ATLAS LPNHE top quark studies and around

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Aurélien Demilly (PhD sept 2011 →)
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Guillaume Lefebvre (PhD sept 2011 →)
Mélissa Ridel
Timothée Theveneaux-Pelzer (PhD → 2012)
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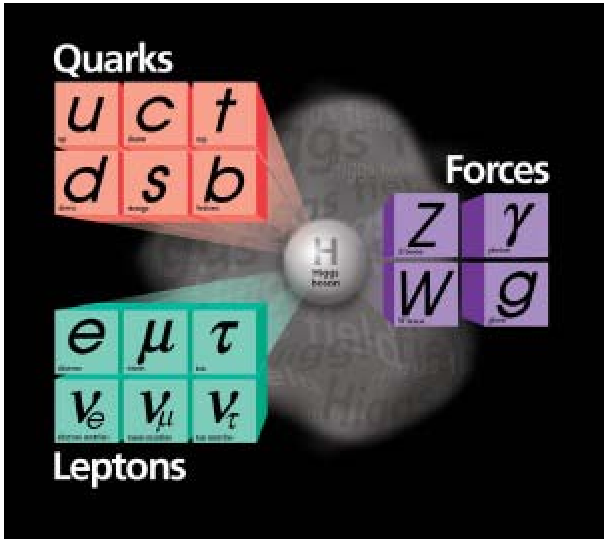
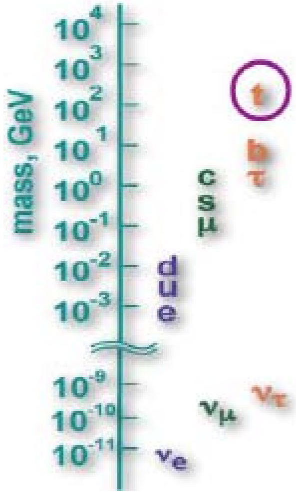
This talk covers activities of persons mentionned above on top quark activities or directly related to it
All of them are also involved in other activities/teaching

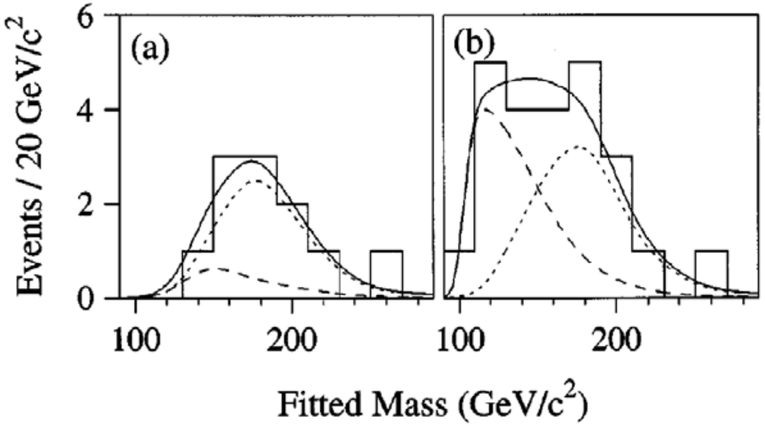
Top quark physics

- **Top quark is rather well known particle**
  - discovered in 1995 at Tevatronby CDF and D0
  - heaviest known elementary particle, m_t~172 GeV, i.e as massive as a Gold atom ! mass known to ~0.6% ! width = ~1.5 GeV, electric charge=2/3, spin=1/2

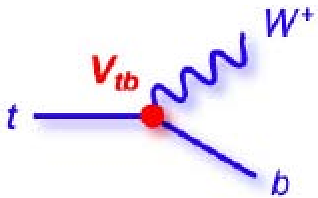




D0, Phys. Rev. Letters {74} 2632 (1995)



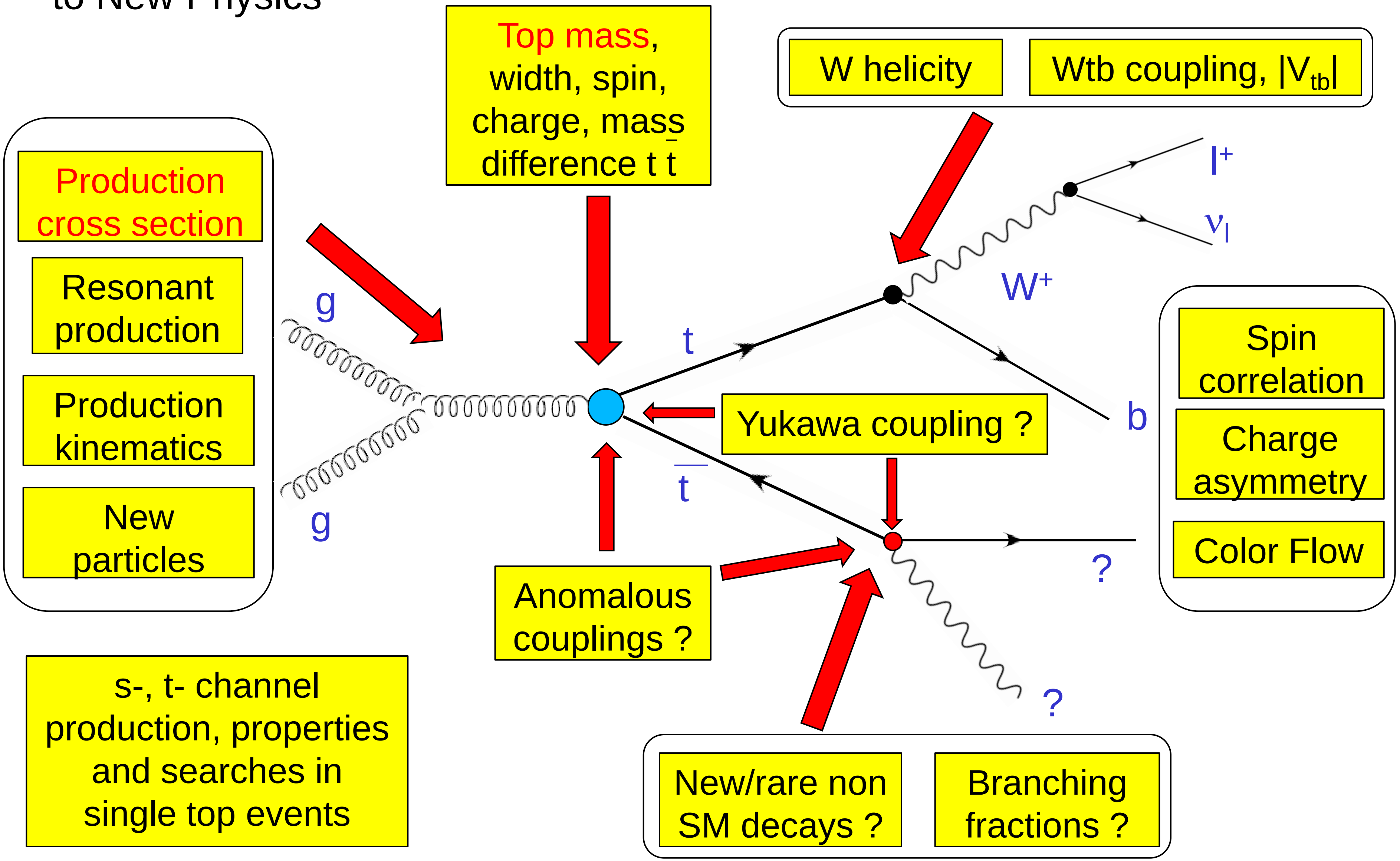
  - very small lifetime $\tau \sim 4\times10^{-25}$ s, it decays before hadronization – we see it bare !
  - it decays through one channel $t\rightarrow W^+b$, BR($t\rightarrow$other)$\leq10^{-3}$
  - the total and differential rates are calculated with O(10%) accuracy



- **Coupling to Higgs ~1 ⇒special role in Electroweak symmetry breaking ?**
- **Special sector to searches for new physics**

What kind of physics to do with Top quark ?

Large physics program available with top quark physics, from Standard Model to New Physics

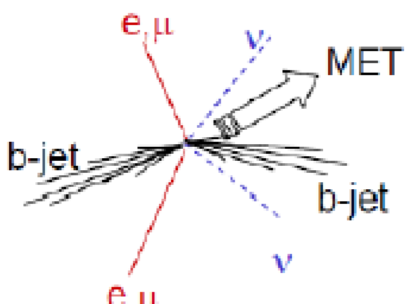


Top quark production and decays

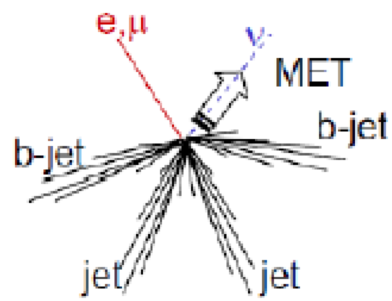
- **Production mechanism**
  - $t\bar{t}$ pair, 85% by gluon fusion, ~15% by qq production
  - single top (not covered here)
- **Top pair production cross section**

  $\sqrt{s}$= 7 TeV : $\sigma(pp\rightarrow tt)_{NLLOapprox} = 165.6^{+11.4}_{-15.7}$ pb

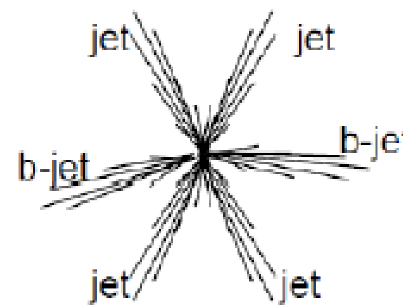
- **Top pair event classification according to W decays**



dileptons



lepton + jets



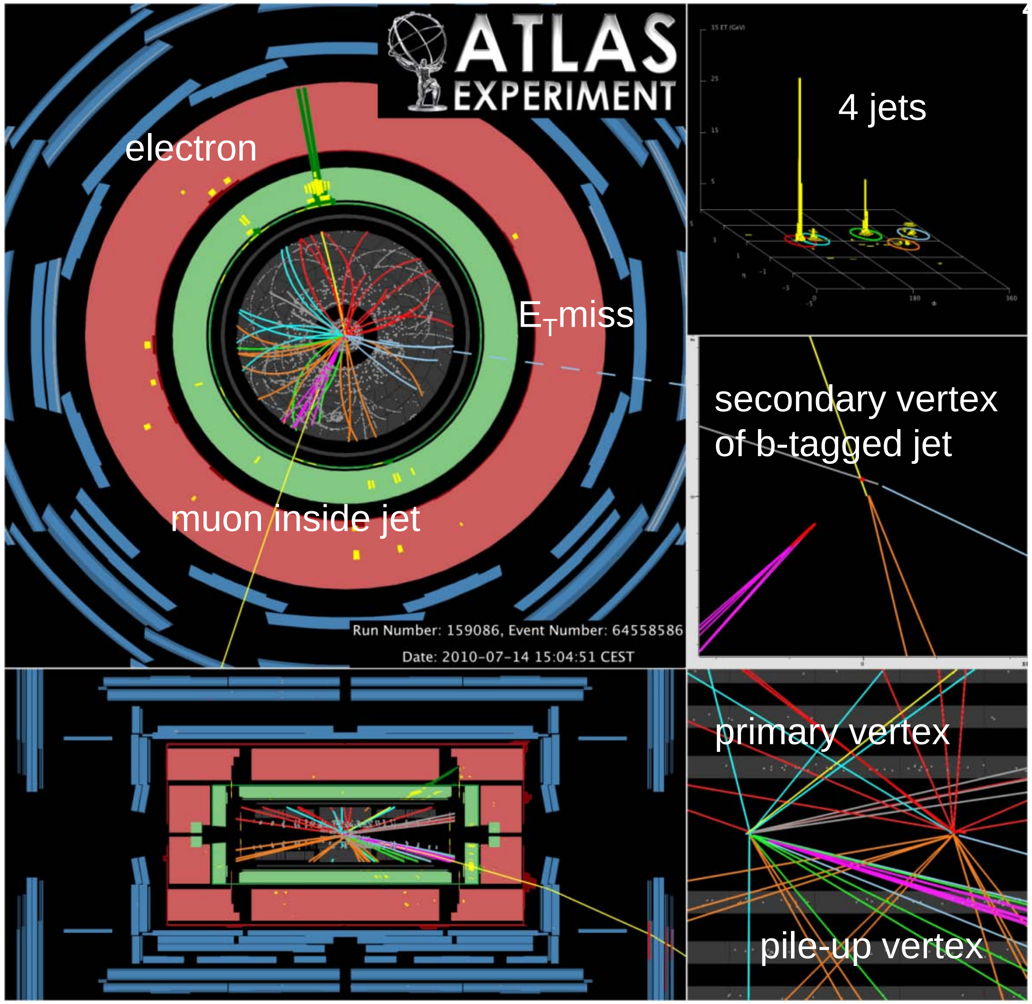
all hadronic

Branching ratio	~5%	~30%	~46%
Final state	2 isolated leptons large ETmiss, 2 b-jets	1 isolated lepton ETmiss 2 b-jets, 2 light jets	no lepton small ETmiss 2 b-jets, 4 light jets
Backgrounds	few (mainly Z+jets)	moderate (mainly W+jets)	huge (mainly QCD)

Tau channels are now studied but are very specific

What do we need to reconstruct Top quark ?

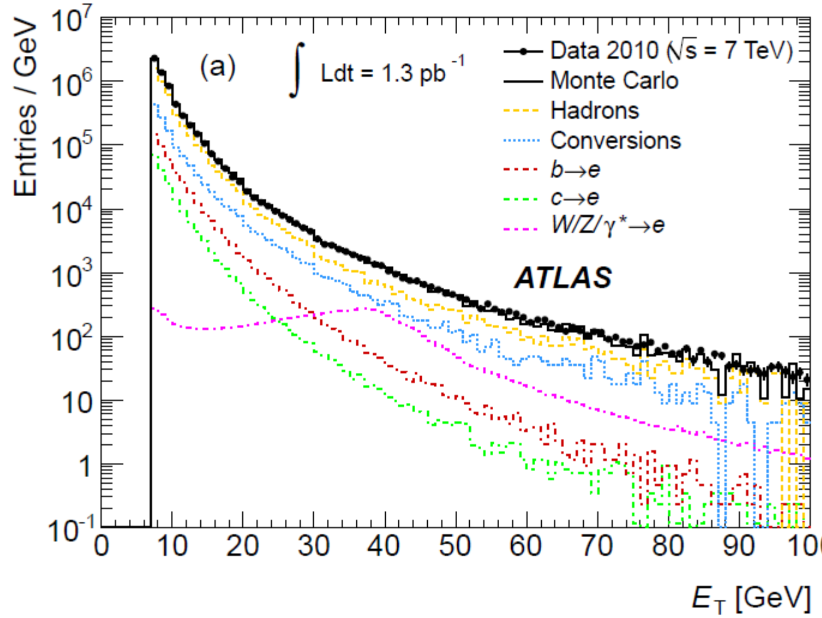
To study top quark it implies good understanding of many different objects reconstructed in all different ATLAS subdetectors

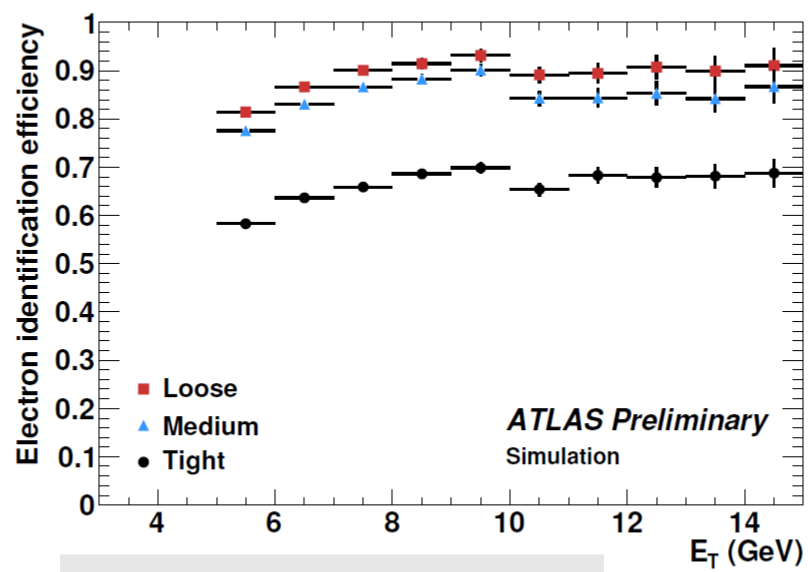


Electron studies

- **Electron sources**
  - W/Z decays
  - heavy flavour decays (b,c→eX)
  - γ conversions
  - fakes from charged hadrons
- **Different identification definitions**
  - **Loose** : acceptance, min track quality, electromagnetic shower width
  - **Medium** : additional shower shapes, hits in silicon detectors, transverse impact parameter, cluster-track matching
  - **Tight** : inner pixel layer hits, E/p, TRT high threshold hits

Large effort in the Combined Performance groups, mostly **e/gamma**:
- co-responsible of reconstruction software (→dec. 2010)
- Monte Carlo studies for expected performance at √s=10 TeV in 2009
- 1st data studies at 900 GeV and 7 TeV



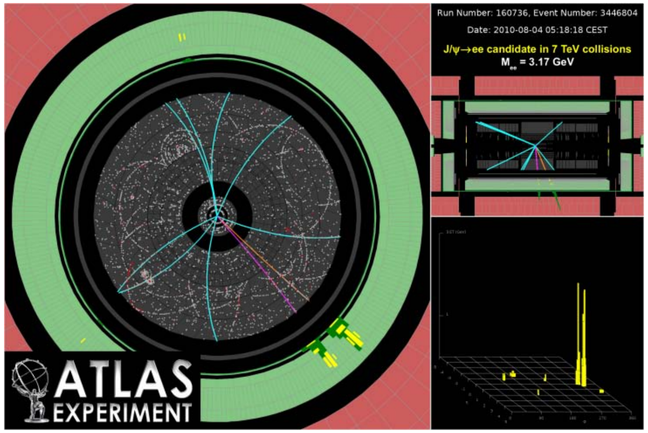


ATL-PHYS-PUB-2011-006

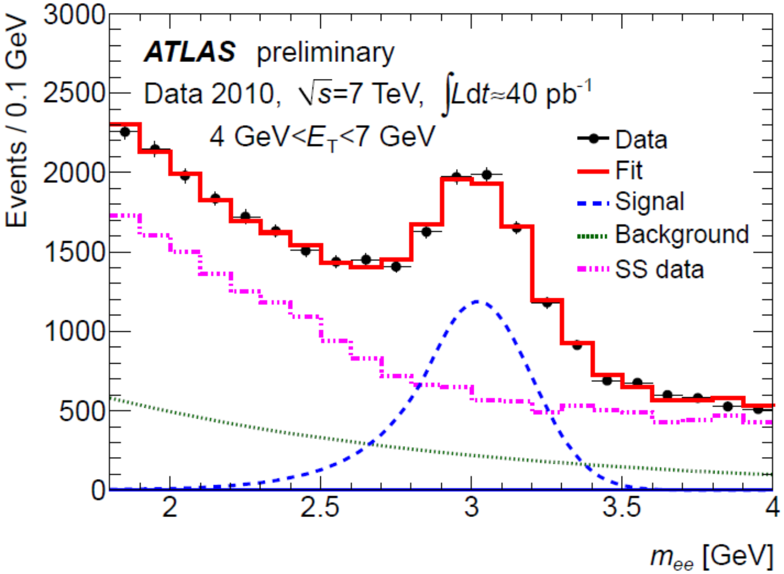
$J/\psi \to e^+e^-$ studies

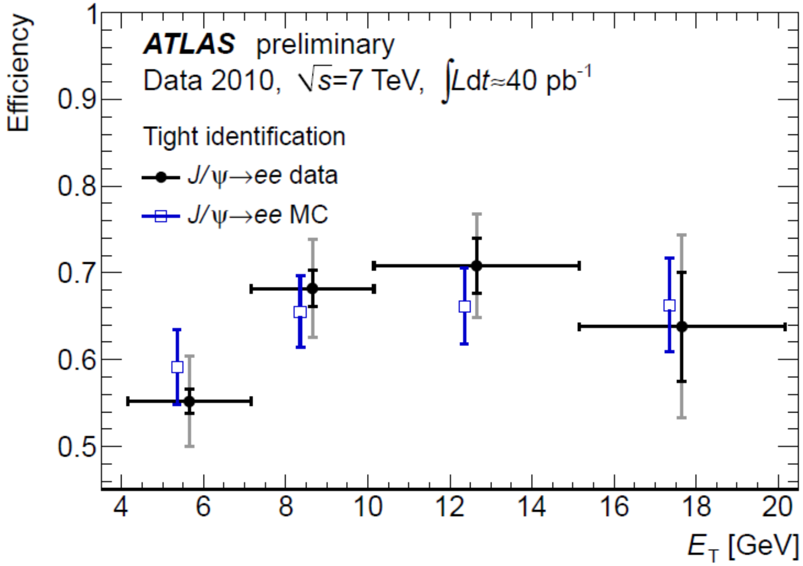
ATLAS-COM-PHYS-2010-058
e/gamma paper performance in preparation
Timothée presented results in Epiphany conference (Cracow) and poster at EPS

- **J/ψ as a tool**
  - main source of isolated low p_T electrons
  - can be used to study detector and electron performance : calibration, efficiency
  - cross-check and comparison of higher p_T results obtained with Z/W



- **Studies in 2010 data**
  - participation to re-discovery with early data
  - measurement of identification efficiency at low p_T using Tag and Probe technique

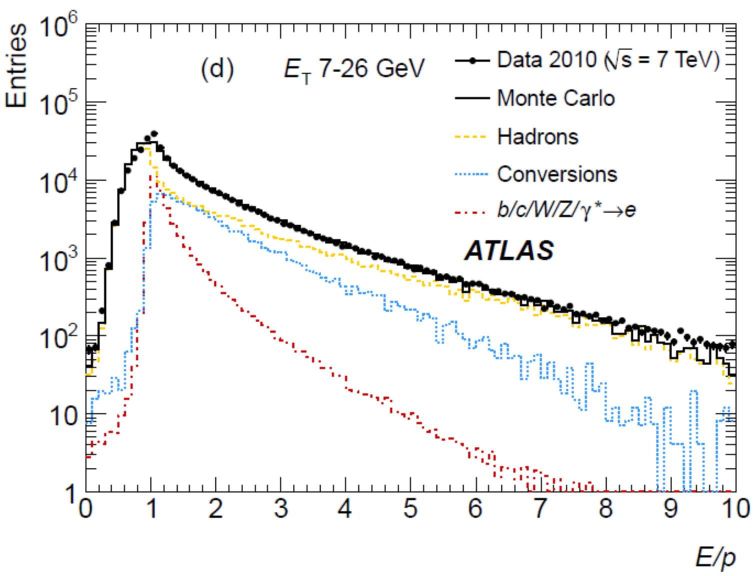


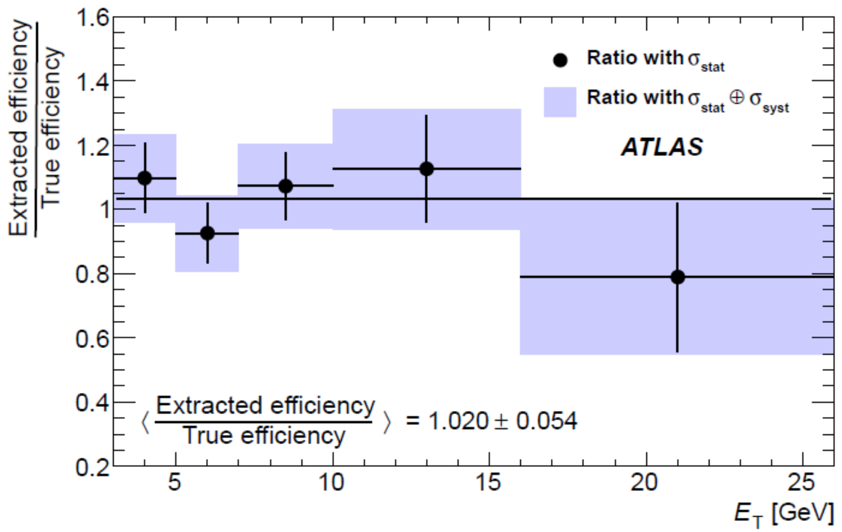


measurement of efficiency in range E_T=4-20 GeV in agreement with simulation

b→eX studies

- **use of electrons in $b\bar{b}$ events**
  - measurement of identification efficiency for non isolated electrons at low p_T
  - development of a Tag and Probe method without resonances
  - signal largely dominated by γ conversions and fakes from charged hadrons
- **Analysis**
  - signal is extracted using discriminating variables applied before and after identification
  - results are in agreement with measurement based on simulation
  - allows a efficiency measurement mostly based on data





More details were provided by Stefania during her PhD defending last Friday !

Electron heavy flavour cross section measurement

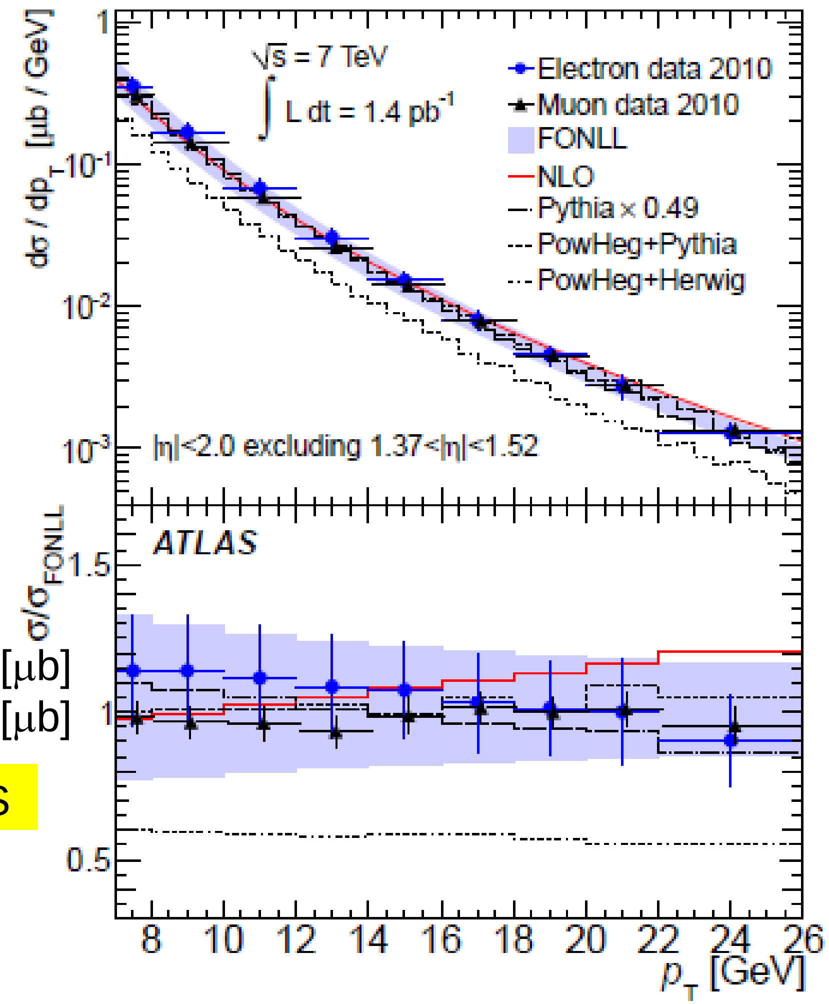
$$\frac{\Delta\sigma_i}{\Delta p_{T_i}} = \frac{N_{sig_i}}{\Gamma_{bin_i} \cdot \int \mathcal{L}dt} \cdot \frac{C_{migration_i}}{\epsilon_{(reco+ID)_i} \cdot \epsilon_{trigger_i}},$$

Differential cross section

- N_{sig} : number of signal lepton with p_T in bin i of width Γ_i
- $\varepsilon_{trigger}$ and $\varepsilon_{reco+ID}$ are the efficiency of trigger and reconstruction level, $C_{migration}$ bin migration factor, $\int\mathcal{L}dt$: integrated luminosity

Analysis (1.4 pb^{-1})

- selection of non isolated electrons and muons
- E_T=7-26 GeV, $|\eta|<2.5$, excluding $1.37<|\eta|<1.52$
- $\varepsilon_{reco+ID}$ with Monte Carlo and data driven methods



Results

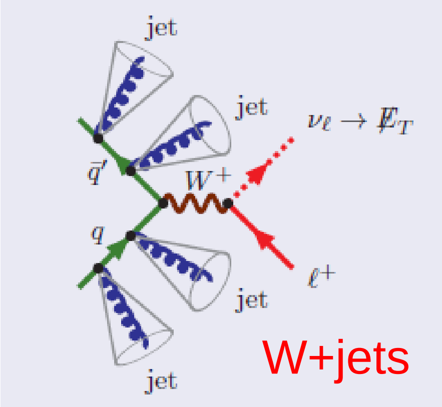
σ^e_{HF} = 0.946 ± 0.020 (stat.) ± 0.146 (sys.) ± 0.032 (lumi.) [μb]
σ^μ_{HF} = 0.818 ± 0.003 (stat.) ± 0.036 (sys.) ± 0.028 (lumi.) [μb]

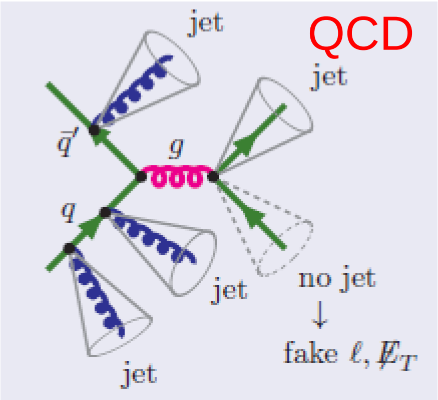
Good understanding of both inclusive e and μ by ATLAS

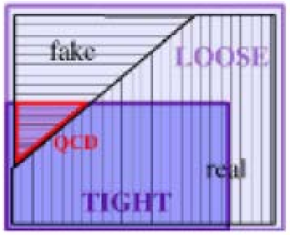
subm to PLB (Mélissa was co-editor)
Stefania presented poster at EPS

Fake electron studies for top analysis

- **Some backgrounds are in common in top studies l+jets or dilepton**
  - W+jets
  - jets faking electrons







- **Matrix method for QCD**
  - Define Loose and Tight identification, evaluate « real » and « fake » efficiencies

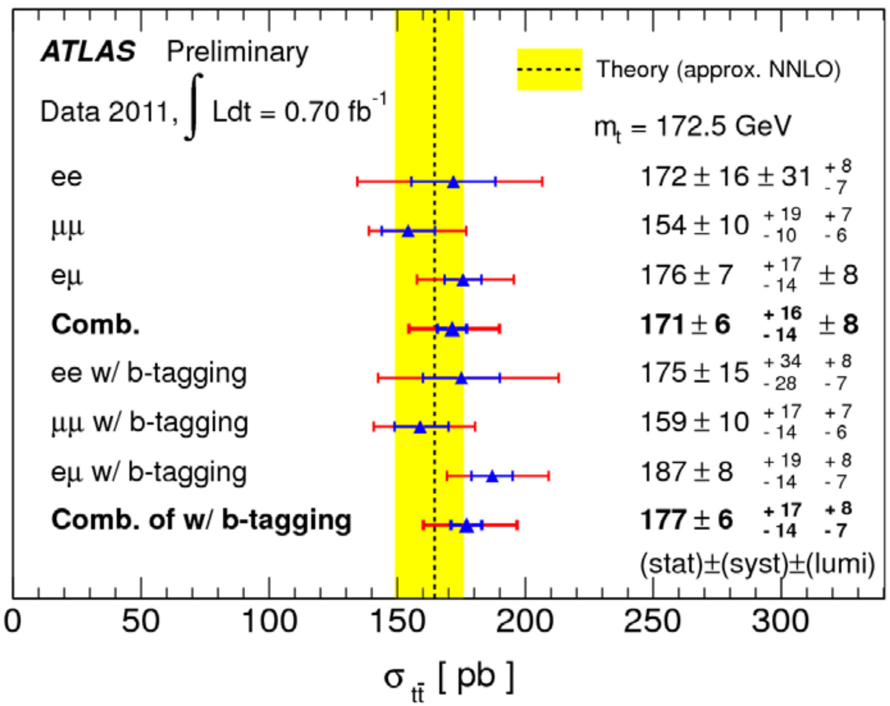
$$N^{loose} = N^{loose}_{real} + N^{loose}_{fake}$$
$$N^{tight} = \varepsilon_{real}\, N^{tight}_{real} + \varepsilon_{fake}\, N^{tight}_{fake}$$

- Loose/Tight differ slightly from what is provided by e/gamma (specific work to be done for top)
– ε_{real} from MC (Z→ll, W+jets), start with data driven method
- ε_{fake} from QCD control region
- study vs N_{jet}, p_T etc

- **Work started since ~May**
  - develop analysis/selection code for dilepton, l+jets for EPS
  - apply the Tag and Probe technique for ε_{real} based on Z or Z+jets events
  - develop the measurement of ε_{fake}

ATLAS top in dilepton cross section

- **Updated result for EPS 2011**
  - analysis on 0.7 fb^{-1} in ee, $\mu\mu$ and eμ channels
  - measurement still dominated by systematic uncertainties
  - large contributions are MC-related
  - larger systematics in electron channels (ID, fakes)
  - need to improve also on Jet Energy Scale



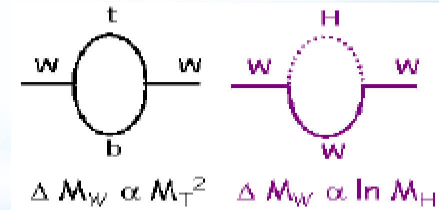
	ee	$\mu\mu$	$e\mu$	Combined
Uncertainty Source	$\Delta\sigma/\sigma[\%]$	$\Delta\sigma/\sigma[\%]$	$\Delta\sigma/\sigma[\%]$	$\Delta\sigma/\sigma[\%]$
Data statistics	-9.3 / 9.8	-6.6 / 6.8	-4.1 / 4.2	-3.3 / 3.3
Luminosity	-4.0 / 4.7	-3.7 / 4.3	-4.3 / 4.7	-4.2 / 4.6
MC statistics	-4.2 / 4.9	-2.8 / 3.2	-1.9 / 2.1	-1.5 / 1.6
Lepton energy scale	0.0 / 0.9	0.0 / 0.5	-0.3 / 0.3	-0.4 / 0.0
Lepton energy resolution	0.0 / 0.6	-0.5 / 0.8	0.0 / 0.5	-0.4 / 0.3
Lepton indent. scale factor	-5.5 / 6.6	-1.2 / 2.7	-3.1 / 3.4	-2.6 / 2.7
Jet energy scale	-10.0 / 10.6	-3.8 / 7.6	-3.7 / 4.5	-5.9 / 5.3
Jet energy resolution	-0.6 / 0.8	-3.1 / 3.6	-0.6 / 0.7	-0.4 / 0.3
Jet reconstr. efficiency	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0
Drell-Yan prediction	0.0 / 0.0	-0.4 / 0.4	0.0 / 0.0	0.0 / 0.0
Fake leptons	-1.6 / 1.6	-0.4 / 0.4	-3.2 / 3.2	-2.0 / 1.9
MC generator	-4.3 / 5.3	0.0 / 0.0	-2.9 / 3.2	-2.1 / 2.3
Parton shower	-4.7 / 5.8	-0.4 / 0.5	-2.9 / 3.2	-2.3 / 2.4
ISR	-7.1 / 0.6	-0.8 / 3.6	-0.5 / 2.4	-2.4 / 2.5
FSR	-13.6 / 0.6	-0.7 / 4.3	-2.4 / 0.5	-1.3 / 1.4
PDF	-2.4 / 2.8	-1.7 / 2.2	-2.4 / 2.7	-2.3 / 2.5
E_T^{miss} reconstruction	-1.0 / 1.1	-0.8 / 1.7	0.0 / 0.0	-0.5 / 0.6
Pile-up	-0.6 / 1.3	-0.5 / 1.5	0.0 / 0.0	-0.5 / 0.5
Detector modeling	-0.6 / 1.1	-0.7 / 1.5	-0.7 / 1.2	-1.0 / 1.3
Theoretical cross-sections	-1.4 / 1.3	-1.7 / 1.8	-2.1 / 2.1	-1.9 / 1.9
All systematics	-20 /18	-7.3 /13	-9.2 /11	-9.3 / 10
Stat + Syst	-22 / 20	-9.9 / 15	-10 / 12	-9.8 / 11

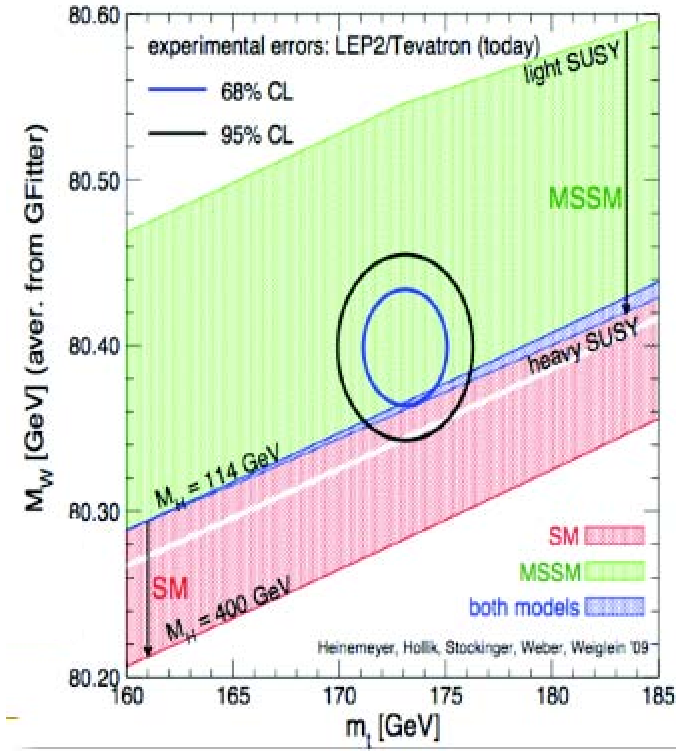
ATLAS-CONF-2011-100

Top quark mass studies

- **A fundamental parameter of the Standard Model**
  - free parameter of LO QCD
  - depending on a renormalization scheme and scale
- **Top and W masses constrain Higgs mass**

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





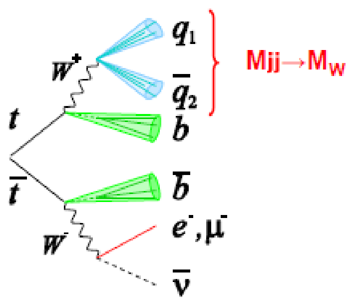
- **Precise top quark measurement also provides constraints on contribution from New Physics**
- **Question will remain : which mass we measure ?**
  - related to pole mass or $\overline{\mathrm{MS}}$ mass scheme ?

Breakthroughs in top mass measurements

In-situ Jet Energy Scale calibration

Jet Energy Scale : ±2% ΔJES ~ ±2 GeV Δm_t

- use W →jj events constraint to obtain in-situ JES
- can be done in l+jet or full hadronic channels, not in dilepton

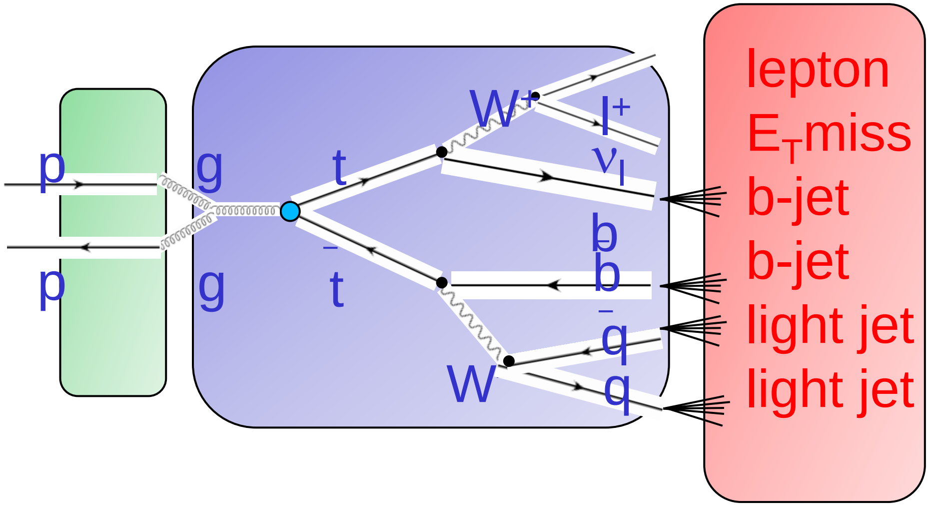


- incorporate JES into likelihood function $L(m_t) \Rightarrow L(m_t, \text{JES})$
- turn JES systematic into statistics uncertainty

Matrix Element Method

- use full event kinematic information more preicse measurement
- for each event calculate probability to belong to certain top mass

$P_{sig}(x;m_t) \propto \int$ PDF × Matrix Element × Transfer function



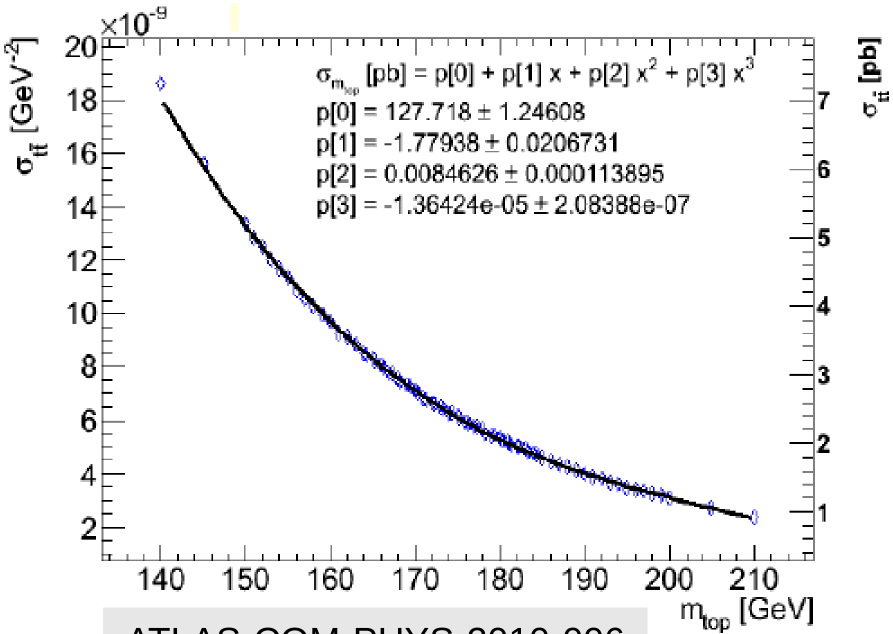
Jet-parton match : $n_{jet}!$ permutation

- b-tagging helps reducing this number
- kinematic fitter to pick-up the permutations with best χ^2

- Matrix Element for a given top mass gives pdf of observables
- likelihood function of top mass for a given set of observables

Top quark mass studies in dilepton channel

- **Prospective work on Matrix Element**
  - done in 2009 @ 14 TeV (PhD P. Cavalleri)
  - adapted @7 TeV in 2010



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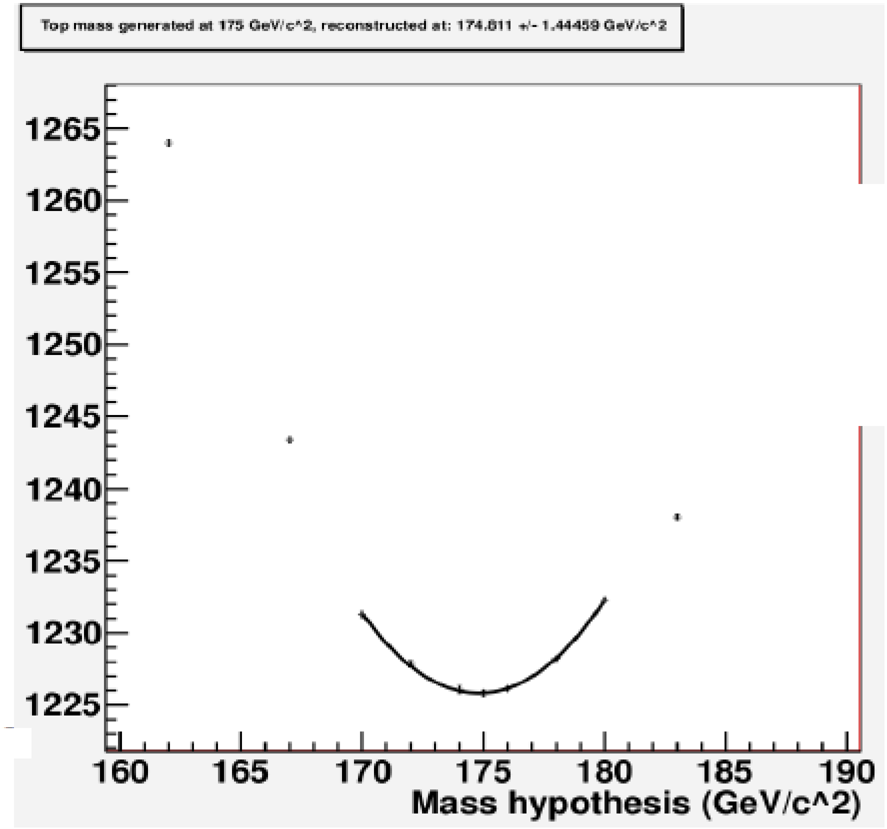
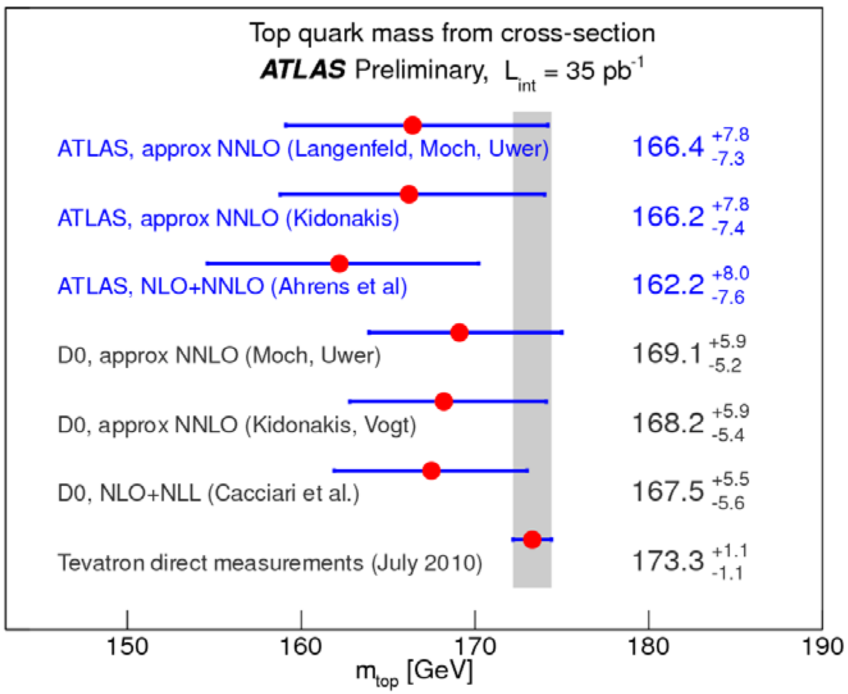
- **Work on 2010/2011 data**
  - look at transfert function
  - recently first tries of full method with 2011 data

- **Work on method**
  - several programs tested, choice of MadGraph, MadEvent, MadWeight
  - jobs send on batch or Grid
  - all steps under control



ATLAS results on top mass measurement

Lepton+jet by cross section



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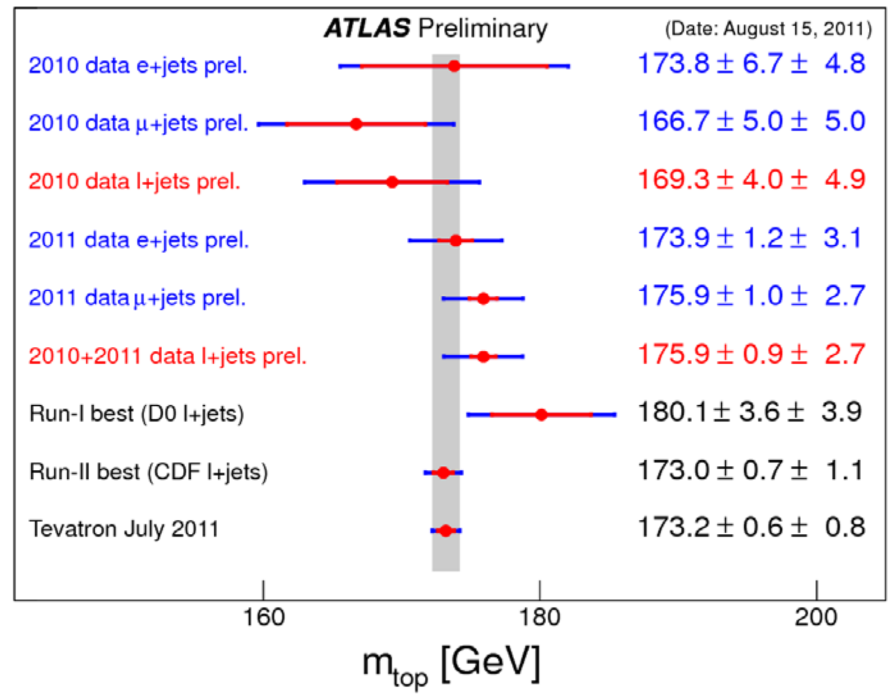
Lepton+jet by Template Method



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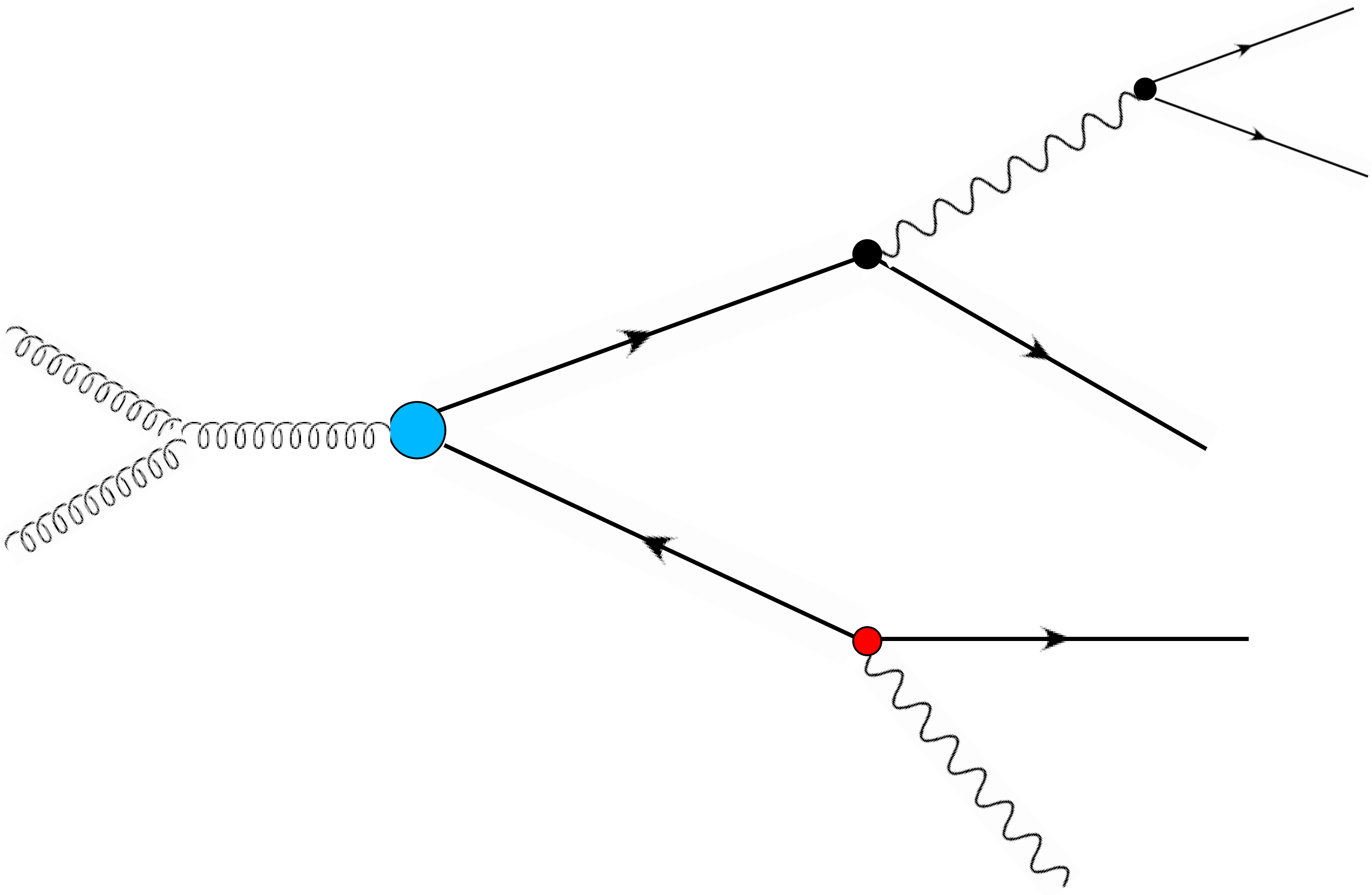
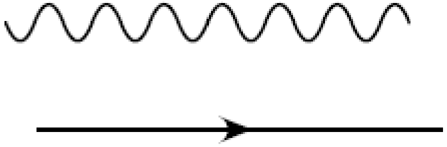
Conclusion

- **General comments**
  - ATLAS experiment at LHC has collected so far >2.5 fb^{-1} of pp collision data
  - detector is performing well and only part of data analyzed yet
  - after several years of preparation on Monte Carlo we have participated on detector good running, data taking and avaibility of data and computing resources on Grid
  - we have also participated on analysis of 2010 data :
    mostly on studies linked to electron performance
  - with 2011 data we have started to participate to dilepton cross section studies as well as first tries of the Matrix Element method developed to measure the top mass in the dilepton channel
- **Where to go ? Follow the PhD students !**
  - **Pietro Cavalleri** : development of Matrix Element method for top mass measurement @14 TeV on Monte Carlo
  - **Stefania Bordoni** : production cross section of electrons from heavy flavour decays
  - **Timothée Theveneaux-Pelzer** : top cross section in dilepton channel, electron-id and fake electrons
  - **Aurélien Demilly** : top mass in dilepton channel
  - **Guillaume Lefebvre** : top studies in full hadronic channel, JES





What do we need to reconstruct Top quark ?

To study top quark it implies good understanding of many different objects reconstructed in all different ATLAS subdetectors

Muons

combined fitted tracks

isolated

central : $|\eta|<2.5$, $p_T>20$ GeV

remove heavy-flavour decays : no muons with $\Delta R<0.4$ of a jet

Triggers

based on high p_T electrons, muons, jets

Electrons

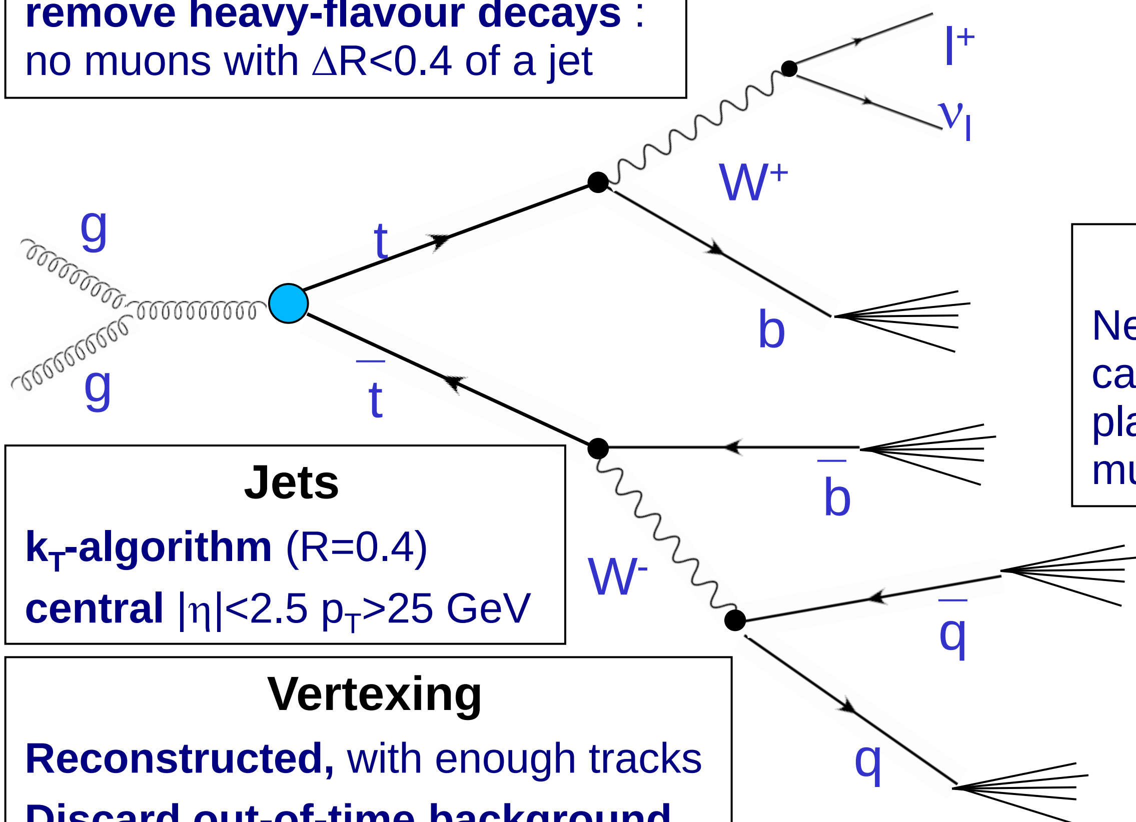
matched track and EM cluster

Tight identification using shower shape variables, track-cluster matching, E/p, transition radiation

isolated

central : $|\eta|<2.5$, $p_T>20$ GeV

Remove close-by duplicate jets



$E_T$miss

Negative vector sum of energy in calorimeter cells, projected in transverse plane, associated with high p_T object, muon momentum, dead material loss

Jets

k_T-algorithm (R=0.4)

central $|\eta|<2.5$ $p_T>25$ GeV

b-tagging

long lifetime of B mesons : track impact parameter resolution, reconstruction of secondary vertex

soft muon from b-decay

Vertexing

Reconstructed, with enough tracks

Discard out-of-time background

Analysis methods

Counting events

Establish selection, estimated expected background → Find number of data events → Subtract expected background from signal events

Templates/Likelihood

Reconstruct the best discriminating variable X (e.g invariant mass) → Form signal and background templates of X → Perform a likelihood fit between data and templates

Matrix Element Method

Form per-event probability based on Matrix Element → Evaluate probability of each event for signal and background hypotheses → Use probability into a likelihood

Neural Networks, Boosted Decision Trees

Find best discriminating variables (need good data/MC agreement) → Input variables from MC to train a multivariate package → Use output as discriminant, likelihood fit between data and MC