Prospects for single-top cross-section measurements in ATLAS

A. Lucotte , **F. Chevallier**

IN2P3 / LPSC Grenoble

Outline

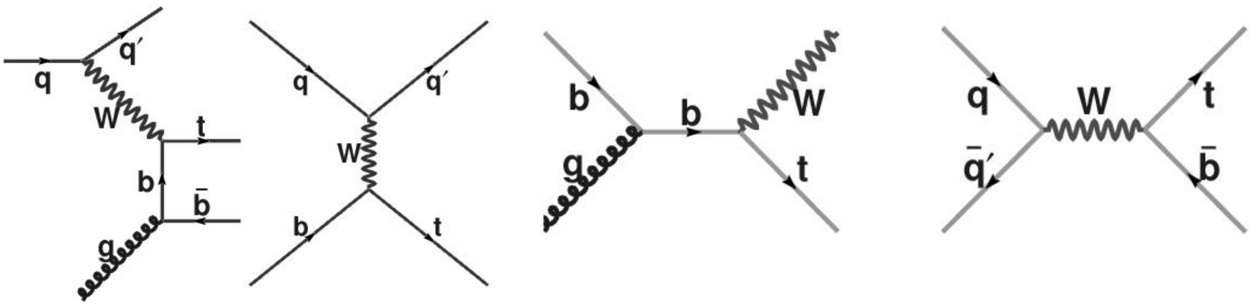
- **Introduction**
  - Context
  - Production @ LHC
- **Single-top analysis :**
  - Relevant Variables
  - Pre-selection
  - s-channel
  - t-channel
  - W+t channel
- **Why the s-channel is so interesting ?**
- **Perspectives & Conclusion**

Single Top cross-section : production & motivations

Single-top production

- **Standard Model : 3 mechanisms**

W-g (t-channel) | W+t | W* (s-channel)



  - Two of them can be seen at theTeVatron (W*,Wg)

  ➔ Still, none of them has yet been observed…

Motivations

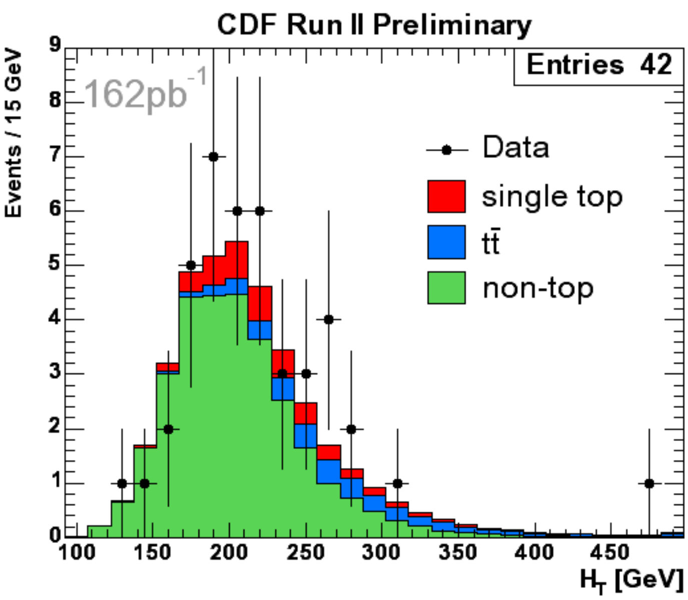
- **Properties of the Wtb vertex :**
  - Determination of $\sigma(pp \rightarrow tX)$, $\Gamma(t \rightarrow Wb)$
  - Direct determination of $|V_{tb}|$
  - Top polarization
- **Precision measurements ➔ probe to new physics**
  - Anomalous couplings
  - FCNC
  } t-channel,Wt
  - Extra gauge-bosons W' (GUT, KK)
  - Extra Higgs boson (2HDM)
  } s-channel
- **Single-top is one of the main background to …**

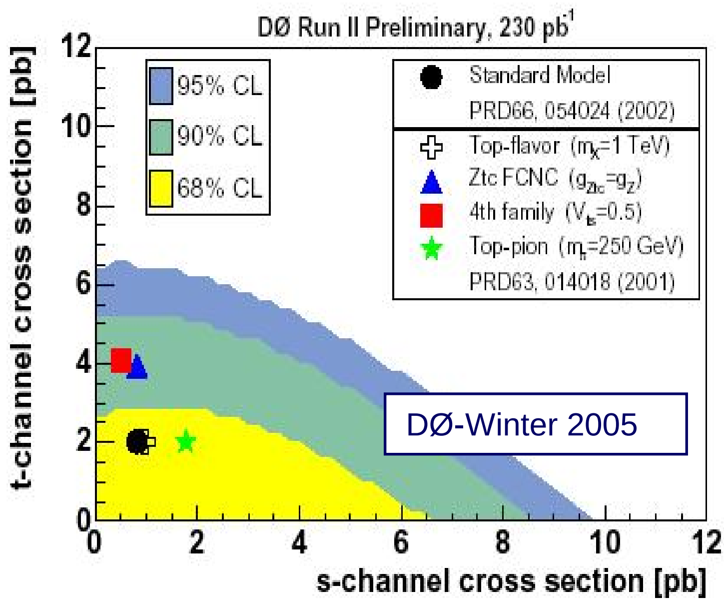
  … Higgs physics…

Single Top cross-section : Reach @ TeVatron

Measurements @ TeVatron

- **2 main contributing mechanisms in SM:**
  - σ^{SM}(W-g) ~ 1.98±0.30 pb / σ^{SM}(W*) ~ 0.88 ± 0.14 pb
- **Present analyses**
  - Low S/B and S/√B stat. limited so far
  - Main Backgrounds : WQQ , W+jets (and ttbar)
  - → W+jets normalized to data





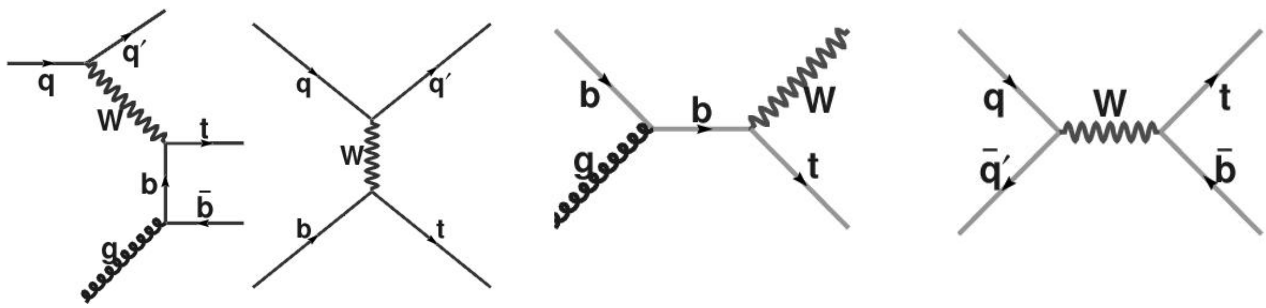
- **Systematics (DØ)**
  - Jet E-scale (~8%), b-tag, trigger modeling (~5%)
  - Jet fragmentation modeling (5%), Luminosity (~ 6.5%)
  - Backgrounds (Uncertainty Wbb,ttb normalization (18%))
- **Expectations @ Run II (2 fb^{-1})**
  - 5σ-discovery ? X-sections known at ~ 25%

Single Top cross-section : Production @ LHC

Cross-sections @ LHC

- All 3 contributing mechanisms in SM:

W-g (t-channel) | W+t | W* (s-channel)



- Computation at NLO available for W* and W-g :
  - Increase of σ(W*) by ~30 %
  - Affect p_T(jet) distribution, H_T etc…

- Parton Distribution Function (PDF) :
  - CTEQ5M1 vs CTEQ6M

hep-ph/0408049

Channel	σ(pb)	Uncertainties		
		PDF	μ-scale (μ/2-2 μ)	Δm_{top} (4.3GeV)
W-g	246.6 ± 8.7	4%	3%	1%
W+t	60 ± ??	10%	?	1%
W*	10.6 ± 0.7	4%	2%	3%

- Theoretical uncertainties:
  - Quark-gluon luminosity --choice of the (b) PDF
  - Renormalization scale μ
  - Δm_{top} (175 to 178 GeV → σ(W*) down by 6%)

Single Top : decay modes & background @ LHC

Single-Top signal

- **Decay modes:** TopReX 4.06
  - W* : W* → t bbar → ($l^+\nu$b) bbar
  - Wg: q'g → t q bbar → ($l^+\nu$b) q bbar
  - W+t: bg → t W → ($l^+\nu$b) qq'

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

Main backgrounds

- **Non Top events :** Herwig / pythia 6.2
  - QCD multi-jets (fake l,…)
  - W+n(jets) → ($l^+\nu$) n(jets)
  - WZ, W+QQ → ($l^+\nu$) Q Qbar (Q=b,c) TopReX 4.06
- **Top pair production** TopReX 4.06
  - t tbar → W^+bbar W^- b → ($l^+\nu$b)bbar ($l^-\nu$bbar) b

Cross-sections

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

→ Our main backgrounds :
~ 1/1000 ttbar
~ 3/1000 Wbb
~ 0.5/1000 W+njets

Single Top : decay modes & background @ LHC

Single-Top signal

- **Decay modes:** TopReX 4.06
  - W* : W* → t bbar → ($l^+\nu b$) bbar
  - Wg: q'g → t q bbar → ($l^+\nu b$) q bbar
  - W+t: bg → t W → ($l^+\nu b$) qq'

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

Main backgrounds

- **Non Top events :**
  - QCD multi-jets (fake l,...)
  - W+n(jets) → ($l^+\nu$) n(jets)
  - WZ, W+QQ → ($l^+\nu$) Q Qbar (Q=b,c)

Herwig / pythia 6.2

TopReX 4.06

- **Top pair production** TopReX 4.06
  - t tbar → W^+bbar W^- b → ($l^+\nu b$)bbar ($l^-\nu$bbar) b

Note: this analysis is *preliminary*:
Based on LO generators used…
(only NLO x-sections are used)
→ Results probably optimistic
→ All analyses will have to be re-run with relevant generators…

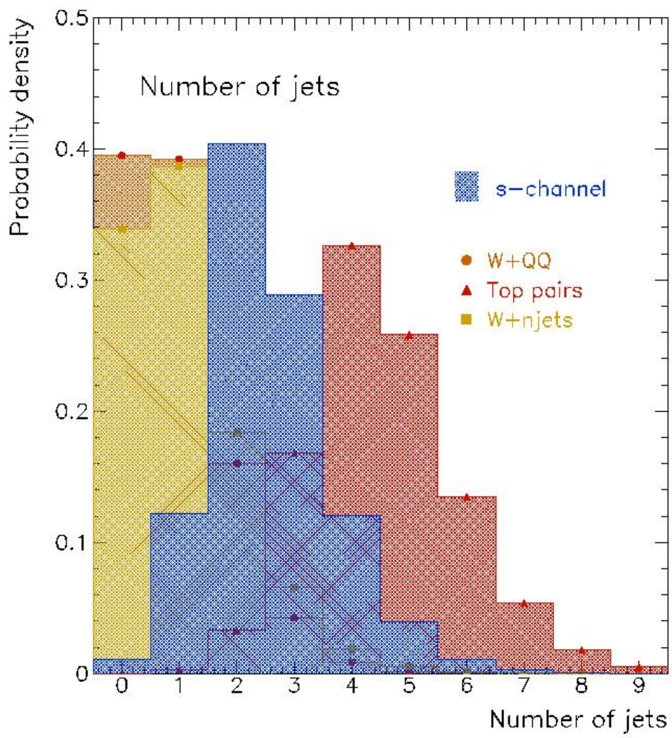
Single-top @ LHC :

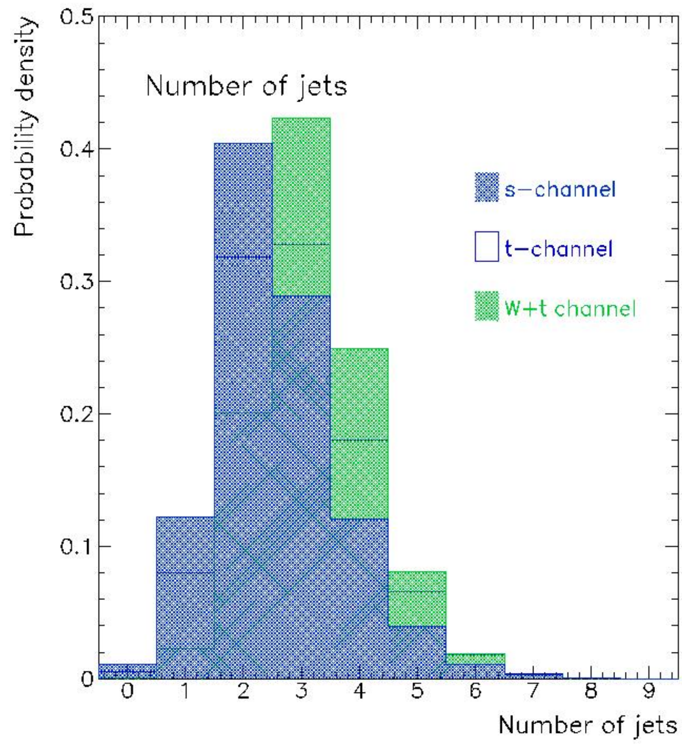
Discriminant Variables & Pre-Selection

Discriminant Variables : N(jet)

Characteristics

- Number of jets with p_T >15 GeV/c
  - W* channel : exactly 2 jets in 40% evts
  - Wbb, W+jets : ≥ 2 jets in less than 25% evts
  - ttbar : ≥ 4 jets in more than 75% evts
  - W+t channel : ≥ 3 jets in more than 70% evts
  - Wg channel : one (b-)jet is outside acceptance



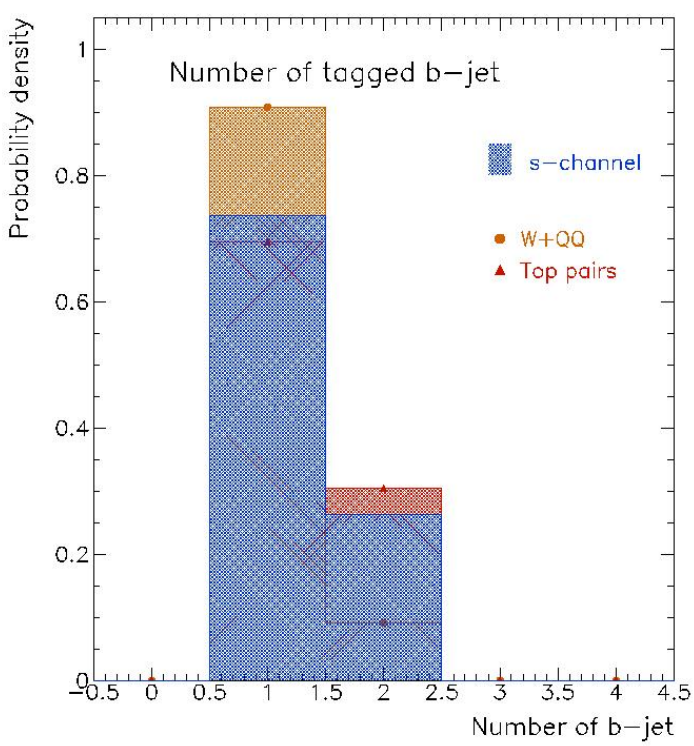


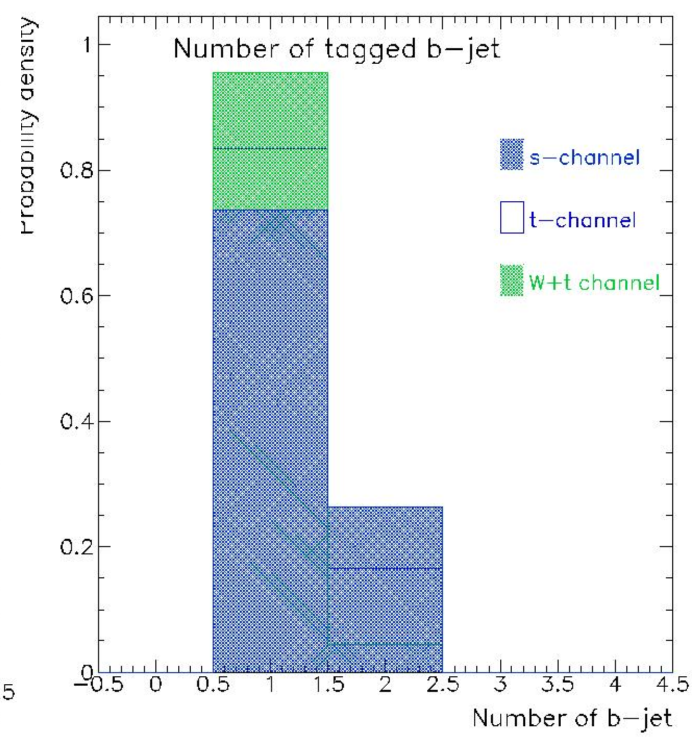
- Discriminating power:
  - N(jet) ≥ 2 will reduce WQQ, Wjets
  - N(jet) ≤ 4 will reduce ttbar
  - N(jet) = 2 will favor W*
  - N(jet) = 3 will favor W+t

Discriminant Variables : N(b-tag)

Characteristics

- **Number of b-tags with p_T > 30 GeV/c**
  - ε_b = 60% in |η| < 2.5
- **Among ≥ 1-btag sample :**
  - W* & ttbar : ~ 30% events with 2 b-tags
  - Wg channel : ~18% (2 b-tags)
  - W+t channel : < 5% (no 2nd b)
  - WQQ channel : < 9% with 2 b-tags



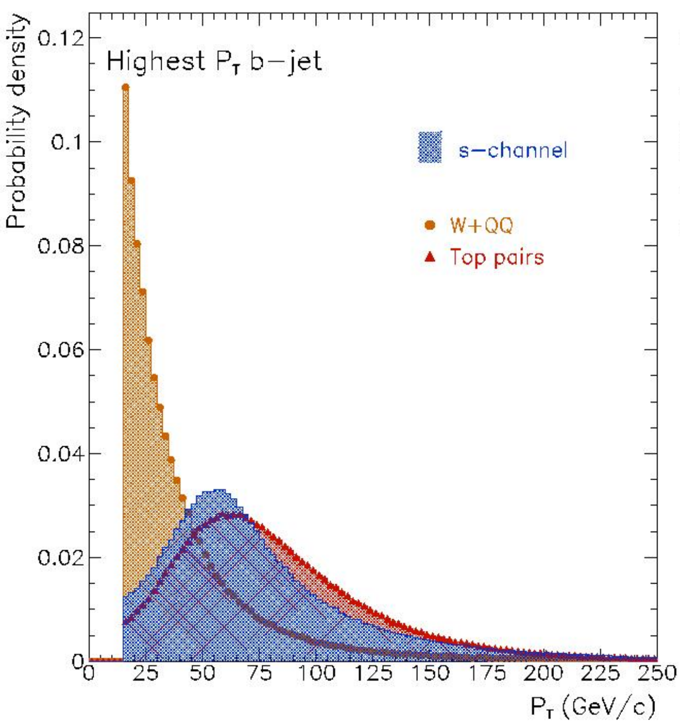


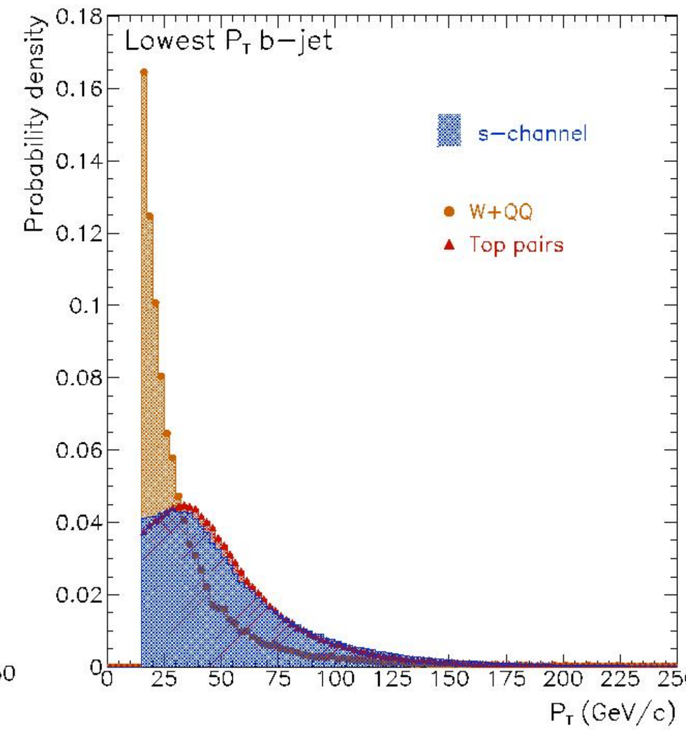
- **Discriminating power :**
  - N(b-tag) = 1 exactly for W+t analysis
  - N(b-tag) = 2 exactly for W* analysis
    while reducing WQQ,Wjets,W+t,Wg

Discriminant Variables : b-jet

Characteristics

- **High p_T b-tagged jets**
  - **Top events : harder spectrum**
  - **WQQ events : softer b-jets**
- **b-jet Topology**
  - **W* & Wg & ttbar : ΔR(b,b) ~ 1.0 - 1.5**
  - **WQQ events : b-jets closer to each other**



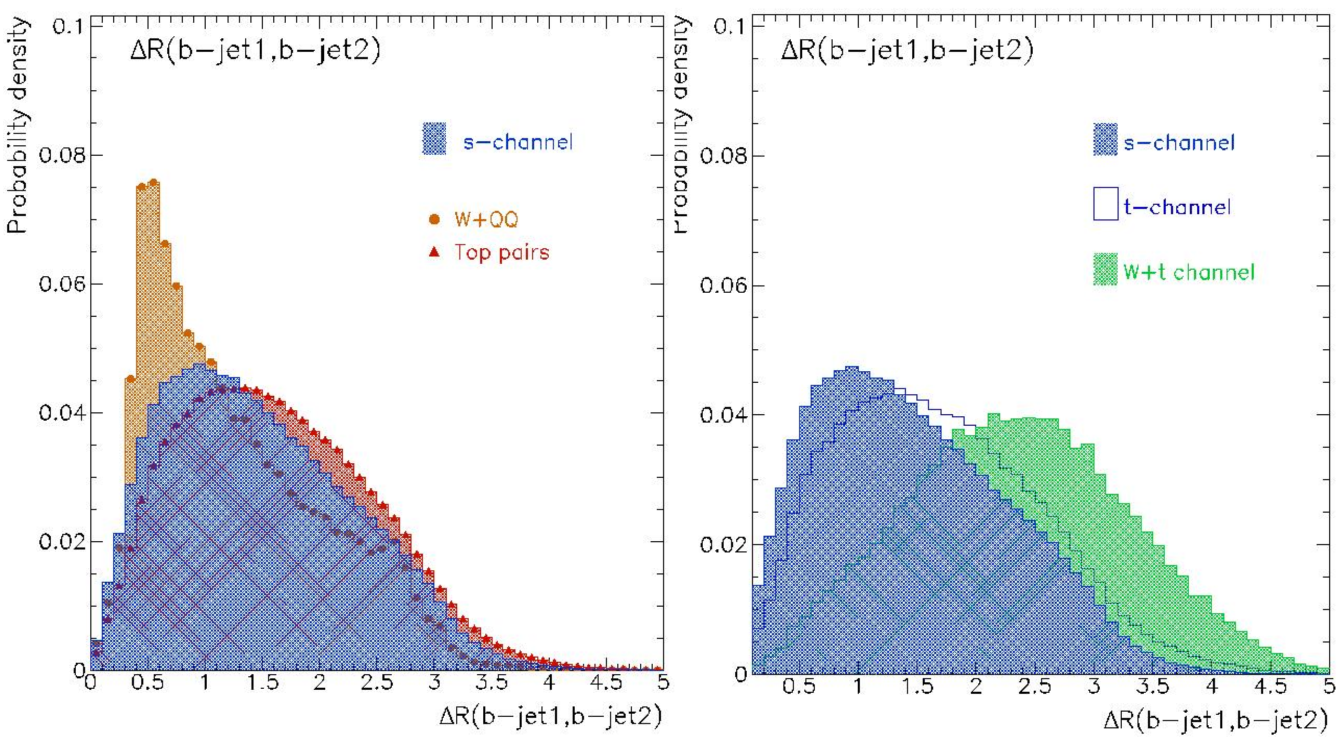


- **Discriminating power**
  - **Higher-p_T & well separated b-jets favor W*/ttb/Wg**
  - **Softer and closer b-jets favor WQQ selection**

Discriminant Variables : b-jet

Characteristics

- High p_T b-tagged jets
  - Top events : harder spectrum
  - WQQ events : softer b-jets
- b-jet Topology
  - W* & Wg & ttbar : ΔR(b,b) ~ 1.0 - 1.5
  - WQQ events : b-jets closer to each other

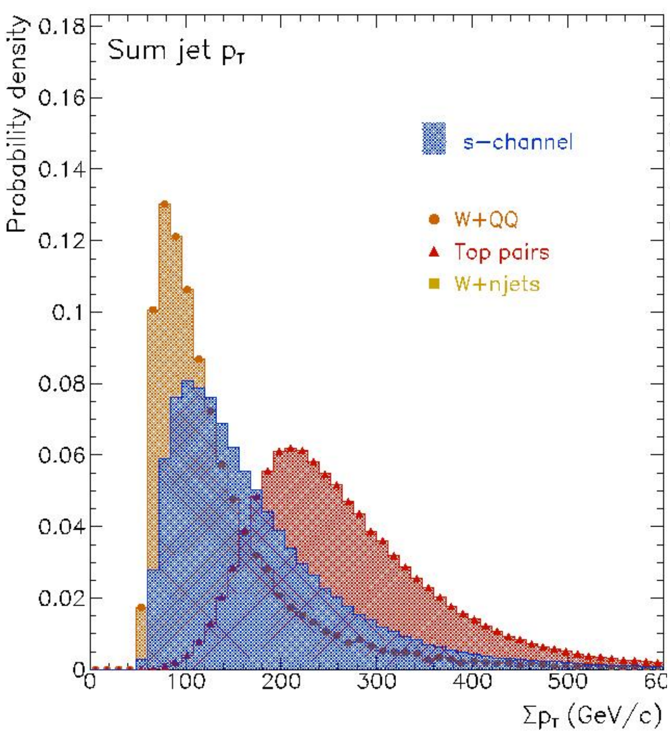


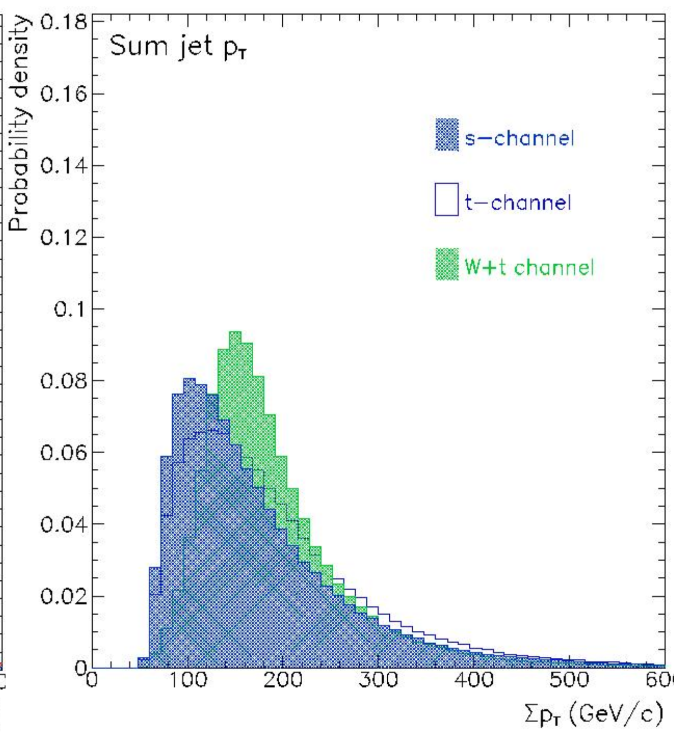
- Discriminating power
  - Higher-p_T & well separated b-jets favor W*/ttb/Wg
  - Softer and closer b-jets favor WQQ selection

Discriminant Variables : P_T

Characteristics

- **Sum of all objects E_T in the event**
  - **$H_T = \Sigma p_T(jet) + p_T(l) + mE_T$ or $P_T = \Sigma p_T(jet)$**
- **Samples**
  - **W* & Wg & W+t : H_T more discriminant than P_T**
  - **WQQ, W+jets : H_T and P_T lower than top events**
  - **ttbar events : H_T ~ 350 GeV/c & P_T ~ 230 GeV/c**





- **Discriminating power**
  - **Single-top : H_T more discriminant vs WQQ than P_T → use of leptonic and mE_T information is relevant**
  - **ttbar events : high values of HT /PT favor ttbar**

Discriminant Variables : H_T

Characteristics

- **Sum of all objects E_T in the event**
  - **$H_T = \Sigma p_T(jet) + p_T(l) + mE_T$ or $P_T = \Sigma p_T(jet)$**
- **Samples**
  - **W* & Wg & W+t : H_T more discriminant than P_T**
  - **WQQ, W+jets : H_T and P_T lower than top events**
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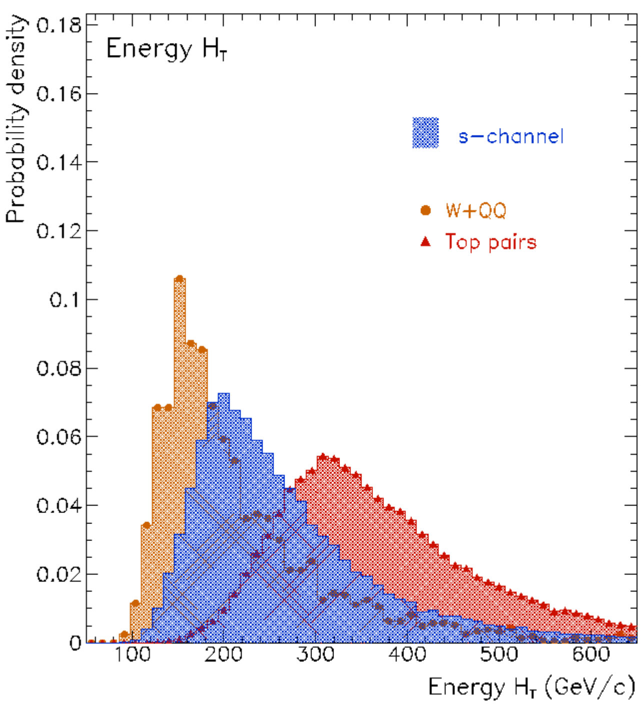
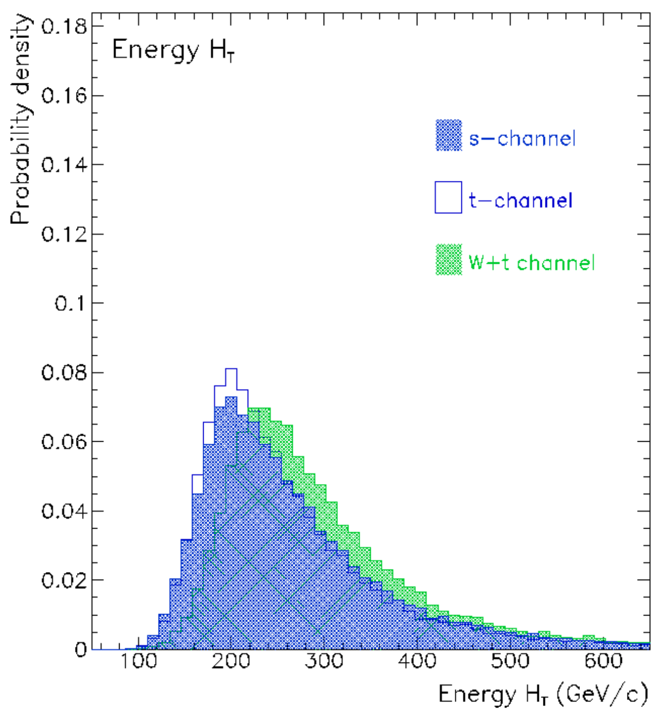


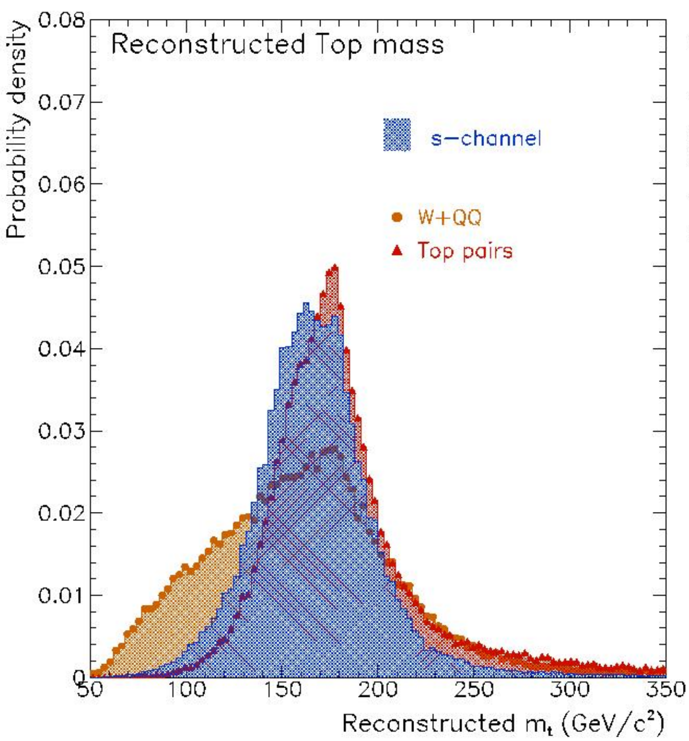


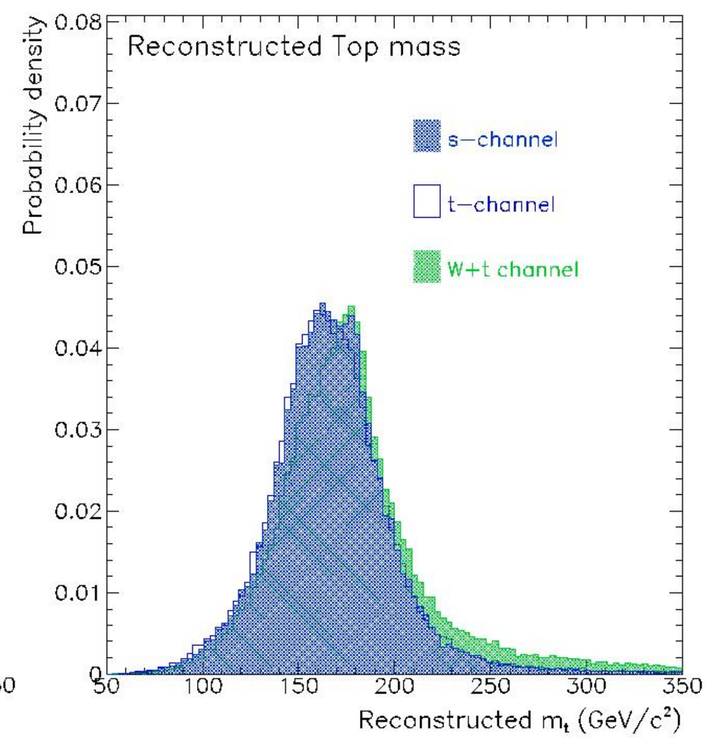
- **Discriminating power**
  - **Single-top : H_T more discriminant vs WQQ than P_T**
    → use of leptonic and mE_T information is relevant
  - **ttbar events : high values of HT /PT favor ttbar**

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

Characteristics

- **Determination of M(lνb)**
  - **Interpret $p_T(\nu)$ as missing E_T**
  - **Compute $p_l(\nu)$ using the W-mass constraint**
    → 2-fold ambiguity (use real part if solution is complex)
  - **Compute M(lνb) combinations**
    → Take $p_L(\nu)$ and b-jet : closest value to m_{top}



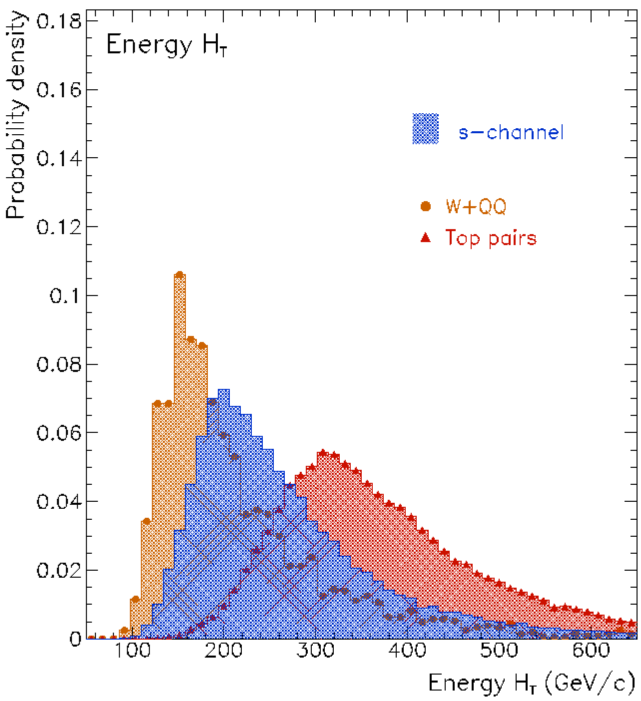


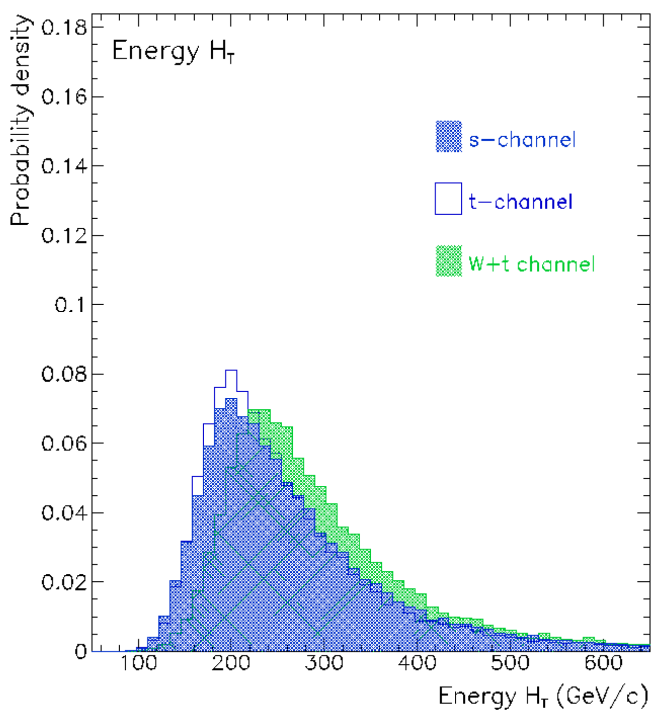
- **Discriminating power**
  - **Reduce non-top events WZ, WQQ, W+jets**

Single-top : Pre-Selection

Strategy

- Common selection for all 3 single-top samples :
  - 1 High pT Lepton + mET
  - → reduce non-W events
  - At least two high-p_T jets
  - → reduce W+jets events



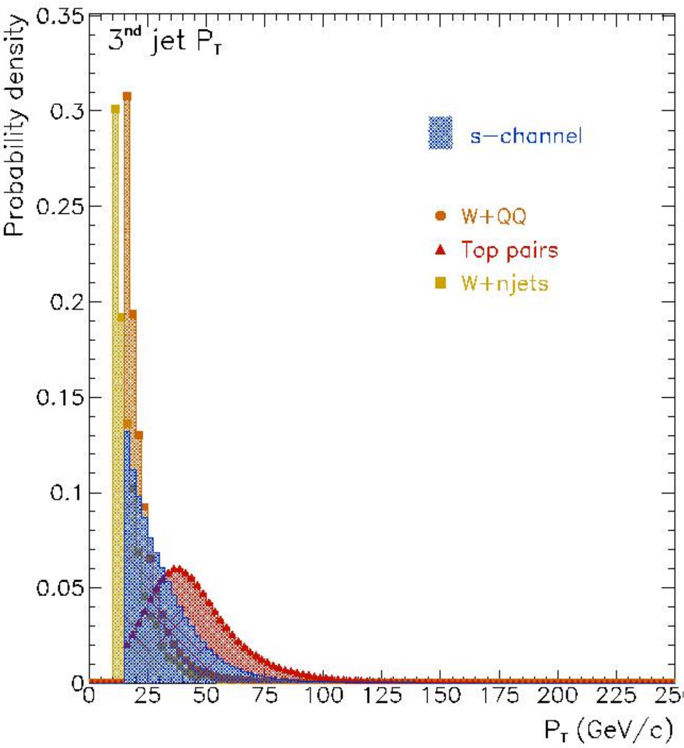


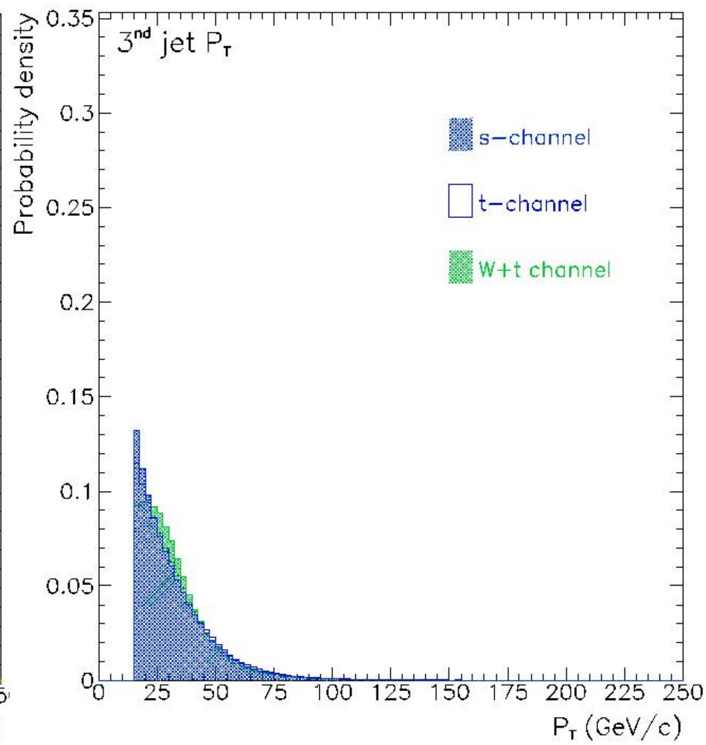
- Main results :
  - Single-top ~22-26%
  - ttbar ~ 38%
  - WQQ ~ 1.5% , W+njets < 1/1000

S-channel : strategy

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 $M_{l\nu b}$ within m_{top} ± 25 GeV/c²**
  - **Window in H_T**

S-channel : results

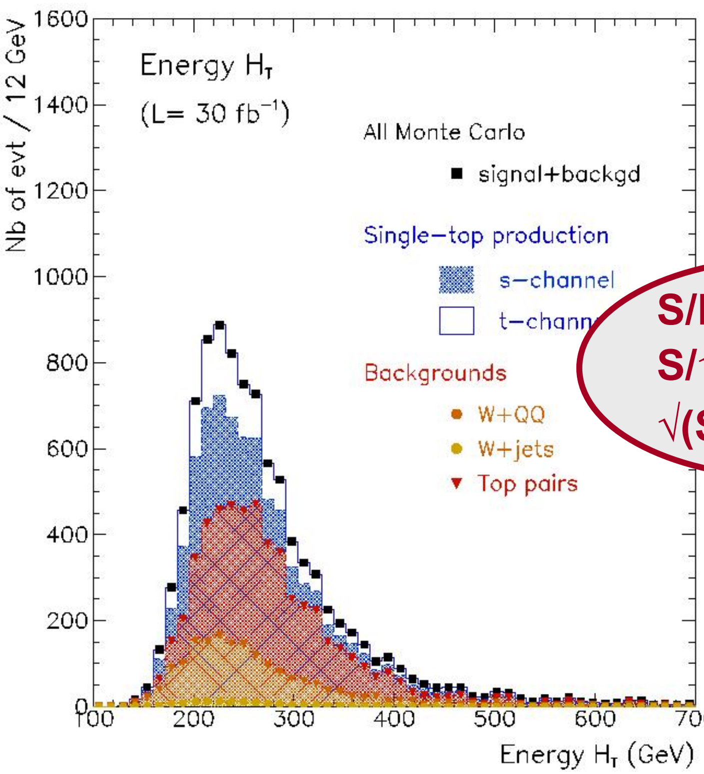
Sequential Analysis

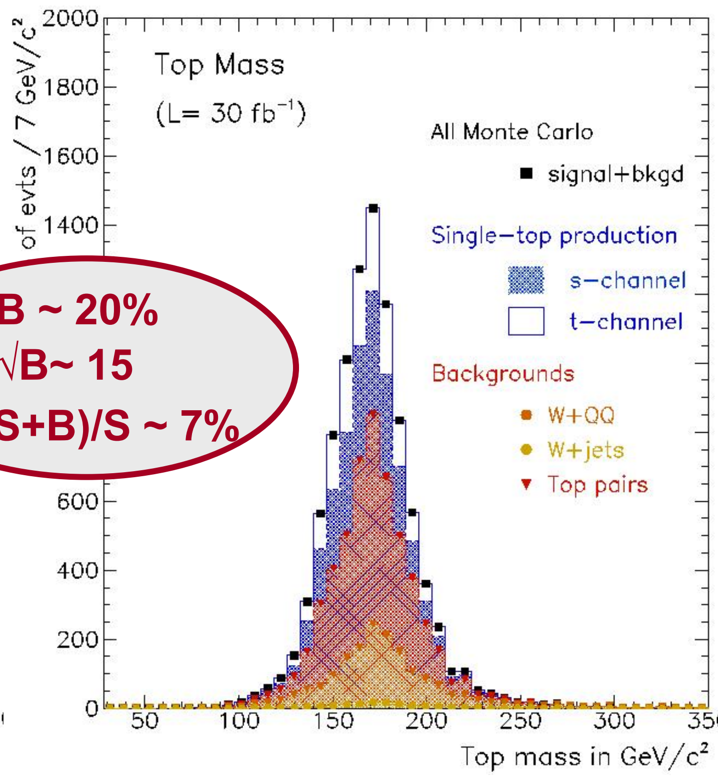
- **Selection efficiency**

	W*	Wg	W+t	tt	WQQ	W+jets
Pre-Selection ε(%)	26.2	23.7	22.4	38.3	1.46	0.05
Selection ε(%)	1.73	0.105	0.002	0.035	0.059	0.0001
N^{event}(30 fb^{-1}) ± MC stat.	1,141 ± 7	1,680 ± 48	10 ± 3	2,580 ± 150	1,148 ± 38	170 ± 85

  - N(jet) = 2 → reduces tt by a factor ~ 20 vs W*
  - 2 high-p_T b-jets → reduces WQQ by ~2 and Wg by ~8
  - $M_{l\nu b}$ and H_T → reduce non-top by ~2

- **Distributions with 30 fb^{-1}**



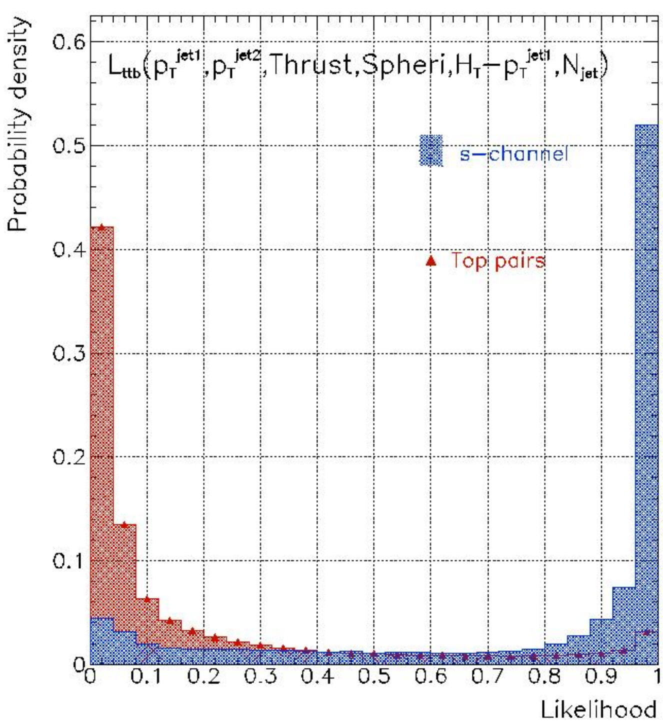


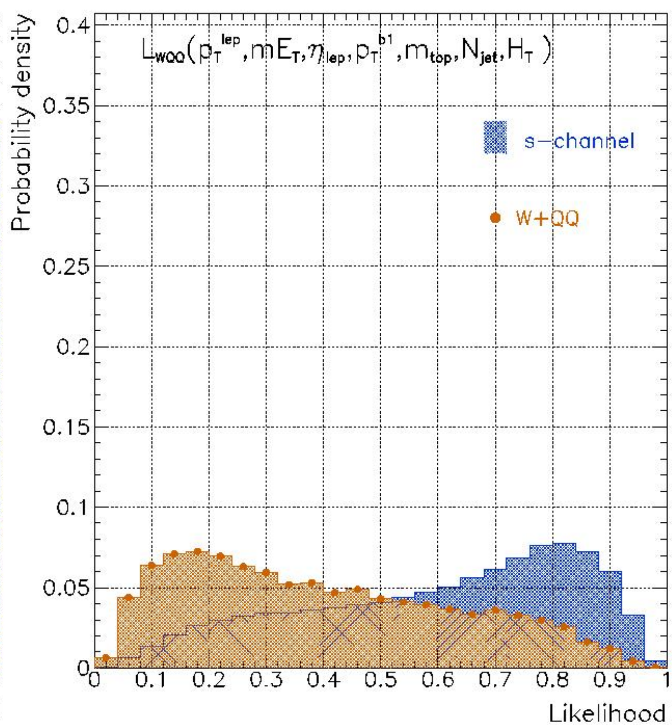
S/B ~ 20%
S/√B~ 15
√(S+B)/S ~ 7%

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")
  - **Neural Net**





- **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

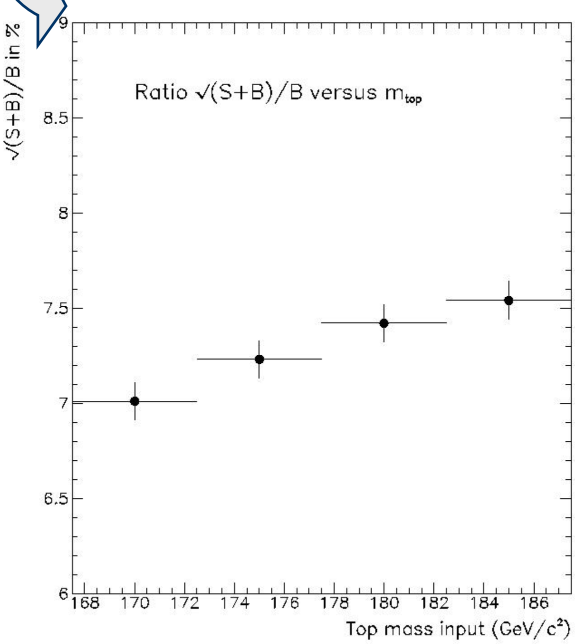
Systematics

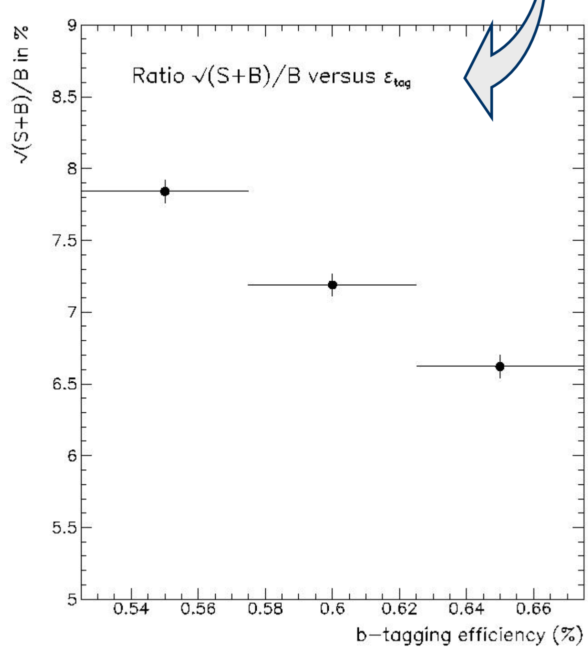
- **Experimental systematics**

  Main sources that degrades the expected precision by

  - **Input Top mass : ~ 0.5%**
  - **b-tagging efficiency & mistag rates : ~ 0.7%**
  - **(b)-jet Energy scale : ~ 2% (p_T, H_T, m_t cuts)**

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





- **Theoretical uncertainty**
  - **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)

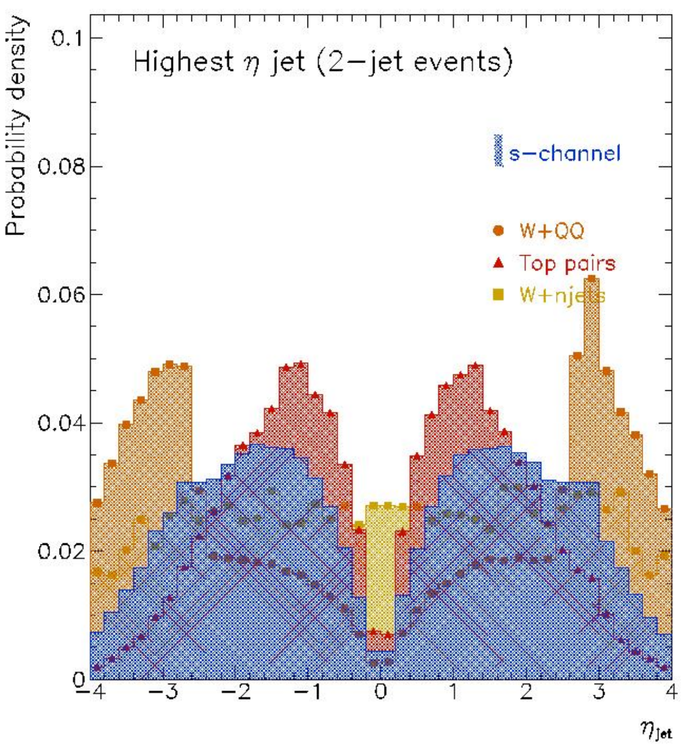
    $(\Delta\sigma/\sigma)_{WQQ}$ = 30% ? $(\Delta\sigma/\sigma)_{Wjets}$ = 50% ?

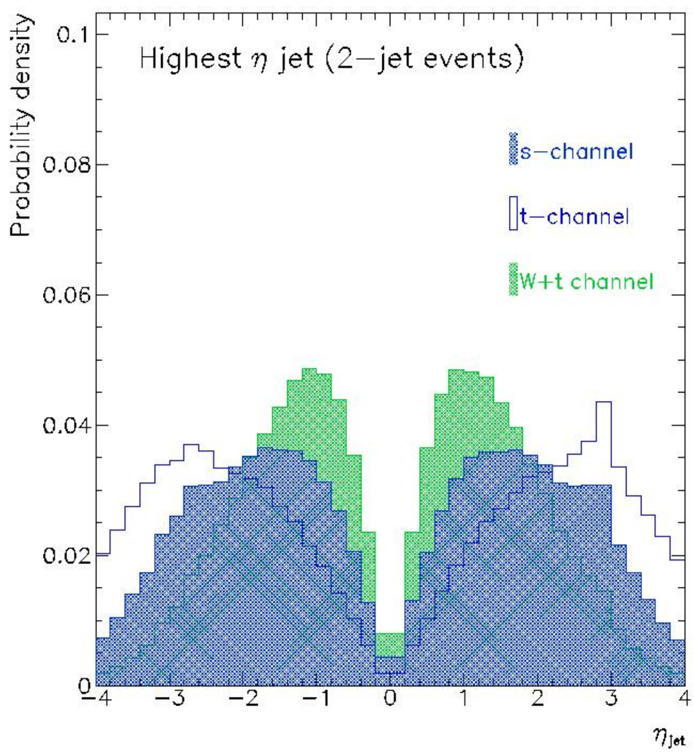
    → σ_{backgd} predictions : ~0.8%

Wg channel : strategy

Sequential analysis

- Selection criteria
  - Number of jets : N(jet) = 2
  - Presence of a high-p_T b-tagged jets (p_T>40GeV/c)
    Wg evts have 1 b-jet escaping the acceptance
    → requires **only** 1 b-tagged jet
  - Presence of a high-p_T forward jet
    → 1 jet with $|\eta|>2.5$ and $p_T \geq 50$GeV/c





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

Wg channel : results

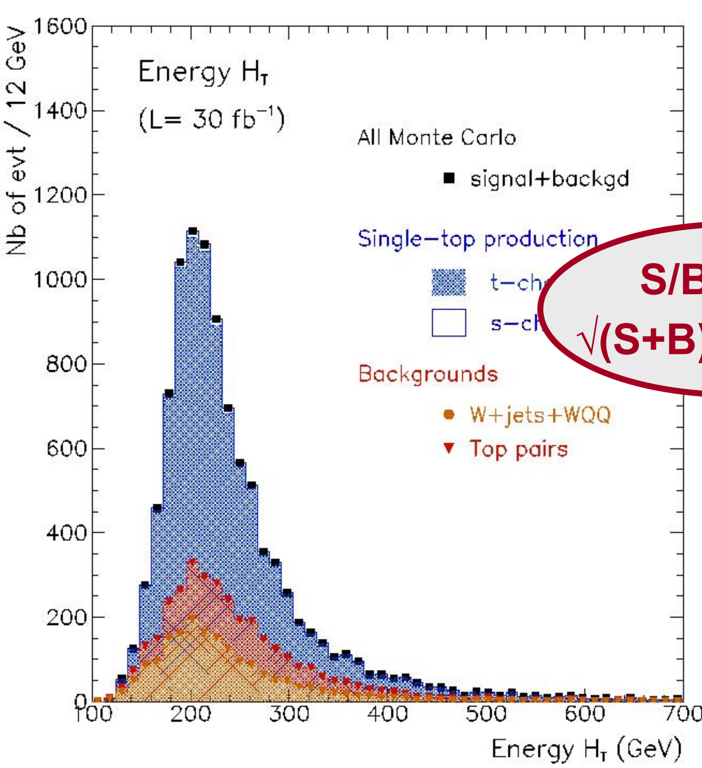
Sequential Analysis

- **Selection efficiency**

	W*	Wg	W+t	tt	WQQ	W+jets
Pre-Selection (%)	26.2	23.7	22.4	38.3	1.46	0.05
Selection ε(%)	0.22	0.44	0.023	0.007	0.006	0.0013
N^{event}(30 fb^{-1}) ± MC stat.	150 ± 6	7,080 ± 160	125 ± 13	500 ± 150	130 ±40	1,500 ± 750

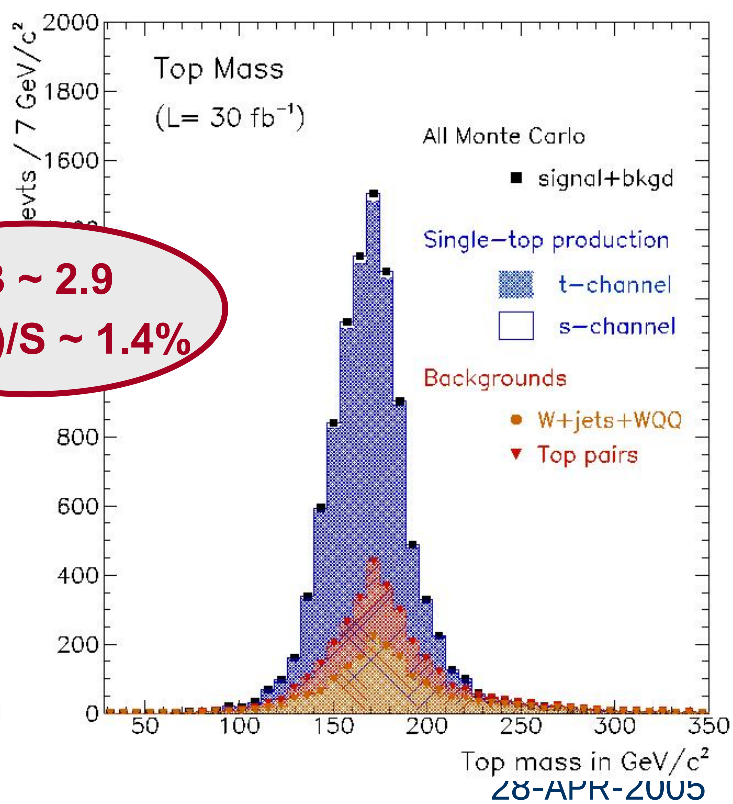
  - N(jet) = 2 → reduces tt by ~6 vs Wg
  - 1 high-p_T fwd jet → reduce tt (by ~5), Wt(~10), Wjj(~2)
  - Great uncertainty on WQQ / W+jets backgrounds

- **Distributions with 30 fb^{-1}**



S/B ~ 2.9

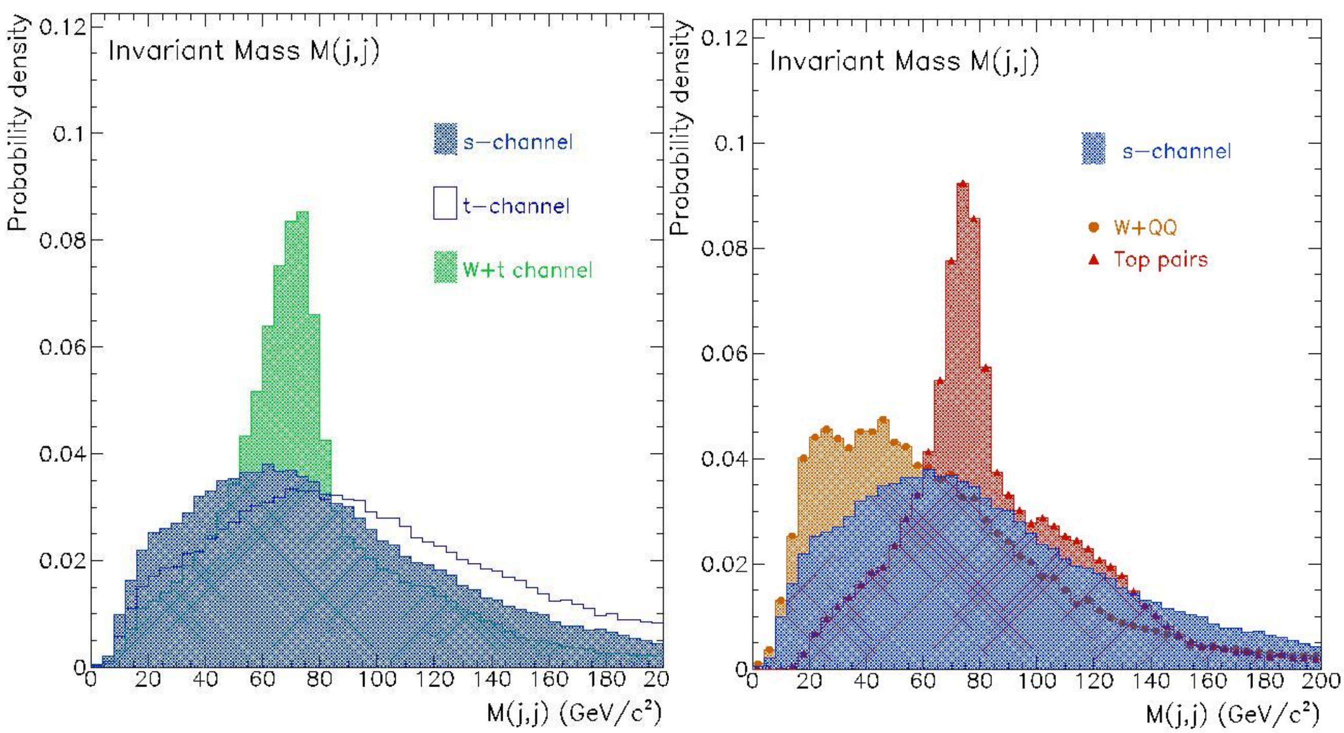
√(S+B)/S ~ 1.4%



W+t channel : strategy

Analysis Strategy

- **Selection of a specific topology**
  - **Number of high-p_T jets Njet) = 3**
  - **Presence of a high-p_T b-tagged jets**
    → Only **one b-jet in W+t events**
  - **Presence of a W-boson mass peak**
    → requires 60 < M(j,j) < 90 GeV/c^2



  - **Reconstruct M_{lvb} within ±25 GeV/c^2**
  - **Window in H_T or Invariant Mass**

W+t channel : results

Sequential Analysis

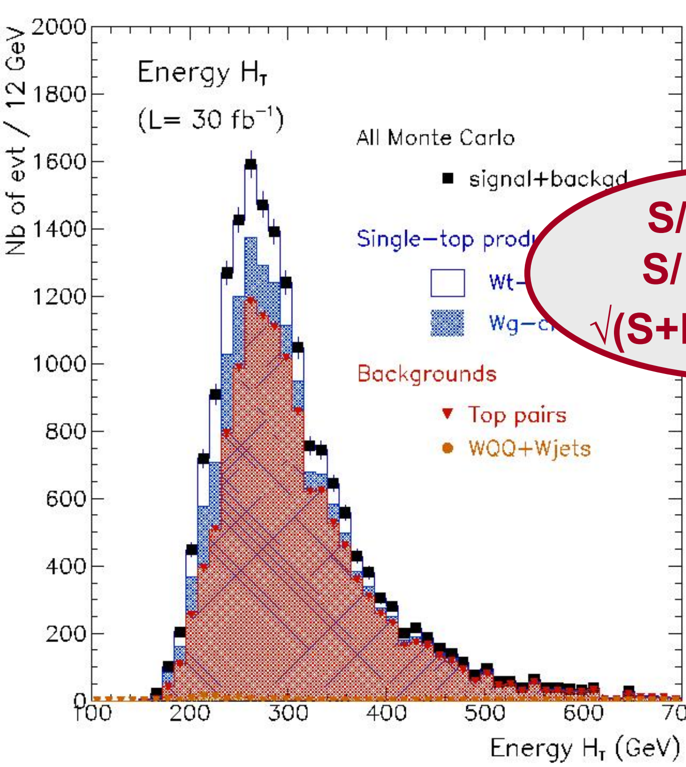
- **Selection efficiency**

	W*	Wg	W+t	tt	WQQ	W+jets
Pre-Selection ε(%)	26.2	23.7	22.4	38.3	1.46	0.05
Selection ε(%)	0.16	0.25	0.88	0.35	0.004	0.0003
N^{event}(30 fb^{-1}) ± MC stat.	105 ± 5	4,050 ± 80	4,720 ± 80	26,300 ± 400	90 ± 20	xxx ± 85

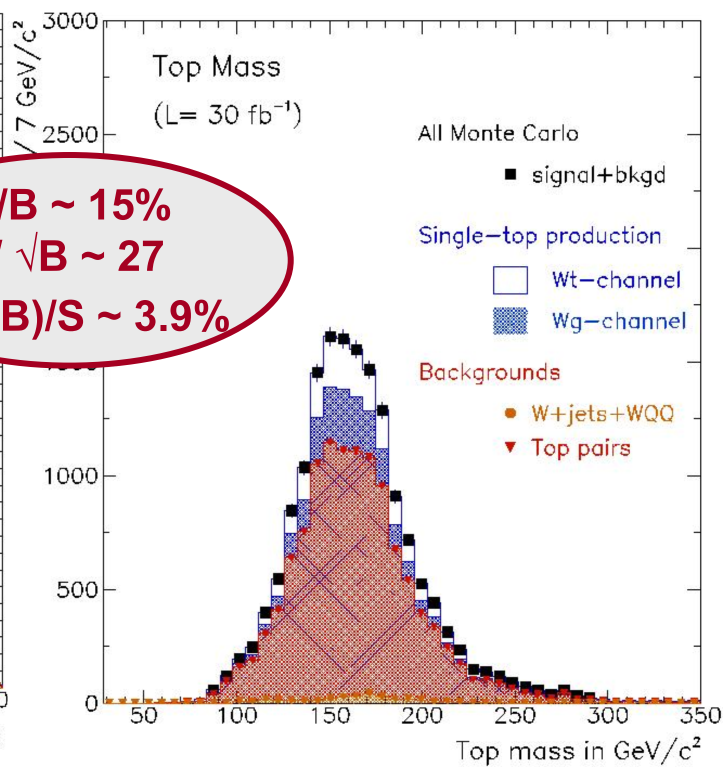
  - N(jet) = 3 → reduces Wjj & WQQ ~3.5 wrt W+t
  - M(jj) ~ M_W → reduces WQQ/jets by ~3 wrt W+t

  → Good knowledge of tt background is mandatory

- **Distributions with 30 fb^{-1}**



S/B ~ 15%
S/ √B ~ 27
√(S+B)/S ~ 3.9%



Why measuring the s-channel precisely ?

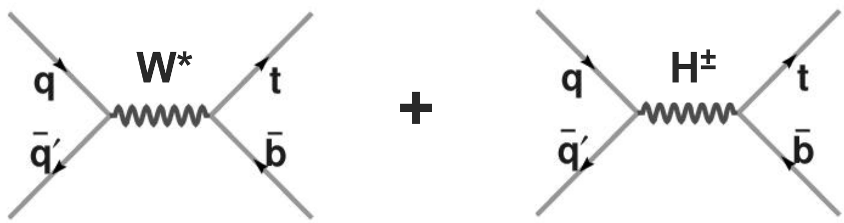
an example :

the search for a heavy charged Higgs

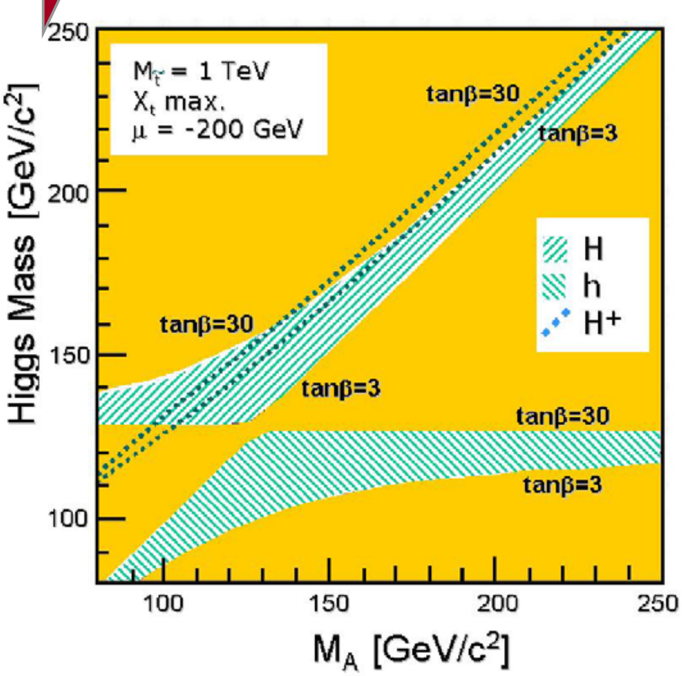
S-channel with 30 fb^{-1} : sensitivity to a Higgs $H^{\pm}$

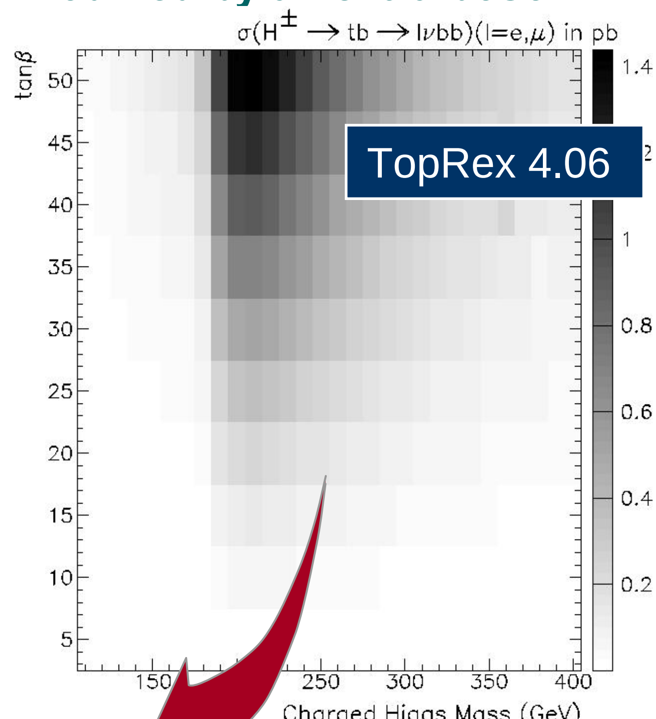
Charged Higgs and single-top

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



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





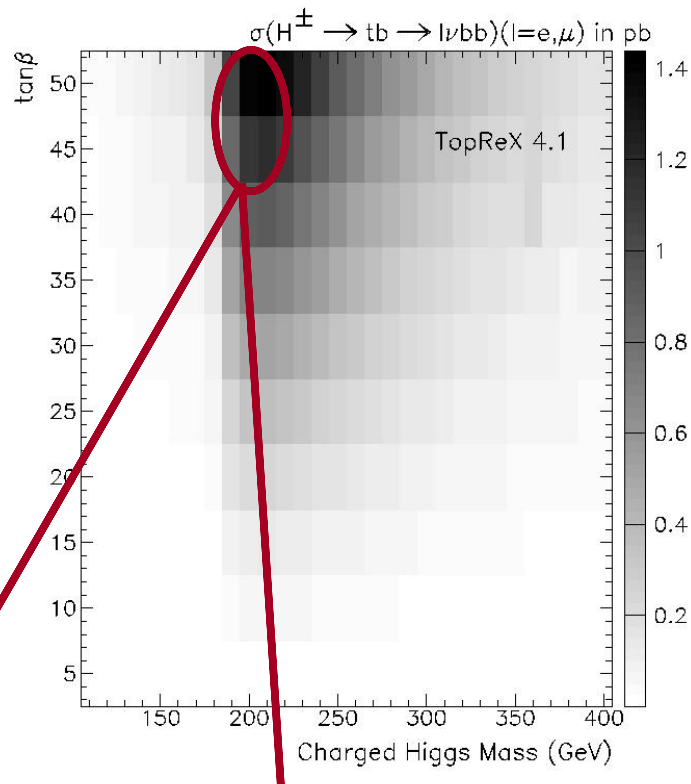
- **Cross-section σ($H^{\pm}$→tb) in MSSM**
  - Relevant for m_H above top mass
  - Can be as high as ~700 fb for high tanβ

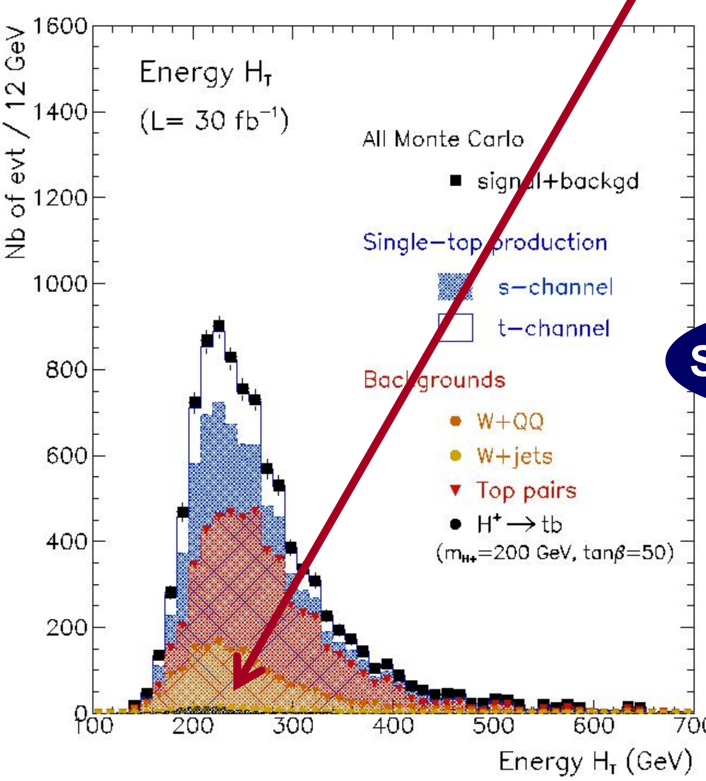
S-channel with 30 fb^{-1} : sensitivity to a Higgs H$^{\pm}$

Sensitivity to H$^{\pm}$

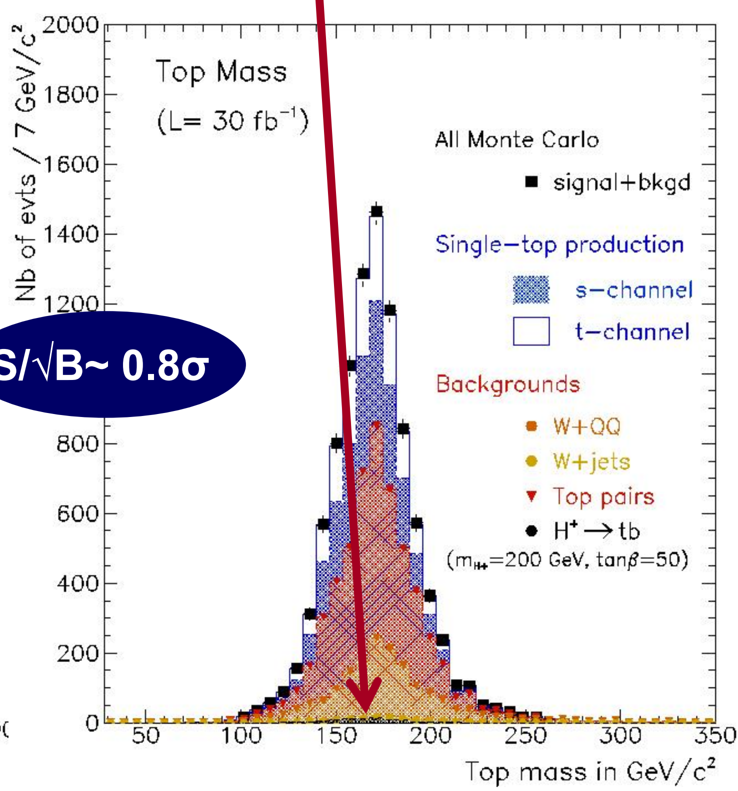
- **Cross-section**
  - **Decreases with m_H**
  - **Increases with tanβ**
- **Efficiency**
  - **ε = 0.16±0.01%**
  - **Increases with m_H**

$m_{H\pm}$=200 tanβ=50
N~60±5





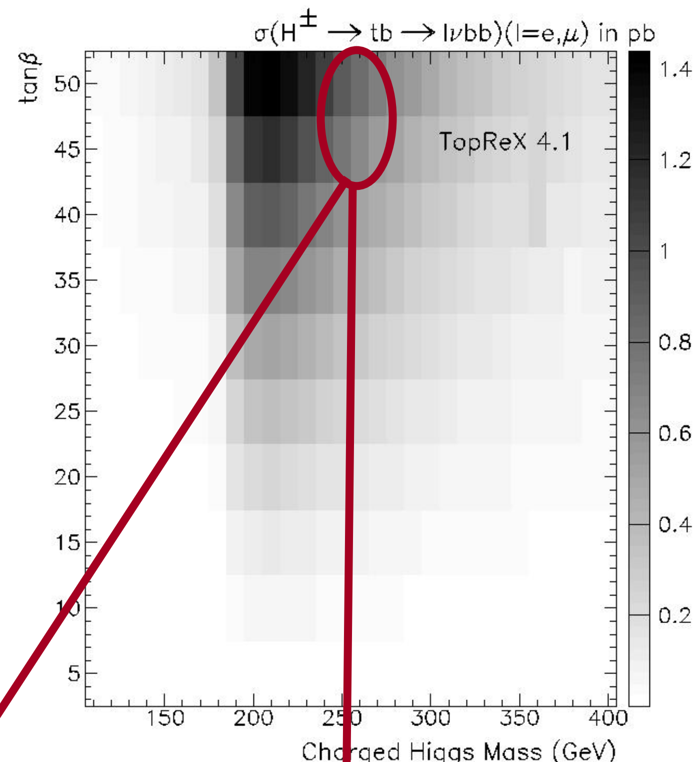
S/√B~ 0.8σ



S-channel with 30 fb^{-1} : sensitivity to a Higgs H$^{\pm}$

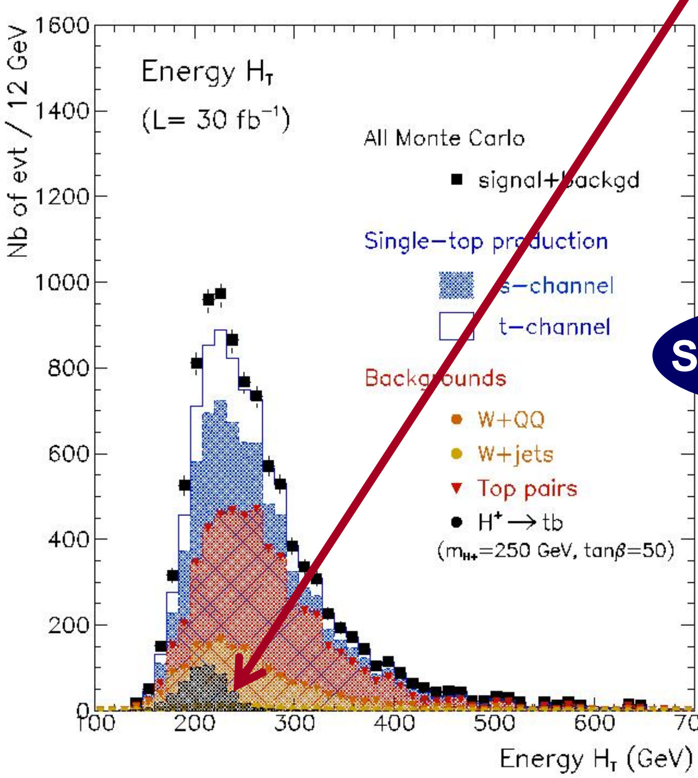
Sensitivity to H$^{\pm}$

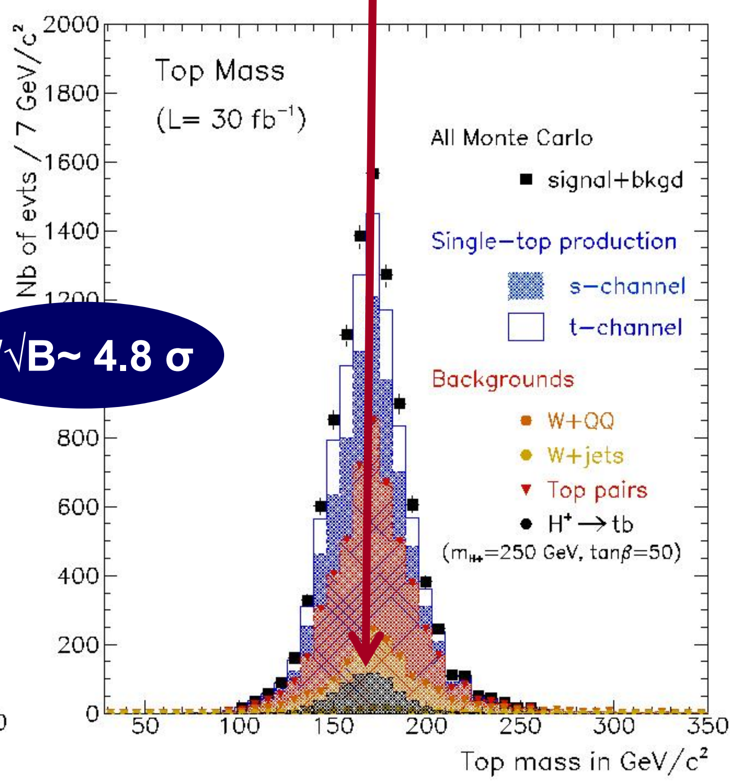
- **Cross-section**
  - Decreases with m_H
  - Increases with tanβ
- **Efficiency**
  - ε = 1.92±0.04%
  - Increases with m_H



$m_{H\pm}$=250 tanβ=50
N~365±10

S/√B~ 4.8 σ



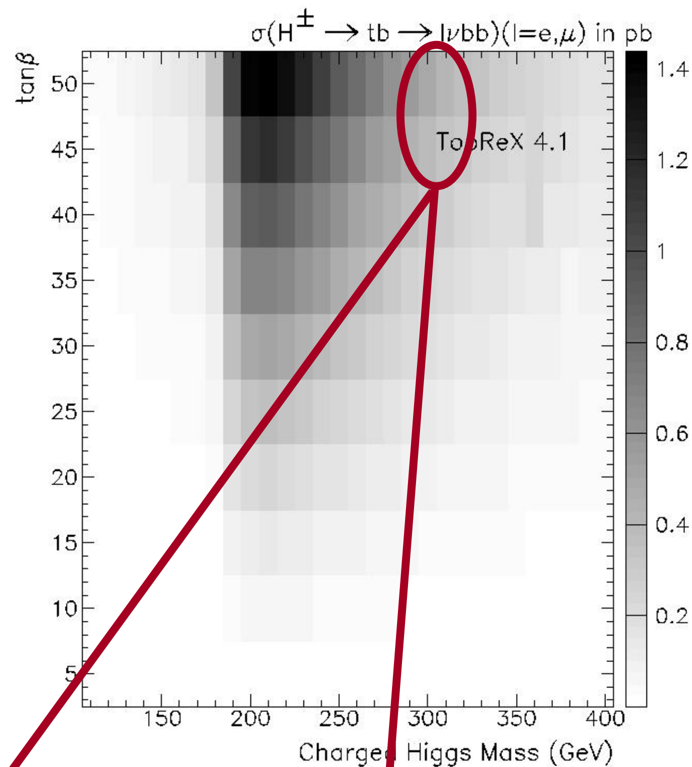


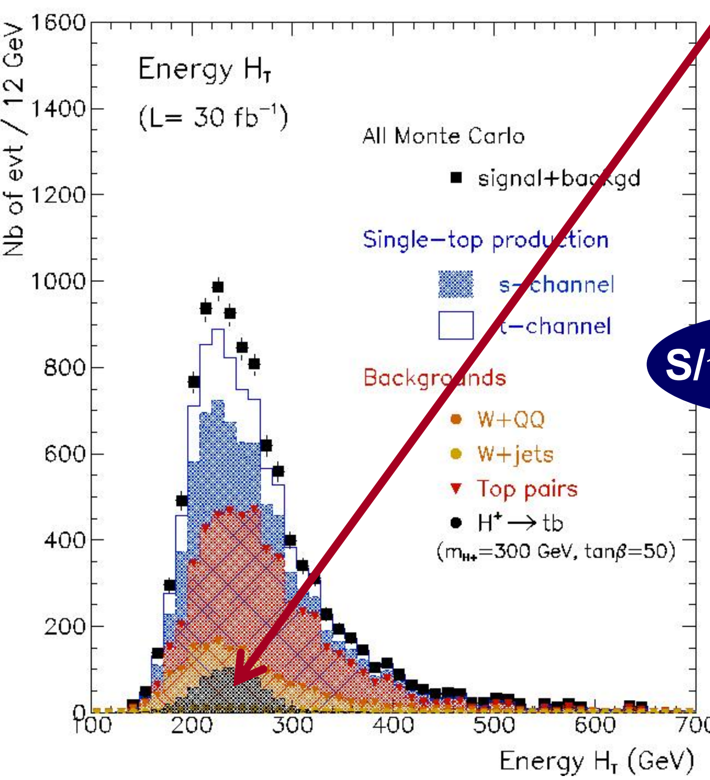
S-channel with 30 fb^{-1} : sensitivity to a Higgs $H^{\pm}$

Sensitivity to $H^{\pm}$

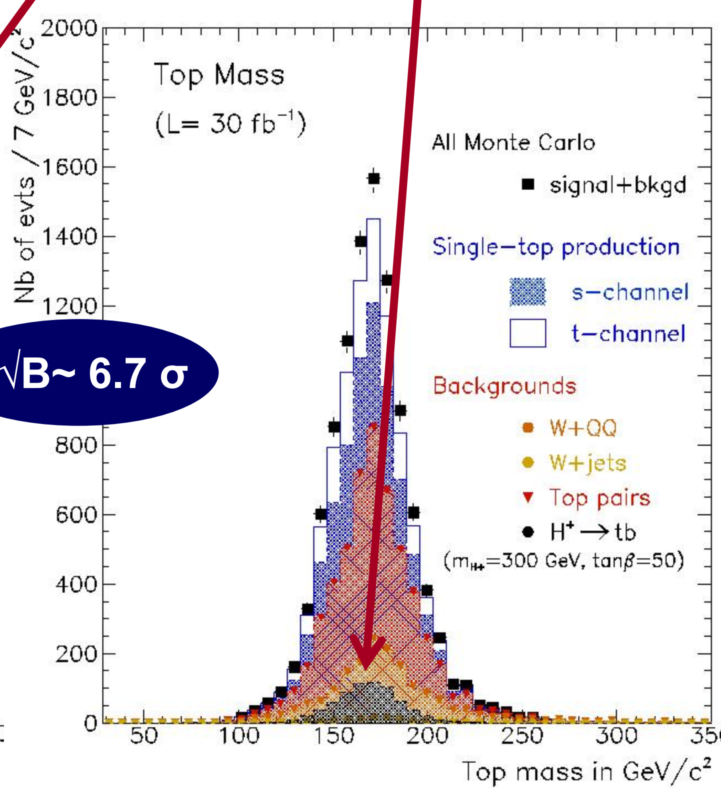
- **Cross-section**
  - Decreases with m_H
  - Increases with tanβ
- **Efficiency**
  - $\varepsilon = 3.46 \pm 0.06\%$
  - Increases with m_H

$m_{H\pm}$=300 tanβ=50
N~500±10





S/√B~ 6.7 σ



Conclusion

Single-top Measurements

- **Precision measurement possible @ LHC**
  - S-channel is more difficult than any other channels
    tt pair and WQQ, Wjets major backgrounds
    Wg is also a significant background
    → Stat. precision is about ~7 % in 30 fb^{-1}
    → Can be significantely improved with Likelihood, NN
  - W-g channel
    Higher signal cross-section
    Contamination by tt pair & W+jets required
    → Stat. precision ~ 1-2%
  - W+t channel
    top-pair is the major backgd
    Wg is also a significant background
    → Stat. precision ~ few %

- **Sources of systematics**
  - JES should be a dominant source of error
  - b-tagging knowledge (model.) is crucial
  - Limitation in background knowledge
    → Absolute need for NLO generators (W+t, W*, Wg, tt)
    → Use of data (ttbar, WQQ, W+jets)
  - Improved analysis required : likelihood & NN

Perspectives

Single-top Measurements

- **Single-top analyses :**
  - Performed with LO generator
    → NEED to switch to NLO (for S and B)
  - Performed with Fast Simulation
    → Need to use FullSim

TeVatron Contribution…

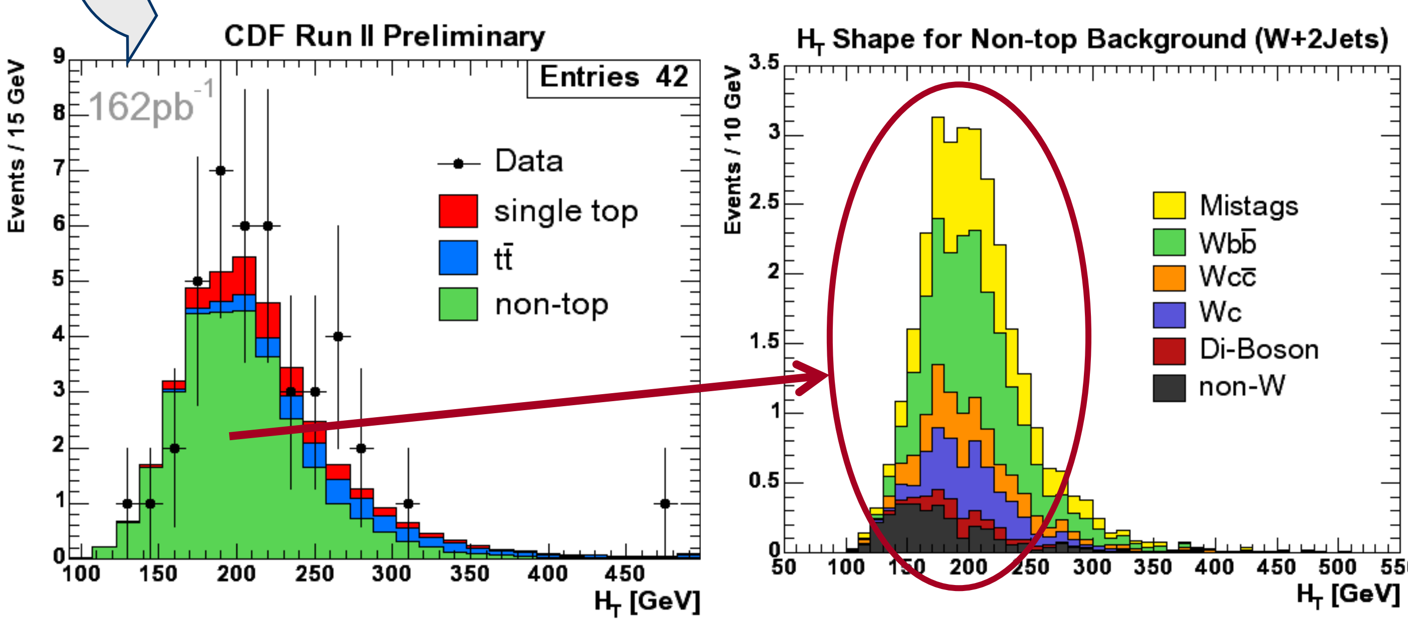
- **Knowledge of main backgrounds**

  Use of tt, Wbb and W+jets from the data

  → Validation of NLO (tt, single-top) generators at low √s

  → Validation of Wbb/cc & W+jets generators at low √s

  → Use of techniques NN, likelihood etc…



C.P. Yuan et al, hep-ph/0409040
hep-ph/0408180, Q. Cao, R.Schwienhorst