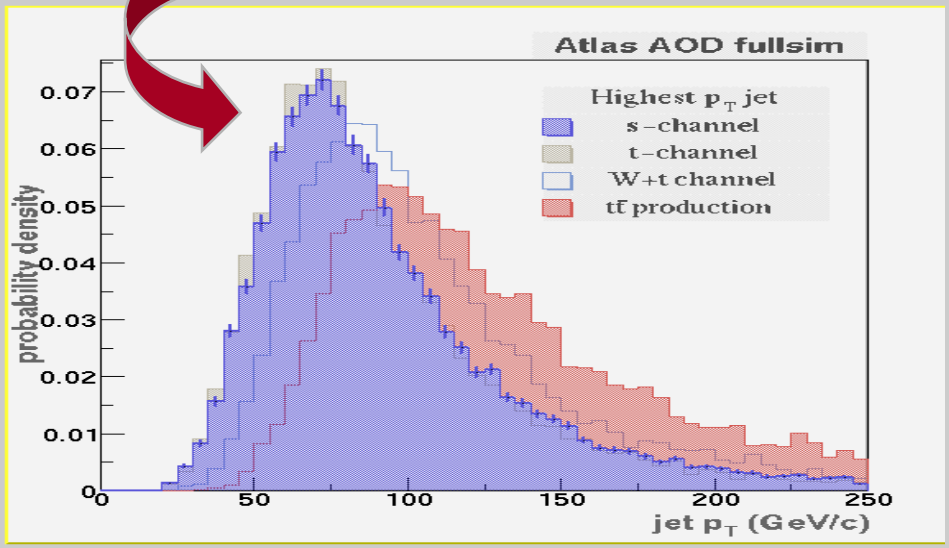
s-channel : checks

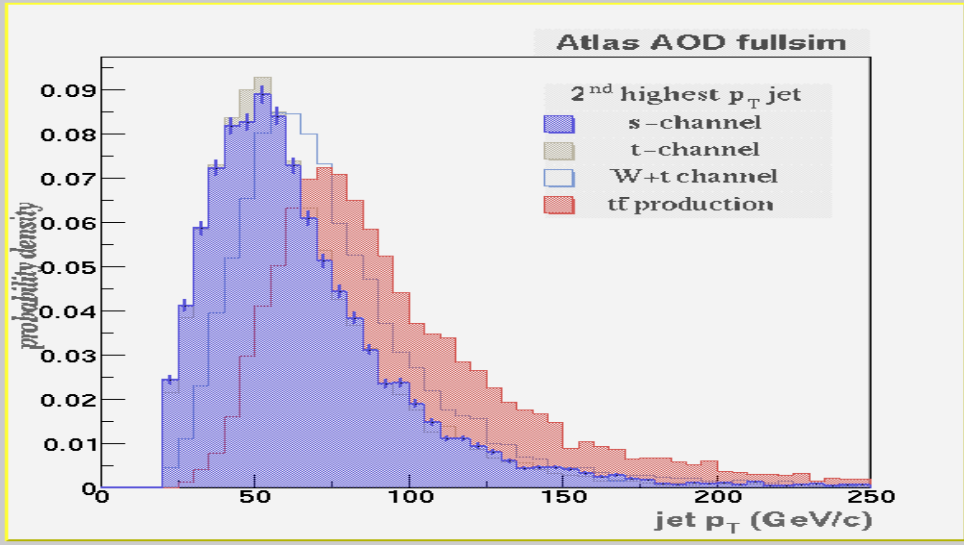


High p_T jets and N(jet)

Jet Definition

- ***Characteristics***
  - **ParticleJetContainer**
  - **Cone R = 0.7**
  - **Acceptance : $|\eta| < 5.0$**
  - **Momentum : p_T(jet) ≥ 25 GeV/c**





- ***FullSim vs AtlFast:***

  Atlfast shows softer spectra (Cone 0.4)
- ***Discriminating power***

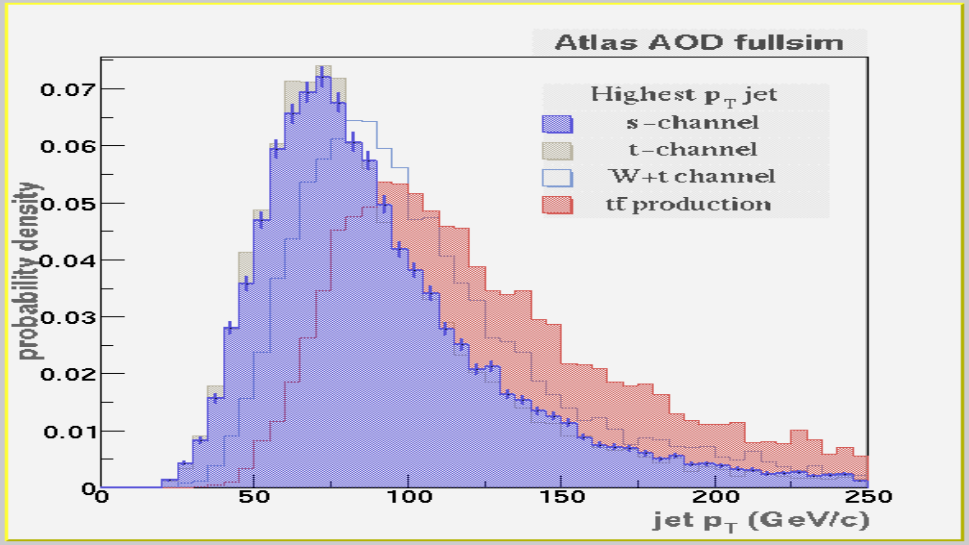
  Top events have harder spectra than W+n(jet), QCD…

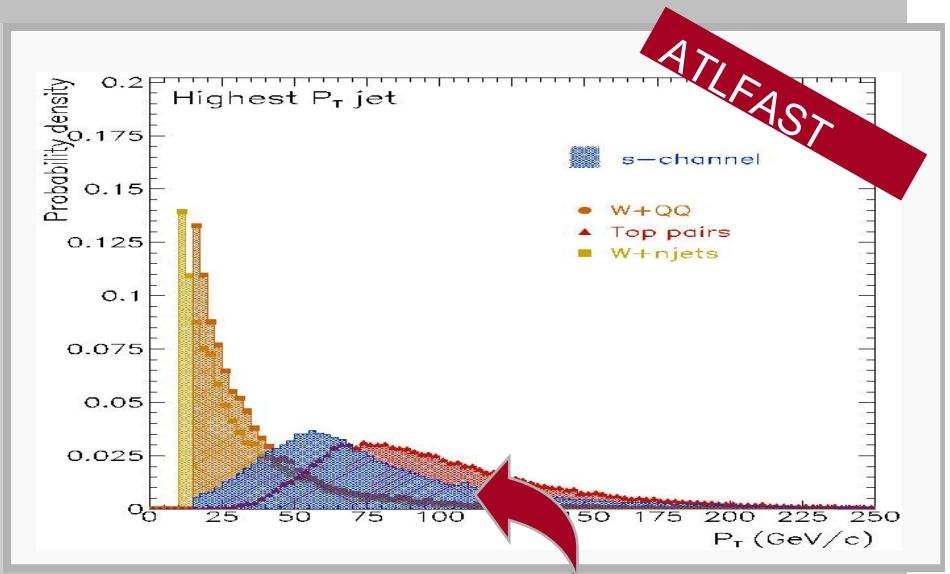
  Third Jet Veto against ttbar → as f(p_T)

High p_T jets and N(jet)

Jet Definition

- ***Characteristics***
  - **ParticleJetContainer**
  - **Cone R = 0.7**
  - **Acceptance : $|\eta| < 5.0$**
  - **Momentum : p_T(jet) ≥ 20 GeV/c**





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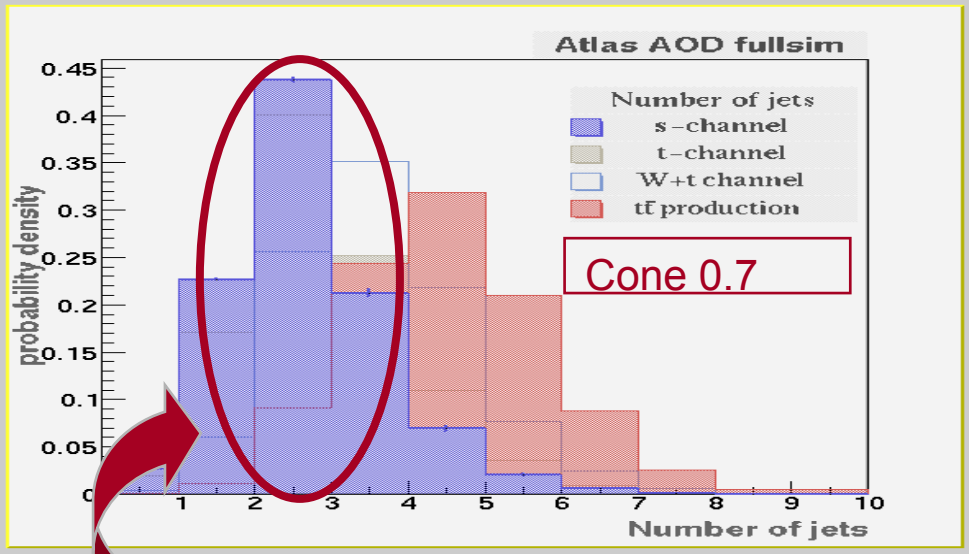
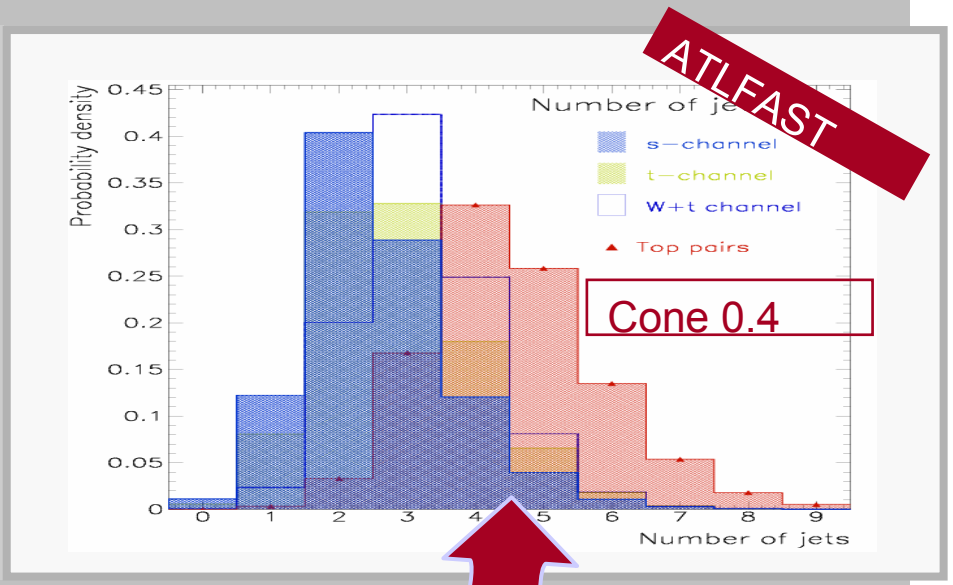
High p_T jets and N(jet)

Jet Definition

- ***Characteristics***
  - **ParticleJetContainer**
  - **Cone ΔR = 0.7**
  - **Acceptance : |η| < 5.0**
  - **Momentum : p_T(jet) ≥ 15 GeV/c**





- ***Number of jets :***

  N(jet) = 2 → used for s-channel, t-channel

  N(jet) ≤ 3 → reduce ttbar

  Reasonable agreement with AtlFast (Cone 0.4…)

High p_T b-tagged jet : p_T

Characteristics

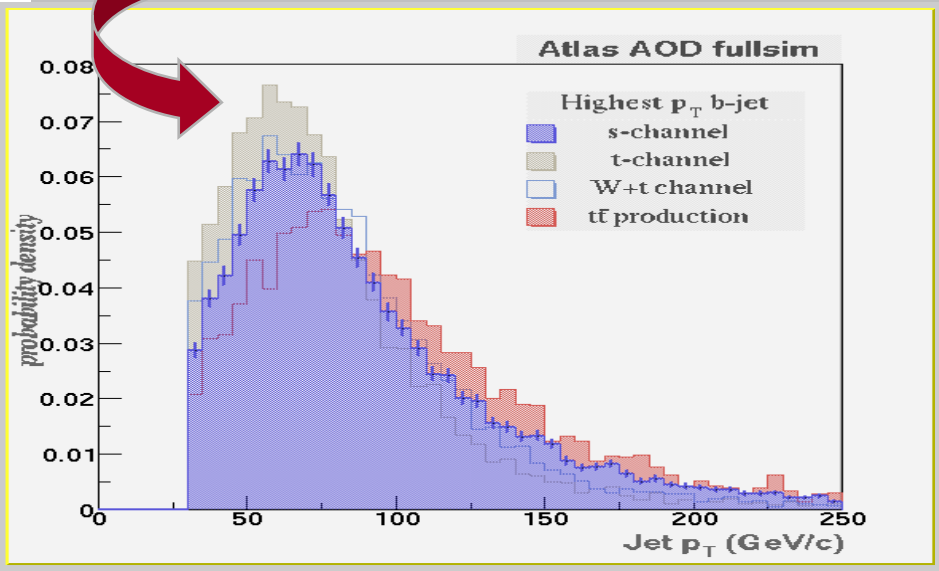
- *Jet b-tagging*

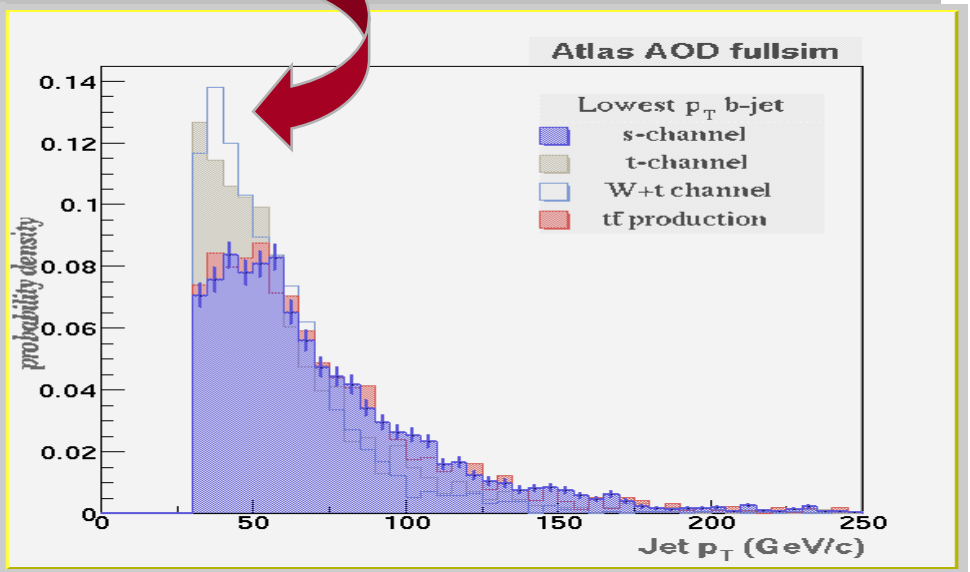
  Jet Cone ΔR= 0.7

  $|\eta_{b\text{-jet}}| \leq 2.5$

  Likelihood L > 0.9

  p_T > 30 GeV/c





- *Discriminating power :*

  N(b-tag) = 1 exactly for W+t analysis

  N(b-tag) = 2 exactly for W* analysis FullSim vs Atlfast :

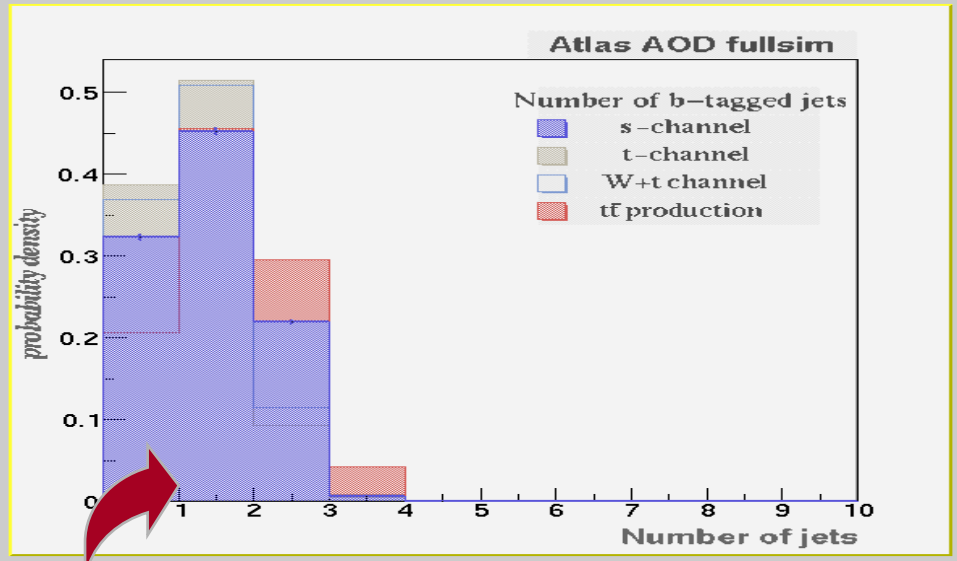
- *FullSim vs Atlfast :*

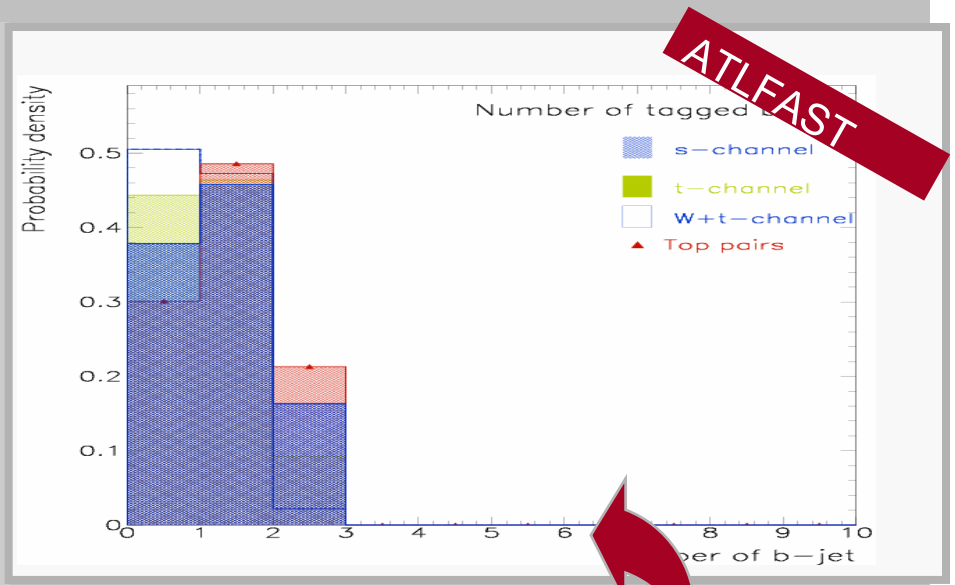
  Consistent results (cone 0.7 in FullSim…)

High p_T b-tagged jet : N(b-jet)

Characteristics

- *Jet b-tagging :*
  - Jet Cone ΔR= 0.7
  - $|\eta_{b\text{-jet}}| \leq 2.5$
  - Likelihood L > 0.9
  - p_T > 30 GeV/c





- *Discriminating power :*
  - N(b-tag) = 1 exactly for W+t analysis
  - N(b-tag) = 2 exactly for W* analysis
- *FullSim vs Atlfast :*
  - Consistent results (cone 0.7 in FullSim, cone 0.4 AtlF.)

High p_T b-tagged jet : efficiency

Definition

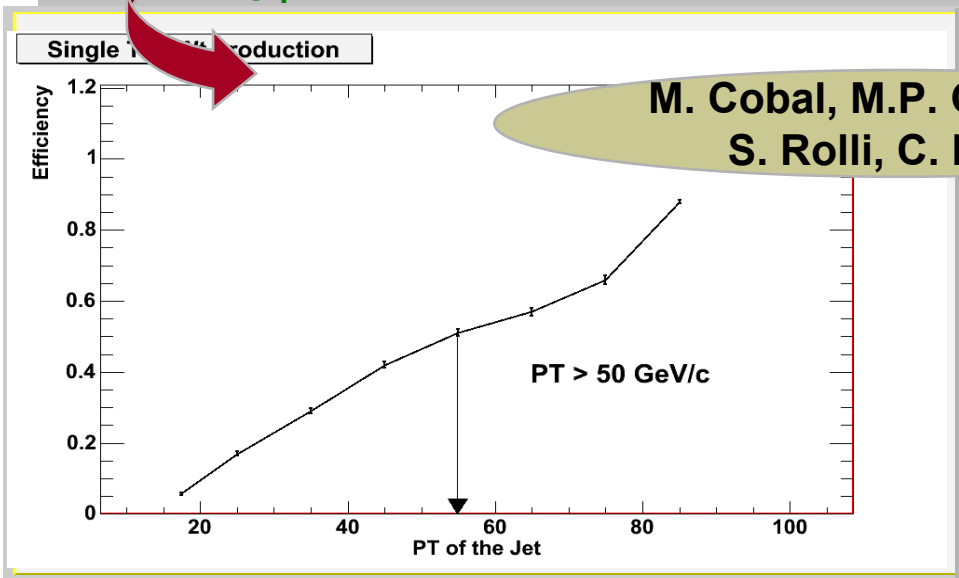
- ***Jet b-tagging :***

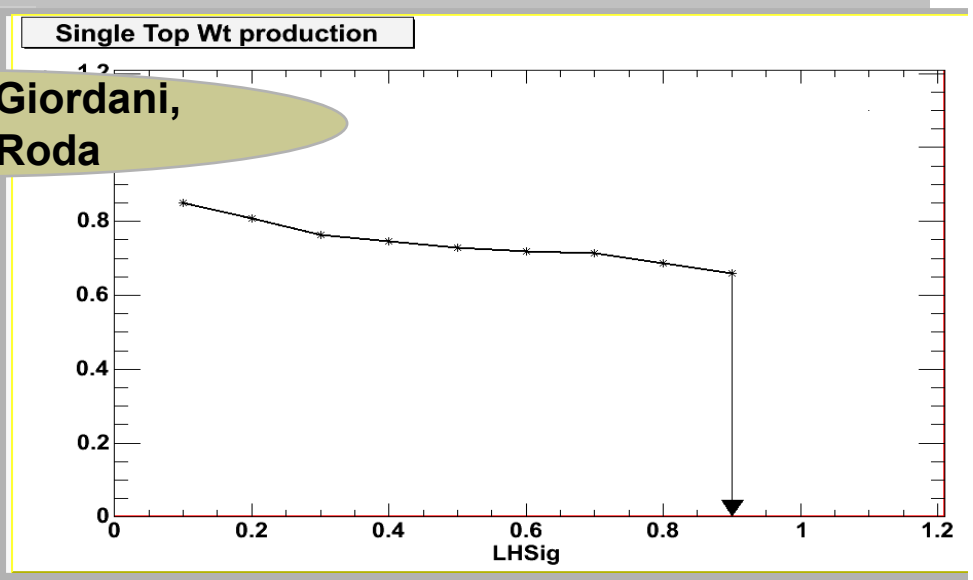
  Jet Cone ΔR= 0.7

  $|\eta_{b\text{-jet}}| \leq 2.5$

  Likelihood L > 0.9

  p_T > 30 GeV/c





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- ***Discriminating power :***

  N(b-tag) = 1 exactly for W+t analysis

  N(b-tag) = 2 exactly for W* analysis

- ***FullSim vs Atlfast :***

  Consistent results (cone 0.7 in FullSim, cone 0.4 AtlF.)

Discriminant Variable : H_T

Characteristics

- ***Sum of all objects E_T in the event***

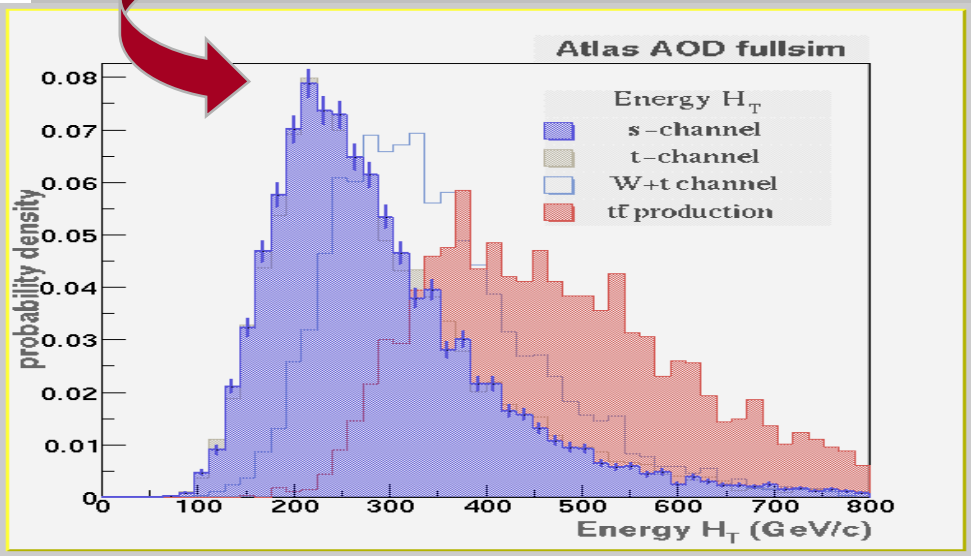
  $H_T = \Sigma p_T(jet) + p_T(l) + mE_T$ or $P_T = \Sigma p_T(jet)$

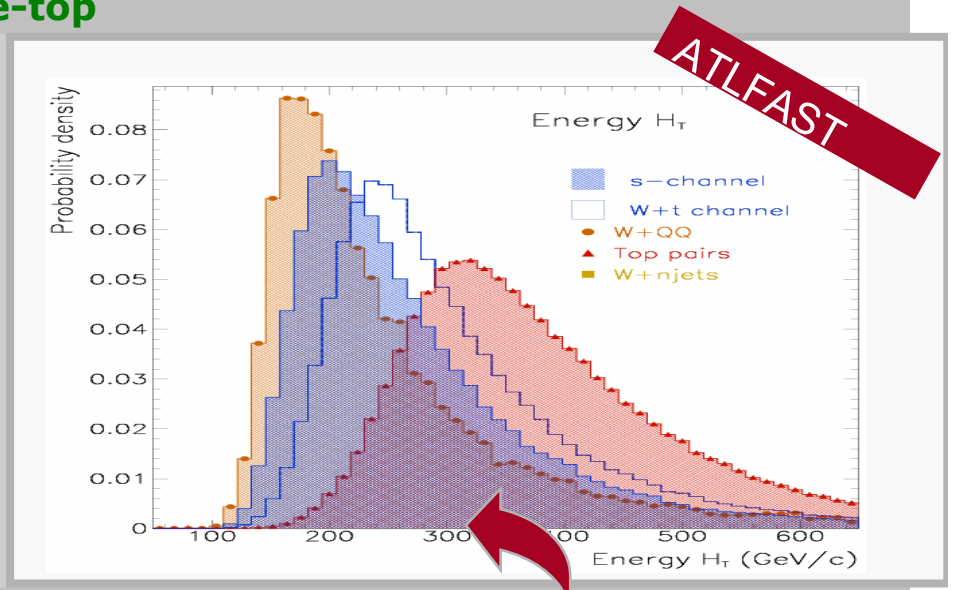
  Note : can also use M_{tot}, P_{tot}..

- ***Discriminating power :***

  WQQ, W+jets : H_T lower than top events

  ttbar events : H_T higher than single-top





- ***FullSim vs AtlFast :***

  Reasonable agreement for all samples

  (smaller dependence in cone algorithms)

Discriminant Variable : $M_{l\nu b}$

Determination of M(lνb)

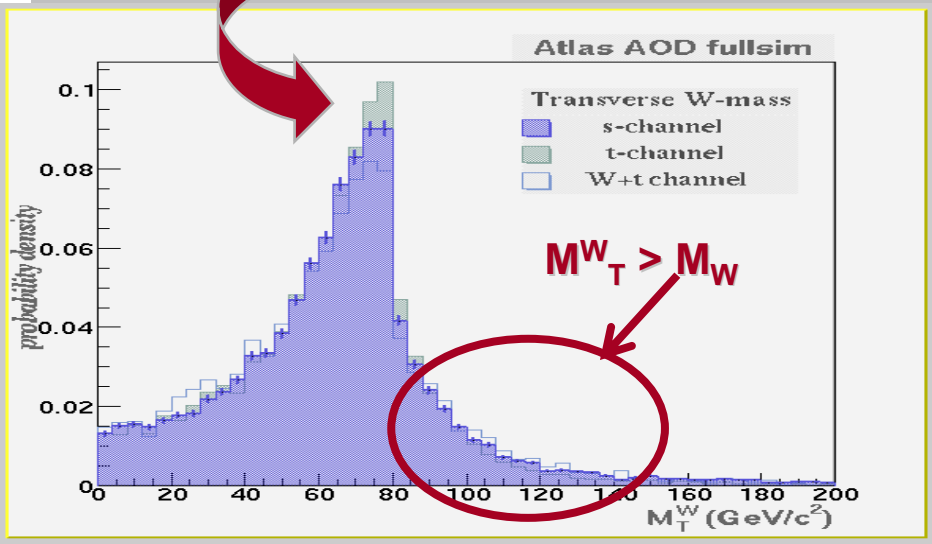
(1) Determination of $p_l(\nu)$

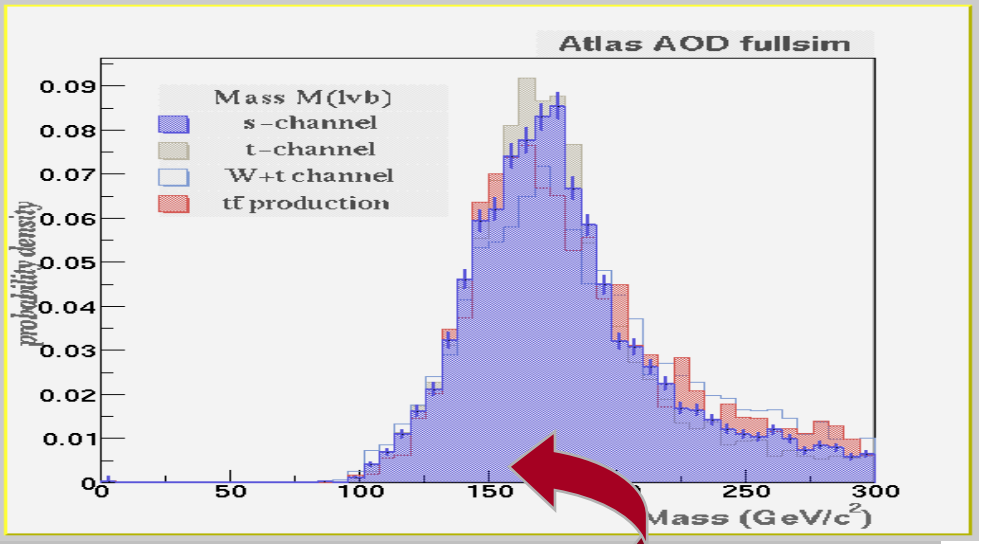
Interpret missing E_T as $p_T(\nu)$

Compute $p_l(\nu)$ using the W-mass constraint

→ $p_l(\nu)$ solutions : 2-fold ambiguity

→ no solution : $M^W_T > M_W$ → use real part for $p_l(\nu)$





(2) Detemination of M(lνb)

Take $p_L(\nu)$ and b-jets giving the closest value to m_{top}
Reasonable agreement with Atlfast

Discriminant Variable : $M_{l\nu b}$

Determination of M(lνb)

(1) Determination of $p_l(\nu)$

Interpret missing E_T as $p_T(\nu)$

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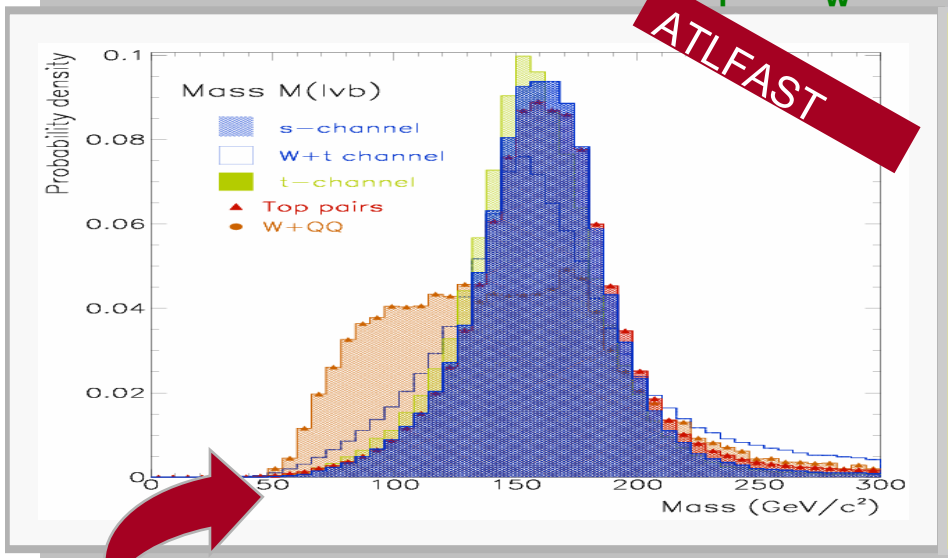
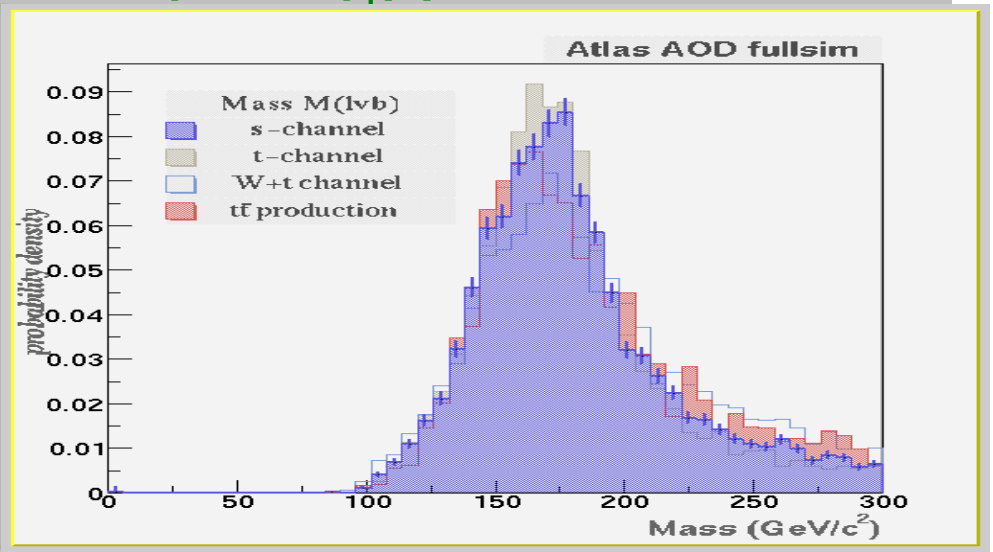




(2) Detemination of M(lνb)

Take $p_L(\nu)$ and b-jet giving the closest value to m_{top}

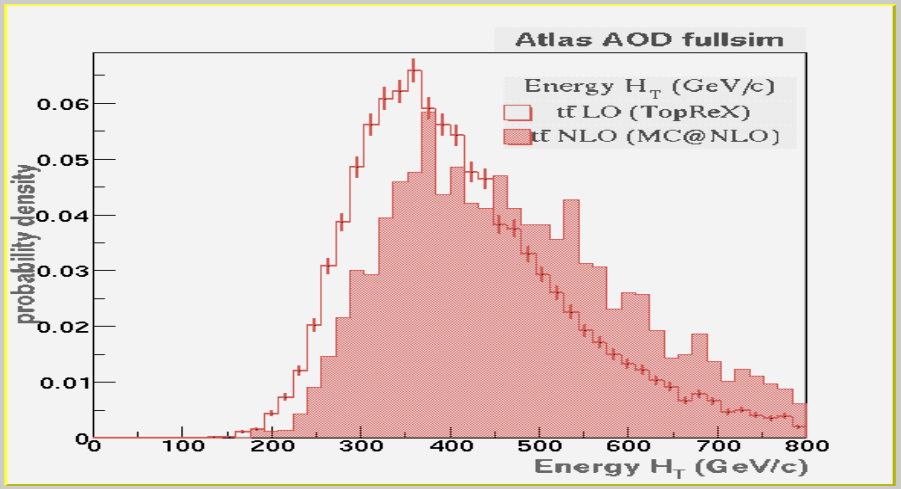
Reasonable agreement with Atlfast

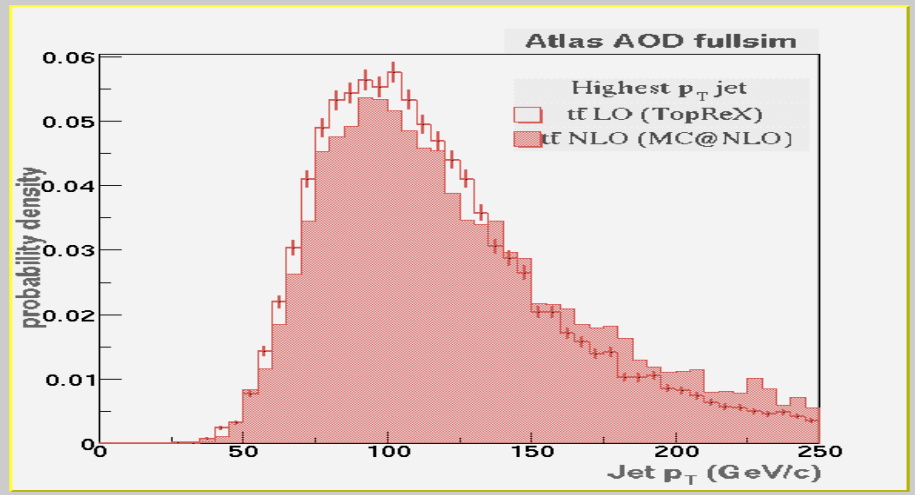
Single Top cross-section : Influence of NLO/LO corrections

Signal and Background

- *Computation @ NLO available for W* and W-g :*

  Affect p_T(jet) distribution, H_T etc…





S-channel : 3rd jet Veto

Sequential analysis

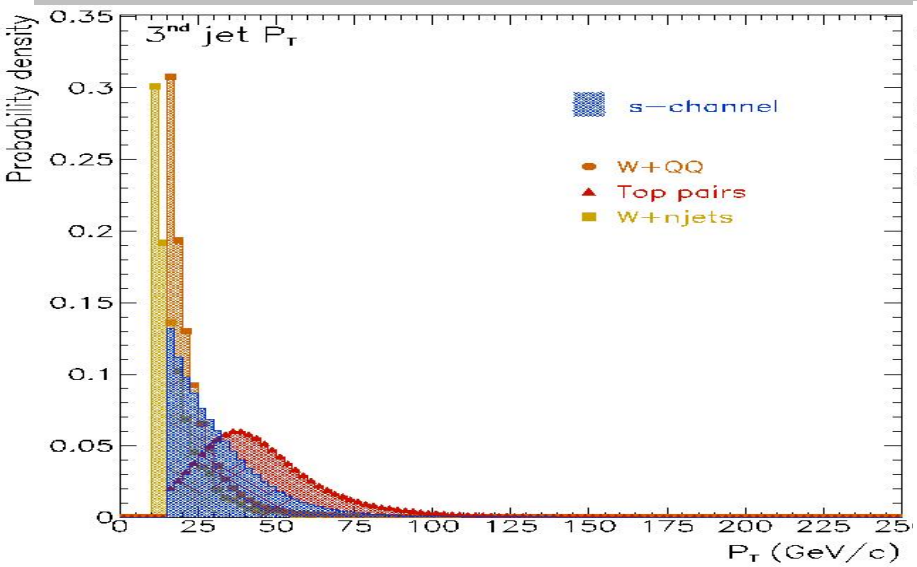
- ***Selection criteria***

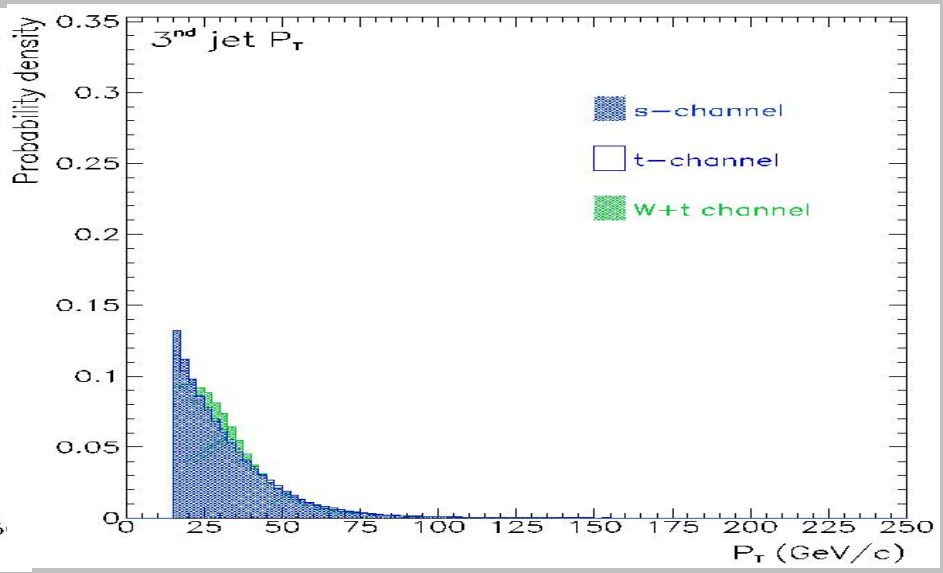
  Number of jets : N(jet) = 2

  Presence of two high p_T jets

  Presence of two central, high-p_T b-tagged jets

  → Wg usually have 1 b-jet escaping the acceptance





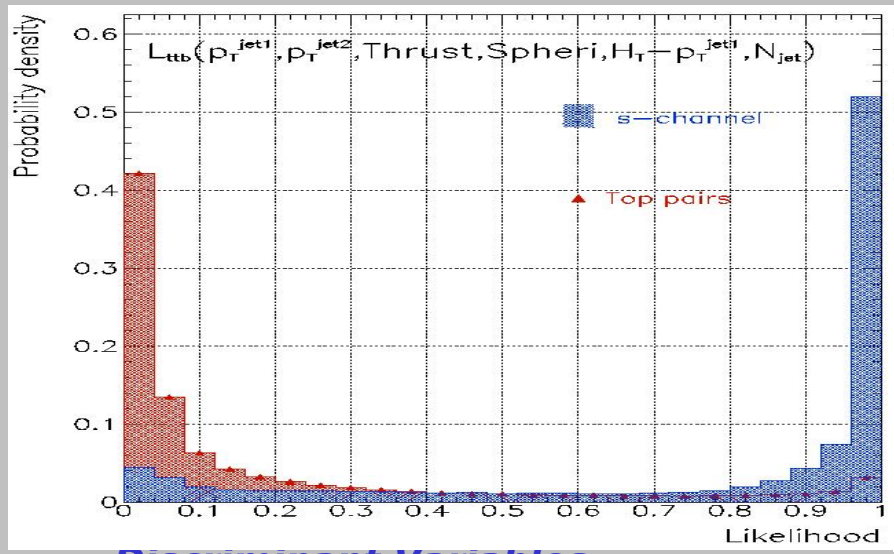
Reconstruct M_{lvb} within m_{top} ± 25 GeV/c^2

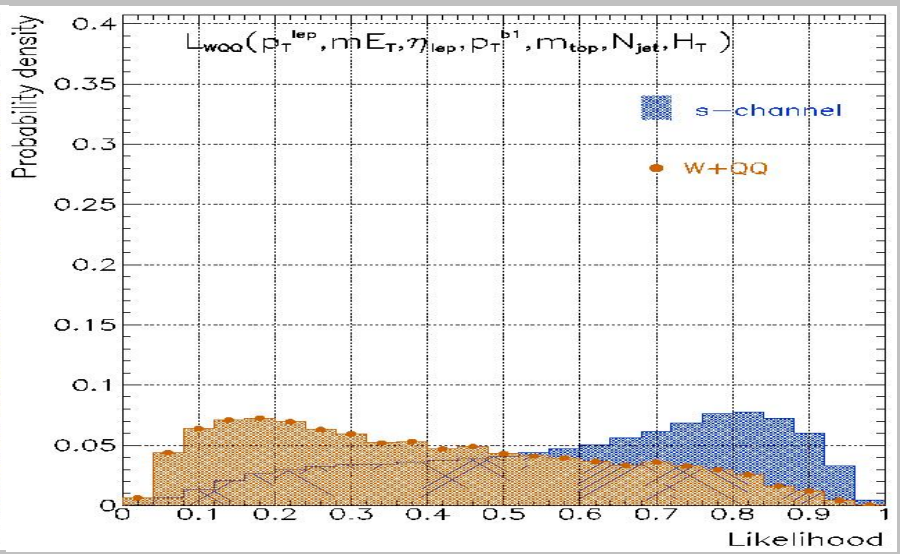
Window in H_T

S-channel : future improvements

Improved Analyses

- ***Classify the analyses***
  - **According to Nb of b-tagged jets**
- ***Use of more refined techniques***
  - **Likelihoods defined against ttbar and WQQ**
    - **→ L_{ttb} and L_{WQQ} ("a la DØ")**





- ***Discriminant Variables***
  - **Event global shapes are useful**
  - **Angular correlations (lepton-b, b-b ..)**
  - **Total Invariant mass, energy sum etc…**
  - **In all cases N(jet) appears to be a "relevant" parameter**

S-channel : systematics

Systematics

- *Experimental systematics*

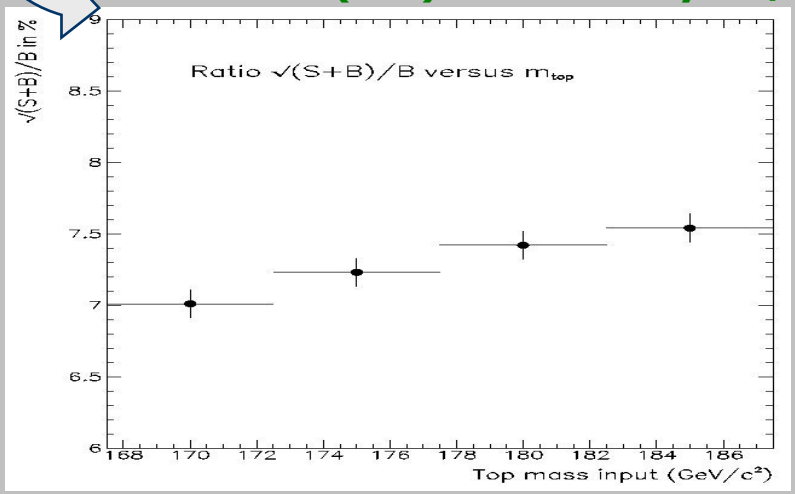
  Main sources that degrades the expected precision by

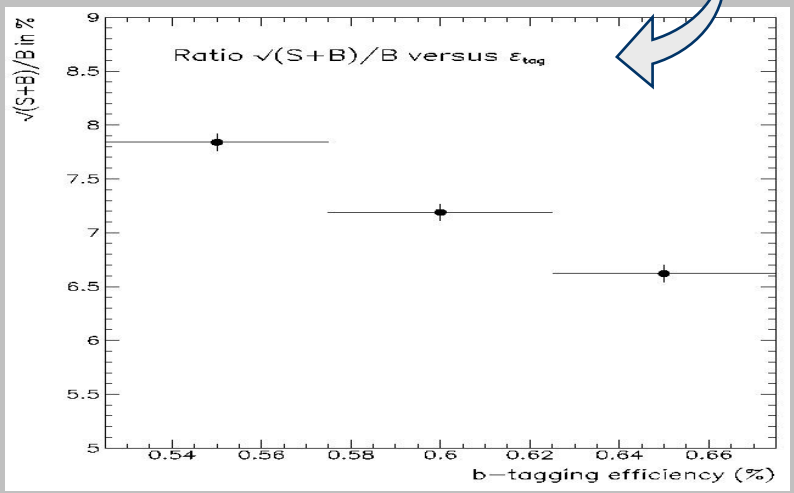
  Input Top mass Uncertainty by ~ 12%

  b-tagging efficiency & mistag rates by ~ 10%

  (b)-jet Energy scale : ~ 20% (p_T, H_T, m_t cuts)

  Absolute σ(W*) : luminosity ΔL/L ~ ±5%





- *Theoretical uncertainties*

  Affects p_T distributions (hence P_T,H_T,m_t, ...)

  Affects cross-sections :

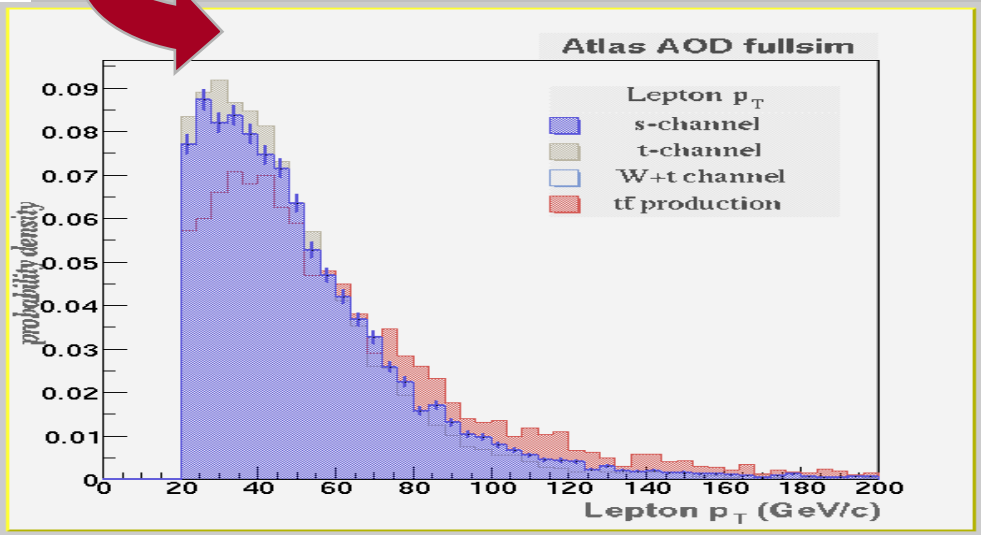
  $(\Delta\sigma/\sigma)_{ttb}$ = 12% (NLO) $(\Delta\sigma/\sigma)_{Wg}$= 3.5% (NLO)

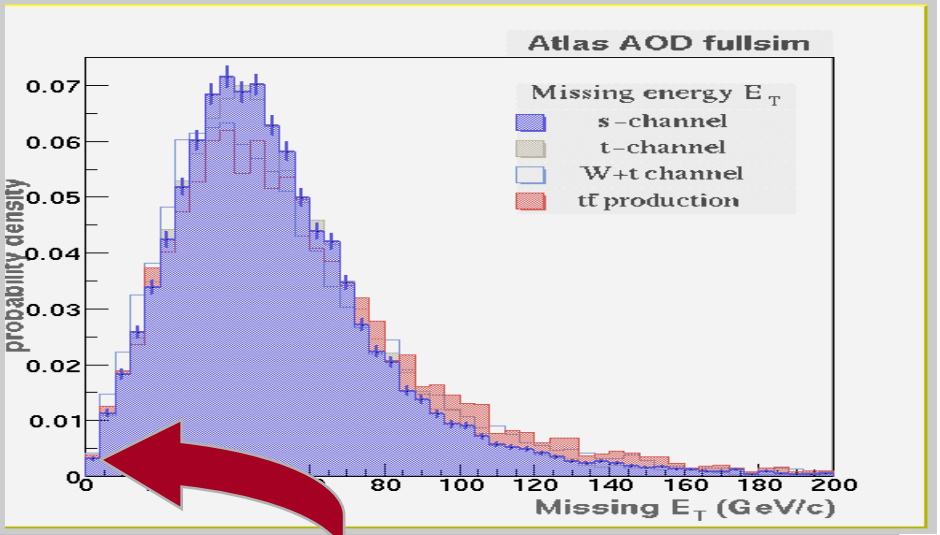
  $(\Delta\sigma/\sigma)_{WQQ}$ = 30% ? $(\Delta\sigma/\sigma)_{Wjets}$ = 50% ?

Lepton and missing E_T

Lepton Definition

- *Characteristics*
  - Reconstruction : ElectronCollection
  - Highest electron : $p_T \geq 20$ GeV/c
  - Acceptance : $|\eta| < 2.5$
  - → Matched with Truth electron





Missing E_T Definition

- *Characteristics*
  - MissingEtContainer = "MET_Final"
  - $mE_T \geq 20$ GeV/c