Top Physics
with the ATLAS detector

Arnaud Lucotte

(IN2P3 / LPSC Grenoble)

on behalf of the ATLAS collaboration

Outline

- **Motivation**
- **Top pair production :**
  - Mass measurement
  - Cross-section measurement
- **Single-top production :**
  - Single-top cross-section
  - Search for charged higgs
- **Conclusion**

Top Quark Physics : Motivations

Top Quark : a tool for precise EW Sector studies

A special role in the EW sector

- Top, W and Higgs masses enter radiative corrections in theoretical calculations of many observables
  → Precision on (m_t,m_W) constrains m_H
- Heaviest elementary particle known
  → Yukawa couplings close to 1.0
- CKM Matrix element V_{tb}

A special role in QCD & the quark family

- Test of QCD
- Vast swath of phase space available to the decay
  → short lifetime (< t_{QCD}=28x10^{-25} s)
  → Window on properties of bare quark

Top Quark : a probe to new physics

A special role in (all) various extensions of the SM:

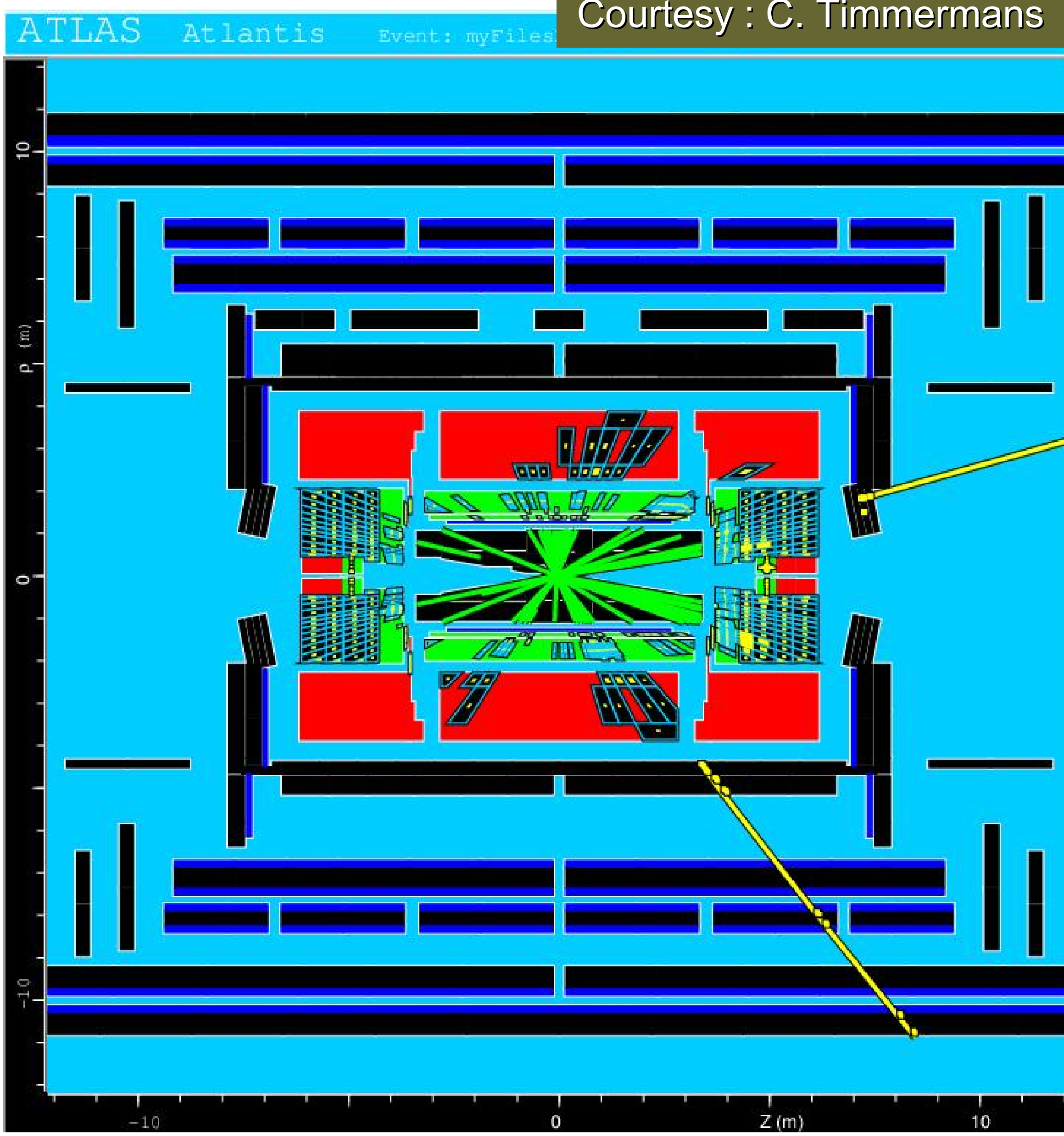
- Searches for new (heavy) particles
  → flavor/mass dependent couplings
  → extra-bosons : W+,
  → Higgs boson H^+

A link to the (new) theory fundamentals

- Central role in
  → Technicolor : strong interaction @ TeV
  → SUSY : given its (high) mass, room for SUSY Top decays

Top pair production :
Top mass and cross-section

Courtesy : C. Timmermans



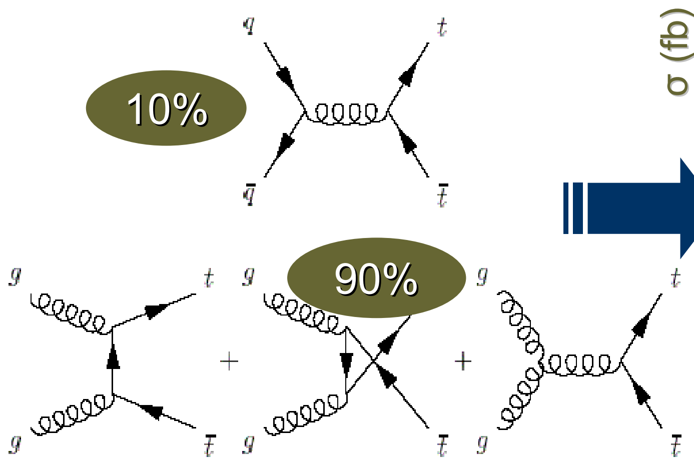
Top pair : production & decay

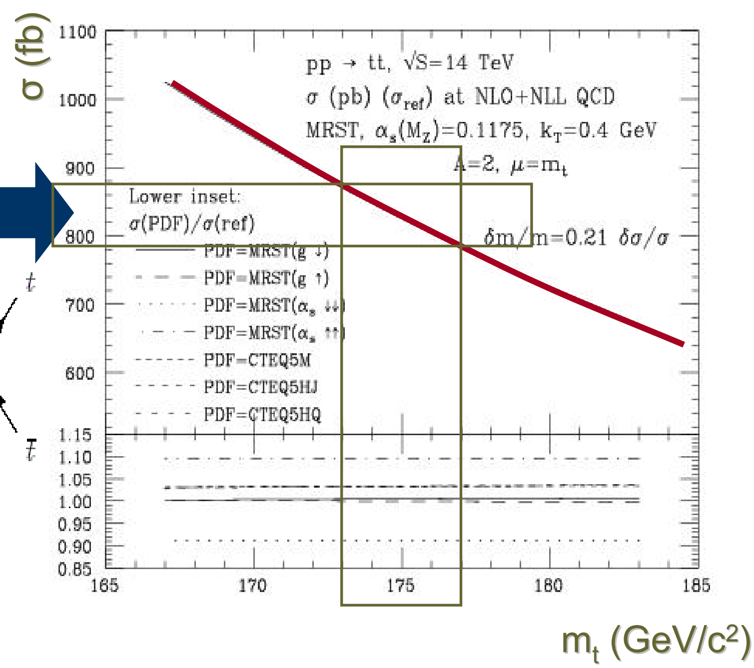
Top pair production

SM Total cross-section

NLO calculations σ_{tt} = 835 pb ± $10\%_{pdf}$ ± 6% $_{\mu\text{-scale}}$

- Production via gluon-fusion (90%) and quark anihilation
- Dependence in Top Mass : $\delta\sigma_{tt}/\sigma_{tt} \approx 5 \times \delta m_t/m_t$





Top pair decay modes

SM Branching ratio :

- BR(t→W+b) ≈ 1

tt final state	BR (pb)	N_{evt} (10 fb^{-1})
tt → (lν)b (jj)b	30%	2.5x 10^6
tt→(lν)b(lν)b	5%	400,000
tt→(jj)b (jj)b	44%	3.7x 10^6

"lepton+jets"

"di-lepton"

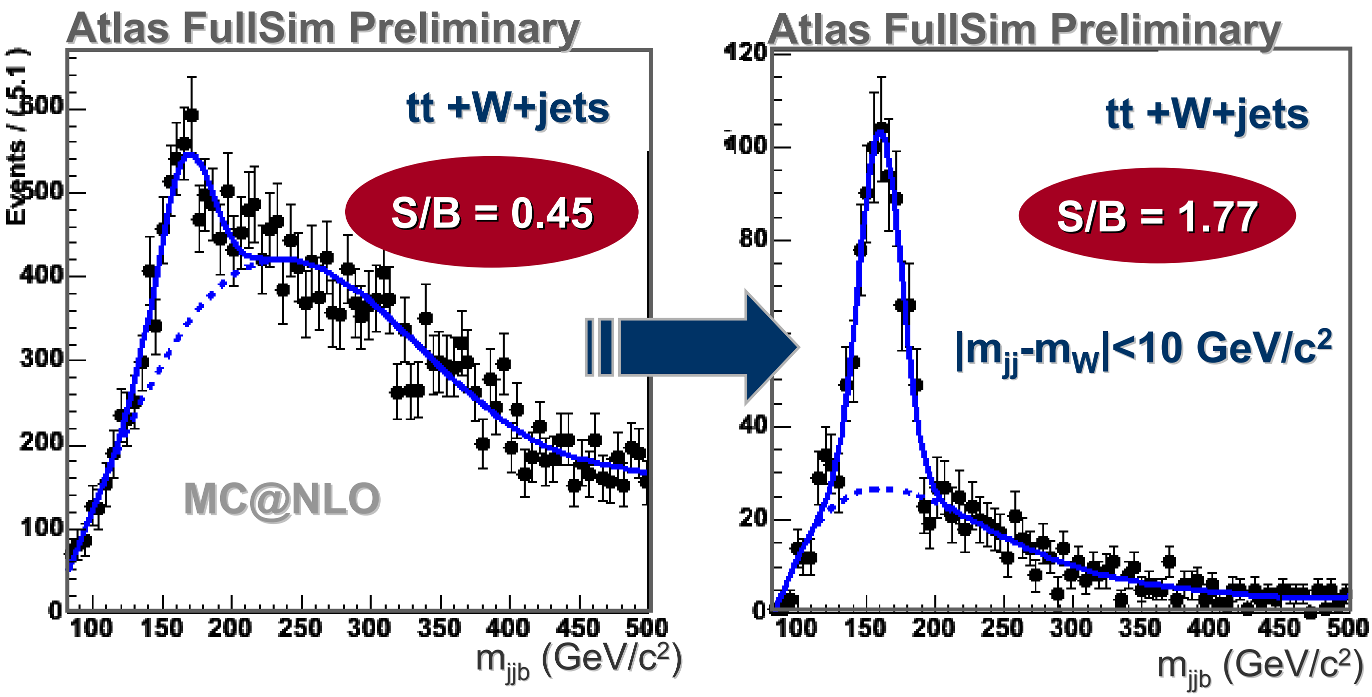
"full-hadronic"

1 or 2 weeks of the ATLAS data…

Top pair events in 300 pb^{-1}

Selection

- Missing E_T, 1 lepton, ≥4 jets , NO b-tag !!
  → efficiency ~ 5.3 %
  → Apply extra cut on hadronic W mass



Expected performance

- Signal + background (comb. + W+jets):
  Mass: $m_t \sim 160 \pm 1.2$ GeV/c^2
  Resolution: $\sigma(m_t) \sim 15.4 \pm 2.0$ GeV/c^2
- Use for commissioning :
  → Start of light jet calibration
  → b-tagging algorithms
  → b-jet calibration

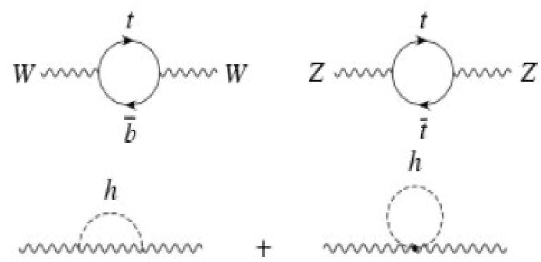
Top Mass measurements

Top Mass measurement : motivations ...

Precision measurements in the EW sector

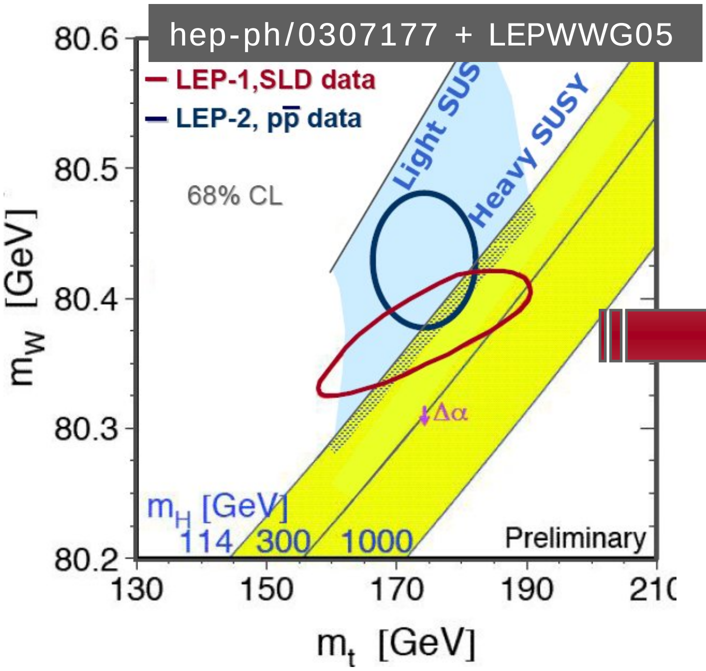
Boson masses relation:

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}\frac{1}{1-\Delta r}$$



$$(\Delta r)_{top}\approx-\frac{3}{8}\frac{G m_t^2}{\sqrt{2}\pi^2}\frac{1}{\tan^2\theta_W}$$

$$(\Delta r)_{Higgs}\approx\frac{11}{24}\frac{G M_Z^2\cos^2\theta_W}{\sqrt{2}\pi^2}\log\frac{m_H^2}{M_Z^2}$$



Present Measurements :

→ constraint Higgs Mass m_H < 285 GeV/c^2 (95%CL)

→ do not indicate any clear departure from SM (yet)

→ equal weight to χ^2 from : $\Delta m_W \approx 0.7\%\ \Delta m_t$

15 MeV → 2 GeV

LHC precision measurements :

Consistency checks with direct m_H measurements

→ MSSM (1-loop): $m_h^2 = m_Z^2 + \frac{3G_F m_t^4}{\pi^2\sqrt{2}}\ln\left(\frac{M_t^2}{m_t^2}\right)$

s-top mass

hep-ph/0303092

Top Mass measurement : motivations ...

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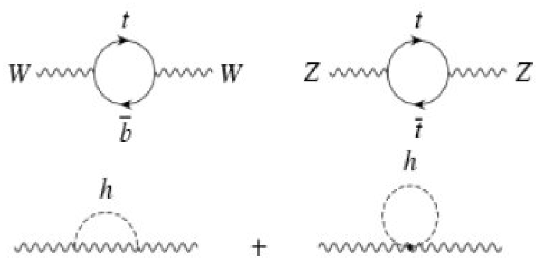

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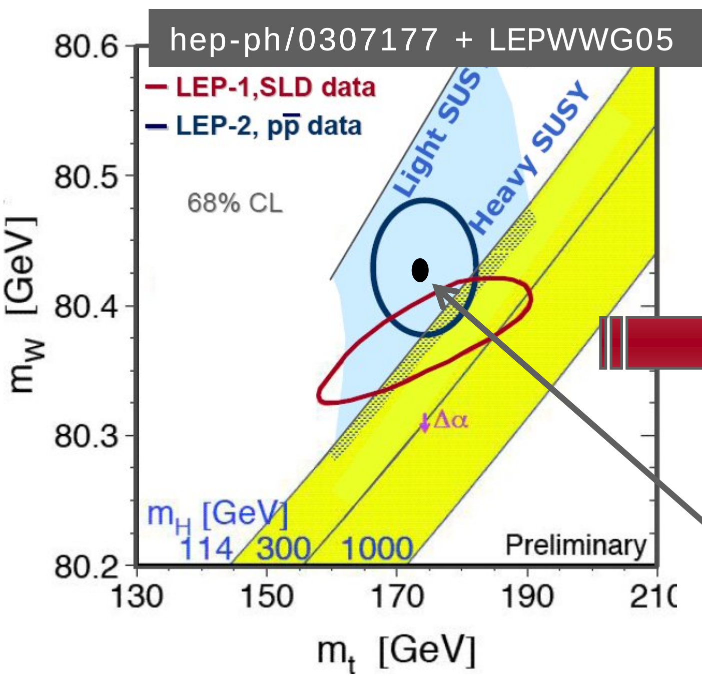

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$\Delta m_W \approx 0.7\% \, \Delta m_t$

Δm_t=1 GeV/c²
Δm_W=15 MeV/c²

LHC precision measurements

- Consistency checks with direct m_H measurements
- Determination of the underlying framework requires :

→ $\Delta m_W \approx$ 15 MeV/c² vs $\Delta m_t \approx$ 1 GeV/c²

Top Mass using "lepton+jets" : Event Selection

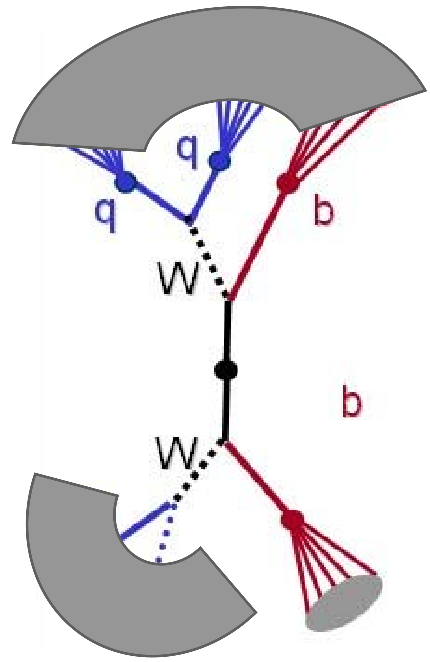
Strategy

(1) "leptonic top" to tag the event

- 1 high-p_T lepton
- high missing Energy
- at least 4 high-p_T jets
- at least 1 high-p_T b-tagged jet

(2) "hadronic top" to measure the mass

- Identify b-quark jets
  - → 2 samples : 2 btag (1 btag)
- W-boson reconstruction from jj
  - → in-situ light jet calibration
- Top quark reconstruction from jjb



Event yields @ 10 fb^{-1}

Processus	σ x BR (pb)	ε(%)	N_{events}
bb→lv+jets	2.2×10^{6}	3×10^{-8}	15
W+jets→ lv+ jets	7.8×10^{3}	2×10^{-4}	930
Z+jets →l^+l^-+jets	1.2×10^{3}	6×10^{-5}	150
WZ → lv + jets	3.4	1×10^{-2}	12
WW → lv + jets	17.1	7×10^{-3}	10
ZZ → l^+l^- + jets	9.2	5	5
Tt → (lv)b (jj)b	250	3.5%	87,000

Main background from wrong combinations in tt events

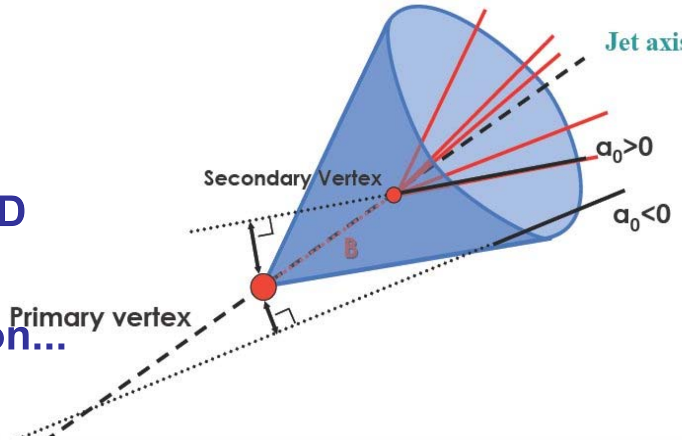
Top Mass using "lepton+jets" : b-tagged jet

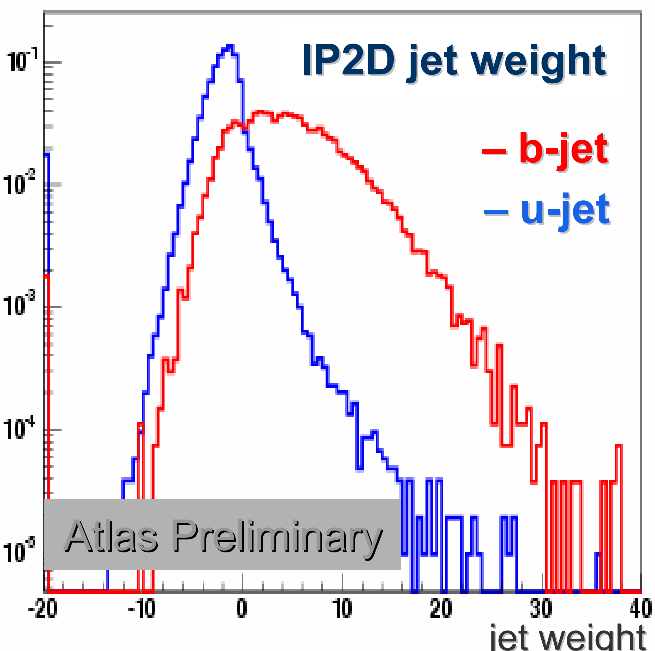
b-tagging algorithms

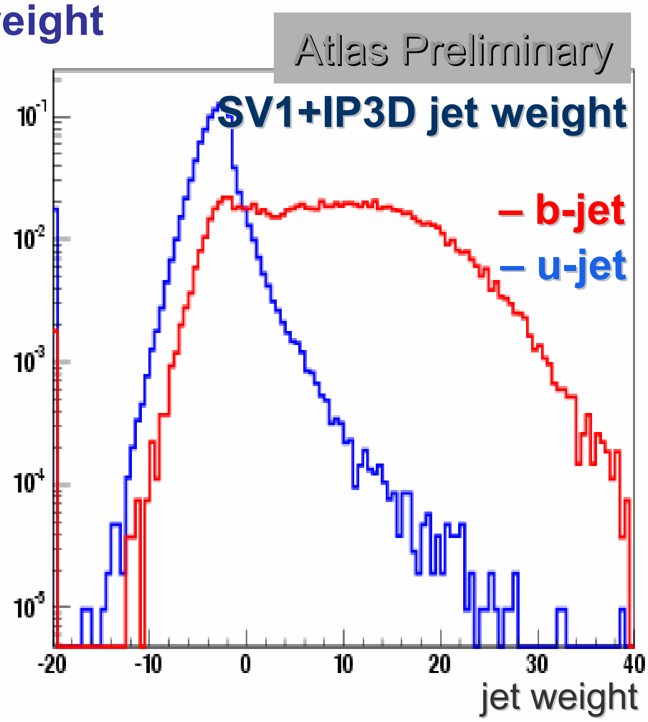
Several taggers

- Soft lepton tag
- Impact parameter 2D/3D
- Secondary Vertex
  Mass, charged fraction...
- Lifetime tag ...

→ Combined likelihood/weight







Performance

- Typical results on top pair events :

	R_u (50%)	R_u(60%)
IP2D	160	55
IP3D	230	85
SV1+IP3D	500	185

- Ongoing studies:

→ Geant-3 vs Geant-4
→ underlying event
→ jet algorithm

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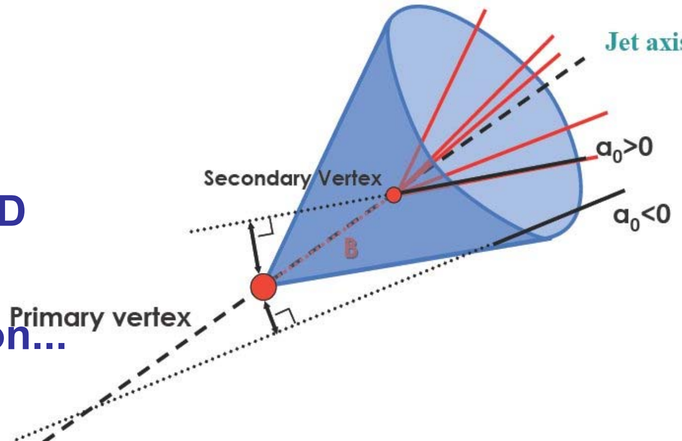

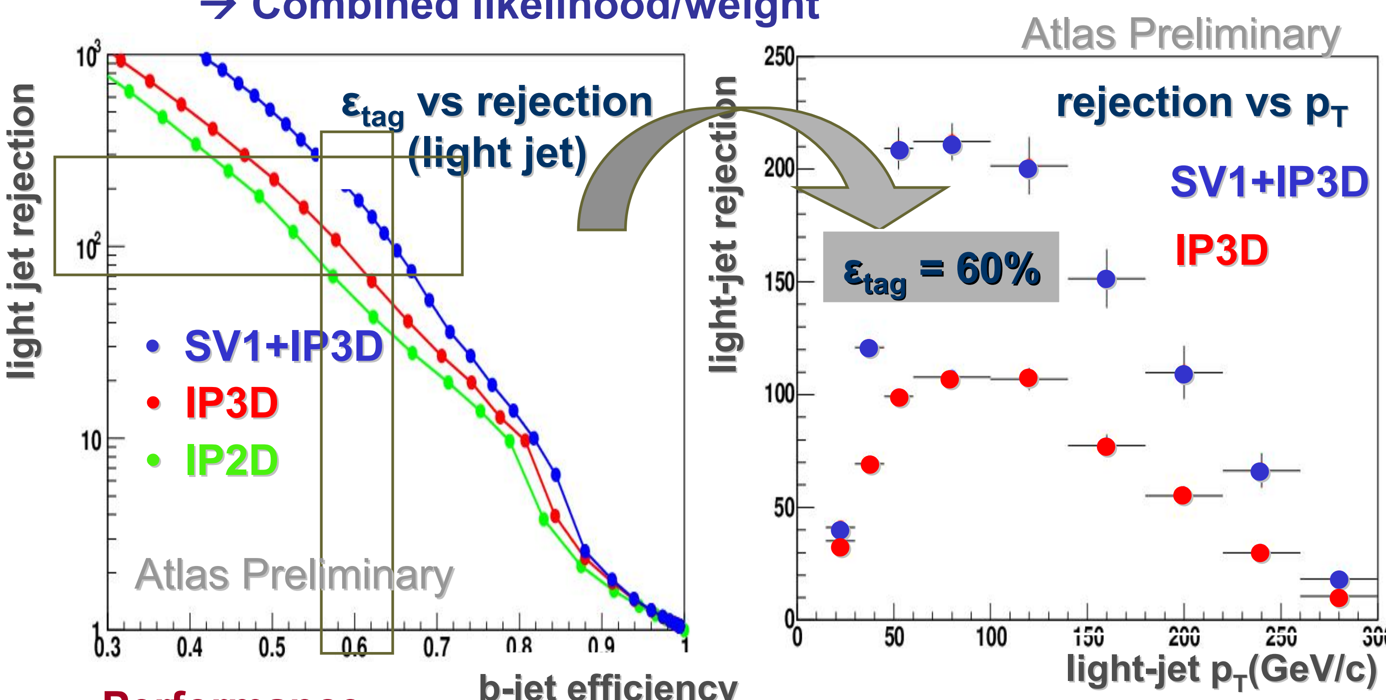

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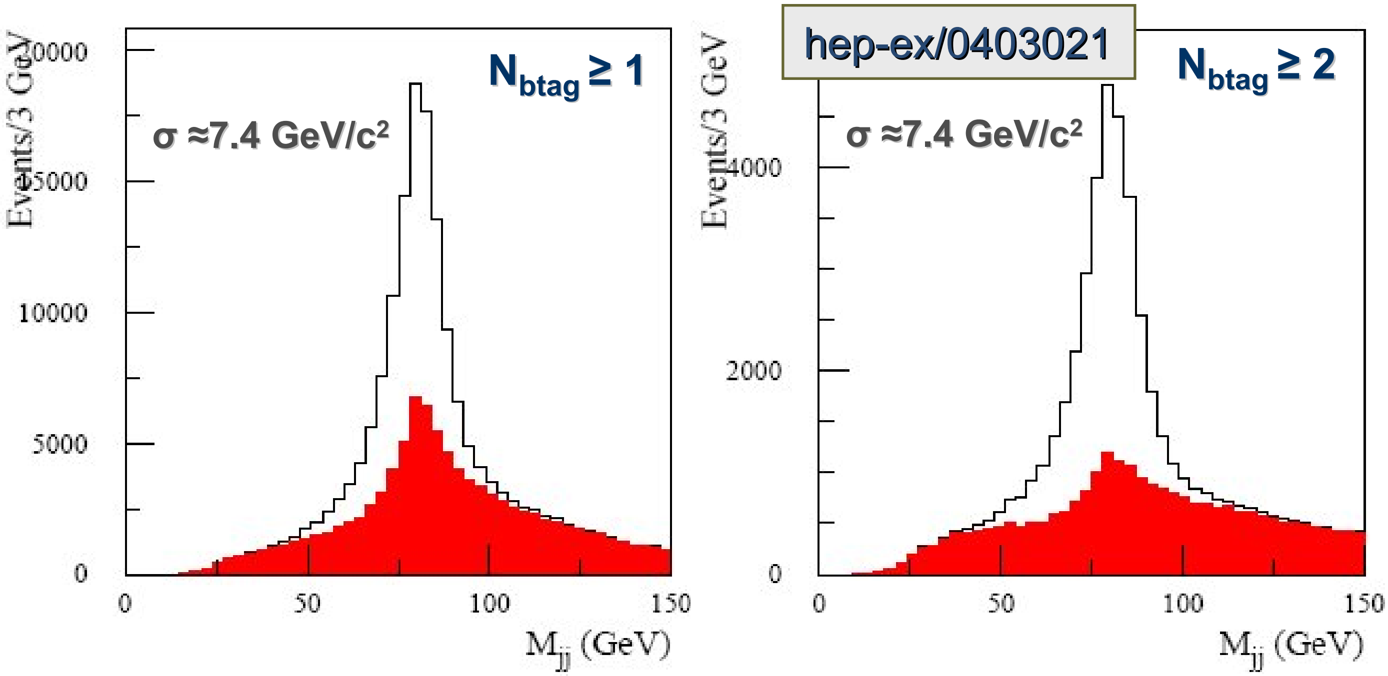
Top Mass using “lepton+jets” : W-boson reconstruction

W-boson reconstruction

Jet association :

- Select (jj)-pair with minimum $|m_{jj} - m_W|$
- Sample W-purity : 66% (55%) w/ efficiency : 3.2%

hep-ex/0403021



Light Jet calilbration

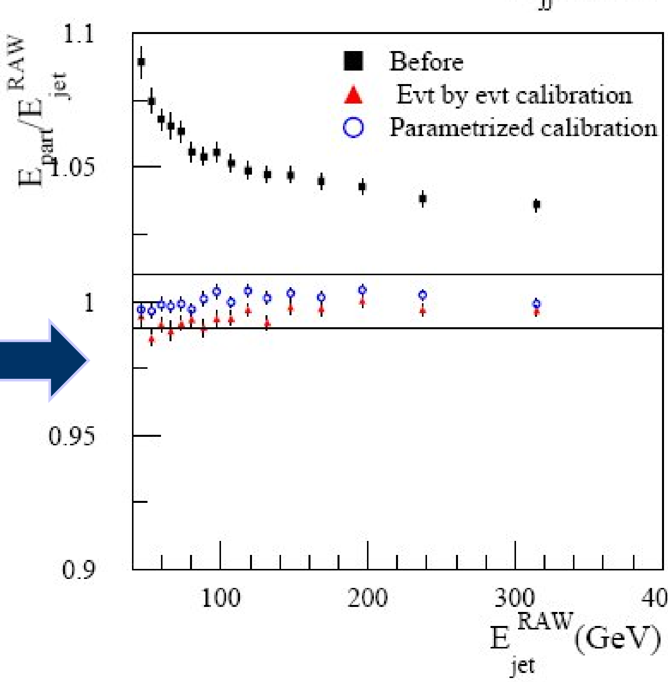
In situ calibration with of W→jj

- Correct for jet energy
- Correct for jet direction

→ Absolute energy scale obtained at 1% level

Z+jets calibration

- Cross-checks with exterı processus

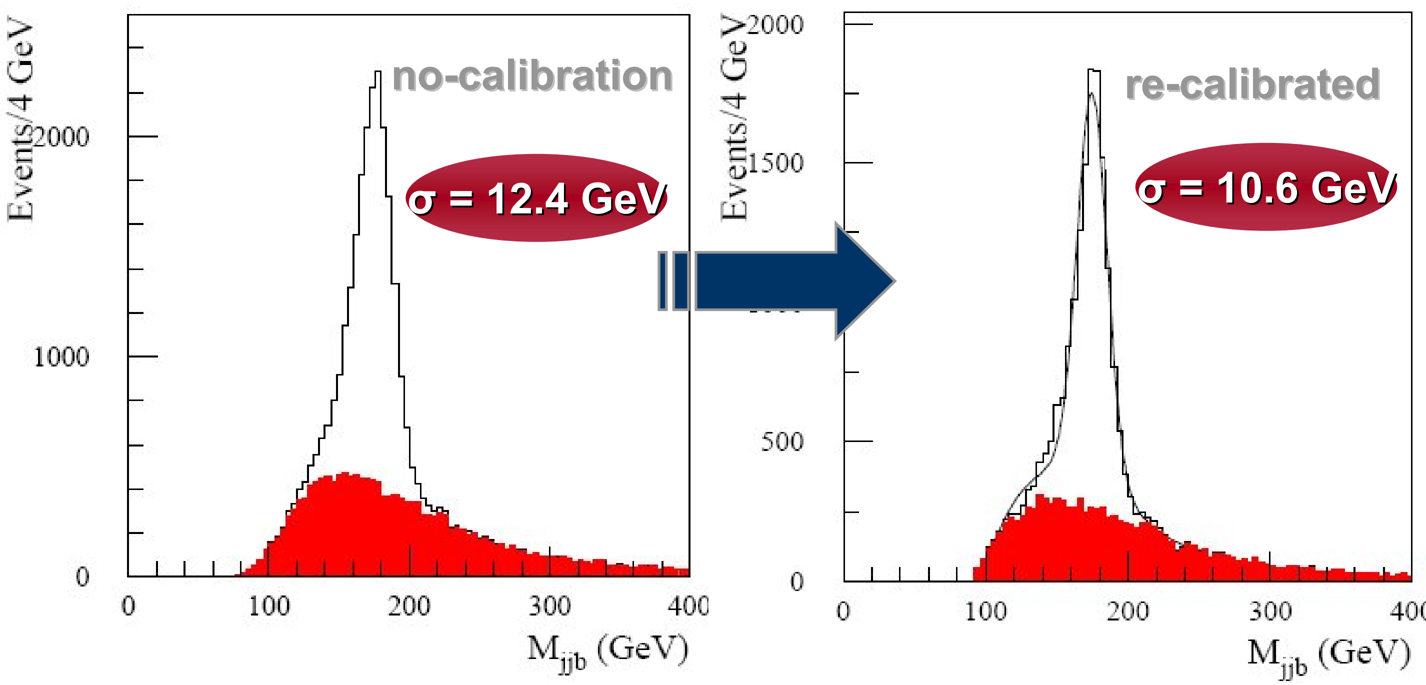


Top Mass using "lepton+jets" : Top reconstruction

Top Quark reconstruction

Association of hadronic W and b-jet :

- Combination leading to the highest p_T^{top}
  or that maximizes $\Delta R(l,b)$ / minimizes $\Delta R(b,W \rightarrow jj)$
  → Top Purity : 69% (65%) w/ efficiency : 1.2% (2.5%)



Event Yield :

~30K (80K) events in 2 b-tag (≥1b-tag)

- Physics bckgd ~ 100 events
- Good linearity m_{jjb} vs m_t^{gen} and $|m_{jjb} - m_t^{gen}| < 100$ MeV/c^2
- Mass resolution : $\sigma \approx 11$ GeV/c^2 (13 before calibration)

Top Mass using "lepton+jets" : systematic uncertainties

Top mass uncertainty

Main systematics :

hep-ex/0403021

sources of uncertainty	$\delta m_t (GeV/c^2)$
light jets energy scale	0.2
b-jet energy scale	0.7
Initial State Radiation	0.1
Final State Radiation	1.0
b-quark fragmentation	0.1
Combinatorial backgd	0.1
Total SYSTEMATIC	1.3
Total STATISTICAL	0.07

Δm_t for a 1% miscalibration

Energy scale :

- Knowledge at the 1% level :
  - → light jets: makes use of an in-situ calibration
  - → b-jets : use of Z+b jets

ISR / FSR :

- ISR affect the number of jets N(jet)
- FSR affect the jet-energy scale, selection of jets, N(jet)
  - → known up to ~10% (~ α_s uncertainty)

b-quark fragmentation :

- b-quark fragmentation based on Peterson ε_b

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20% of Δm_t for :
m_t(ISR ON)-m_t(ISR OFF)
m_t(FSR ON)-m_t(FSR OFF)

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change in Peterson : ε_b = -0.006 / -0.0035

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change in backgd shape

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hep-ex/0403021

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Initial State Radiation	0.1	0.1
Final State Radiation	1.0	≤ 0.5
b-quark fragmentation	0.1	0.1
Combinatorial backgd	0.1	0.1
Total SYSTEMATIC	1.3	0.9
Total STATISTICAL	0.07	0.12

Improvements :

- Use of a kinematic fit on the entire tt event
  → reconstruct hadronic / leptonic top
- Use Constraints event / event :
  $m_{jj} = m_W$ & $m_{l\nu} = m_W$
  $m_{jjb} = m_{l\nu b}$ → (X^2, m_t^{fit})
  → Select lower X^2 to reduce contamination from badly reconstructed b-jets (FSR)

– $\Delta m_t \sim 1$ GeV/c² seems achievable provided 1% calibration Jet-energy scale
– Systematics–limited measurement : b-jet energy scale & FSR are dominant

Top Mass in the "di-lepton" channel

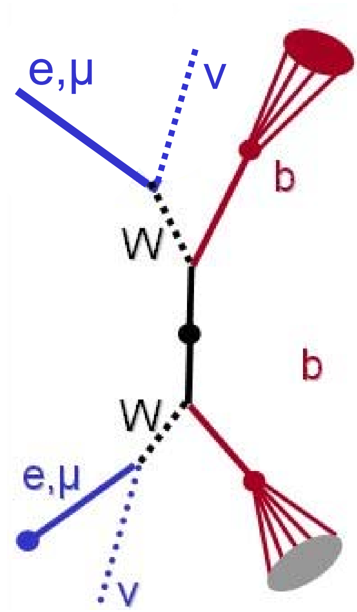
Procedure

(1) Selection & yield @ 10 fb^{-1}

- 2 high-p_T leptons
- high missing Energy
- 2 high-p_T jets
  - → 80,000 evts & S/B ~ 10

(2) Reconstruct fully tt event :

- Assess neutrino's momenta
  - → 6 eqs ($\Sigma p_T=0, M_{l\nu}=m_W, M_{l\nu b}=m_t$)
  - → ε ~ 97% w/ Purity ≈ 73%



(3) Top mass determination :

- Evt/evt: m_t → solve system → weight (using kinematics & topology)
- All evts: mean weight per m_t
  - → $m_t^{fit} = m_t$ w/ highest <weight>

Performance with 10 fb^{-1}

Mass resolution :

- $\sigma \approx 13$ GeV/c^2

Systematics :

- Choice of PDF
- b-jet energy-scale

V. Simak et al.

	δm_t
b-jet energy scale (1%)	0.6
b-quark fragmentation	0.7
ISR / FSR modelisation	0.6
Parton Distr. function	1.2
Total SYSTEMATIC	1.6
STATISTICS & method	0.3

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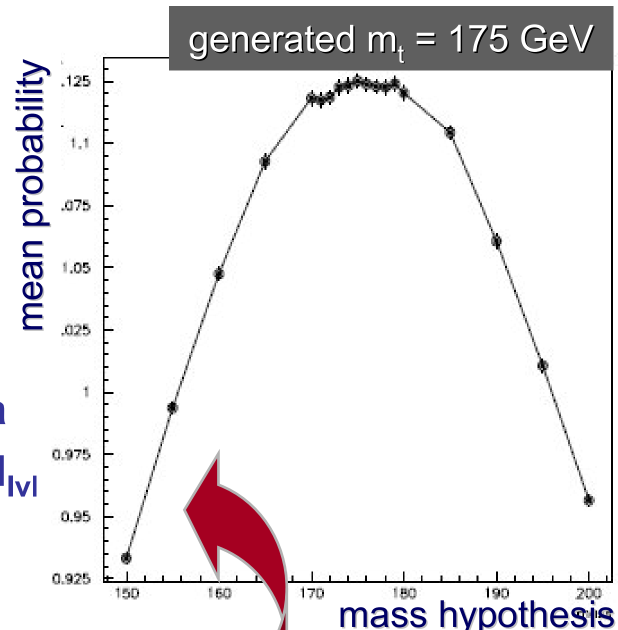

Performance with 10 fb^{-1}

Mass resolution :

- σ ≈ 13 GeV/c^2

Systematics :

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b-jet energy scale (1%)	0.6
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ISR / FSR modelisation	0.6
Parton Distr. function	1.2
Total SYSTEMATIC	1.6
STATISTICS & method	0.3

Top mass in the "full hadronic" channel

Procedure

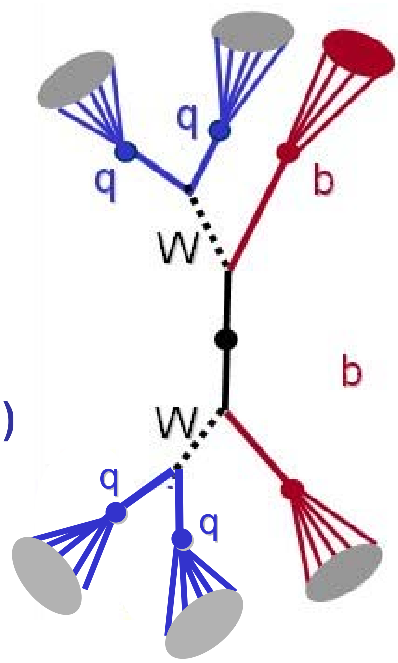
(1) Selection & yield @ 10 fb^{-1}

- at least 6 central high-p_T jets
- 2 high-p_T b-tagged jets
  - → 100,000 evts & S/B ~ 1/19 (QCD)

"most challenging channel"

(2) Analysis :

- Jet energy variables (H_T, ETb, ΔRjj..)
- Event shape variables
- Kinematic fit to m_t
  form W→ jj (X^2_W) & t→ Wb (X^2_t)



Performance with 10 fb^{-1}

Event yields :

- Keep events with
  $p_T^{top} \geq 200$ GeV/c
  $130 < |m_{jjb}| < 200$
- Resolution σ ≈ 13 GeV/c^2
- → Signal ~ 3,300 events
- → S/B ~ 18/1

Systematics:

- dominated by FSR
- light-jet and b-jet energy scale

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	δm_t
light jet energy scale	0.8
b-jet energy scale	0.7
Initial State Radiation	0.4
Final State Radiation	2.8
b-quark fragmentation	0.3
Background	0.4
Total SYSTEMATIC	3.1
Total STATISTICAL	0.2

Top pair production : cross-section measurement

Cross-section measurement

Strategy :

- Same pre-selection as for m_t measurements

Performance :

- Uncertainty $\delta\sigma^{stat}$ ~negl.
- Systematics dominated :
  - machine : $\Delta L/L \sim 5\%$
  - b-tagging ε & mistag rates
  - ISR/FSR, pdf, Jet energy scale

Atlas Preliminary

	N_{event} @ 10^{33}	$\Delta\sigma/\sigma^{stat}$
1 month	70,000	0.4%
1 year	300,000	0.2%

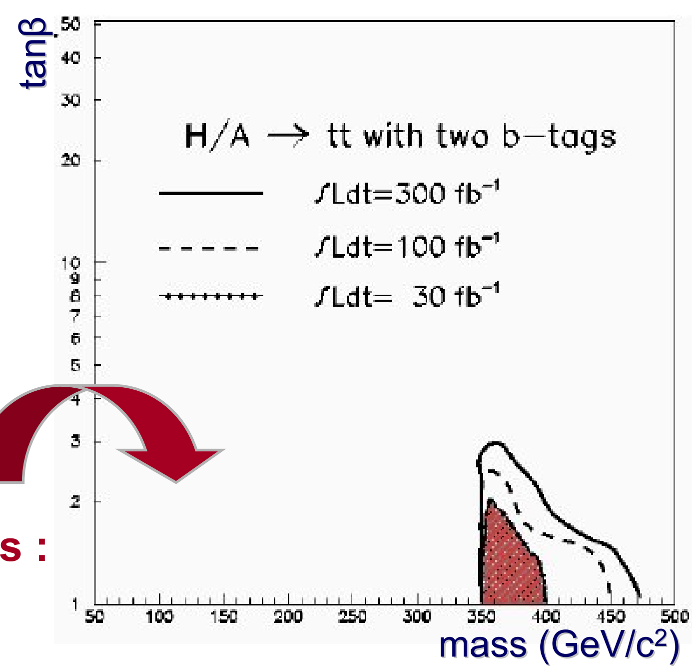
Interpretations

Test of QCD :

- (m_t, σ_{tt}) measurements
  → $\Delta\sigma/\sigma \sim 6\%$
- $\Delta\sigma_{tt}/\sigma_{tt}^{theo} = 10\%$
  → $\Delta m_t \sim 3$ GeV/c^2

Sensitivity of $d\sigma_{tt}/dM_{tt}$:

- High mass resonance
  → for eg. H/A→tt



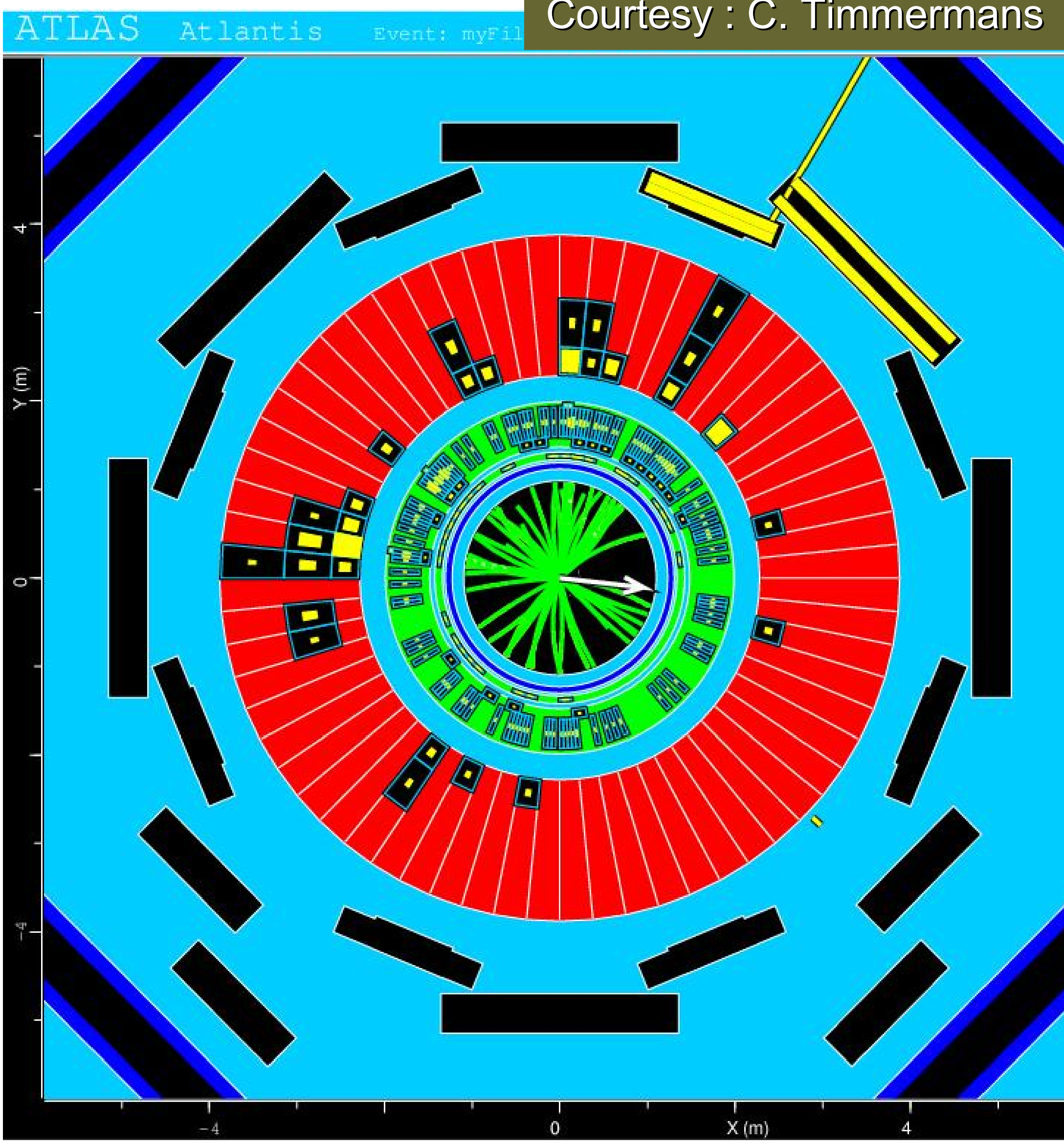
Sensitivity of σ_{tt} to New Physics :

- SUSY EW corr. < 4%
- SUSY QCD corr. < 10%

→ Consistency check with direct evidence ?

Single-top cross-section measurements

Courtesy : C. Timmermans



Single-top cross-section measurements

Motivations :

Properties of the Wtb vertex :

- Determination of $\sigma(pp \rightarrow tX)$, $\Gamma(t \rightarrow Wb)$
- Direct determination of $|V_{tb}|$
- Test of V-A, top polarization

Probe to new physics :

- Anomalous couplings, FCNC
- Extra gauge-bosons W' (GUT, KK)
- Extra Higgs boson (2HDM)

Single-top is one of the main background to ...

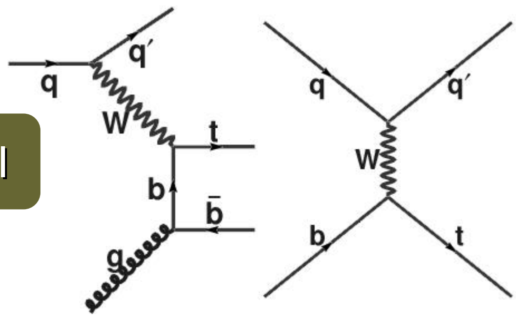
... Higgs physics with jets...

Single Top cross-section : Production @ LHC

Production at the LHC

All 3 contributing mechanisms in SM

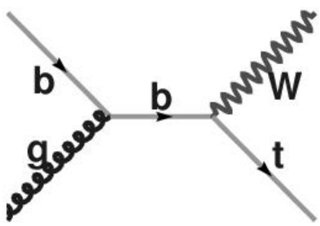
t-channel



1 high-p_T lepton + mE_T
1 high-p_T forward jet
1 high-p_T b-quark jet

σ^{NLO}~155(t)+95(t')
= 250±9 pb

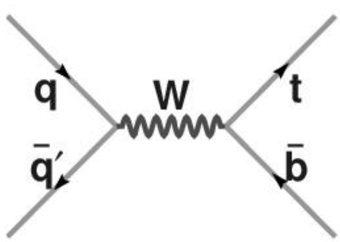
W+t channel



1 high-p_T lepton + mE_T
2 high-p_T jet
1 high-p_T b-quark jet

σ^{LO} ~ 60 ± 15 pb

S-channel



1 high-p_T lepton + mE_T
2 high-p_T b-quark jet

σ^{NLO} ~ 10 ± 0.7 pb

Theoretical uncertainties are significant :

– NLO/NLL available for s-, t- and (new) W+t channels
– Main uncertainty due to the choice for the (b,g) PDF
– Choice of renormalization scale μ
– Top mass uncertainty : Δm_{top}

Δtheo= ± 4-8%

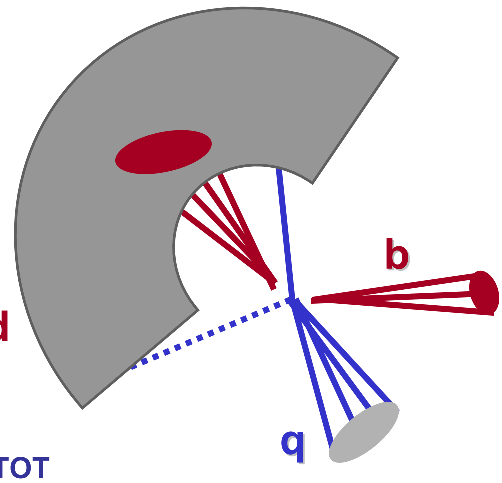
Single Top :
Event Selection

Procedure

(1) Select and tag event
- 1 high-p_T lepton
- high missing Energy
- at least 2 high-p_T jets
- at least 1 high-p_T b-tagged jet

(2) Discriminate vs non-top background
- Reconstruct a Top mass $M_{l\nu b}$
- Use event shape & high H_T or M_{TOT}

(3) Discriminate vs top backgrounds
- Number of b-jets
- Event topology



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

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

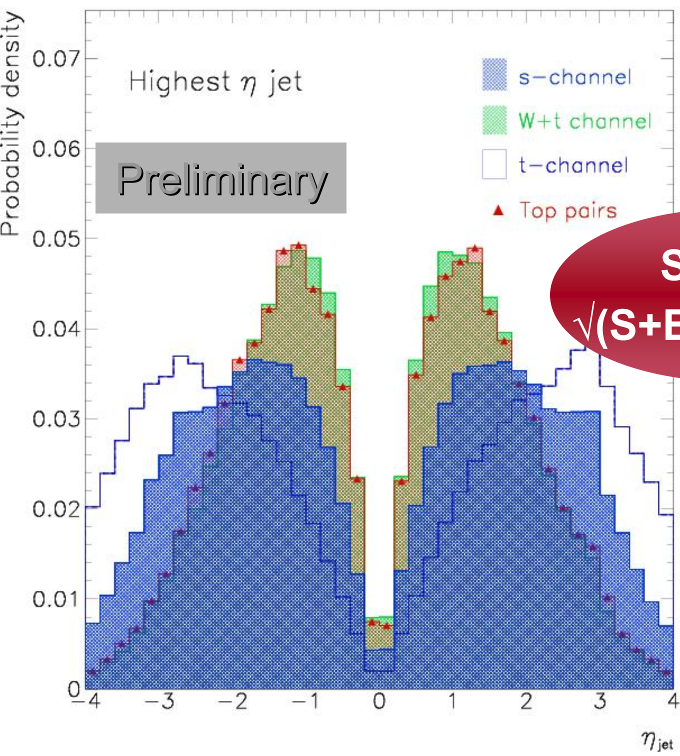
→ Use of DATA !

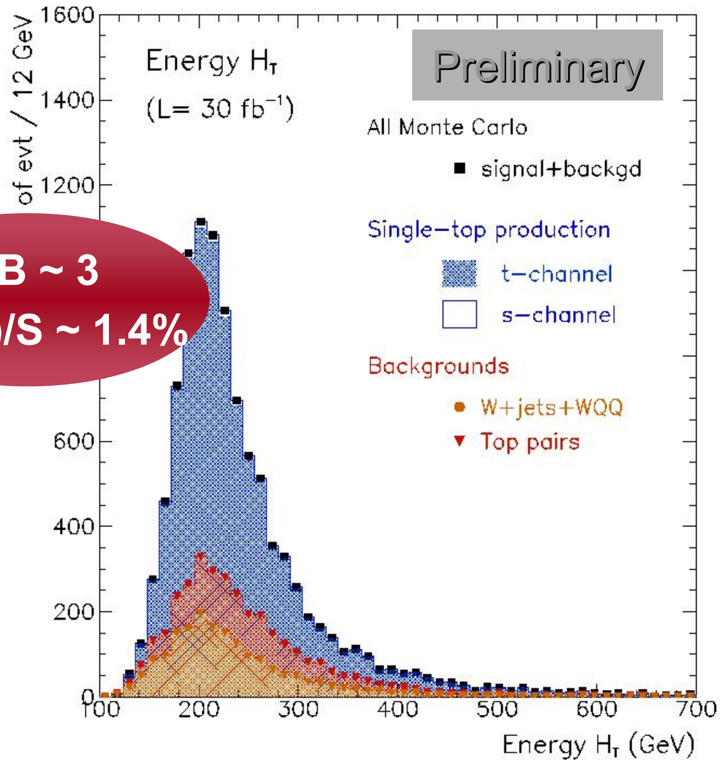
t-channel cross-section

Selection

Specific criteria :

- Exactly 2 high-p_T jets:
  - 1 high p_T central b-jet
  - 1 forward light jet $|\eta|>2.5$
- Reconstruct Top with : $|m_{lvb} - m_t^{gen}| < 25$ GeV/c^2
- Window in H_T or M_{tot}





S/B ~ 3
$\sqrt{(S+B)}/S \sim 1.4\%$

Performance :

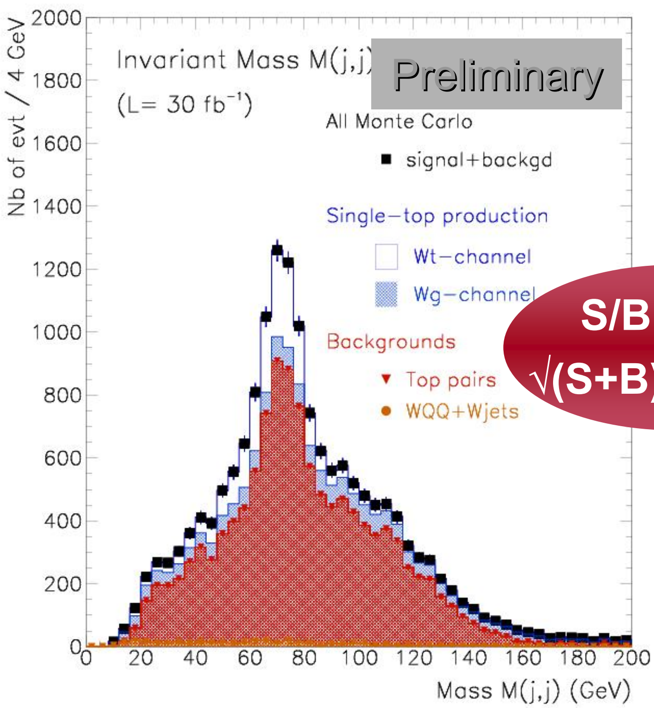
- Efficiency $\varepsilon \approx 0.44\%$ and N(30fb^{-1}) ~ 7,000 events
- Main backgrounds : W+jets , top pair
- Main systematics (lumi excepted):
  - b-tagging efficiency & mistag rates, JES

W+t channel cross-section

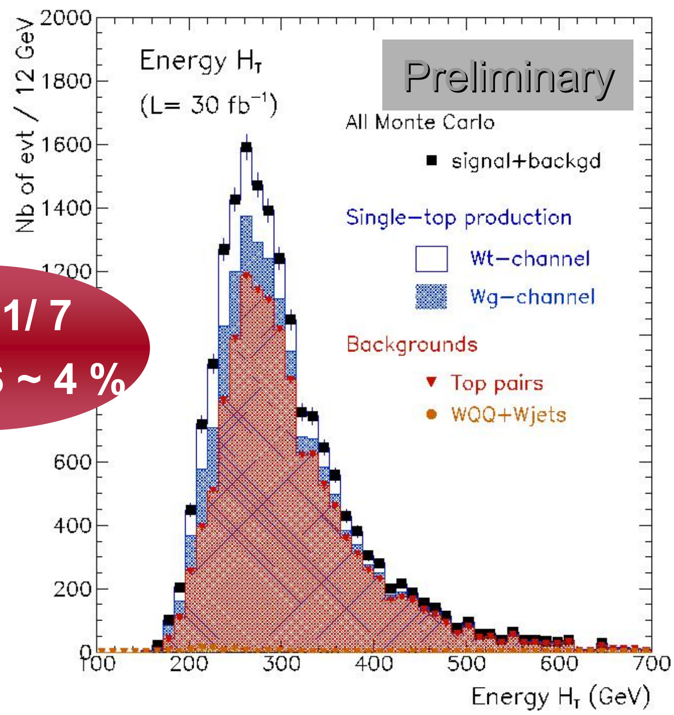
Selection

Specific criteria :

- Exactly 3 high-p_T jets
  1 high p_T central b-jet (p_T> 50 GeV/c)
- Reconstruct a W→ jj with : 60 <m_{jj} < 90 GeV/c^2
- Reconstruct leptonic Top : $|m_{l\nu b} - m_t|$< 25 GeV/c^2
- Window in H_T or M_{tot}



S/B ~ 1/ 7
√(S+B)/S ~ 4 %



Performance :

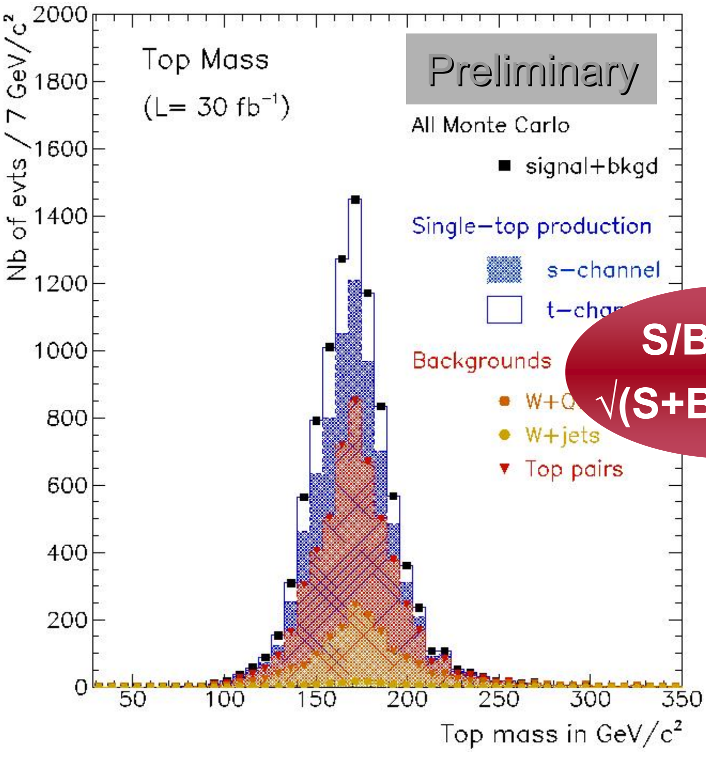
- efficiency ε ≈ 0.90% and N(30fb^{-1}) ~ 4,700 events
- Main background : top pair, t-channel
- Main systematics (lumi excepted):
  b-tagging efficiency & mistag rates, JES
  Background estimate (exp., theo., use of data?)

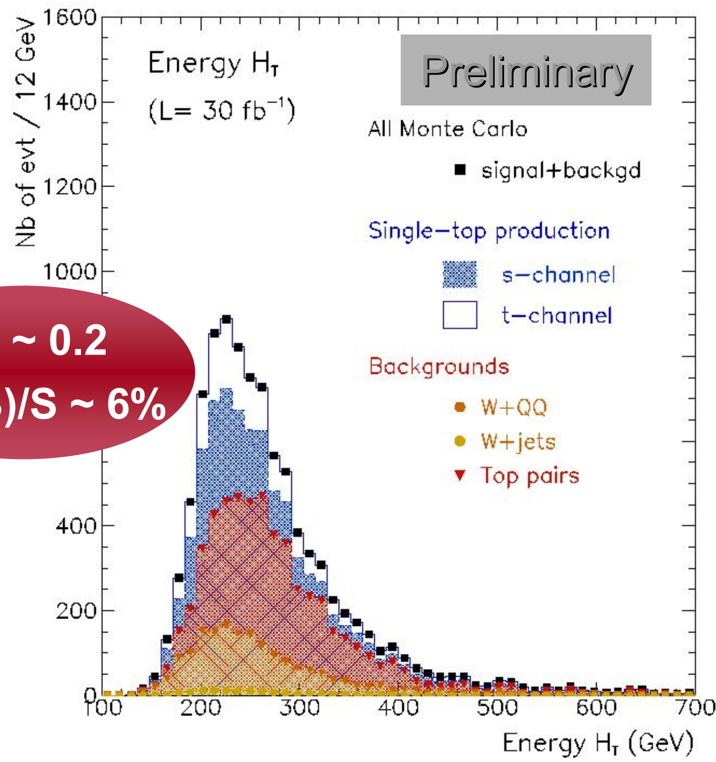
s-channel cross-section

Selection

Specific criteria :

- **Exactly 2 high-p_T jets:**
  2 high p_T central b-jet ($|\eta|<2.5$)
- **Reconstruct Top with: $|m_{l\nu b} - m_t^{gen}| < 25$ GeV/c^2**
- **Window in H_T or M_{tot}**





S/B ~ 0.2
√(S+B)/S ~ 6%

Performance :

- **Efficiency $\varepsilon \approx 1.72\%$ and N(30fb^{-1}) ~ 1,100 events**
- **Main backgrounds : top pair, t-channel**
- **Main systematics (lumi excepted):**
  b-tagging efficiency & mistag rates
  Background estimates (use of data)

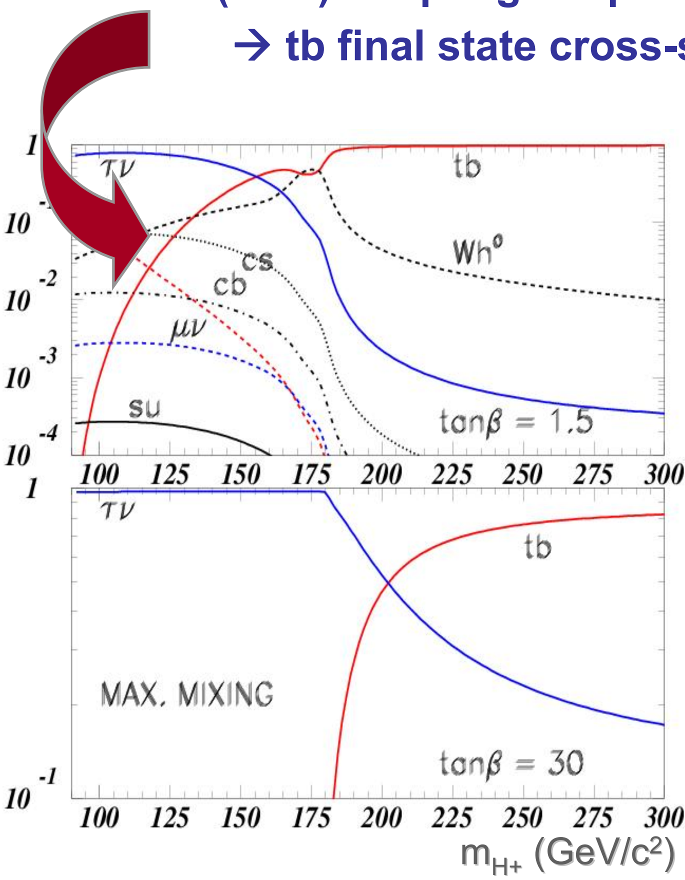
likelihood analysis under development

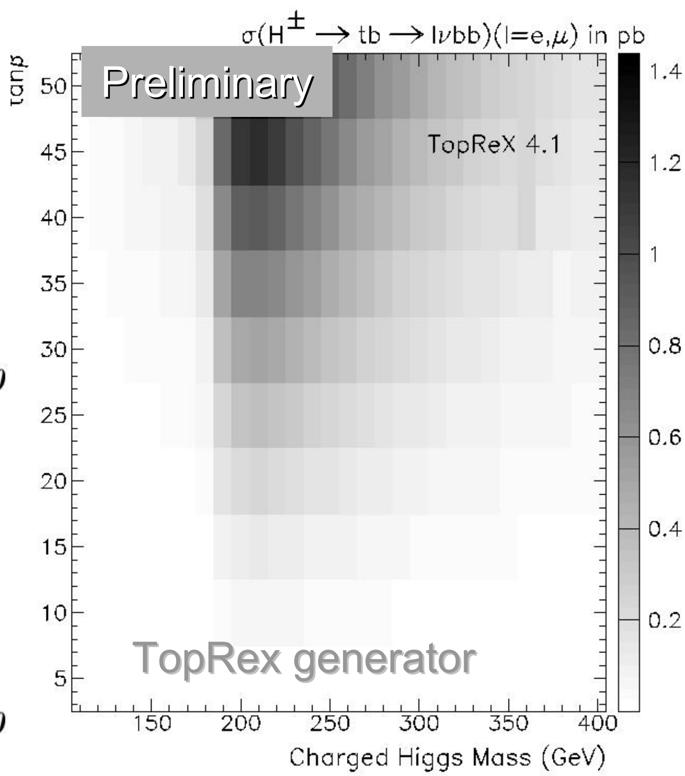
s-channel with 30 fb^{-1} : Why is it so interesting ?

Charged Higgs & single-top

Production mode in 2 HDM :

- 5 higgs: 3 neutral (A,h,H) + 2 charged ($H^{\pm}$)
- Mass spectrum predicted in MSSM
- ($H^{+}tb$) couplings depends on $m_{H\pm}$ and tan β
  - → tb final state cross-sections are modified by an H^{+}





Event Selection :

- Use same analysis as developed for the s-channel
  - → efficiency increases with m_{H+}
- Systematics limited measurements
- Only standard sequential analysis so far

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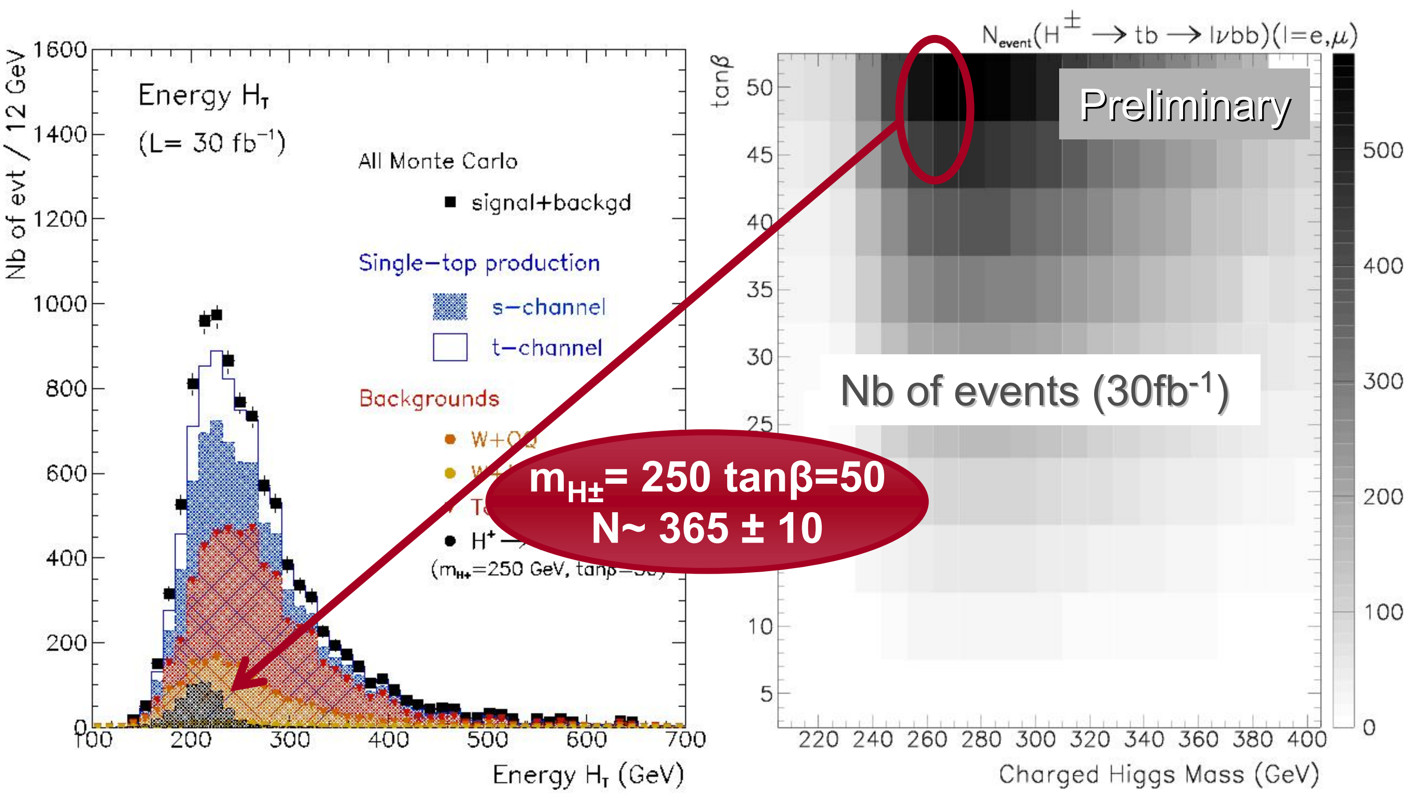

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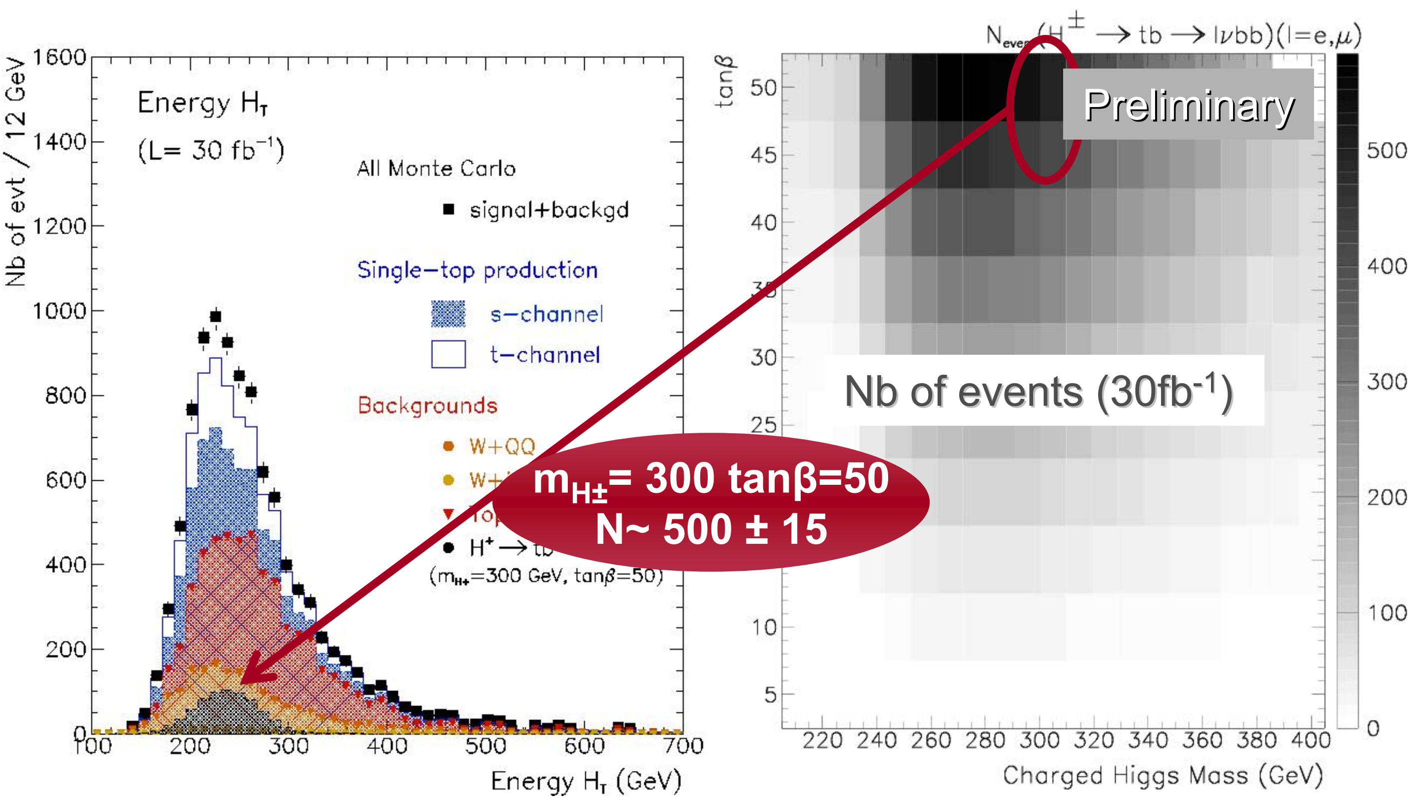

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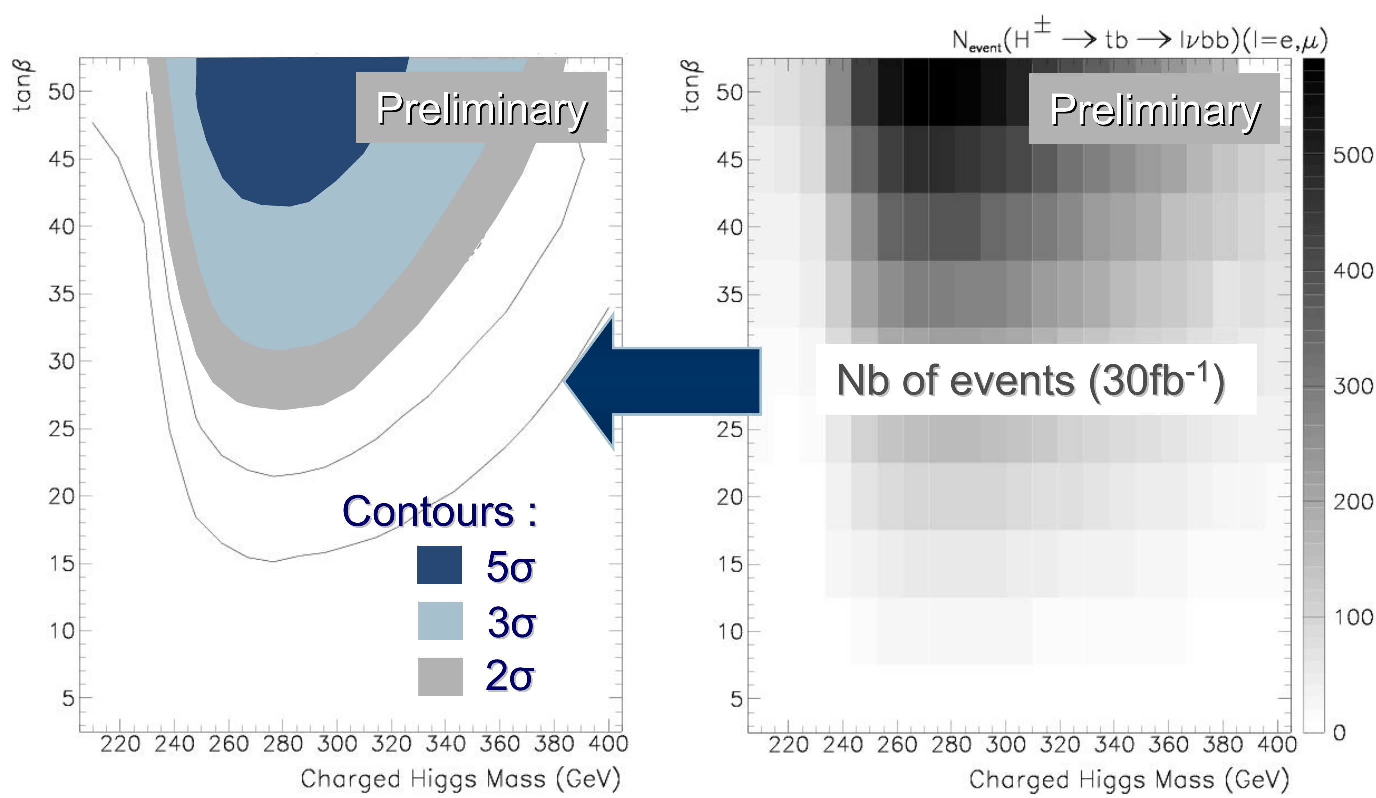

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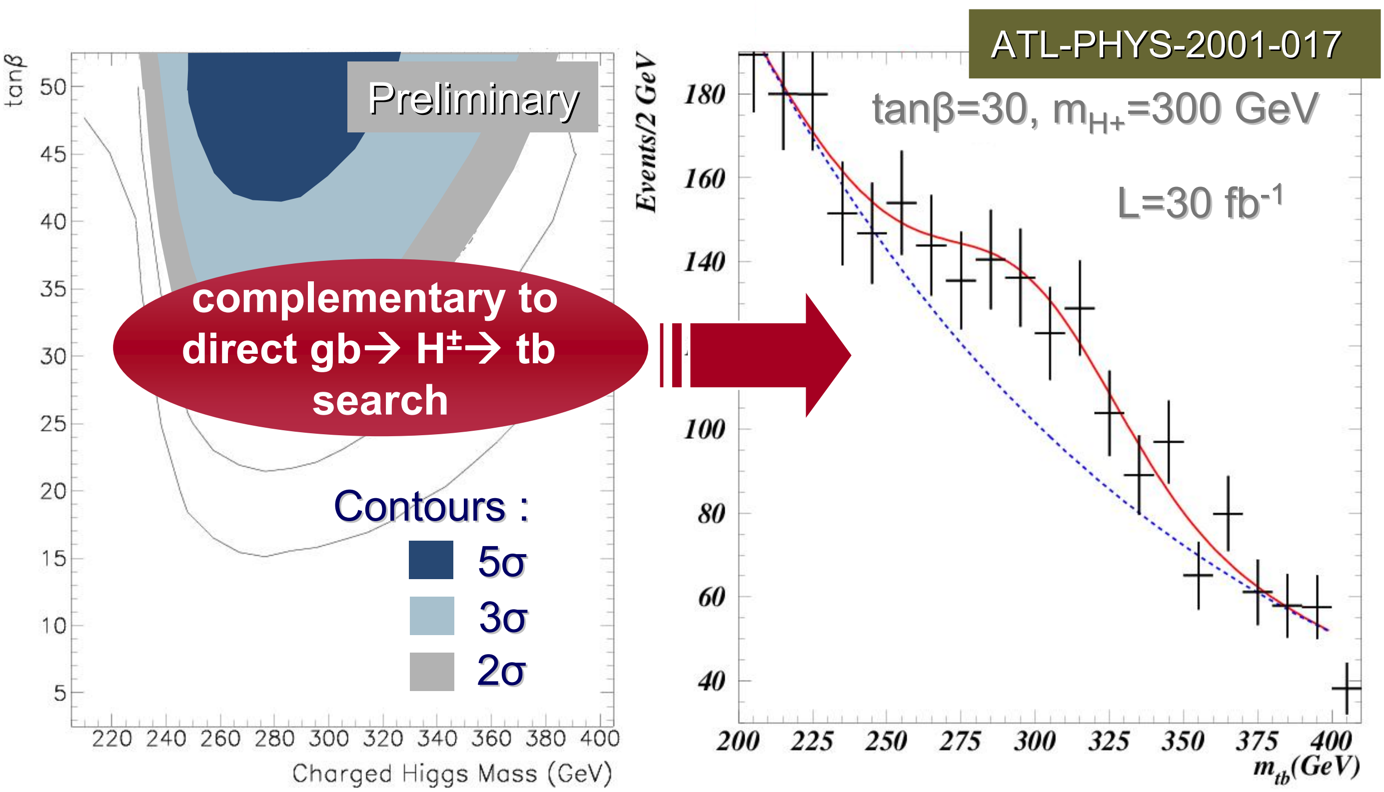

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  → efficiency increases with m_{H+}
- Systematics limited measurements
- Only standard sequential analysis so far

Conclusion & perspectives

Top pair production

LHC as a "top factory"

- more than 300k events a year
  → measurements will be systematics limited

Top mass measurements:

- Total uncertainty of ~1 GeV/c^2 seems achievable
- Main systematics :
  → 1% level calibration of (b)-jet energy scale
- Together with $m_W \approx 15$ MeV/c^2
  → constraint m_H / m_h

Cross-section measurements:

- Systematics limited measurements
  → luminosity determination ...
- Cross-check of direct m_t measurements
- Test of QCD at 6% level

Single-top production

Cross-section measurements;

- Specific tests of EW production
- t-channel, W+t channel
  → Statistical sensitivity to V_{tb} at ~1% level
  → Tests of anomalous couplings, FCNC
- s-channel, W+t channel
  → probe to new extra boson in (3 years low luminosity)

Thanks to :

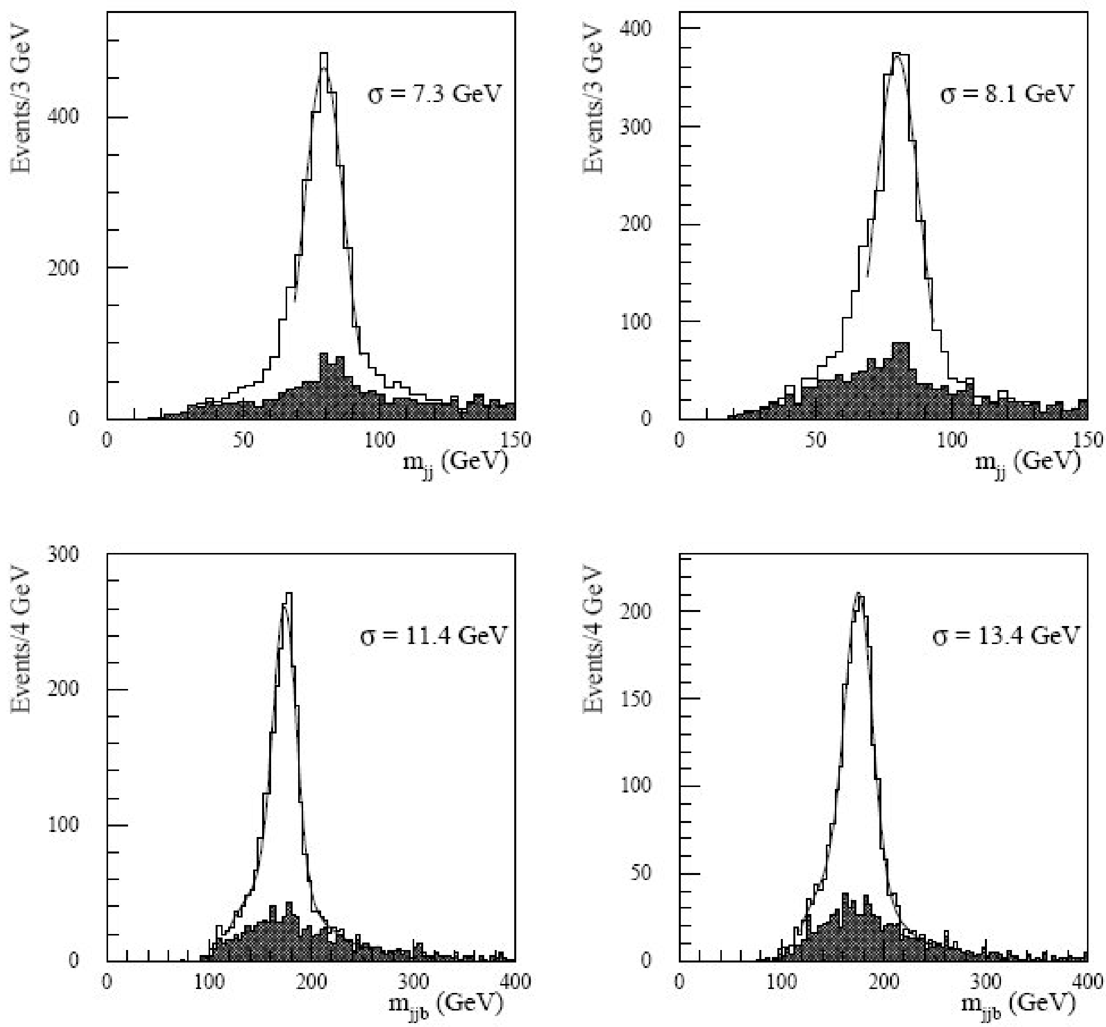
Bentvelsen, Van Vulpen et al.

Correard, Devivie, Rozanov, Vacavant et al.

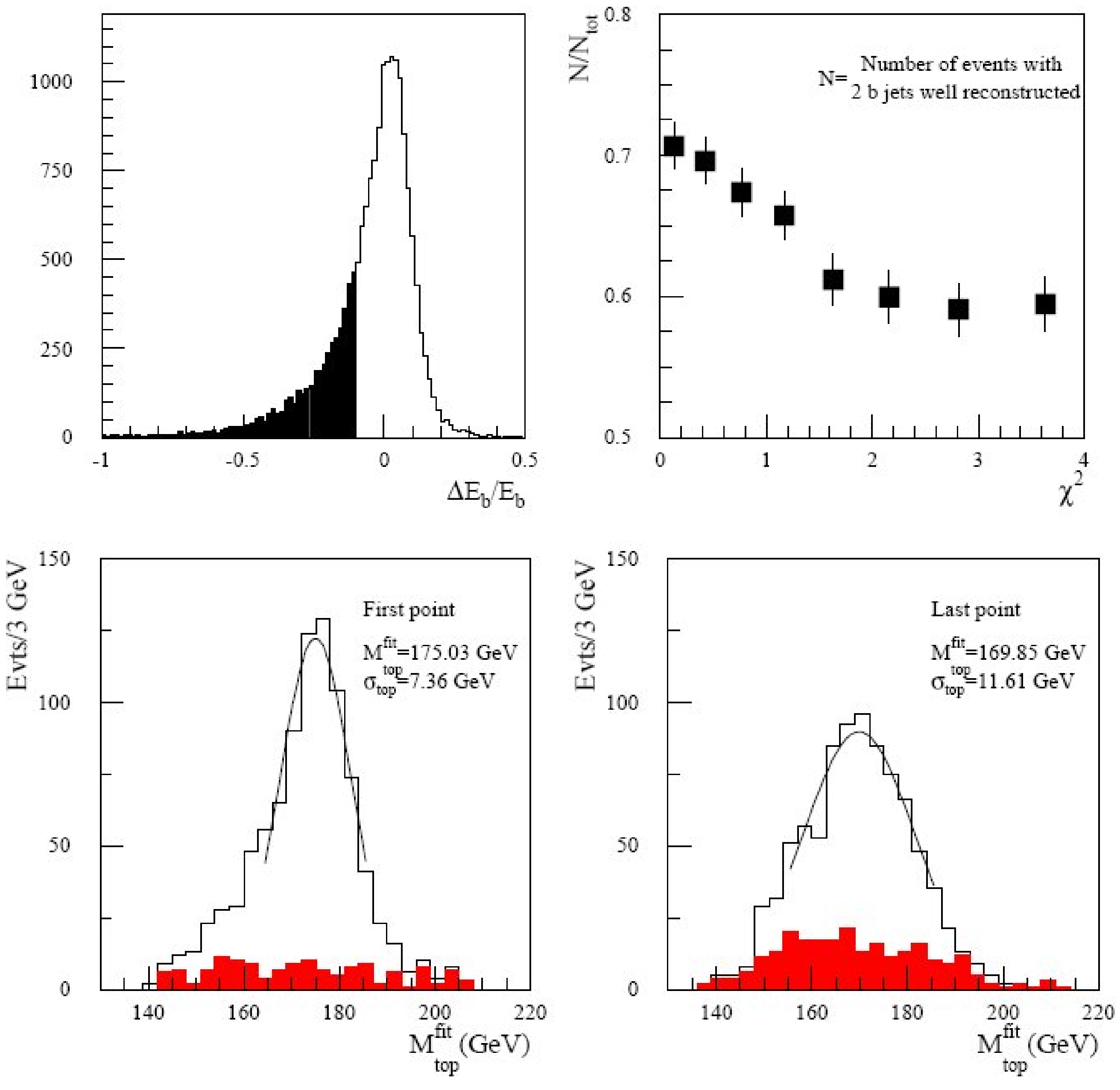
D. Pallin, P. Roy et al.

BACKUP SLIDES

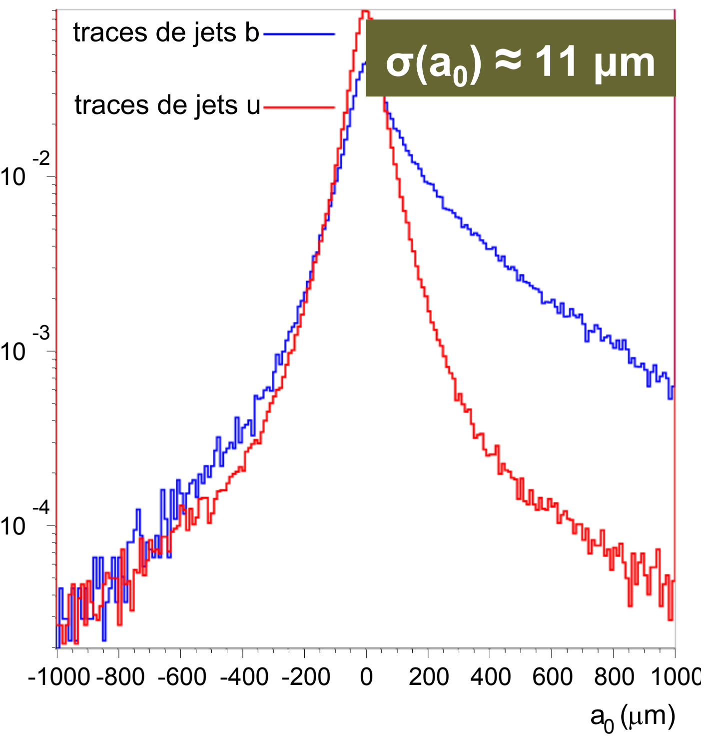
Fast simulation vs Full Simulation

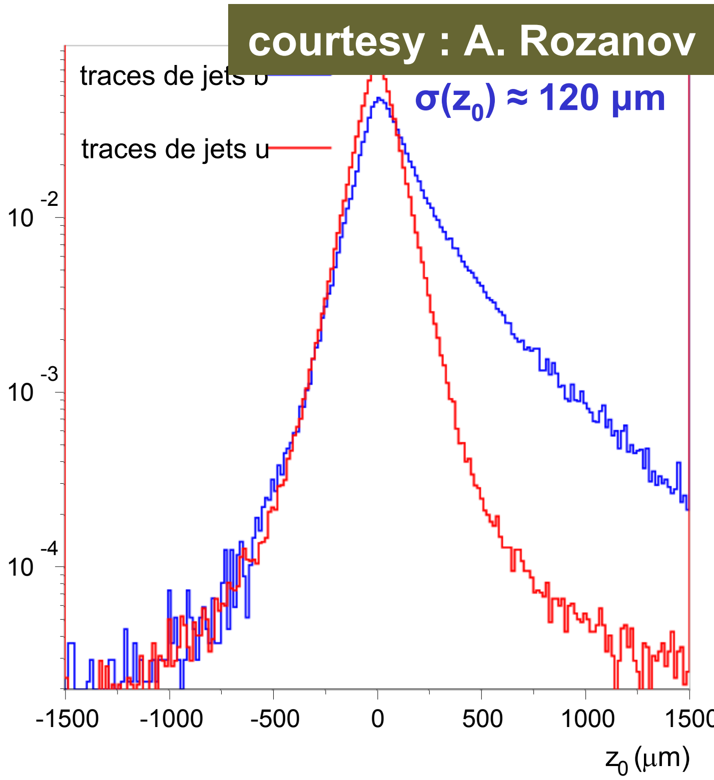


“lepton+jets” : systematics



b-tagging : 3D impact parameter





Conclusion

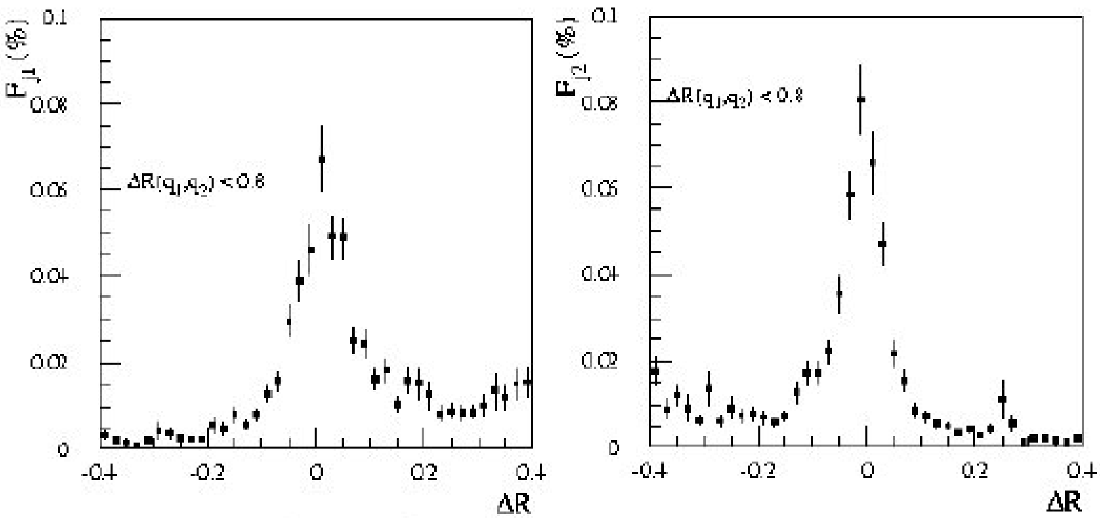
Physics

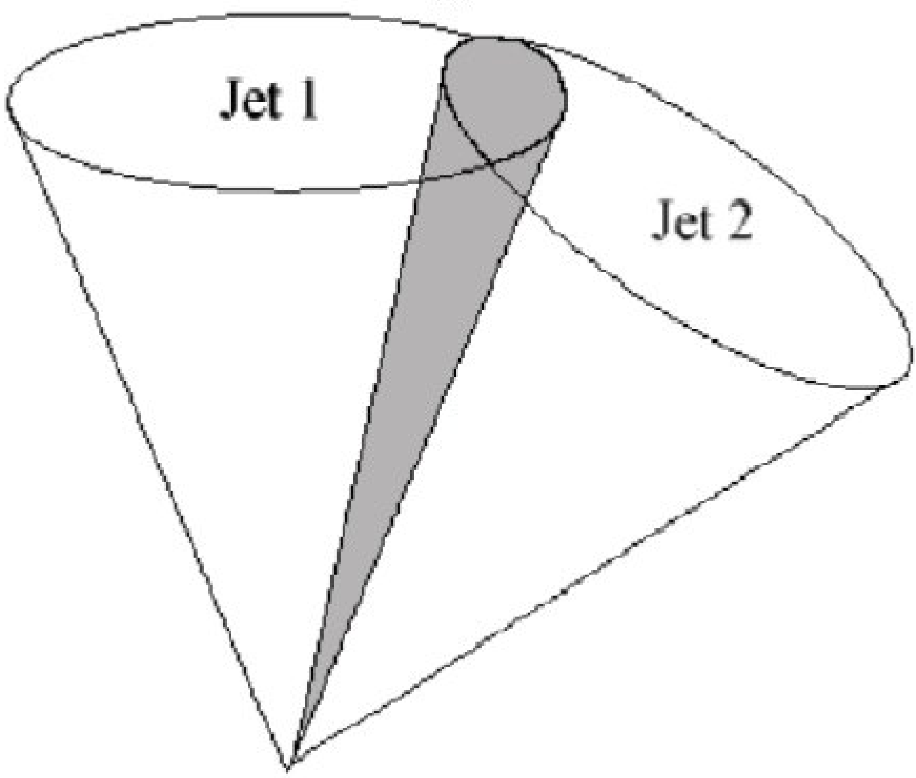
- **Precision measurements are only possible @ LHC**
  - s-channel
    - tt , WQQ, W+jets, W+g major backgrounds
    - Statistical Precision ~ few % with 30 fb^{-1}
  - W-g channel
    - Higher signal cross-section (cont. by tt & W+jets)
    - Expect statistical precision of ~1-2%
  - W+t channel
    - top-pair is the major backgd
    - Expect statistical precision of ~ few %
- **Systematic uncertainty**
  - JES should be a dominant source of error
  - b-tagging knowledge & model. (eff, rejection) is crucial
  - Background knowledge is important
    - → Use of data is mandatory (ttbar, WQQ, W+jets))

FullSim

- **Results seem compatible with AtlFast, but :**
  - All backgrounds have to be reestimated (new Gen.)
  - FullSim have to be used for systematic studies
    - (JES, b-tagging, electron ID, calibration)

Light jet energy scale : sharing between two jets



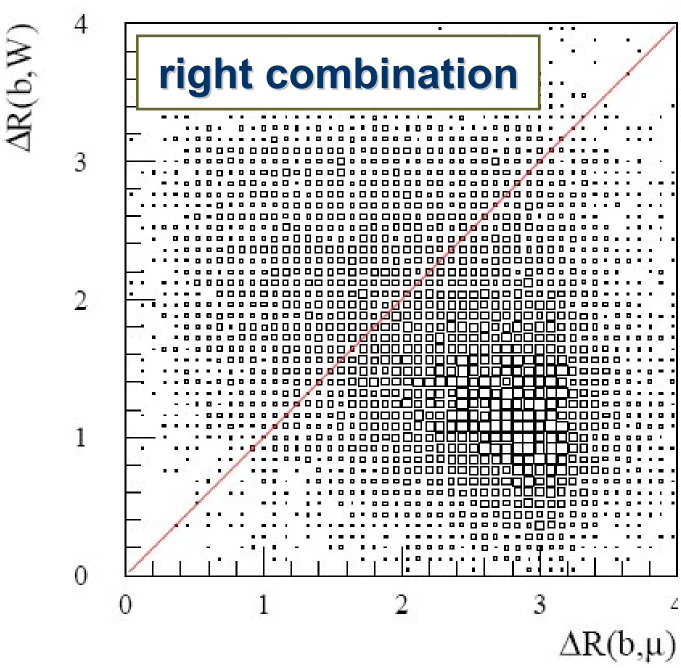


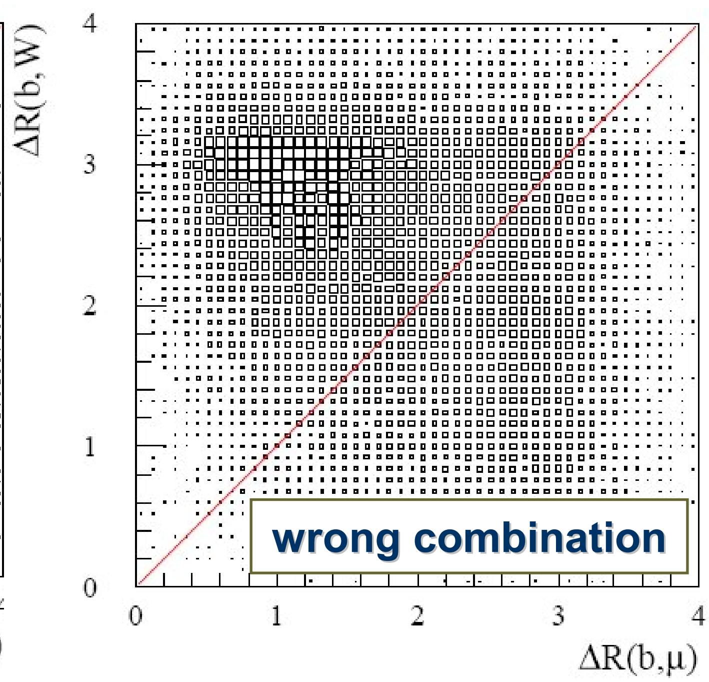
Top Quark Mass measurement : Top Quark reconstruction

Top Quark reconstruction

Association of hadronic W and b-jet :

- Combination leading to the highest p_T^{top}
  or that maximizes $\Delta R(l,b)$ / minimizes $\Delta R(b,W \rightarrow jj)$
  → right (jjb) combination in ~ 80% cases

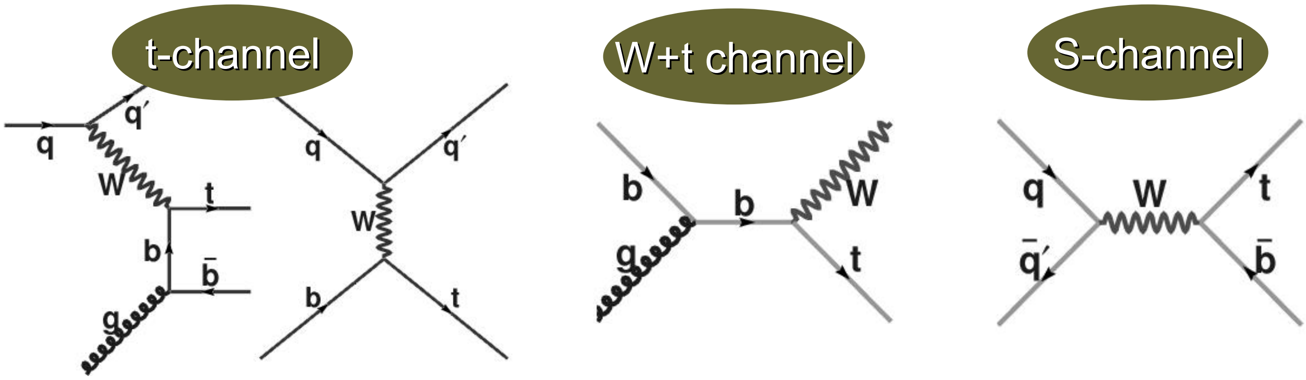




Single Top cross-section :
Production @ LHC

Production at the LHC

All 3 contributing mechanisms in SM



Theoretical prediction

NLO/NLL available for W* and W-g only

→ affect significantely σ as well as p_T(jet), H_T etc…

hep-ph/0408049

Channel	σ(pb)	Uncerta		
		PDF	μ-scale	Δm_{top}
W-g	246.6 ± 8.7	4%	3%	1%
W+t	60 ± 20?	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%)