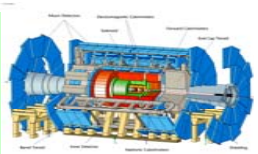
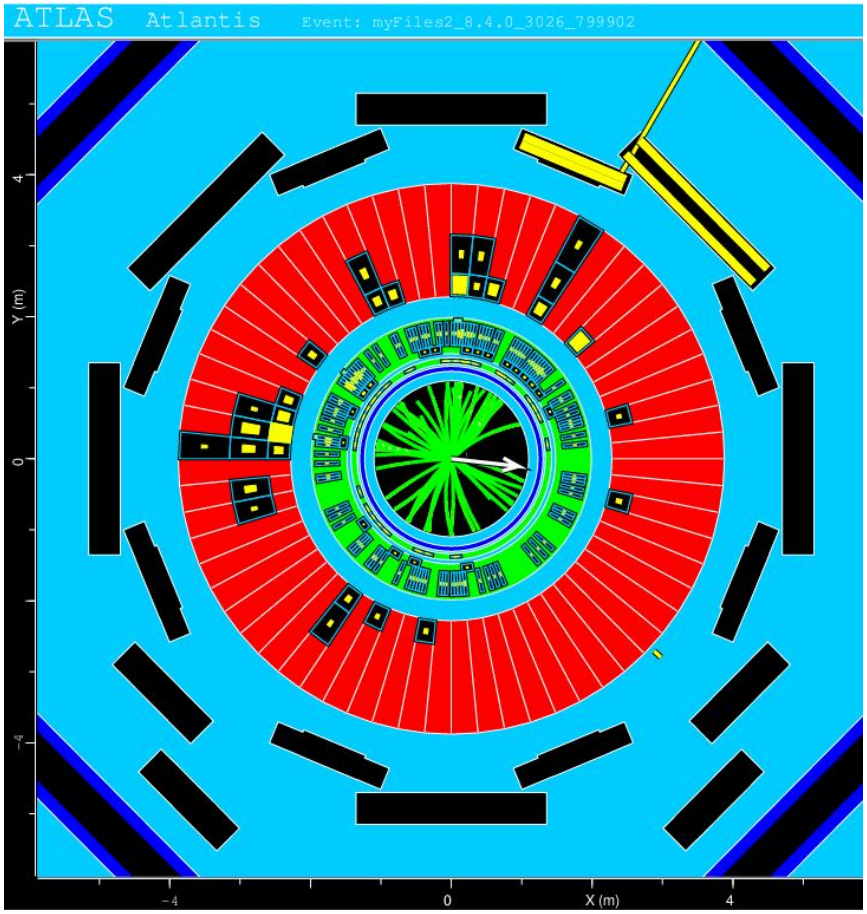
# Single top production at the LHC



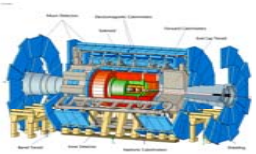
**Andrea Giammanco**
CP3 / UCL, Louvain-la-neuve, Belgium
**(on behalf of the CMS and ATLAS collaborations)**

- Importance of the EW single top
- From Tevatron to LHC
- $|V_{tb}|$ extraction
- Ongoing analyses:
  - t-channel
  - s-channel
  - Wt



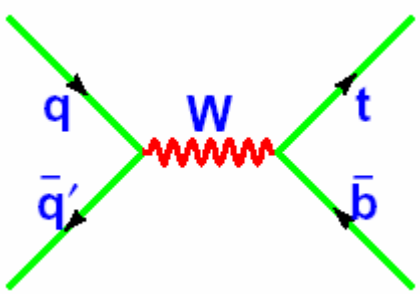

Single top event as seen with ATLAS
(Courtesy C.Timmermans and A.Lucotte)

# Single top



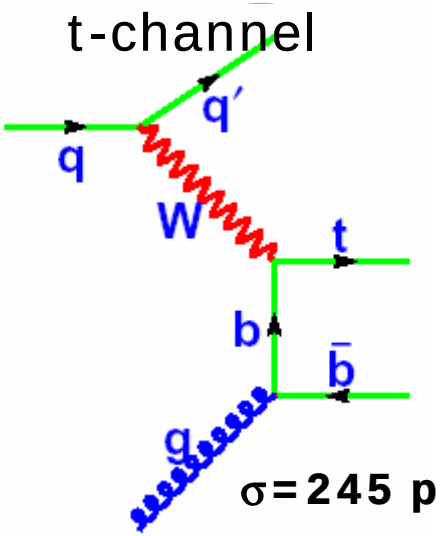
Three production modes in the Standard Model:

s-channel



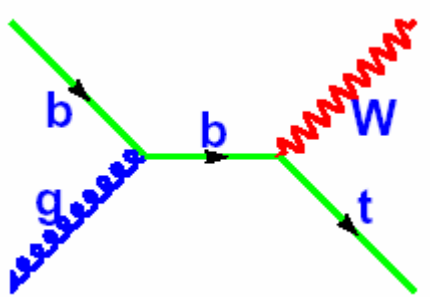

**σ=10 pb**

t-channel




**σ=245 pb**

W+t




**σ=60 pb**

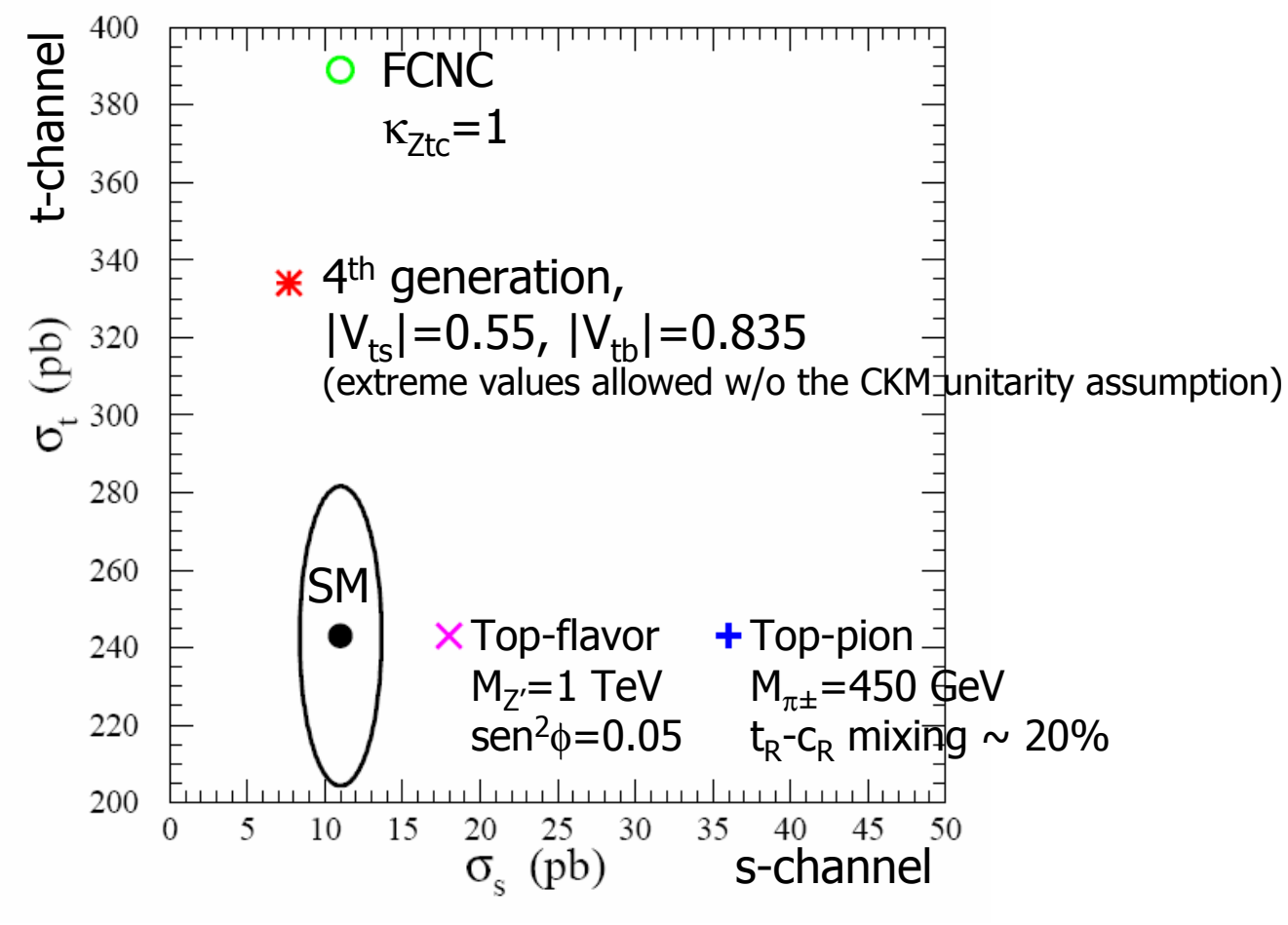
- Never observed so far
- Directly related to $|V_{tb}|$

(not a $V_{tb}/\Sigma V_{ti}$ ratio ⇒ no assumption on the number of quark generations)

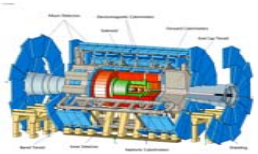
- Sensitivity to new physics: FCNC (t-ch.), new gauge bosons or KK excitations (s-ch.), $H^{\pm} \rightarrow tb$ …
- Background to tt, $WH \rightarrow l\nu bb$, some SUSY and BSM final states
- Possibility to study top properties (mass, polarization, charge) with very little reconstruction ambiguities
- Together they provide complementary informations on Wtb coupling, since they probe it for $q^2<0$, $q^2>0$, $q^2=0$

# Single top and New Physics

T.Tait, C.-P.Yuan, Phys.Rev. D63 (2001) 0140018



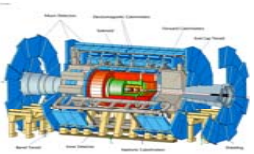
# From Tevatron to LHC...



| | 1.96 TeV | 14 TeV | |
|---|---|---|---|
| ttbar pairs | $5.06^{+0.13}_{-0.36}$ pb | $833^{+52}_{-39}$ pb | (x170) |
| Single top (s-channel) | 0.88±0.12 pb | 10±1 pb | **(x10)** |
| Single top (t-channel) | 1.98±0.22 pb | 245±17 pb | (x120) |
| Single top (Wt channel) | 0.15±0.04 pb | 60±10 pb | (x400) |
| Wjj (*) | ~1200 pb | ~7500 pb | (x6) |
| bb+other jets (*) | ~$2.4 \times 10^5$ pb | ~$5 \times 10^5$ pb | (x2) |

(*) with kinematic cuts in order to better mimic signal
Belyaev, Boos, and Dudko [hep-ph/9806332]

# Theoretical errors @ LHC



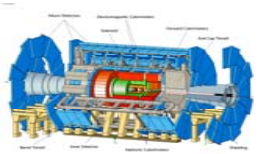
(Z.Sullivan, Phys.Rev. D70 (2004) 114012)

| Process | PDF | μ-scale (μ/2-2μ) | $\Delta m_{top}$ (4.3 GeV) |
|---|---|---|---|
| s-channel | 4% | 2% | 3% |
| t-channel | 4% | 3% | 1% |
| Wt | ? | <5% | 1% |

(it should be similar to t-channel and gg→tt)

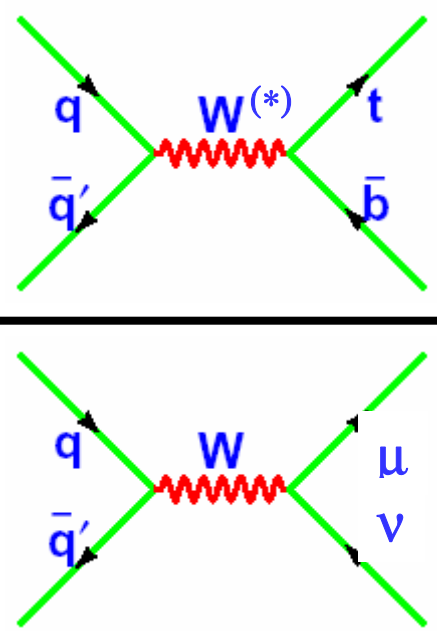
Smaller than @ TeV, because we will be "luckier": better known x region for the gluon PDF

# Direct $|V_{tb}|$ extraction: single top / single W



In principle, systematics coming from PDF (both in total x-section and in shape of the observables) would disappear by normalizing s-channel events over single W events:

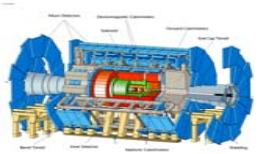
$$R(|V_{tb}|) = \frac{\text{s-channel}}{\text{single W}}$$




(with care in choosing coherent cuts for the two processes, to avoid the reintroduction of the same errors in a subtler way)

The same for gb→Wt / gb→Zb ? (Z→μμ)
Zb not so abundant as W (140 nb), but still a good deal: 1000 pb (Wt: 60 pb).
Unfortunately nothing similar can be easily exploited for t-channel.

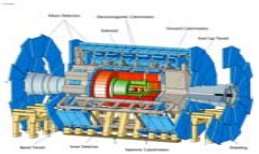
# Status of the LHC analyses

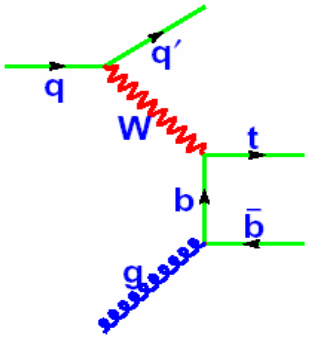


- **CMS:**
  - analyses are ongoing for the **Physics TDR** (deadline: april 2006)
  - old papers: mostly fast simulation (CMSJET, in fortran), limited use of full simulation (CMSIM, based on Geant 3)
  - Physics TDR: new full simulation (OSCAR, based on Geant 4) for as many samples as possible, and the new fast simulation (FAMOS) when the full simulated sample is not available
- **ATLAS:**
  - Physics TDR in 1999 with large use of fast simulation (ATLFAST), and full simulation for the studies most sensitive to detector effects
  - physics papers continued to be published since then
  - ATLFAST continued to be updated and improved
  - limited use of full simulation (based on Geant 4) so far (mostly for checks of the reliability of the fast simulation)

**All the results shown in this talk are preliminary.**

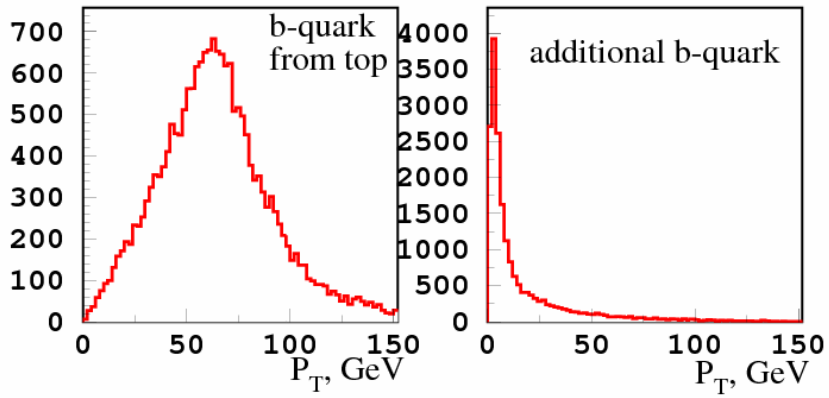
# t-channel

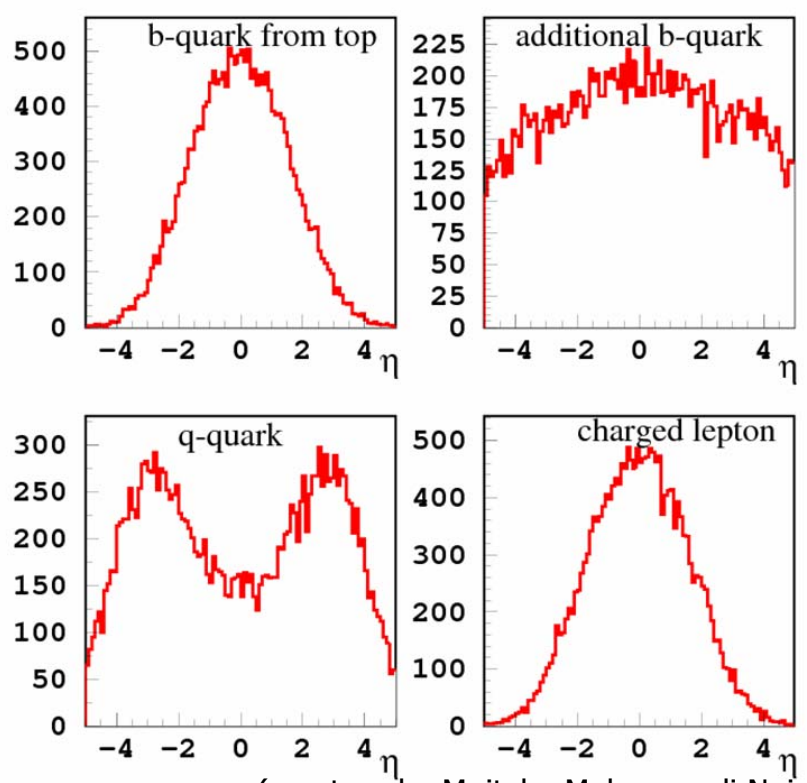





- Most characteristic feature: the "recoil" light quark.
- (But we cannot exploit $Q_l \times \eta_j$ …)
- The additional b quark is often unobservable due to low $P_T$.
- At parton level:

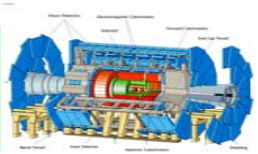
(with CompHEP)



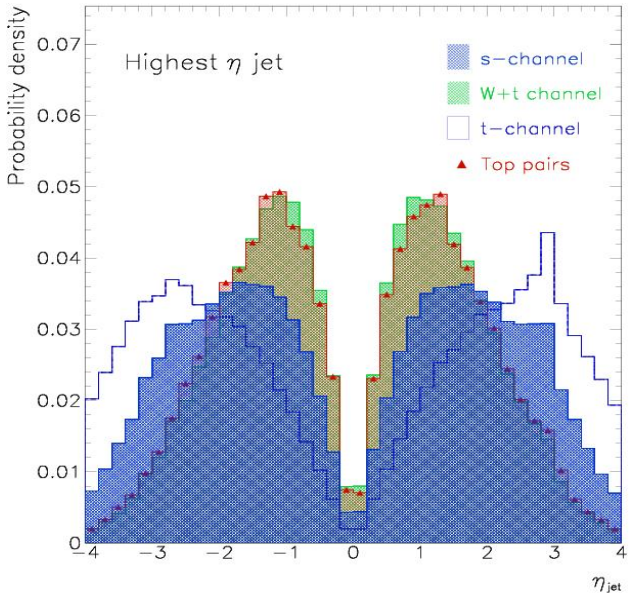

(courtesy by Mojtaba Mohammadi Najafabadi)

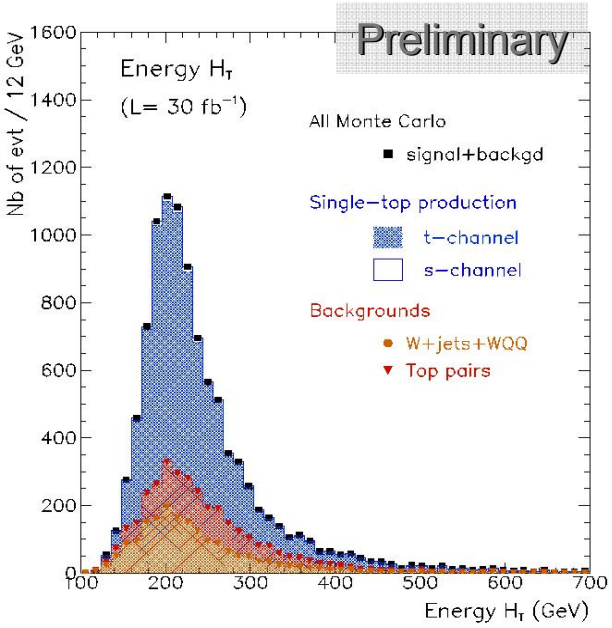
# t-channel, ATLAS



(Courtesy by A.Lucotte)

- Selection
  - Exactly 2 high-$P_T$ jets:
    1 high $P_T$ central b-jet
    1 forward light jet $|\eta|>2.5$
  - Reconstruct Top using the central b-jet and the $\nu$ solution giving minimum $|m_{lvb} - m_t^{gen}|$
  - Resolution better than 25 GeV on $M_{top}$
  - Window in $H_T$ or $M_{top}$
- Performance :
  - Efficiency $\varepsilon \approx 1.3\%$, $N(30fb^{-1}) \sim 7{,}000$ events
  - Main backgrounds : W+jets , ttbar
  - Main systematics (lumi excepted):
    b-tag efficiency & mistag rates, JES

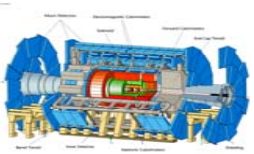



**S/B ~ 3**

**$\sqrt{(S+B)/S} \sim 1.4\%$ @ 30 $fb^{-1}$**

# t-channel, CMS

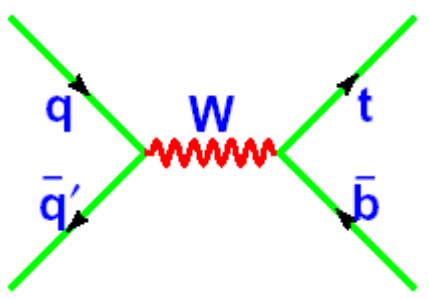


- Selection
  - Exactly 2 high-$P_T$ jets:
    1 high $P_T$ central b-jet
    1 forward light jet $|\eta|>2.5$
  - Reconstruct Top w/ the central b-jet and the lowest-$|P_z|$ $\nu$ solution
  - Window in $M_{top}$
  - $\Sigma_T$ cut

$$\vec{\Sigma}_T = \vec{P}_{T,\mu} + \vec{E}_{T,miss} + \vec{P}_T(bjet) + \vec{P}_T(forw.jet)$$

- Performance :
  - Efficiency $\varepsilon \approx 2.5\%$, $N(10fb^{-1}) \sim 4{,}500$ events

# s-channel




In principle more difficult than t-channel:

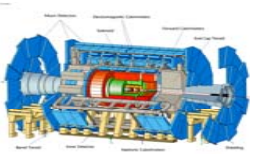
- Smaller cross section (1/25)
- There is not the characteristic feature of the extra forward jet
- t-channel itself is a very similar background

When reconstructing the top, a further ambiguity (apart from the usual one on $\nu$ solution) arises from the presence of two b-jets in the final state.

Most popular W-b pairing criteria:

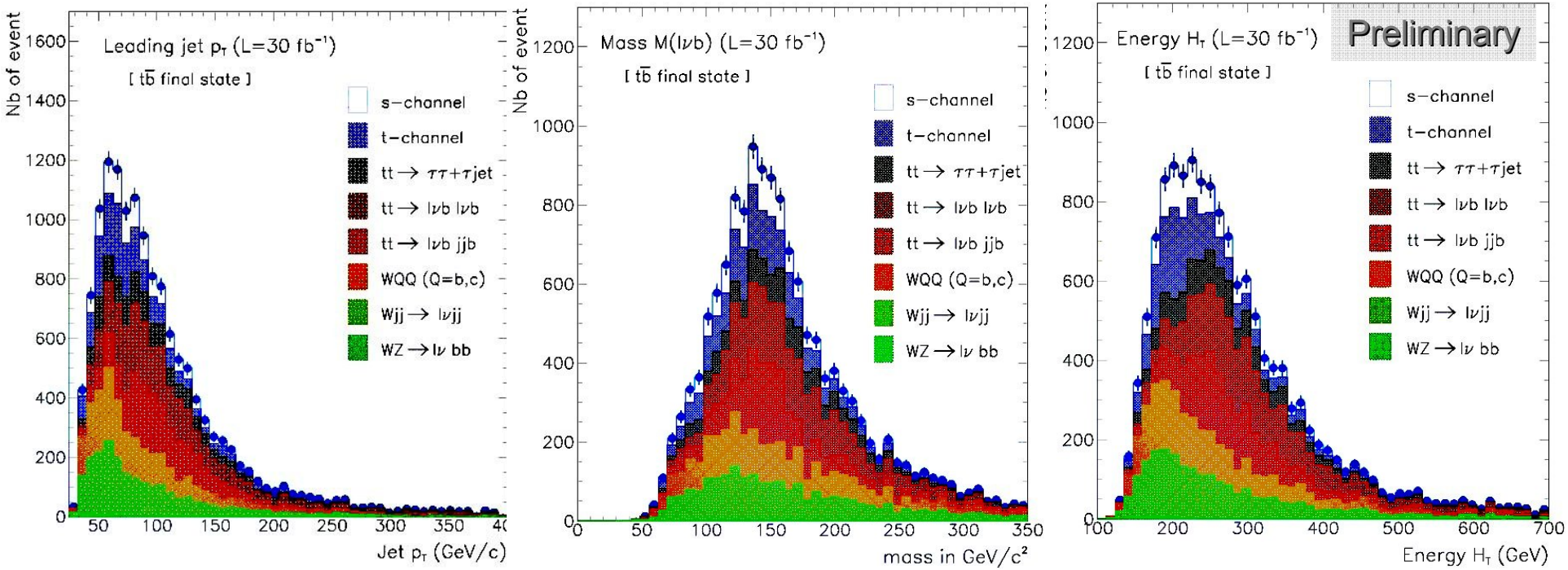
- jet giving minimum $|m_{lvb} - m_t^{gen}|$ (requires a good control of jet and MET calibration; easier at ATLAS than at CMS)
- jet giving the highest $P_T$ to the reconstructed top

# s-channel, ATLAS



(Courtesy by A.Lucotte and F.Chevallier)

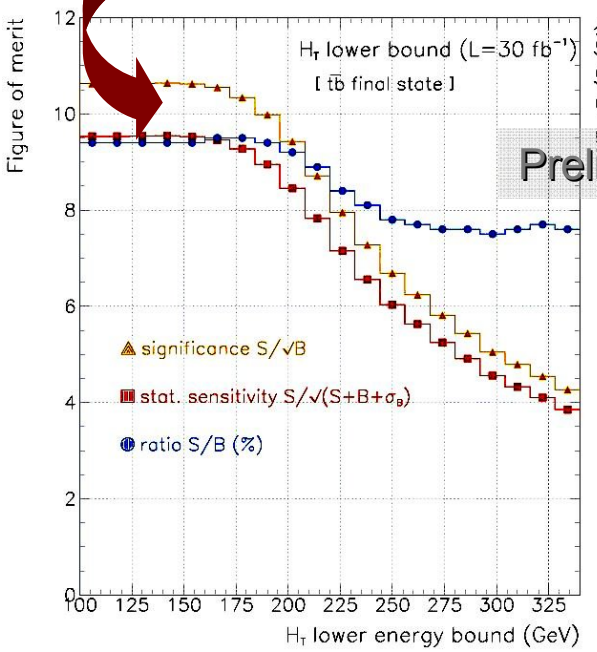
- Selection :
  - Splitted analysis for t+bbar and tbar+b final states
    → Asymmetric for single-top, symmetric for ttbar and W+jets
  - Exactly 2 central high-$P_T$ jets, both identified as b-tagged jets
  - Reconstruct Top w/ highest-$P_t$ lvb combination
  - Window in $H_T$ or $M_{top}$

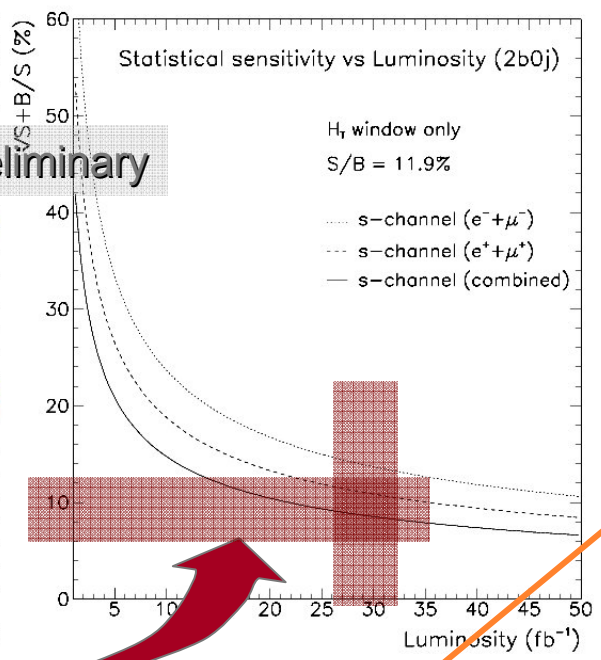


# s-channel, ATLAS (2)

(Courtesy by A.Lucotte and F.Chevallier)

- Performance
  - Standard selection + topol. Selection ($H_T$, $M_{top}$)
    → optimization of $H_T$ lower/upper bounds:



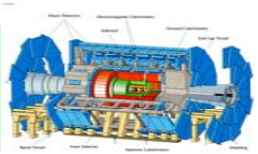

| Uncertainties (30 fb$^{-1}$) | δσ/σ (%) |
|---|---|
| jet energy scale | 3.4 |
| ISR/FSR modelling | 7.3 |
| b-tag & mistag | 6.4 |
| bckgd theoretical | 8.0 |
| Total Systematics | 13 |
| Total Statistics | 9 |

- Statistical sensitivity : 7% to 12% (corresponding to 15% to 10% syst.) depending on topological sel. (and S/B)
- Systematics dominated measurement: exp:11%, th: 8%, lumi: 5%

Overestimated! It is 10% of ISR on – ISR off.
More realistic estimations are under study.

**Use of data necessary**

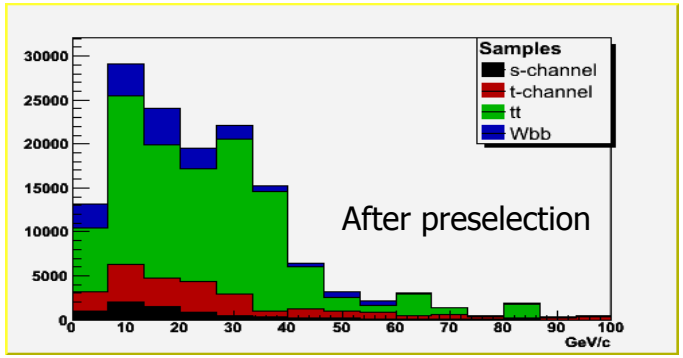
# s-channel, CMS



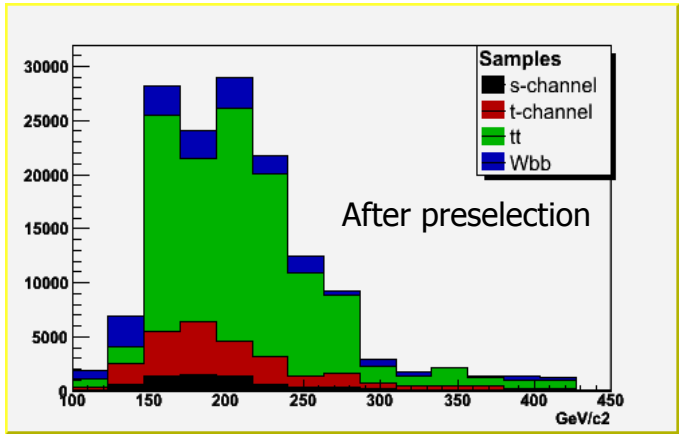
- Preselection
  - 1 high-$P_T$ lepton
  - Exactly 2 high-$P_T$ jets, both b-tagged
  - Missing Energy
- Topological selection
  - Reconstruct Top w/ the lowest-$|P_z|$ $\nu$ solution and the b-jet with "jet charge" opposite to the lepton (if both opposite, the one giving the highest-$P_T$ top is chosen)
  - Window in $M_{top}$
  - $\Sigma_T$ cut
  - Other topological variables are used, most notably M(tb) (directly related to $\hat{s}$)

$$q_{bjet} = \frac{\sum_i q_i \left|\vec{j}\cdot\vec{p}_i\right|^{\kappa}}{\sum_i \left|\vec{j}\cdot\vec{p}_i\right|^{\kappa}}$$

Preliminary

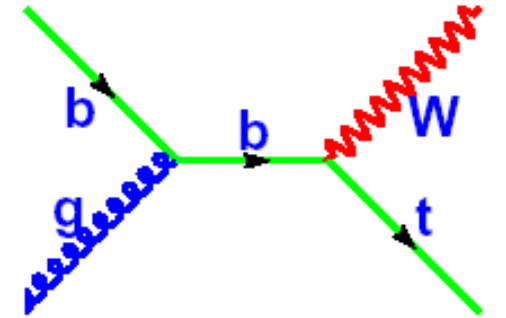



$$\vec{\Sigma}_T = \vec{P}_{T,\mu} + \vec{E}_{T,miss} + \sum_{bjets} \vec{P}_T$$



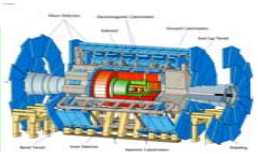

*M(tb)*

# Wt channel




- Background to gb→$H^{\pm}t$
- Very difficult channel: signal is overwhelmed by ttbar background (ttbar with a b-jet outside acceptance is a perfect Wt fake)
- Also not trivial to define what the signal is (at NLO: entangled with ttbar diagrams!), see talk by Fabio Maltoni

# Wt, ATLAS

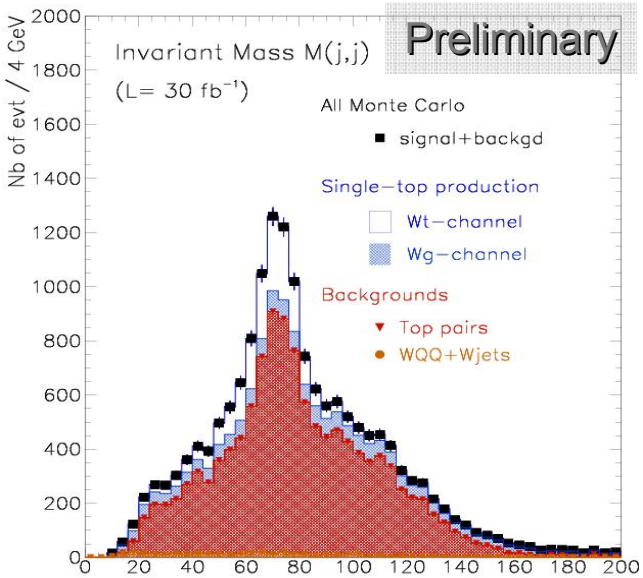


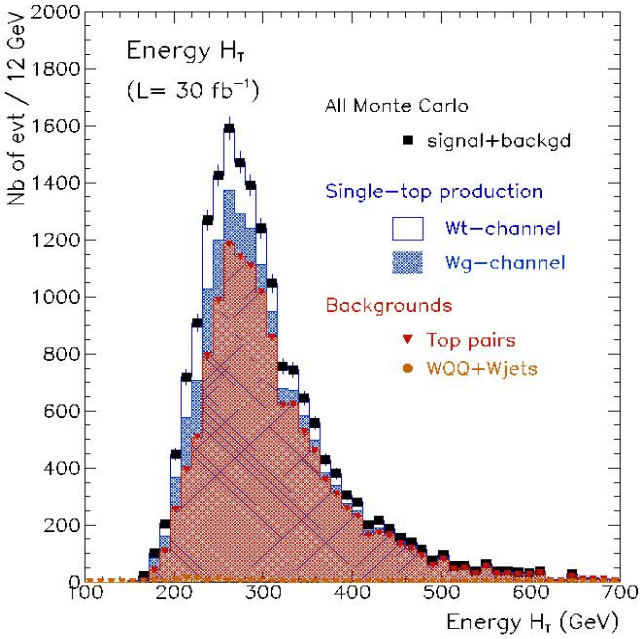
(Courtesy by A.Lucotte)

- Selection :
  - At least 3 high-$p_T$ jets :
    w/ only 1 high $P_T$ central b-tagged jet
  - Reconstruct a W→ jj: 60 <$m_{jj}$ < 90 GeV/$c^2$
  - Reconstruct leptonic Top : minimum |$m_{lvb}$–$m_t$|
  - Window in $H_T$ or $M_{top}$

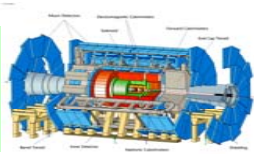
- Performance :
  - efficiency ε ≈ 0.90%, N(30fb$^{-1}$) ~ 4,700 events
  - Main background : ttbar, t-channel
  - Main systematics (lumi excepted):
    b-tag efficiency & mistag, JES

**S/B ~ 1/7**
**√(S+B)/S ~ 4% @ 30 fb$^{-1}$**



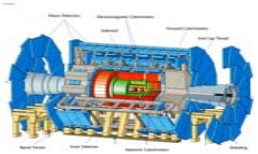



# Wt, dileptonic final state



- From Fabio's talk on thursday:
  - Study at parton level
  - Dilepton sample with ONLY one (b-tagged) jet. Smaller statistics but also better ttbar rejection: S/B~1/3
  - After 10 $fb^{-1}$: 4000 Wt, 13000 tt, (120k Zb)
  - $\Rightarrow \sqrt{(S+B)}/S=2\%$
- Moreover, much less dependence on jet energy scale (no resonance is reconstructed)
- A dileptonic analysis just started in CMS (too preliminary to be shown here, hopefully ready for the Physics TDR)

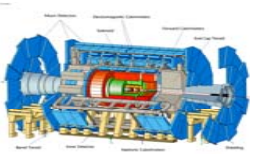
# Conclusions



- Single top physics provides a new test ground for the Standard Model and a possible window on new physics
- Precision physics in this sector will be possible at LHC
- One of the three production modes, Wt, will be measurable at LHC for the first time
- Analyses under way in ATLAS and CMS

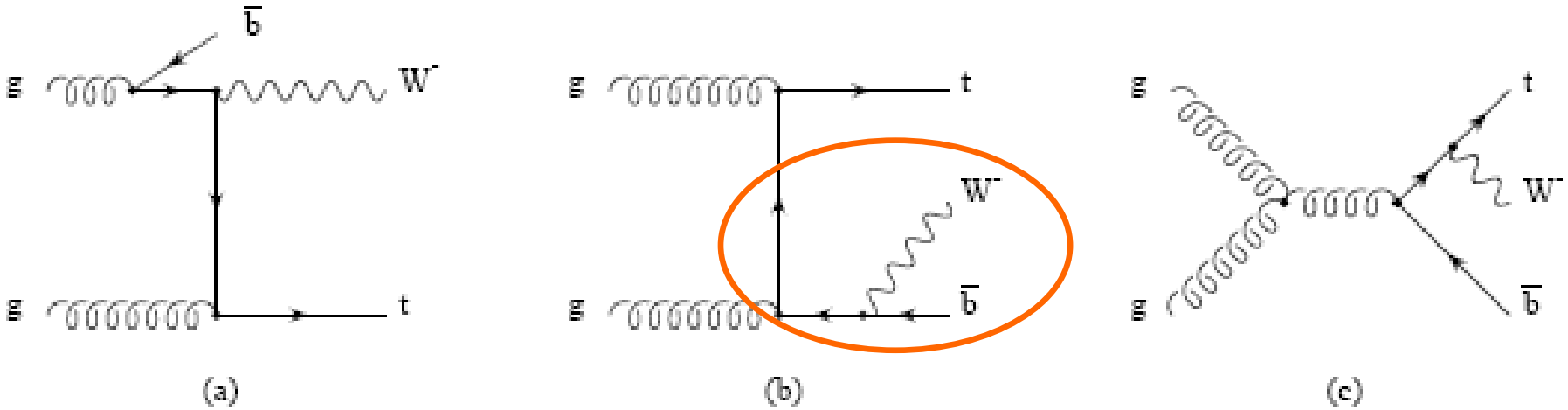
**Acknowledgements: Joachim Mnich, Arnaud Lucotte, Fabio Maltoni**

# Backup slides



# Wt: Theoretical point of view

**Problem:** At NLO, Wt mixes with tt.
A MC-friendly definition of tW is needed in order to avoid double counting.
**Solution (Les Houches 2005):** The full set of gg→btW diagrams is left out and Wt is DEFINED by a b-jet veto.
Already implemented in MCFM.





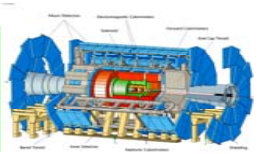
References:

Tait, Phys.Rev. D61 (2000) 034001

Boos and Belayev, Phys.Rev. D63 (2001) 034012

Campbell and Tramontano, Nucl.Phys. B726 (2005) 109-130

# Wt, dileptonic final state



- Tait, Phys.Rev. D61, 034001 (2000):
  - Study at parton level
  - Dilepton sample with ONLY one (b-tagged) jet. Smaller statistics but also better ttbar rejection: S/B~1
  - After 30 $fb^{-1}$: 12000 Wt, 13500 tt, 150 WW+X
  - $\Rightarrow\sqrt{(S+B)/S}=1.3\%$ (too optimistic?)
  - A jet threshold at $P_T$=15 GeV is used: 1 b-jet above this threshold, no other jet above this threshold. But at LHC both jet finding and b-tagging are severely degraded at such low momenta!