Physics with single-top events in ATLAS

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OUTLINE

Introduction
- *Production @ LHC*
- *Motivations*
- *Direct search results*

Single top events at the LHC
- *Phenomenology*
- *Event selection*

Results & beyond SM searches
- *Sensitivity for the 3 channels*
- *Beyond SM sensitivity*

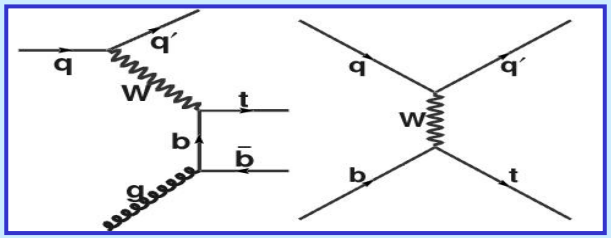
Conclusion

Single top production @ LHC

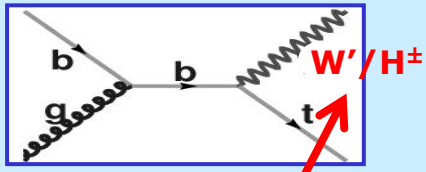
Single-top in the SM

- *3 production mechanisms*

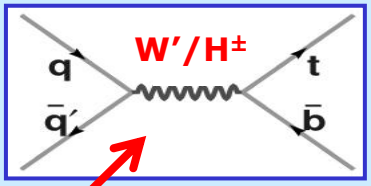
W-g (t-channel)



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 W-t-b vertex :*
  - Determination of σ(pp→tX), Γ(t→Wb)
  - Direct determination of $|V_{tb}|$
  - W, top polarizations
- *Probe to new physics*
  - Anomalous couplings, FCNC → t-, W+t channels
  - Extra gauge-bosons W' (GUT, KK)
  - Extra Higgs boson (2HDM)
  - → s-channel
- *Background for many physics analyses*
  - Higgs physics with jets, SUSY
- *b PDF's constraints*
  - W+t channel

Phenomenology and latest news from the TeVatron…

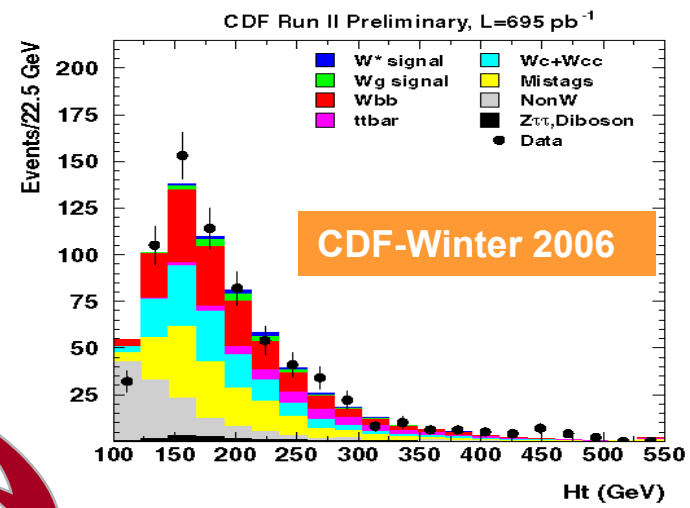
Phenomenology

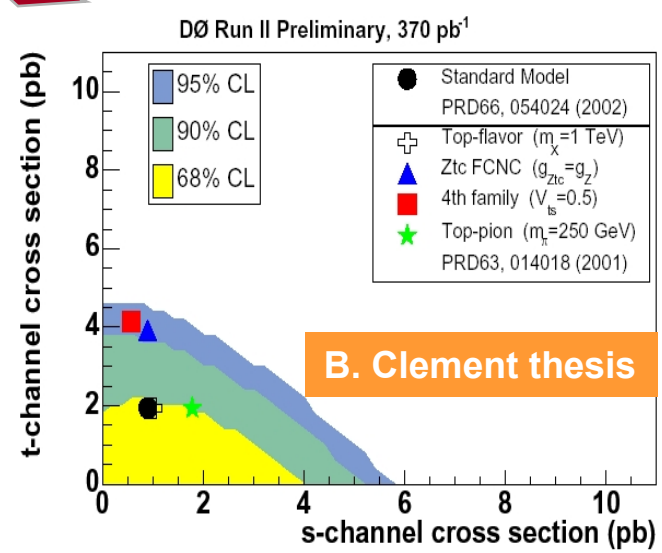
- *Signal & SM backgrounds*
  - Only 2 accessible channels (s- & t-)
  - Small σ vs backgrounds (WQQ , W+jets, $t\bar{t}$)
  - ➔ low S/B, S/√B ratios

Last results from DØ

- *Cross-sections*
  - 95% exclusion : 4.4 pb (Wg) 5.0 pb (W*)
- *What we learn from systematics …*

Single (double) b-tag :	6 % (15%)
Data Normalization :	5 % (15%)
Luminosity :	6.5%
Jet energy scale, resolution, id:	5 %
Trigger turn-on :	5 %
Jet fragmentation	5 %
Lepton id	4 %





Run II extrapolations (D0+CDF, 8 fb^{-1})

Possible discovery for combined channels

3σ evidence for separate channels

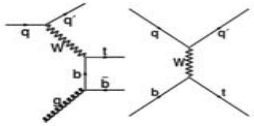
Strategy & cross-sections at the LHC

Strategy

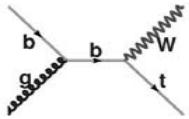
- *Search for leptonic W's*
  - → Central high energy lepton (e, μ)
  - → high $\not{E}_T$
- *Search for high energy jets*
  - → Specific conditions for each channel

Search for top decays

- → Reconstruct top quark candidates
- → High total p_T, m_{lvb}



- 1 forward untaggable b-jet
- 1 high energy jet
- 1 high energy b-jet



- 2 light jets from W
- 1 high energy b-jet

- No light jets (LO)
- 2 high energy b-jets

Backgrounds

- *Physic processes with same signature*
  W+b+jets, $t\bar{t}$ (l+jets), single top
- *Acceptance effects (loss of objets)*
  Z+jets, tt (dilepton), dibosons
- *Reconstruction effects (fake objects)*
  QCD, W+ light jets

Cross-sections

- *Uncertainties*
  pdf, μ, m_Q, m_{top} : 5-15%
  Other single top contamination

Channel	σ^{NLO} x Br (pb)
t-	54
W+t	18
s-	2.2
tt	250
Wbb	70
W+jets	3 850
WZ	17

Single top signature stuck between W+jets & tt
Important systematic related to background → use of data

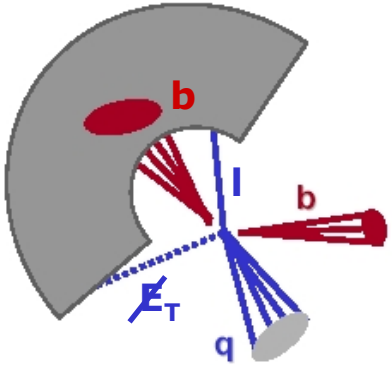
Common pre-selection

Selection of W+jets like events

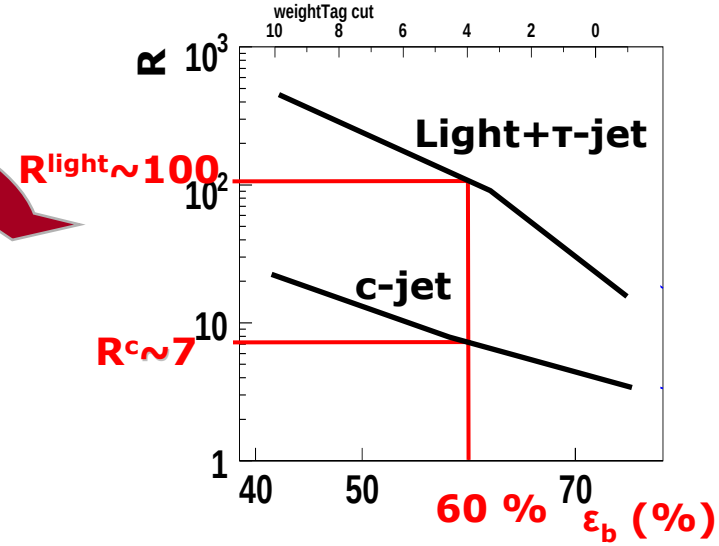
- *1 isolated & central high-p_T lepton*
  - → Reproduce trigger effects
  - → Discriminate against multijets events
- *High $\not{E}_T$*
  - → Reduce Z(->ll)+jets & QCD
- *2^{ndary} lepton veto*
  - → Reduce Z+jets & dilepton tt
- *2 or 3 high-p_T jets*
  - jet veto : p_T^{jet} > 15 GeV/c
  - → Reduce $t\bar{t}$
- *≥1 high-p_T b-tagged jets*
  - $p_T^{b\text{-}jet}$ > 30 GeV/c
  - → Reduce W+jets

Reconstruction of top quark

- *Reconstruction of leptonic W boson*
  - Interpret $\not{E}_T$ as v_T
  - W-mass constraint → 2 solutions for p^{ν}_z
- *Use leptonic W boson + b-tagged jet*
  - → combinatorial background



Topology of a candidate event



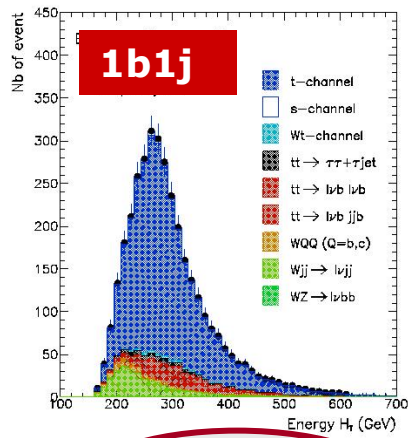
b-tagging performance (full simulation)

t-channel measurement

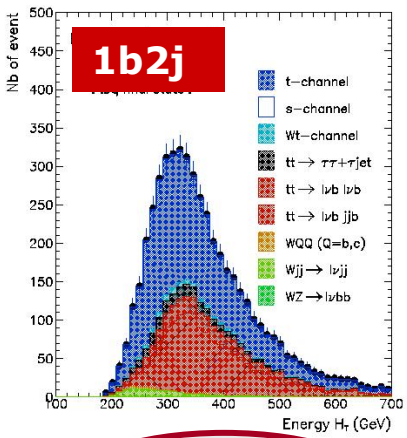
Specific selection

- *1 forward untaggable b-jet*
  - $|\eta_{jet}| > 2.5$
  - $p_T^{jet} > 50$ GeV/c
- *1 central high-p_T b-tagged jet*
  - $p_T^{bjet} > 50$ GeV/c
- *Splitted analysis vs N(jets)*
  - 1b1j 1b2j
  - Central light jet veto
- *Topological cuts*
  - $H_T = \Sigma\, p_T^{jets+v+l}$, m_{top}

$\int L\, dt = 10\ fb^{-1}$



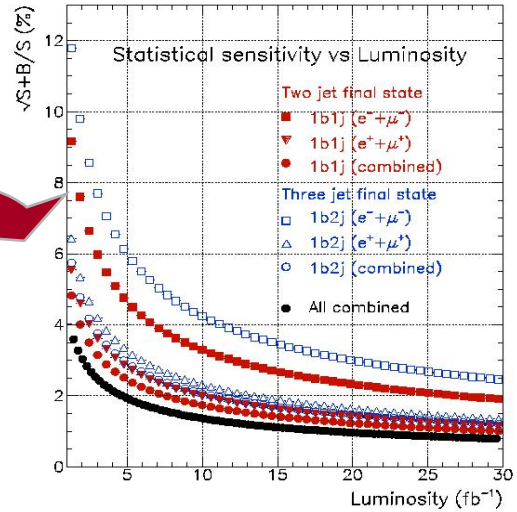
S/B ~ 3
S/√B ~ 100



S/B ~ 1
S/√B ~ 60

Performance

- *Signal selection efficiency*
  - $\varepsilon^{sel} \sim 1\%$ per analysis
- *Main backgrounds*
  - W+jets & $t\bar{t}$
- *Sensitivity 10 fb^{-1}*
  - $\Delta\sigma/\sigma$ = 1.3%(stat) ± 8%(syst) ± 8%(th) ± 5%(lumi)

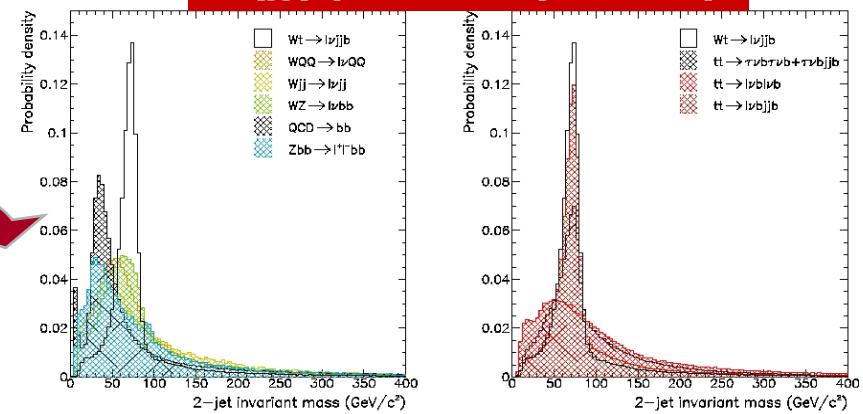


W-t channel measurement

Specific selection

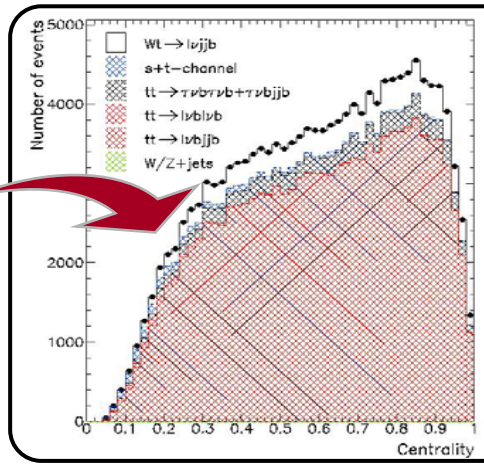
- *1 central high-p_T b-tagged jet*
  - p_T^{bjet} > 50 GeV/c
- *Splitted analysis vs N(jets)*
  - 1b1j 1b2j
  - Central light jet veto
- *1b2j analysis*
  - High p_T jets & m(jj) ~ M_W
  - Centrality cut
- *1b1j analysis*
  - High p_T jets

m(jj) probability density



Performance

- *Signal selection efficiency*
  - ε^{sel} ~ 5 % per analysis
- *Main backgrounds*
  - $t\bar{t}$ & $\bar{t}$-channel
- *Sensitivity 10 fb^{-1}*
  - $\Delta\sigma/\sigma$ = 2%(stat) ± 9%(syst) ± 6%(th) ± 5%(lumi)



$\int L\,dt = 10\ fb^{-1}$

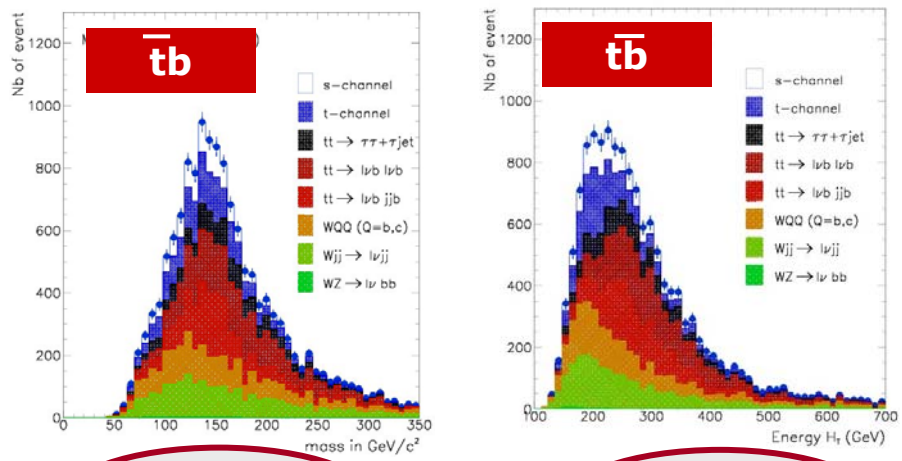
S/B ~ 0.1
S/√B ~ 35

s-channel measurement

Specific selection

- *2 central high-p_T b-tagged jets*
  - p_T^{bjet} > 30 GeV/c
  - Central light jet veto
- *Splitted analysis vs lepton charge*
  - Against symmetric $t\bar{t}$
  - $l^- \rightarrow \bar{t}b$ channel
  - $l^+ \rightarrow t\bar{b}$ channel
- *Possible use of topological cuts*
  - Optimized H_T, $m_{l\nu b}$ cuts
  - → Control variables
  - → S/B enhancement

$\int L\,dt = 30\ fb^{-1}$

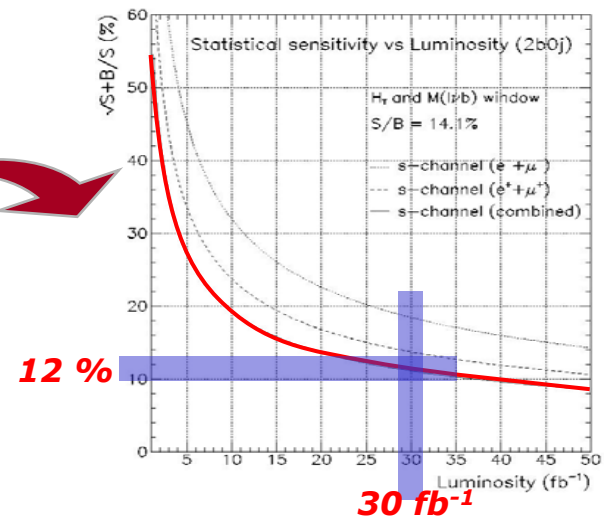


S/B ~ 0.12
S/√B ~ 6

S/B ~ 0.14
S/√B ~ 7

Performance

- *Signal selection efficiency*
  - ε^{sel} ~ 1.5 % per analysis
- *Main backgrounds*
  - W+light jets, $t\bar{t}$, other single top
- *Sensitivity with full selection 30 fb^{-1}*
  - $\Delta\sigma/\sigma$ = 12%(stat) ± 10%(syst) ± 8%(th) ± 5%(lumi)



Systematics (1)

Experimental biases

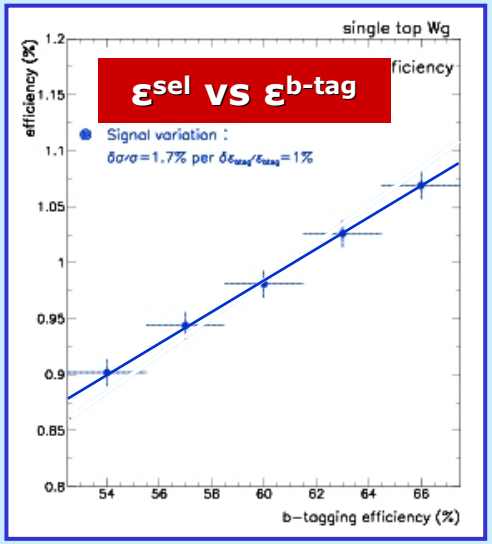
- *b-tagging*

  1b-tag : $\Delta\varepsilon^{sel}/\varepsilon^{sel} = 1.7 * \Delta\varepsilon^{b\text{-}tag}/\varepsilon^{b\text{-}tag}$

  2b-tags : $\Delta\varepsilon^{sel}/\varepsilon^{sel} = 3.4 * \Delta\varepsilon^{b\text{-}tag}/\varepsilon^{b\text{-}tag}$

  Knowledge crucial for background rejection
  Major systematic contribution for s-channel
  But relatively stable S/B

  To reduce b-tagging uncertainties :
  → Use $t\bar{t}$ data ?



- *ISR & FSR*

- *light- & b-JES*

N(b-jets) is one of the main discriminant variables
Data can improve our knowledge of b-tagging performance

Systematics (2)

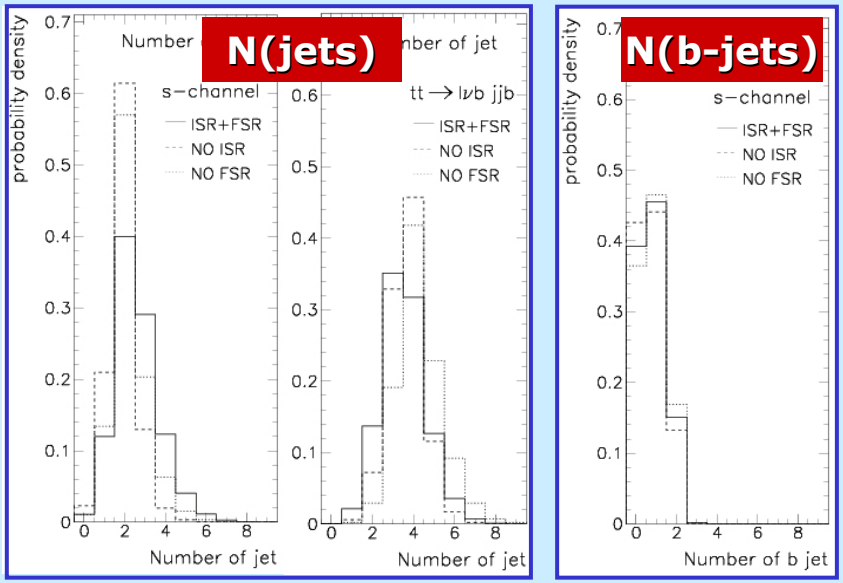
Experimental biases

- *b-tagging*

- *ISR & FSR*

  ISR affects jet multiplicity
  → Shifts in N(jets)
  FSR affects JES
  → out-of-cone radiations
  → Modify ε^{sel}
  $\Delta\varepsilon^{sel}/\varepsilon^{sel} \sim 5\% \oplus 10\%$

  Gluon radiation modelling :
  → Inclusive W data ? (s-channel)
  → Understanding NLO/LO ?



- *light- & b-JES*

N(jets) is one of the main discriminant variables
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Systematics (3)

Experimental biases

- *b-tagging*

- *ISR & FSR*

- *light- & b-JES*

  Affects jet, $\not{E}_T$, topological distributions

  Affects jet veto performance

Single top :

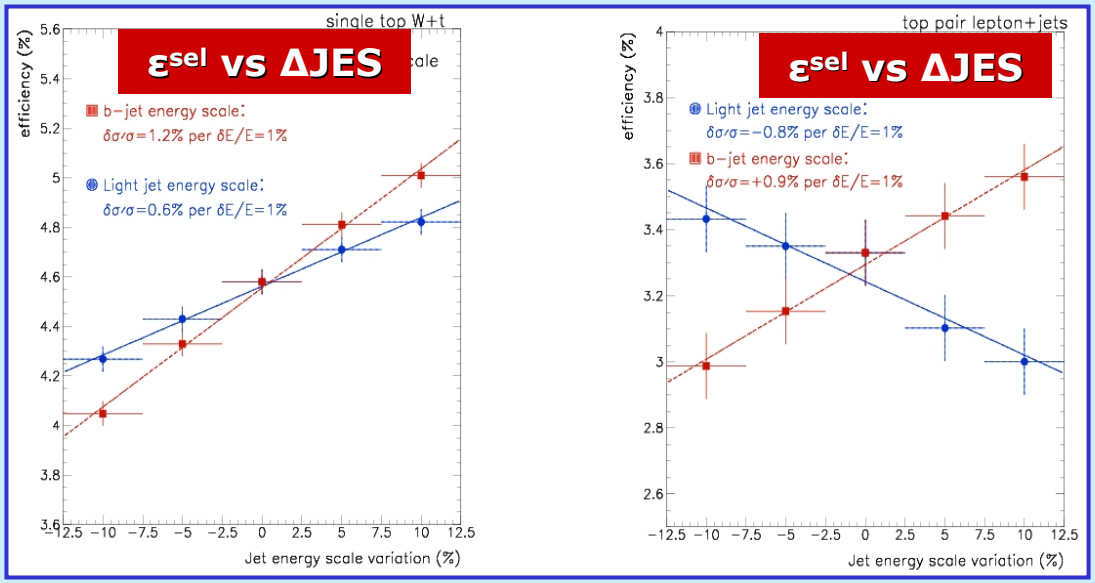
$\Delta\varepsilon^{sel}/\varepsilon^{sel}$ = 0.7 ΔJES (%)

$\Delta\varepsilon^{sel}/\varepsilon^{sel}$ = 1.2 Δb-JES (%)

$t\bar{t}$:

$\Delta\varepsilon^{sel}/\varepsilon^{sel}$ = -1.2 ΔJES (%)

$\Delta\varepsilon^{sel}/\varepsilon^{sel}$ = 1.3 Δb-JES (%)



Goal : 1-2% on Light & b-JES uncertainties
→ JES calibration on (tt) data

Systematics (4)

Theoretical biases to background estimates

- *Generators*

  NLO/LO → σ & distribution shapes of kinematic variables

  Significant remaining uncertainties @ NLO :

  m_Q, μ, PDF, b-fragmentation

  → $\Delta\sigma/\sigma \sim$ 6-20% (single-top)

  → $\Delta\sigma/\sigma$ = 12% ($t\bar{t}$) 30% ? (W+jets)

  Needs a prior work on $t\bar{t}$ & W+jets data

  → σ, distribution shapes

- *m_{top}*

  σ↘ with m_{top}

  $\Delta\sigma/\sigma$ = 1-2% * Δm_{top}

  Affects ε^{sel} (slight effect)

Luminosity

Absolute σ(W*) : luminosity ΔL/L ~ 5%

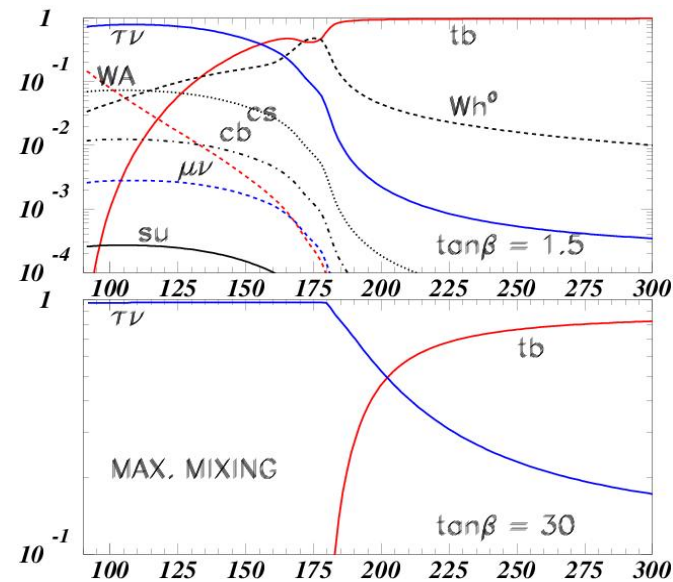
→ Normalization with W→lν production could help

use of data is mandatory :
→ Background knowledge tt & W+jets
→ Luminosity measurement

Single top & charged Higgs bosons searches

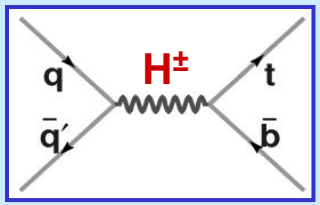
Charged Higgs phenomenology

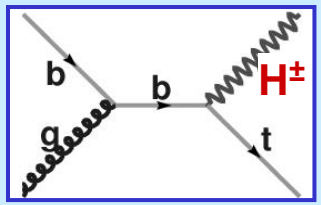
- *Production in 2HDM*
  - 5 higgs : 3 neutral (A,h,H) + 2 charged ($H^{\pm}$)
  - Mass spectrum predicted
  - $H^{\pm}$-q-q' couplings depends on $m_{H\pm}$ and tan β
  - $\sigma(H^{\pm} \rightarrow tb \rightarrow l\nu bb)$ can reach 50% of $\sigma(W^*)$
- *Constraints on $m_{H\pm}$ and tan β (95% C.L.)*
  - $0.5 < \tan\beta < 60$
  - $m_{H\pm} > 90$ GeV/c^2



Charged Higgs & single top

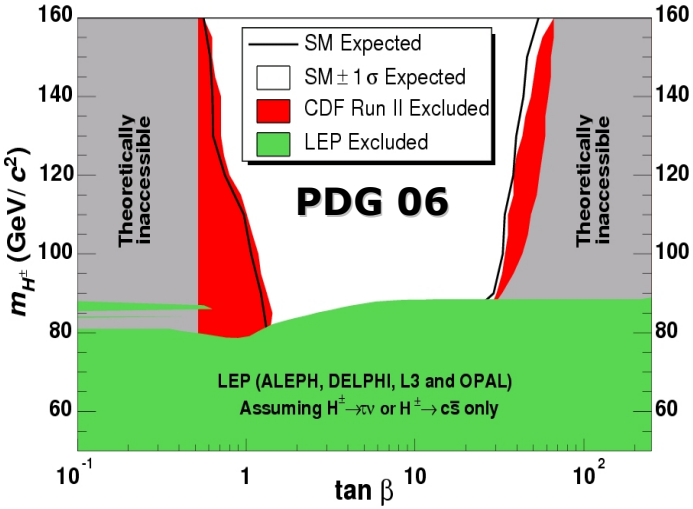
- *SM single top final state rates can be modified*
  - Interference with s- & W+t channel





→ Direct search in m_{tb} & m_{jj}

→ Deviation from SM $\sigma(W^*)$ & $\sigma(Wt)$



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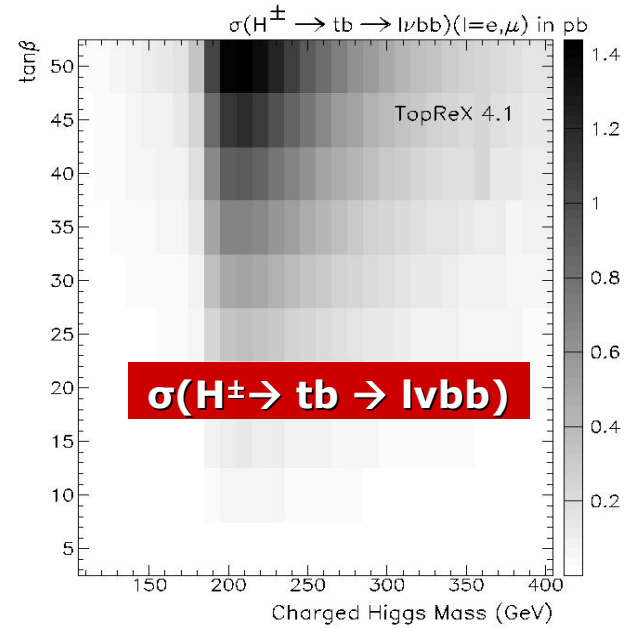

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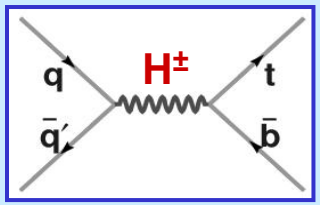

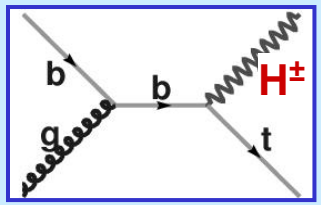

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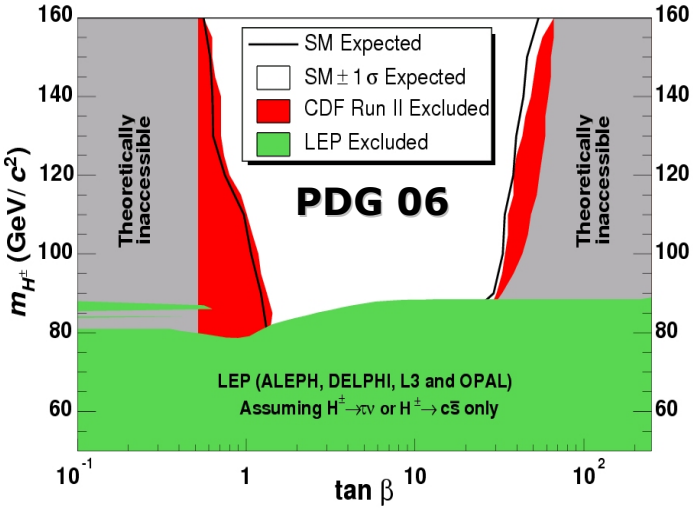


s-channel with 30 fb-1 : Why ?

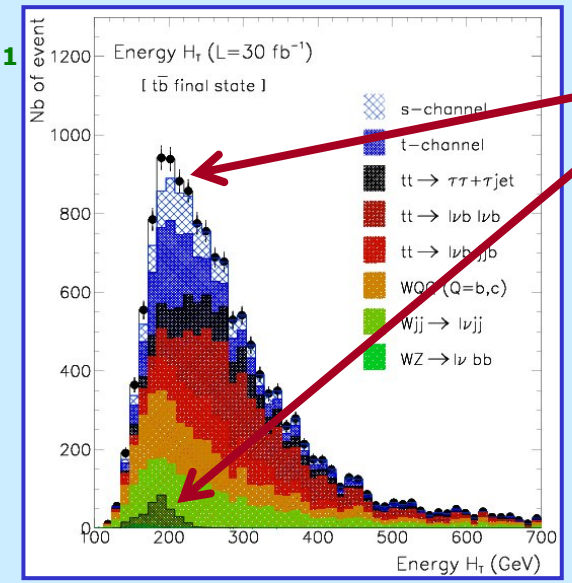
Strategy

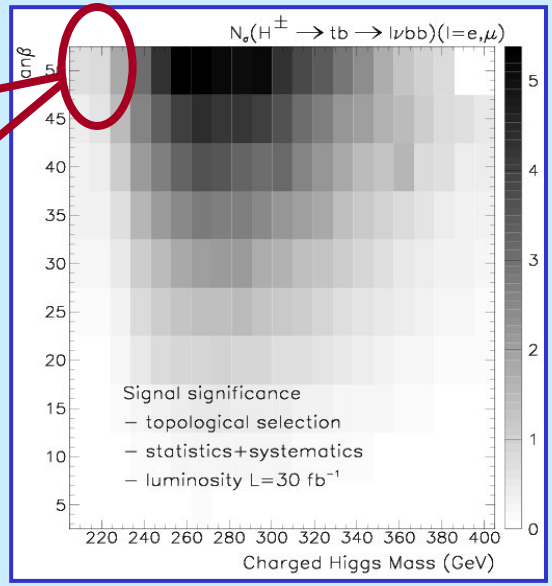
- *Indirect search*
  - Observe deviation from SM σ(s-channel)
  - Limited by the knowledge of backgrounds
  - → Single top, $t\bar{t}$, W+jets
- *Same analysis developped for the s-channel*
  - No specific analysis performed for a $H^{\pm}$ search

Performance in ($m_{H\pm}$,tanβ) plane

- *Selection efficiency*
  - Increases with $m_{H\pm}$ up to 250 GeV/c^2
- *5 σ sensitivity*
  - Possible with 30 fb^{-1}

$m_{H\pm}$= 220, tanβ=50
S/√B ~ 1.3





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  - Increases with $m_{H\pm}$ up to 250 GeV/c^2
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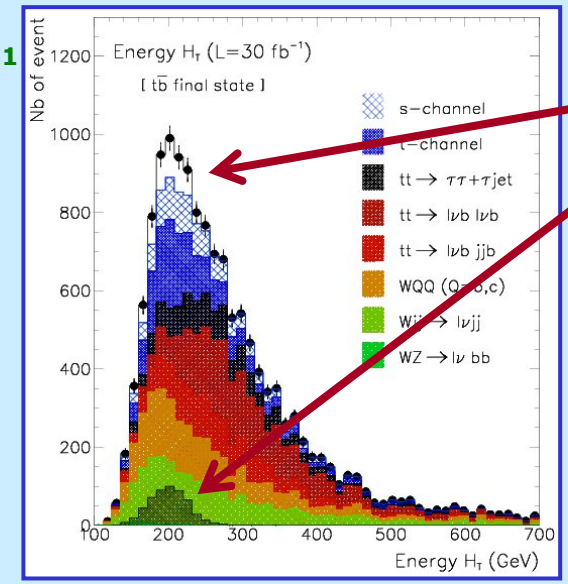
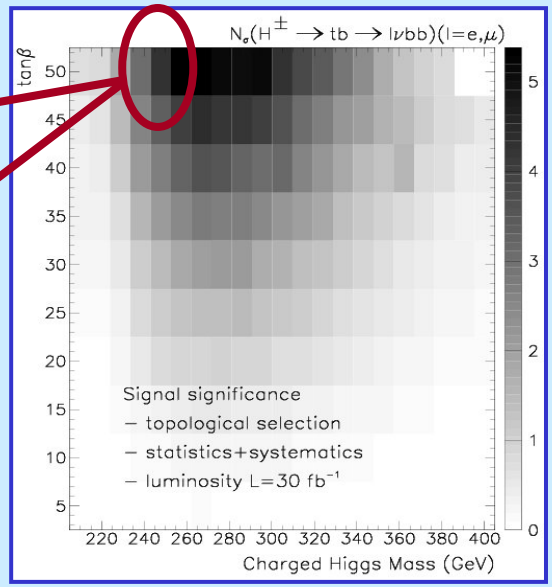
$m_{H\pm}$= 250, tanβ=50
S/√B ~ 5.7





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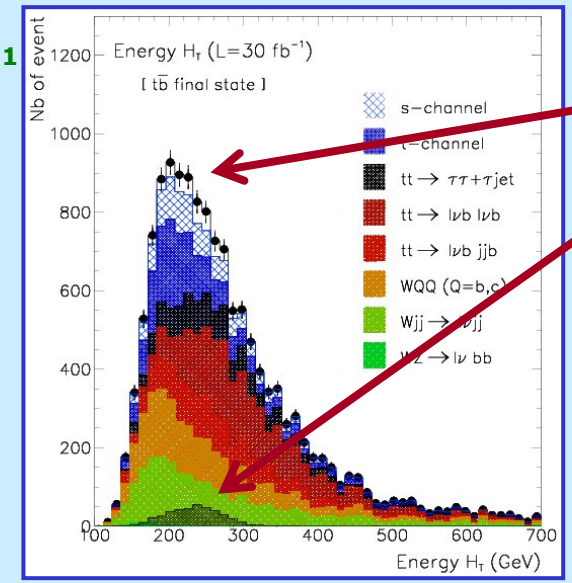
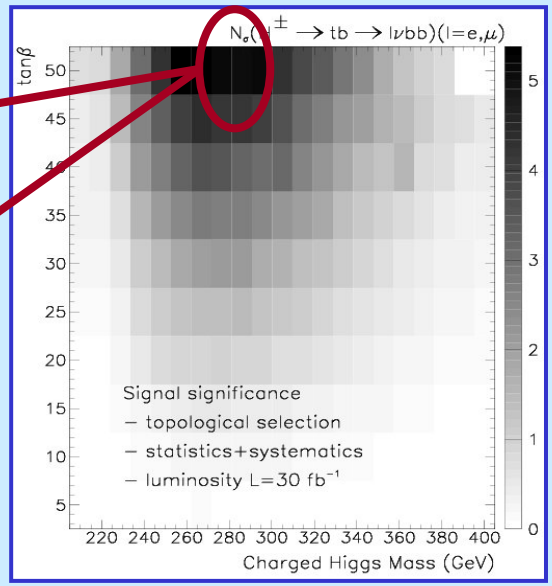
$m_{H\pm}$= 300, tanβ=50
S/√B ~ 3.9





Conclusion

Single-top precision measurements are possible @ LHC

- ***t-channel***
  - Higher signal cross-section
  - → Measurement possible with early data (1 fb^{-1})
  - $t\bar{t}$ is the major background
  - Expect statistical precision of ~ 1-2% (10 fb^{-1})
- ***W+t channel***
  - $t\bar{t}$ is the major background
  - Expect statistical precision of ~ few % (10 fb^{-1})
- ***s-channel***
  - $t\bar{t}$, WQQ, W+jets, t-channel as major backgrounds
  - Statistical precision ~ few % with 30 fb^{-1}

All measurements are systematics limited

- ***Background knowledge is important***
  - need NLO generators
  - Data can provide better background control
- ***Experimental systematics***
  - Jet Energy Scale (H_T, reconstructed mass, …)
  - ISR/FSR uncertainty (#jets, jet energy)
  - b-tagging performance knowledge
  - → → Use of data is mandatory

BACKUP SLIDES

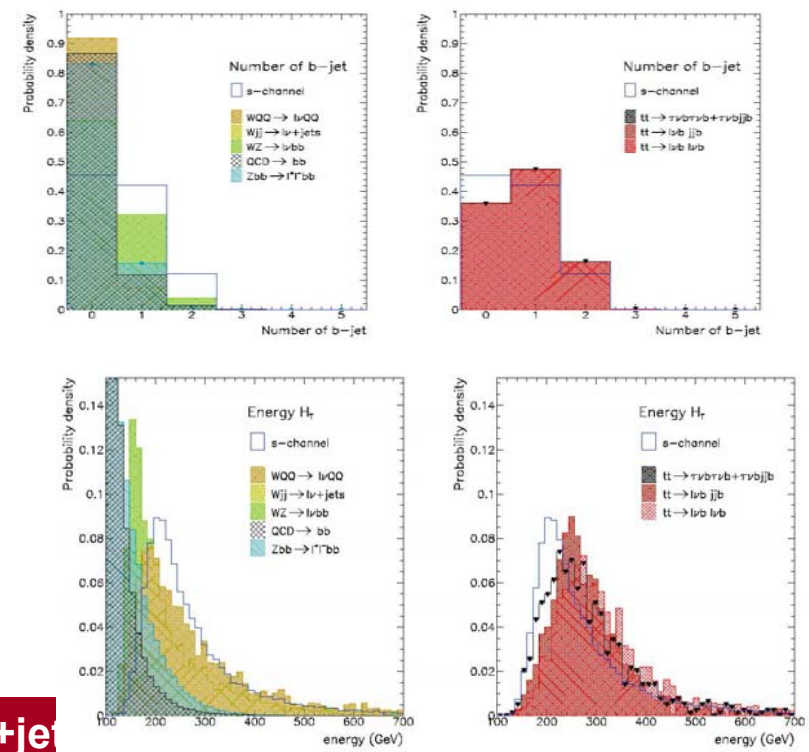
Signal & backgrounds

Backgrounds

- *Physic processes with same signature*
  - W+b+jets, top pairs (l+jets), single top
- *Detector effects (loss of objets)*
  - Z+jets, top pairs (dilepton), dibosons
- *Reconstruction effects (fake objects)*
  - QCD, W+ light jets

Background properties

- *Isolated central high pT lepton*
  - QCD excepted (fake lepton)
- *High $\not{E}T$*
  - QCD & Z+jets excepted (fake ET)
- *High energy light jets*
  - tt → ≥ 3 jets
  - QCD, W+jets → ≤ 2 jets
- *High pT b-tagged jets*
  - tt → ≥ 1 b-tagged jet
  - QCD, W+jets → ≤ 1 b-tagged jet
- *HT=Σ pTjets+v+l*
  - tt → <HT>~300 GeV/c
  - QCD

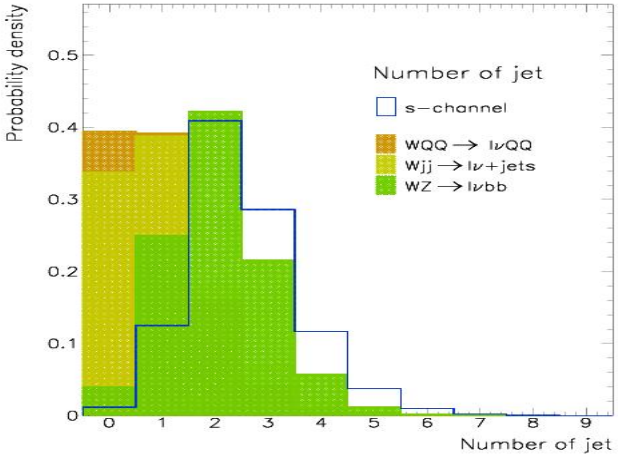


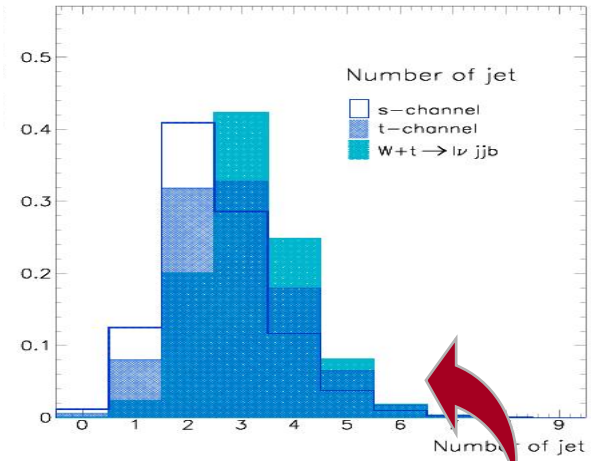
Single top signature stuck between W+jet
Important systematic related to background → use of data

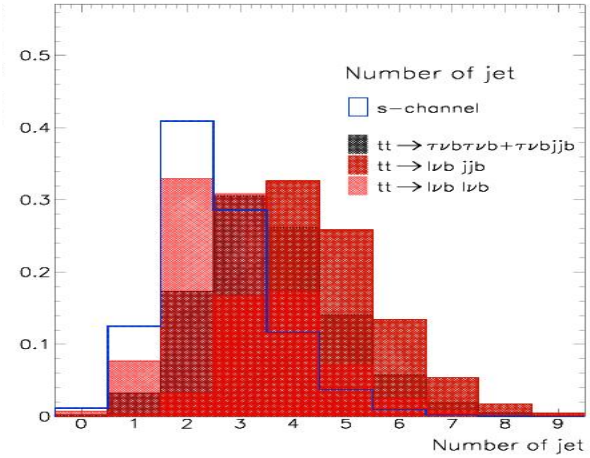
Variables discriminantes : N(jets), p_T^{jet}

Caractéristiques

- *Algorithme de cone R = 0.4*
- *Acceptance : |η| < 5.0*
- *Jets énergétiques (≥ 25 GeV/c)*
  - **resolution (|η| < 3) : σ(E)/E~0.5/√E (GeV)**







Nombre de jets :

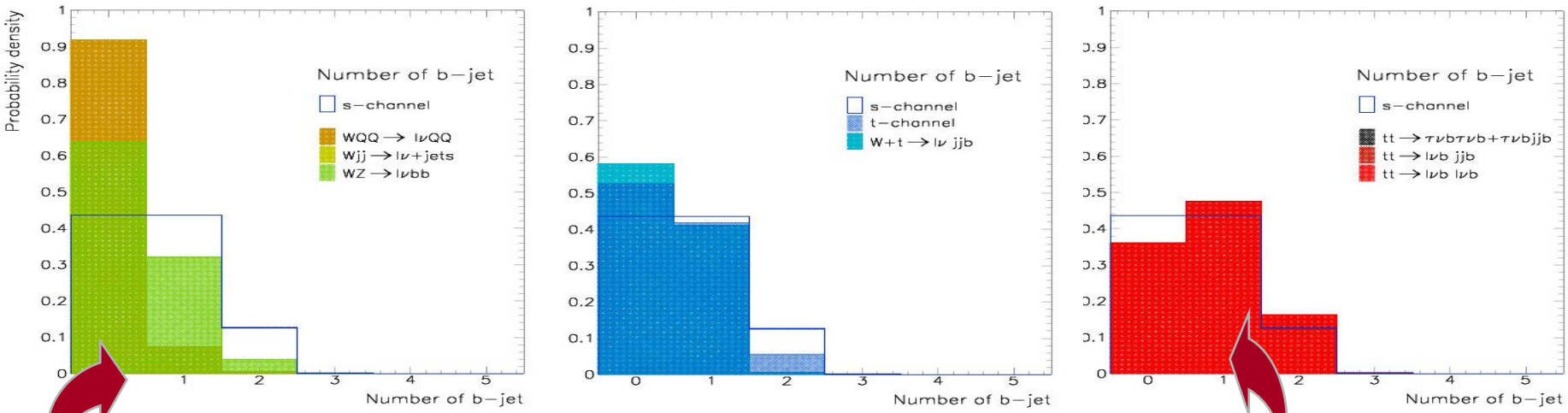
- *Pouvoir discriminant :*
  - **N(jet) ≤ 3 → contre ttbar**
  - **N(jet) ≥ 2 → contre WQQ, Wjets**
  - **N(jet) = 2 → privilégie les voies s & t**
  - **N(jet) = 3 → favorise le canal W+t**
- *Veto contre un 3e jet (p_T)*

La multiplicité en jets permet de separer les différents fonds
→ Nécessité d'un véto sur les jets

Variables discriminantes : N(b-jets), $p_T^{b\text{-}jet}$

Caractéristiques

- *Cone R = 0.4*
- *Likelihood > 0.9*
- $|\eta_{b\text{-}jet}| \leq 2.5$
- $p_T > 30$ GeV/c



Nombre de b-jets :

- *Pouvoir discriminant :*

  N(b-tag) = 1 pour les voies t et W+t

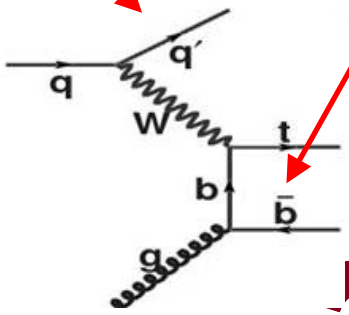
  N(b-tag) = 2 exactement pour la voie s

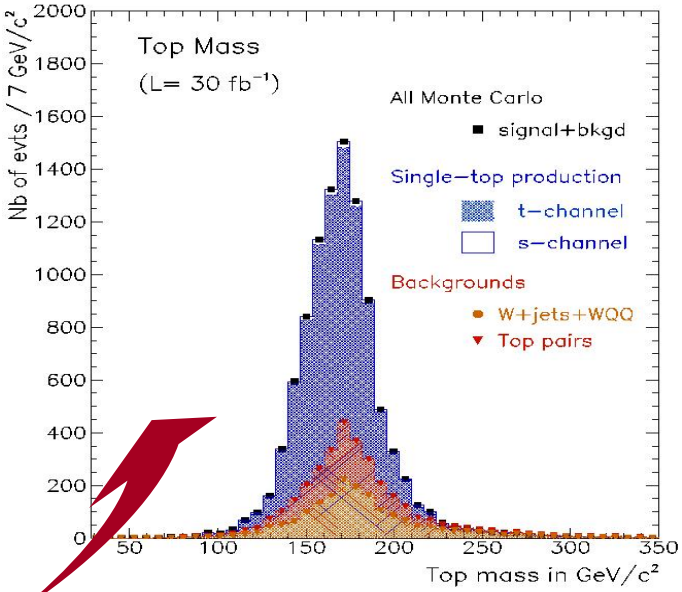
Diminution des fonds W+jets mal connus
Amélioration de S/B et S/√B

Résultats voie t (W-g)

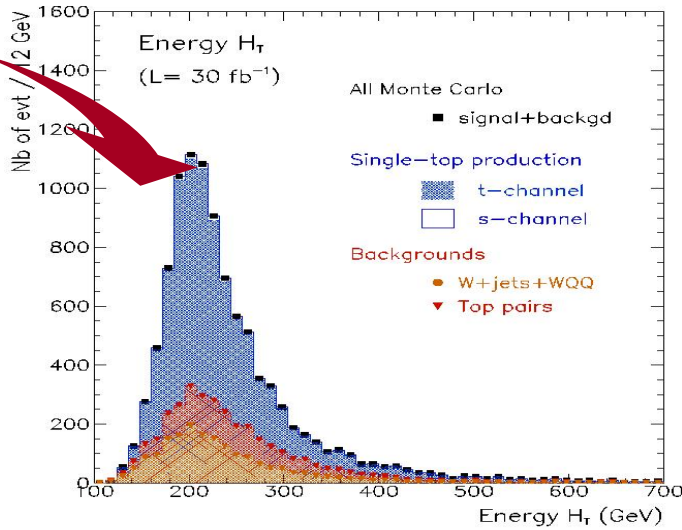
Criteres de sélection

- *N(jets) = 2*
- *Exactement 1 b-jet énergétique*
  - $|\eta|<2.5$, $p_T>50$GeV/c
  - L'autre b échappe a l'acceptance du détecteur
- *1 jet énergétique a grand η*
  - $|\eta|>2.5$, $p_T \geq 50$GeV/c





- *H_T et m_{lvb}*
  - Rejettent QCD et W+jets



Performances

- *Sélection du signal*
  - $\varepsilon \sim 0.4$ %
- *Principaux fonds*
  - tt
  - W+jets

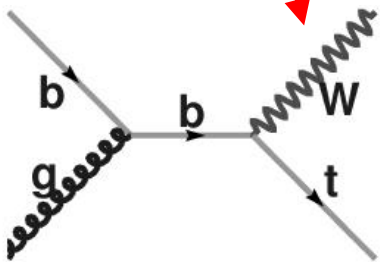
30 fb^{-1}

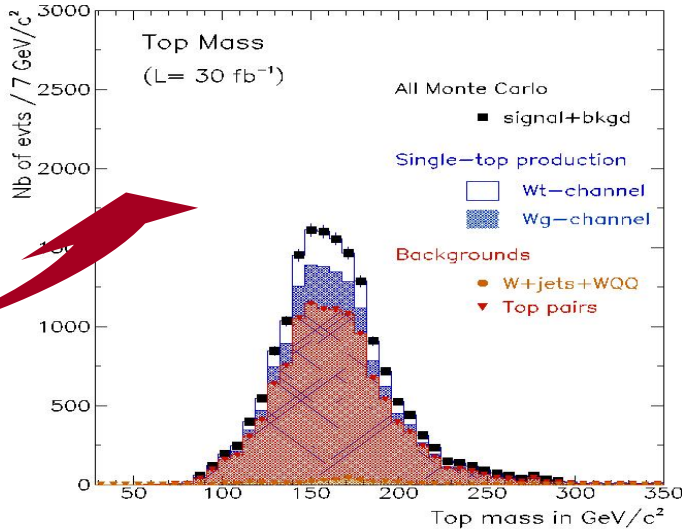
S/B ~ 3
S/√B ~ 140
√(S+B)/S ~ 1.4% (stat)

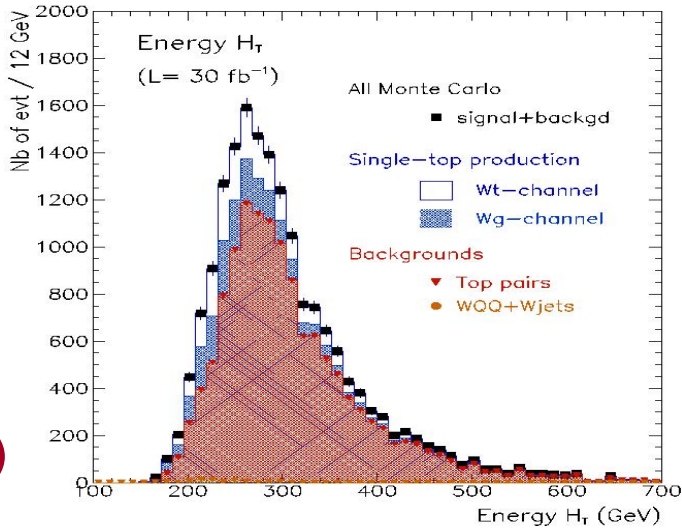
Résultats voie W+t channel

Criteres de sélection

- *N(jets) = 3*
- *Exactement 1 b-jet énergétique*
  - |η|<2.5, pT>30GeV/c
- *Reconstruction du W hadronique*
  - 60 < Mjj < 95 GeV/c2
- *Fenêtres en H_T et ml_{vb}*







Performances

- *Sélection du signal*
  - ε ~ 0.9 %
- *Principaux fonds*
  - tt
  - Single top voie t

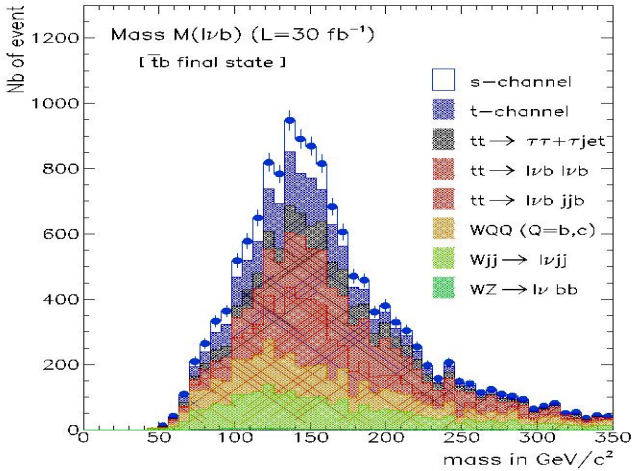
30 fb^{-1}

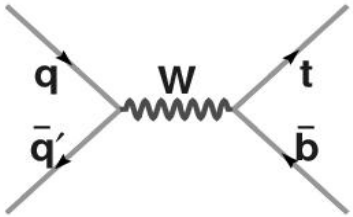
S/B ~ 15%
S/√B ~ 22
√(S+B)/S ~ 4% (stat)

Résultats voie s (W*)

Criteres de sélection

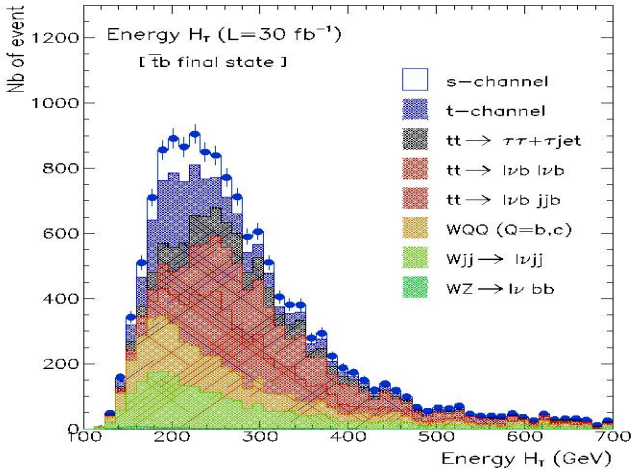
- *N(jets) = 2*
- *Exactement 2 b-jet énergétique*
  - $|\eta|<2.5$, $p_T>50$GeV/c $p_T>30$GeV/c
- *Veto contre 3e jet (pT)*
  - Reduction de tt
- *Veto 2e high-pT lepton*
- *Fenêtres en H_T et $m_{l\nu b}$*





Performances

- *Sélection du signal*
  - $\varepsilon \sim 2$ %
- *Principaux fonds*
  - tt
  - Single top voie t



30 fb^{-1}

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

High p_T b-tagged jet : p_T

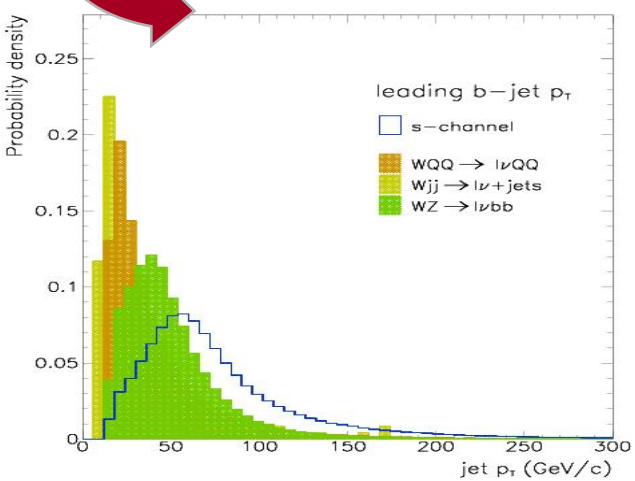
Characteristics

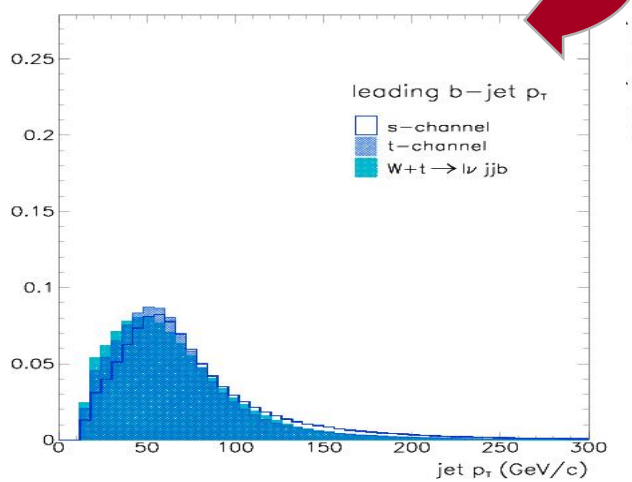
- ***Jet b-tagging***

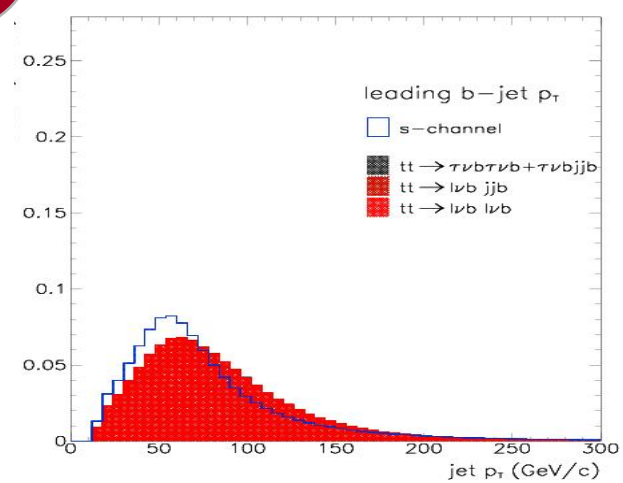
  Jet Cone ΔR= 0.4

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

  p_T > 30 GeV/c







- ***Discriminating power :***

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

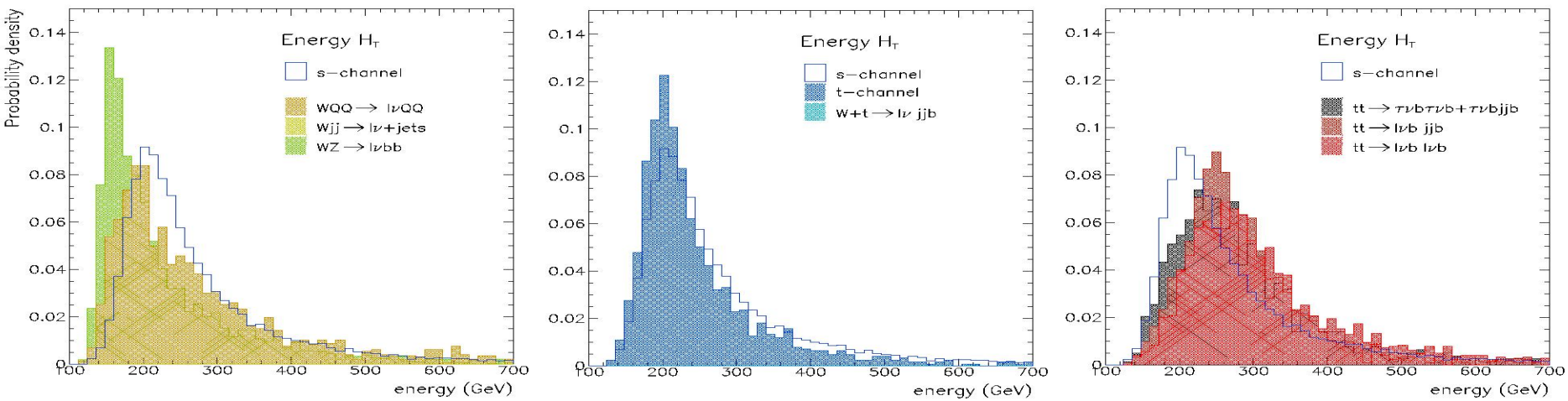
Discriminant Variable : H_T

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)

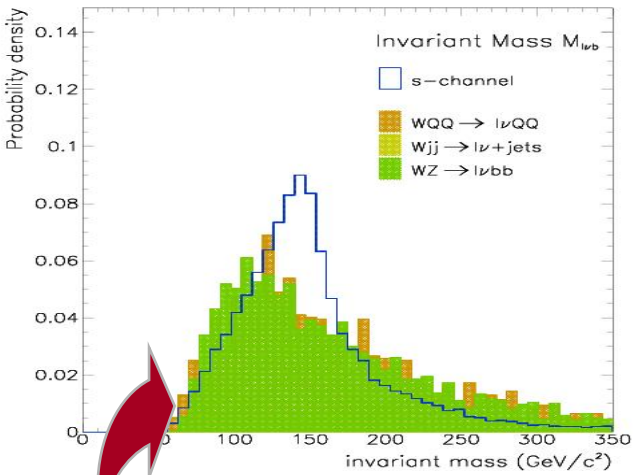
(1) Determination of $p_l(\nu)$

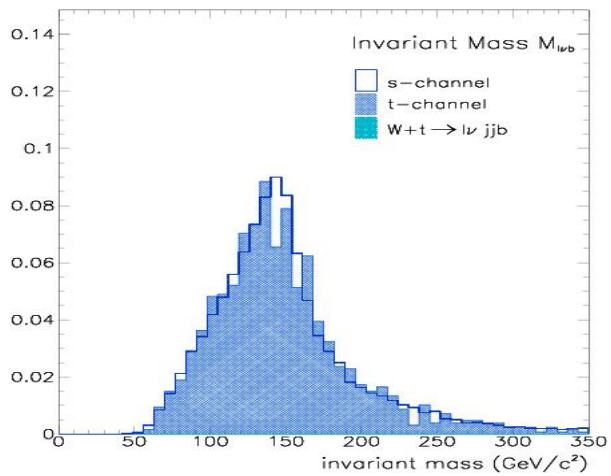
Interpret missing E_T as $p_T(\nu)$

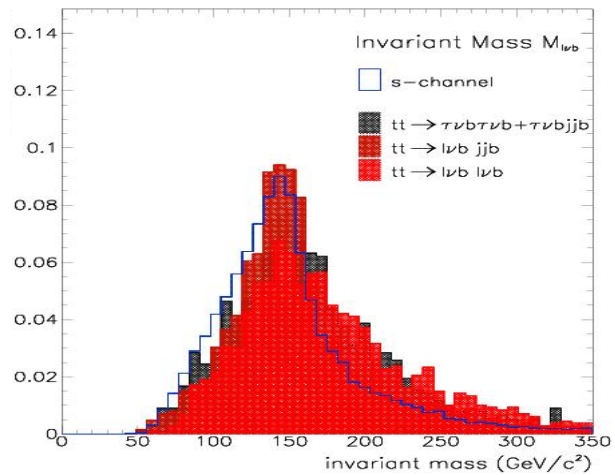
Compute $p_l(\nu)$ using the W-mass constraint

→ $p_l(\nu)$ 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)

S-channel : 3rd jet Veto

Sequential analysis

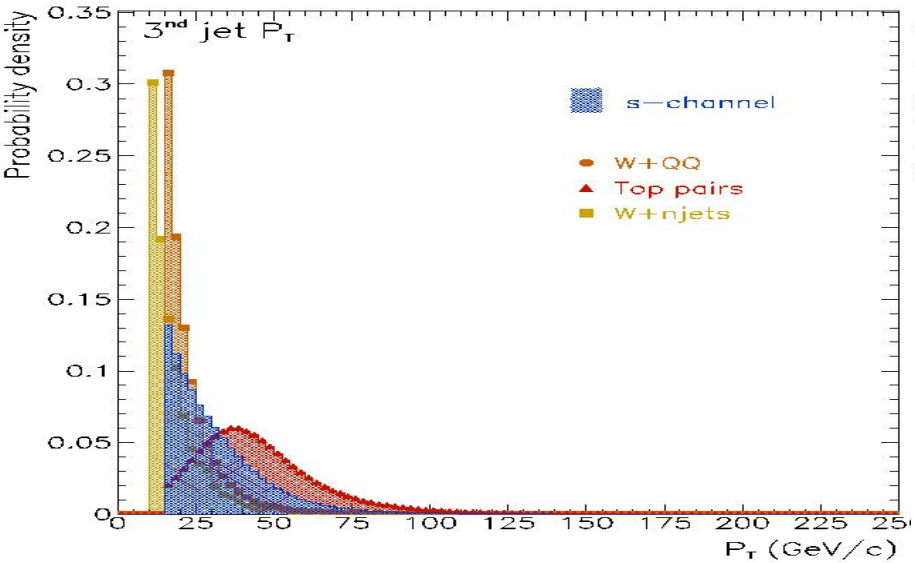
- ***Selection criteria***

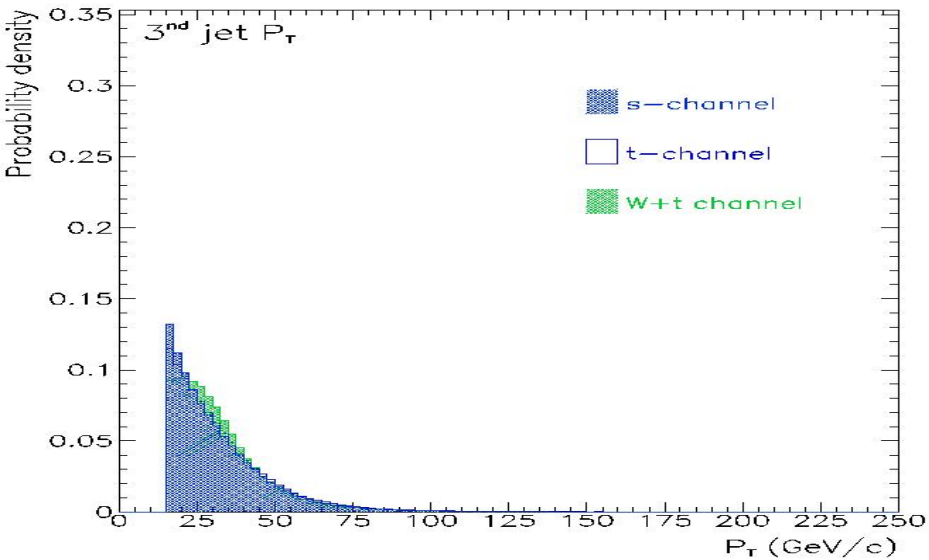
  Number of jets : N(jet) = 2

  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





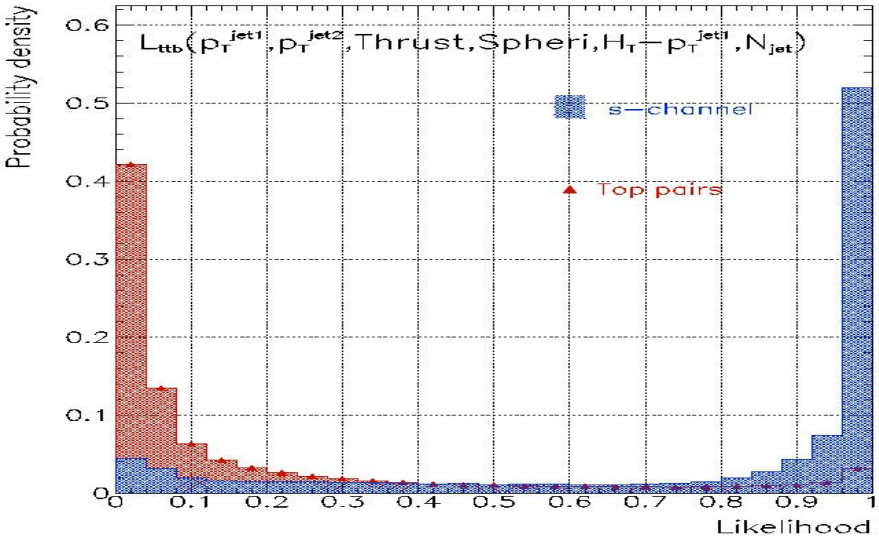
Reconstruct M_{lvb} within $m_{top} \pm 25$ GeV/c^2

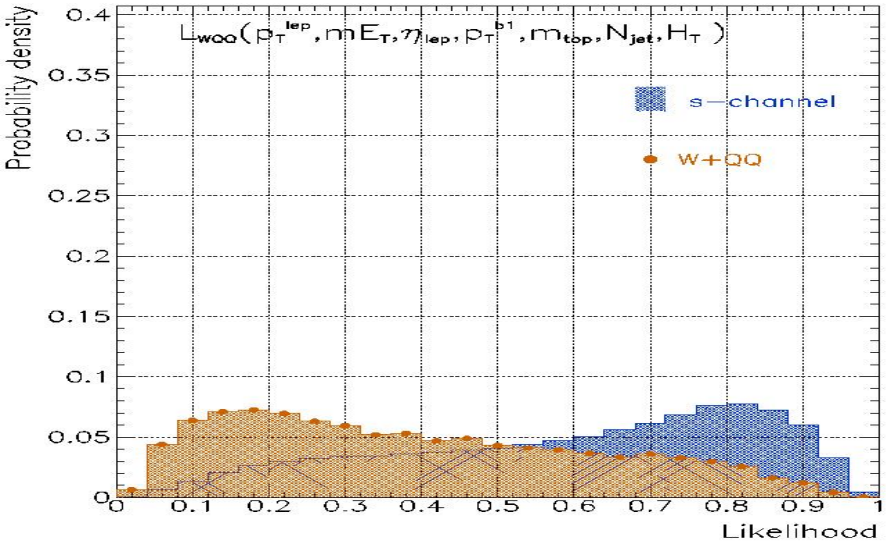
Window in H_T

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**