Study of top quark production in the semileptonic decay mode at the ILC

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Plan

1. Motivation

2. Measurement method

3. Efficiencies

4. Results

The top quark and extra dimensions

Geography and compositeness

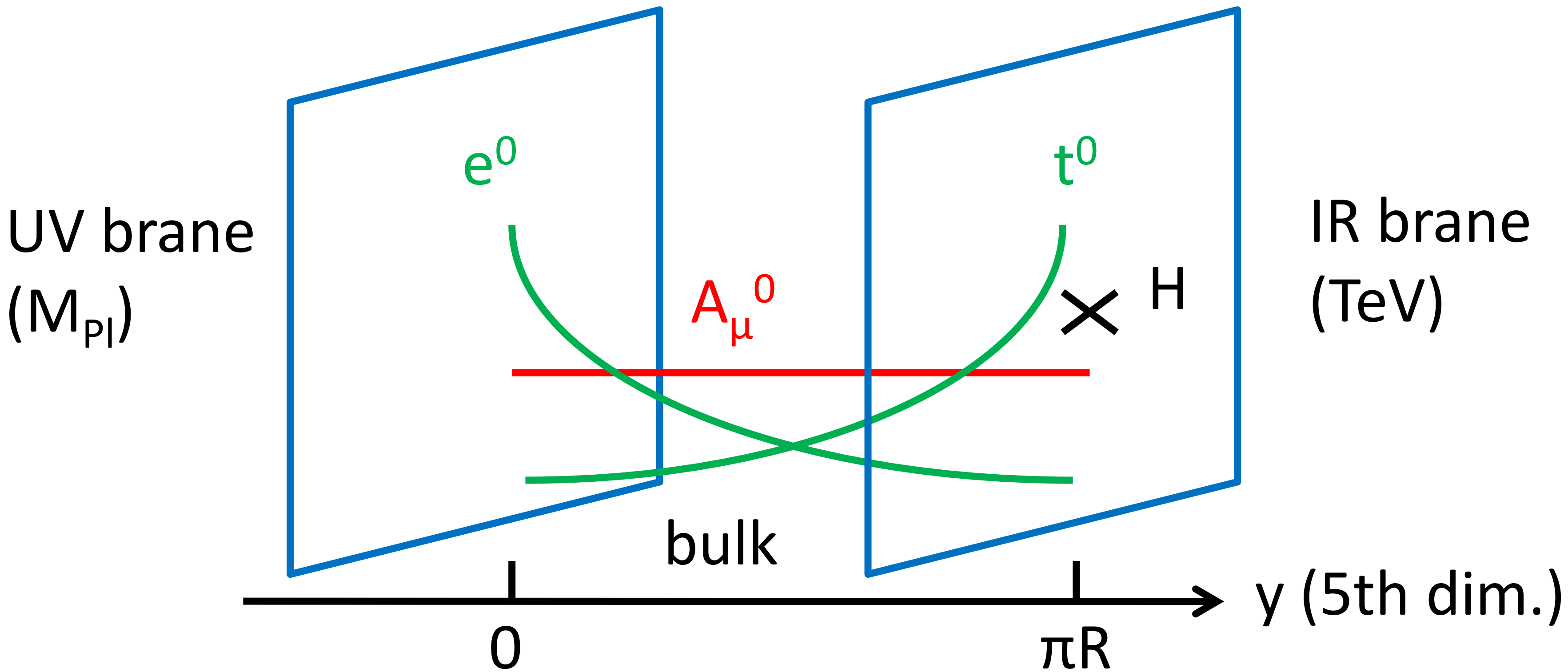
Top couplings

1. MOTIVATION

The top quark and extra dimensions

- Top quark : no hadronisation → clean and detailed observations
- Randal – Sundrum models with extra dimensions provide an elegant way to address the hierarchy problem
- A geographical interpretation of Yukawa couplings is given
- These models can be seen as dual to composite models (AdS/CFT correspondence)
- In these models, the top quark and the Higgs are composite objects

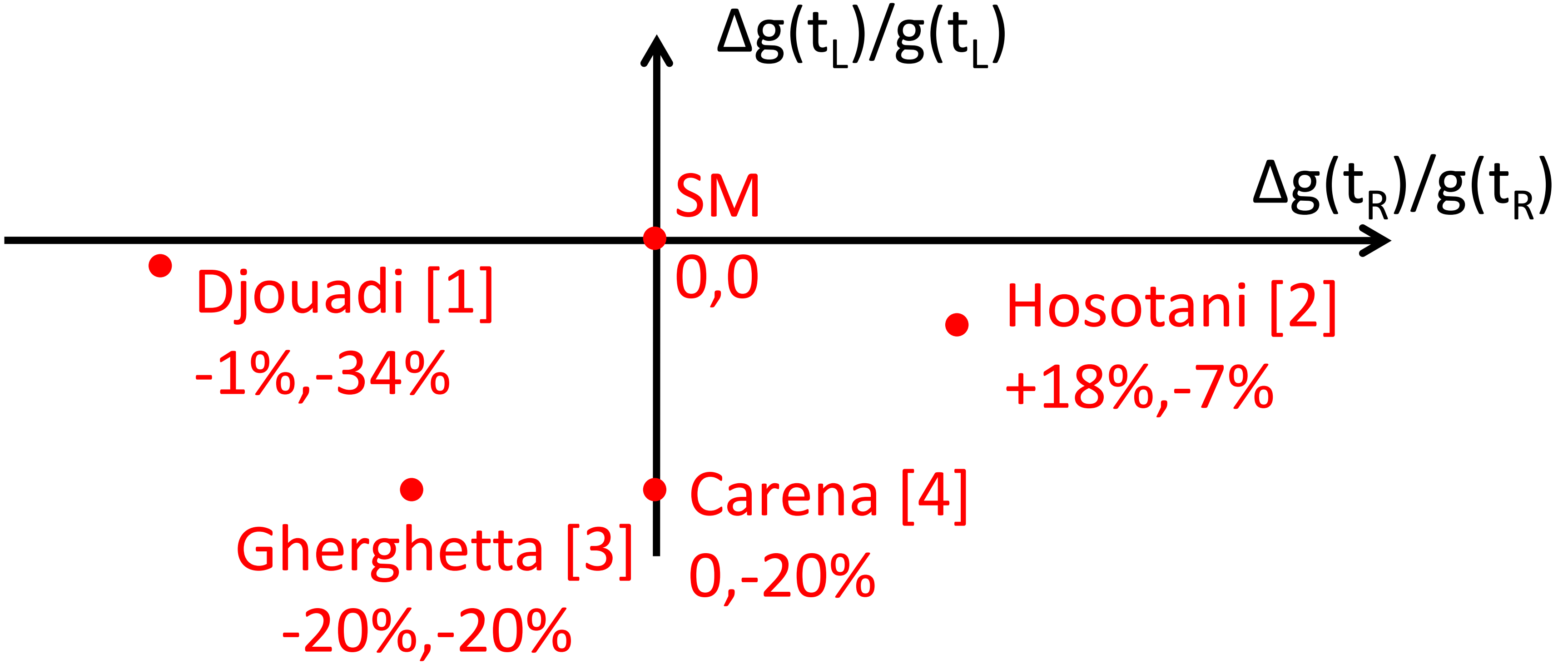
Geography and compositeness



- Higgs on IR brane for gauge hierarchy problem
- SM fermions have different locations along the 5th dimension
- Overlaps leptons – Higgs in the 5th dimension generate good Yukawa couplings with O(1) localisation parameters

Top couplings

- Several RS models predict modified left $g_Z(t_L)$ and right $g_Z(t_R)$ top couplings to Z (via Z-Z_{KK} mixing)



Observables

Top quark cross section

Measurement with the ILD detector

Reconstruction whithin the ILD framework

Requirements

Method adopted

2. MEASUREMENT METHOD

Observables

- Our goal : measure $g_Z(t_L)$ and $g_Z(t_R)$ precisely
- Use of the simulation for the ILD detector at the ILC ($1000 fb^{-1}$) : top produced at 500 GeV
- How : measure $\sigma(tt)$, A_{LR} and A_{FB}
- From A_{LR} and A_{FB}, one deduces $g_Z(t_L)$ and $g_Z(t_R)$ couplings
- Semileptonic decay mode :

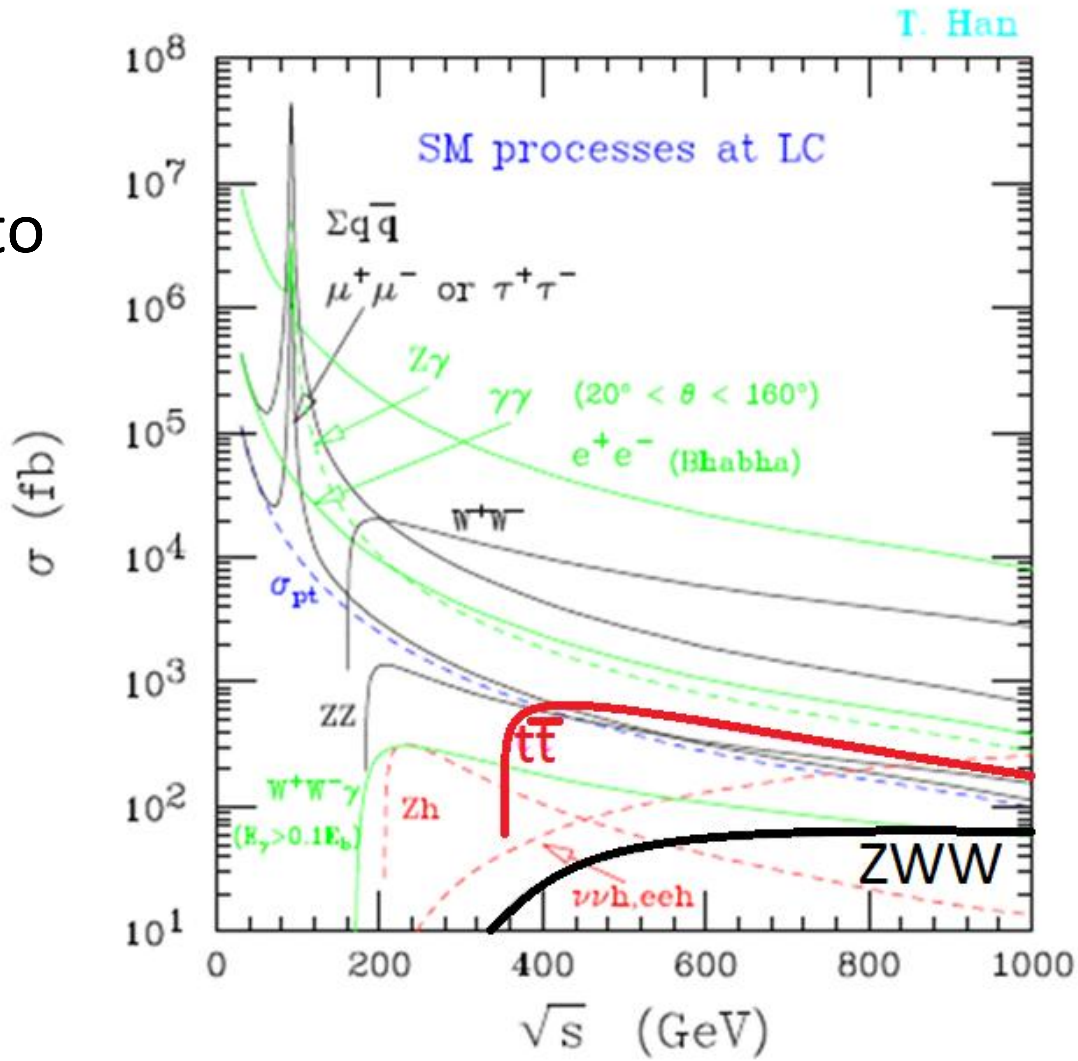
$$tt \rightarrow (bW)(bW) \rightarrow (bqq)(bl\nu)$$

(bqq): Allows reconstruction of the top quark

l: Gives top charge

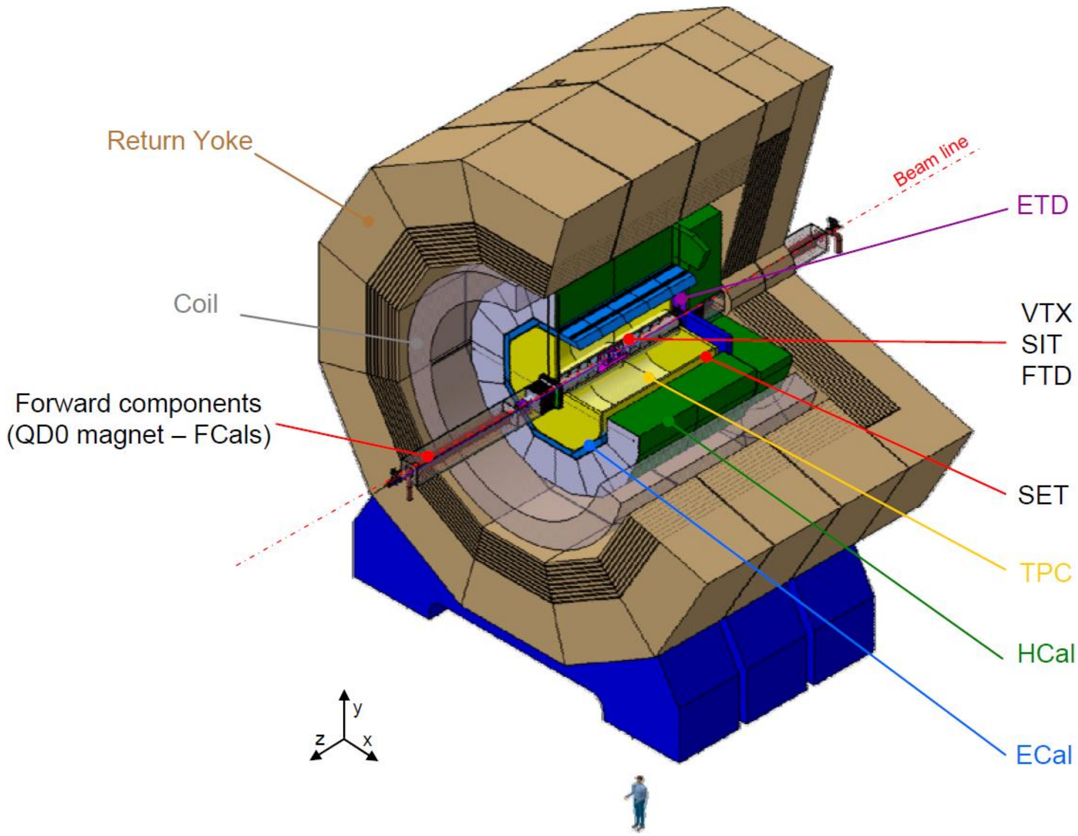
Top quark cross section

- $\sigma(tt) \approx 600$ fb at 500 GeV (≈ 180 fb for SL top into e and μ)
- Major background : ZWW (Z→bb) ≈ 8 fb, same topology
- Almost background free



Measurement with the ILD detector

- ILD optimised for Particle Flow technique (i.e. reconstruct every particle in a jet)



- 3.5 T B-field
- Performances :
  - Vertexing : σ_{IP} = 5 µm (+) 10 µm/p(GeV)$\sin^{3/2}\theta$
  - Tracking : $\sigma(1/p_T) < 5.10^{-5}$ GeV^{-1}
  - Granular calorimetry : $\sigma_E/E = 30\%/\sqrt{E}$

Reconstruction whithin the ILD framework

- tt→(bW)(bW)→(bqq)(blv) = semileptonic decay mode
- 1000 fb^{-1} were generated with Whizard (6f final states e.g. $bbcse\nu_e$)
- Full simulation is done with the ILD detector under GEANT4 (Mokka software)
- « Objects » reconstructed with Particle Flow algorithm (Pandora)
- Data used : samples prepared for the LOIs

Requirements

- tt→bbqqlv (l=e,μ)
  - Need at least 1 b jet (vertex)
  - Find 1 lepton (tracking)
- Method :
  - Find a lepton
  - Force 4 jets clustering
  - Find at least 1 (or 2) b jets
  - Form the top with one b jet + 2 non-b jets left, lepton charge gives the opposite sign of the top

Method adopted

- In this talk :
  - Review of lepton selection efficiency
  - Major backgrounds discussed : ZWW, tt→bbqqτν

- Full study for later :
  - Hadronic top (not checked yet)
  - Add all other backgrounds (purity)
  - Report on systematics of the observables

Identification of leptons

Isolation

Efficiencies and purities of the selected lepton

Efficiencies : angular and energetic

3. EFFICIENCIES

Indentification of leptons

Particle	Momentum cut	Identification	Rejection
Muon	5 GeV	$E_{calo}/P_{track} < 0.5$	0.7%
Electron		$E_{calo}/P_{track} > 0.8$ and $E_{ecal}/E_{calo} > 0.9$	2.1%

- Rather loose cuts :
  - Muon often picks a small pion cluster in the calorimeters
  - Same for electron / photon
- Impose isolation criteria for lepton inside its jet

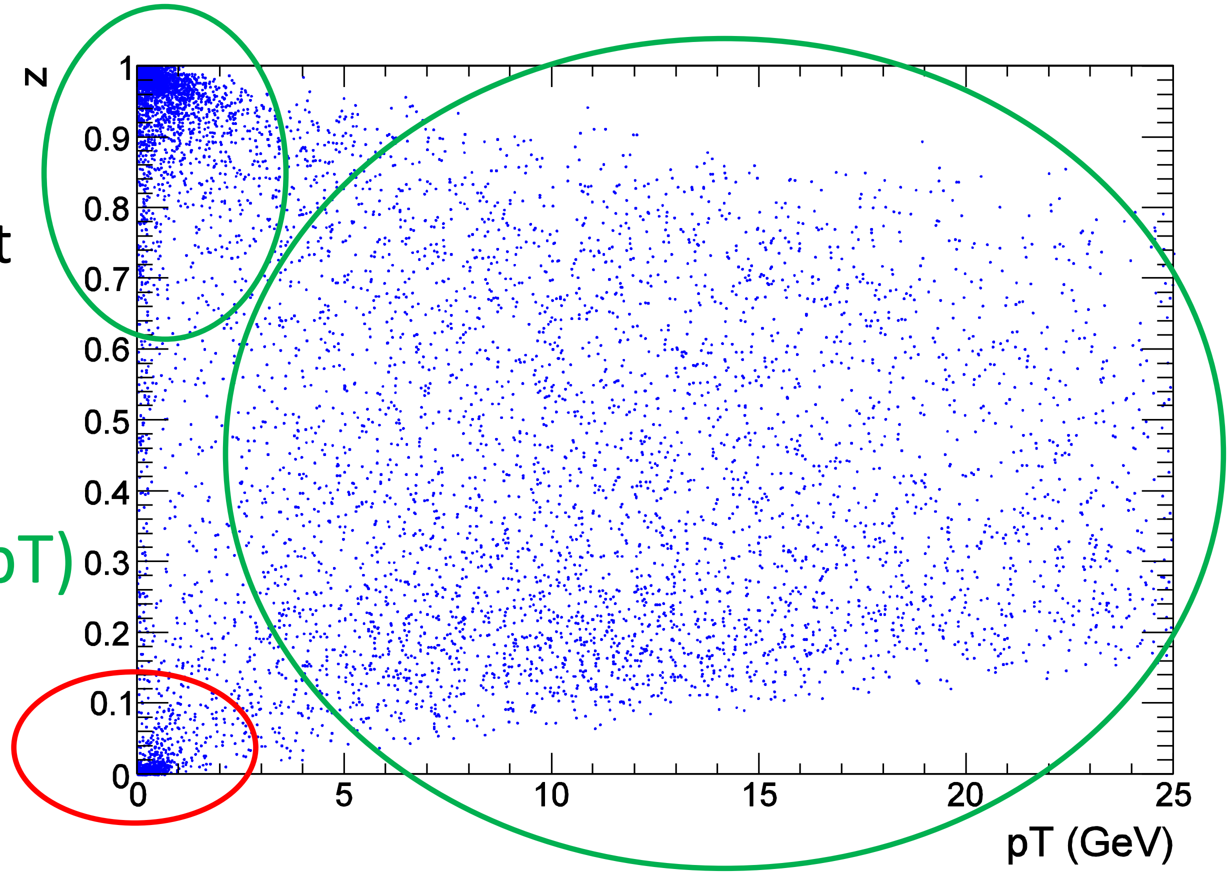
Isolation

- In reconstructed events, look at the true (MC) lepton :
  - Events forced to 4 jets
  - tt→bbqqlv : 4 jets + 1 lepton

True lepton embedded inside a jet

- Define :
  - $z = E_{lepton}/E_{closest\ jet}$
  - pT in the closest jet
- Lepton is :

1. Leading (high z)
2. Or isolated (high pT)
3. Not leading or isolated O(1%)

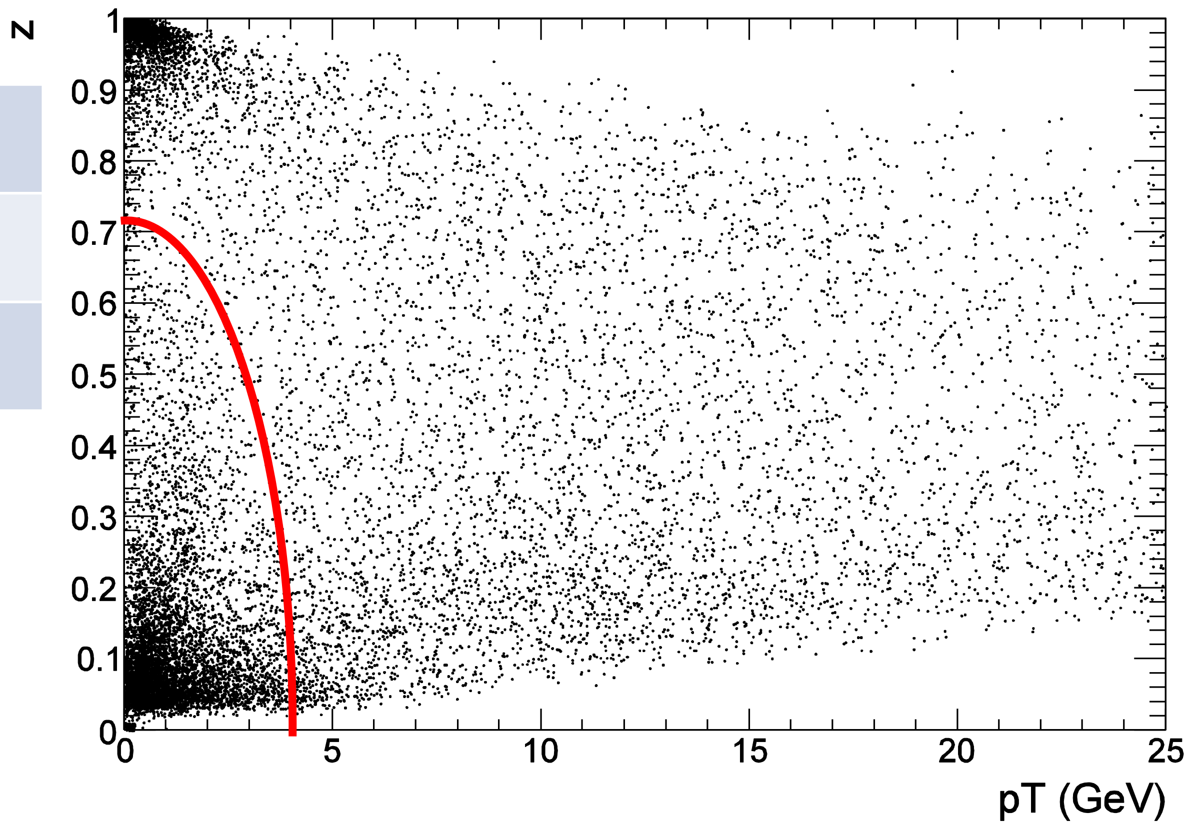


Isolation

- Same view for identified leptons (muons here)
- Isolation criteria : $$\left(\frac{z}{0.7}\right)^2 + \left(\frac{pT}{4}\right)^2 > 1$$ (rejects B→lνX, and mis-ids)
- + highest z (if $N_{leptons}>1$)

Particle	Events left
Muon	94.4 %
Electron	93.5 %

Remark : study done with perfect tracking → best efficiency achievable

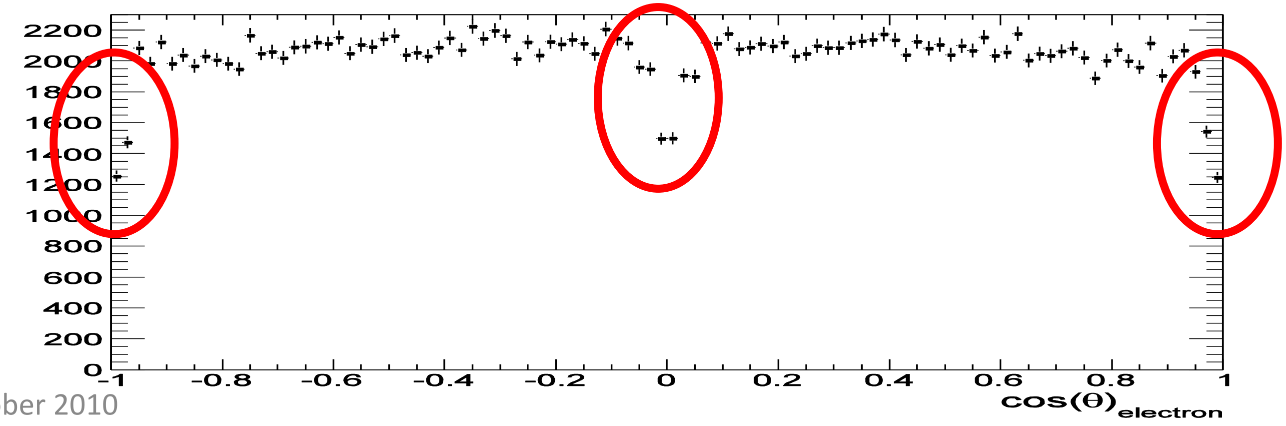


Efficiencies and purities of the lepton

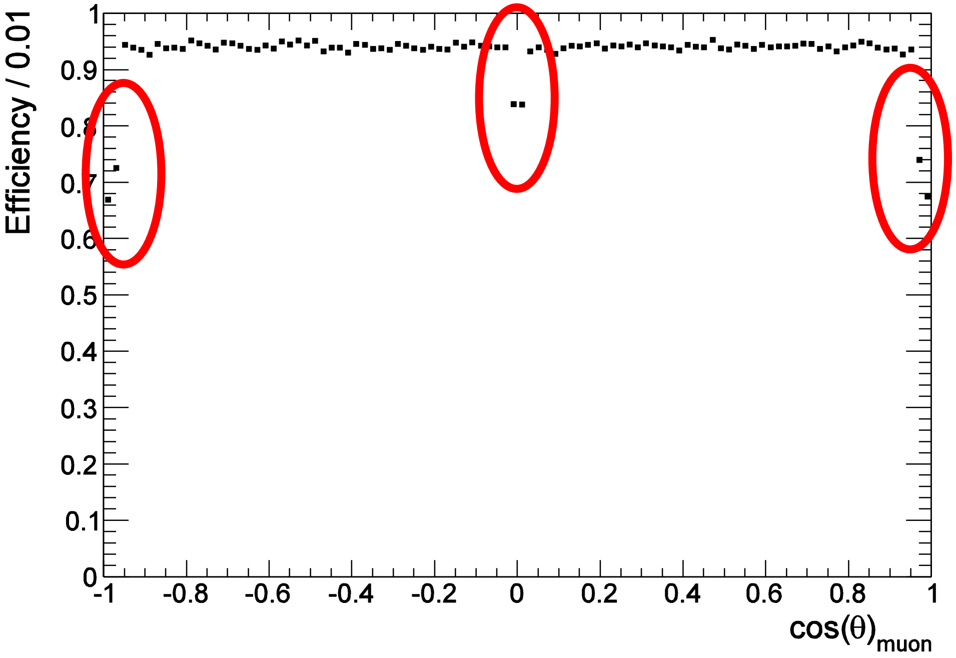
Particle	P « good » ($W_{top} \rightarrow l\nu$)	P « bad » (mis-id)	Events found	Bad leptons
Muon	92.6 %	6.9 %	93.0 %	1.2 %
Electron	87.7 %	9.2 %	88.8 %	2.2 %

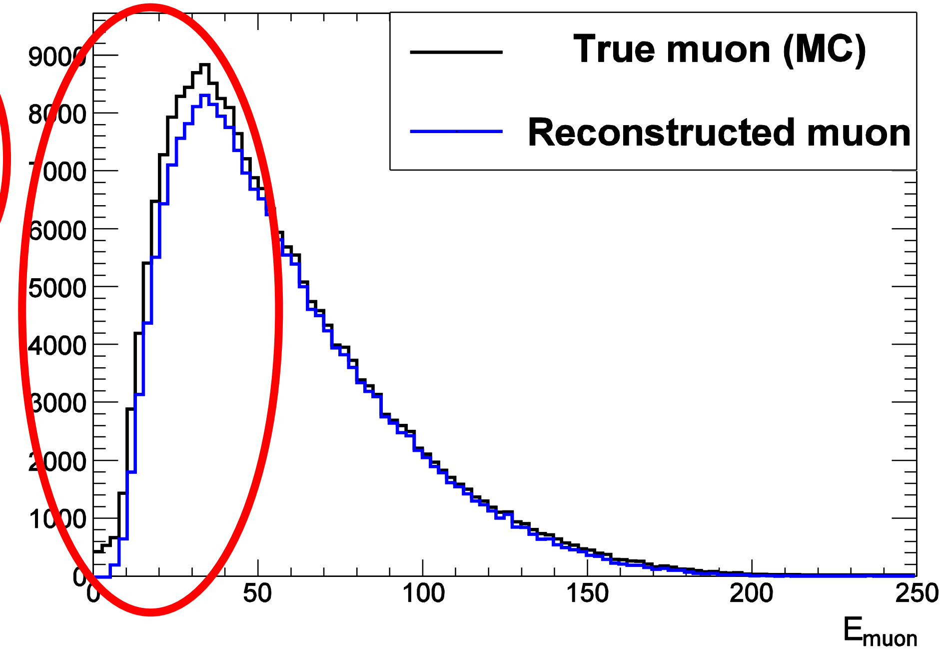
Tracking inefficiencies :

- Muon = 94.4 % - 92.6 % = 1.8 % (|cos θ|>0.97)
- Electron = 93.5 % - 87.7 % = 5.8 % (TPC disk,|cos θ|>0.97)



Efficiencies : angular and energetic





- Effiencies under control :
  - Tracking worse at large angles and in the TPC disk
  - Leptons with small energies are suppressed by isolation

Results

Cross section and A_{LR}

Conclusions and prospects

4. RESULTS

Results

- Simulation done with full e^+e^- polarisation
  i.e. $P(e^+e^-)=(\pm1, \pm1) \rightarrow P(e^+e^-)=(\pm30\%, \pm80\%)$

- ZWW is very small (< 1%) :
  - can be measured : veto on b ($Z \rightarrow$ uu, dd, ss, cc)
  - and substracted

- Comment on $tt \rightarrow bbqq\tau\nu$:
  - Lepton of $\tau \rightarrow l\nu\nu$ decay reconstructed (≈ 35% of τ events)
  - Adds statistics for σ(tt), A_{LR} and A_{FB} (where hadronic top direction will be reconstructed)

Cross-section and A_{LR}

- $\sigma = N/(\varepsilon L)$, $L = 500 fb^{-1}$

- $\sigma(tt \rightarrow SL)_{unpol.}$ = 159.4 fb, $\Delta\sigma/\sigma$ = 0.37% (stat.)
  - Whizard : $\sigma(tt \rightarrow SL)_{unpol.}$ = 159.6 fb (-0.1%)
  - $P(e^+e^-)$= (±30%, ±80%) → $\Delta\sigma/\sigma$ = 0.28%/0.42% (stat.)
- A_{LR} = 0.435, $\Delta A_{LR}/A_{LR}$ = 0.54% (stat.)
  - A_{LR} = 0.37 expected… Whizard problem ?
  - However, interest lies in relative uncertainty
  - $P(e^+e^-)$= (±30%, ±80%) → $\Delta A_{LR}/A_{LR}$ = 0.69% (stat.)

Conclusion and prospects

- To find a lepton (e,μ) in a semileptonic environment
  efficiency > 88% , purity > 98%
- Major backgrounds seem under control (ZWW and tt→bbqqτν)
  - Further checks of backgrounds e.g. top full hadronic decays needed
- σ and A_{LR} can be known at 0.4% and 0.7% statistical uncertainty (systematics guaranteed small due to large purity)
- One step beyond : reconstruct the hadronic top quark to measure A_{FB}, m_{top}
- Next : add background and check purity (cut based analysis foreseen)

Extract efficiency and purity of the selected lepton

Adding electrons and muons

Top physics : LHC and ILC

Angular distribution : top vs lepton

Finding ZWW in bbqqlv events

Comparative distributions ZWW/tt

Semileptonic taus : tt → bbqqτv

Full hadronic tops

Top couplings : bibliography

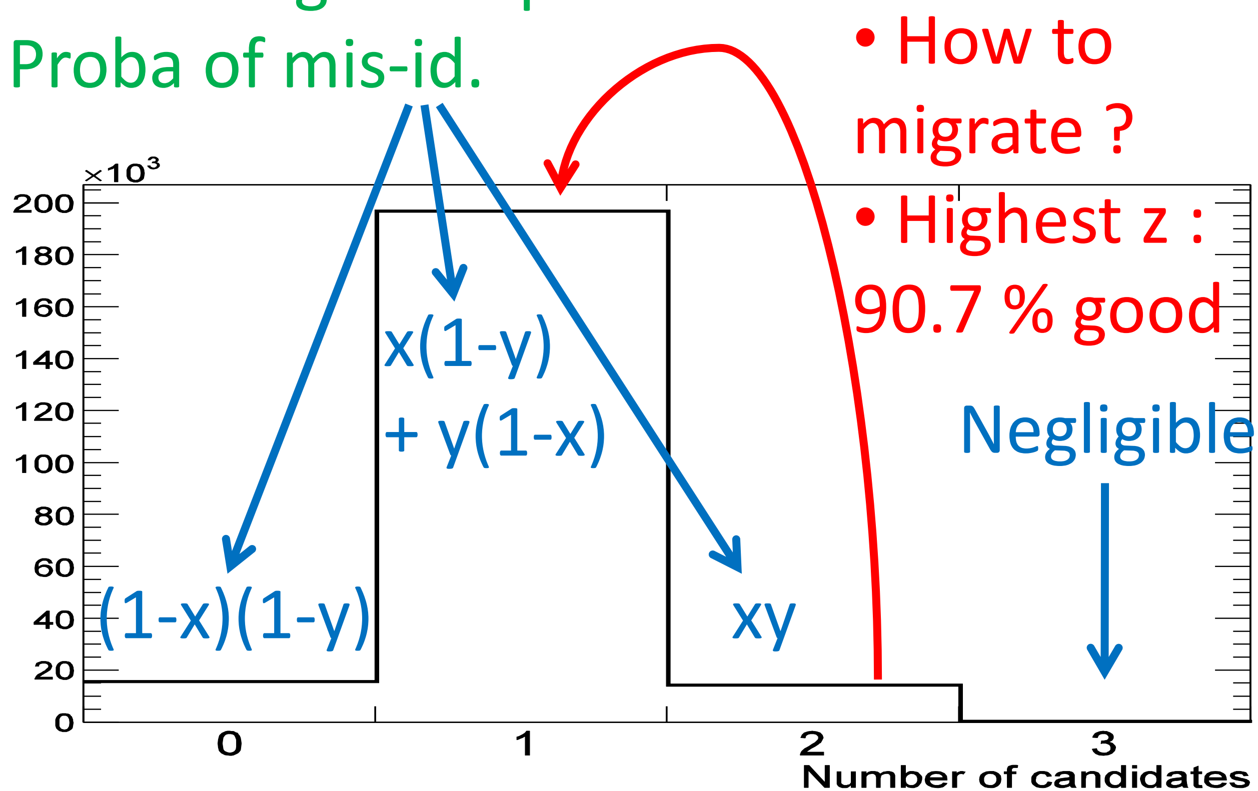
5. ADDITIONAL MATERIAL

Extract efficiency and purity of the selected lepton

- Count number of selected leptons with the previous criteria (at reconstructed level)
- We define x = Proba of good lepton chosen
  y = Proba of mis-id.

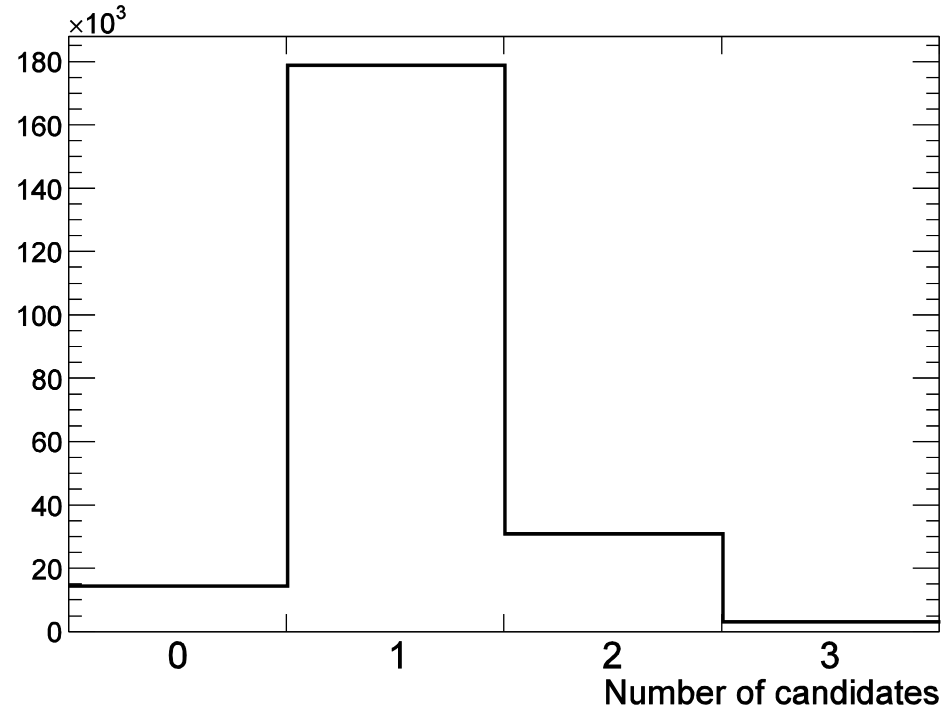
- x = 92.6%
- y = 6.9 %

- After migration : 1.2 % of bad muons



Adding electrons and muons

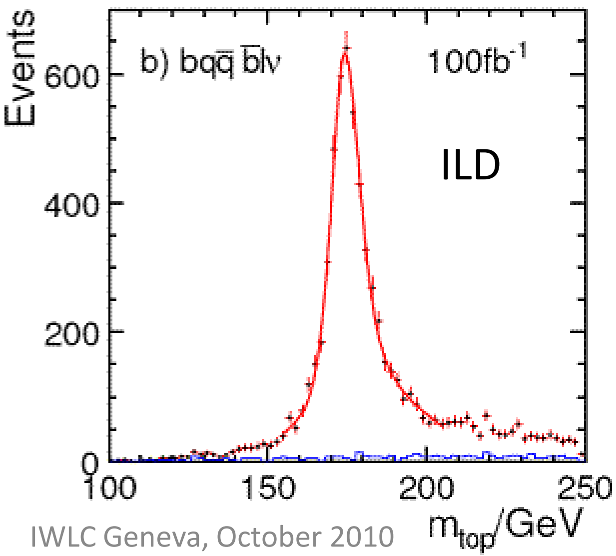
- Now : take any kind of lepton
  - highest z candidate among indentified muons and electrons
- Efficiency expected higher, but purity should decrease

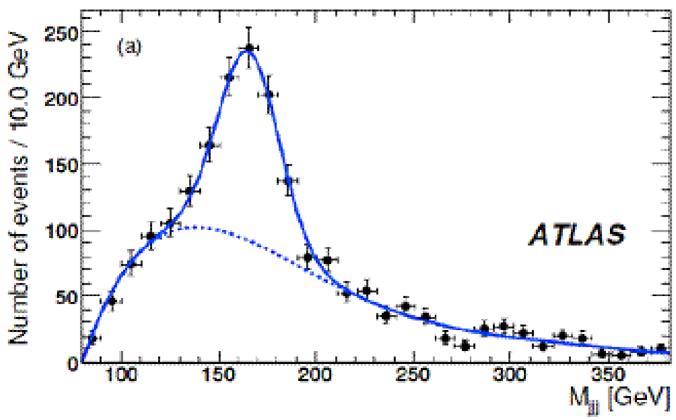


Particle	Efficiency	Bad lepton	Purity
Muon	93.6%	2.9%	97.1%
Electron	89.7%	3.9%	96.1%

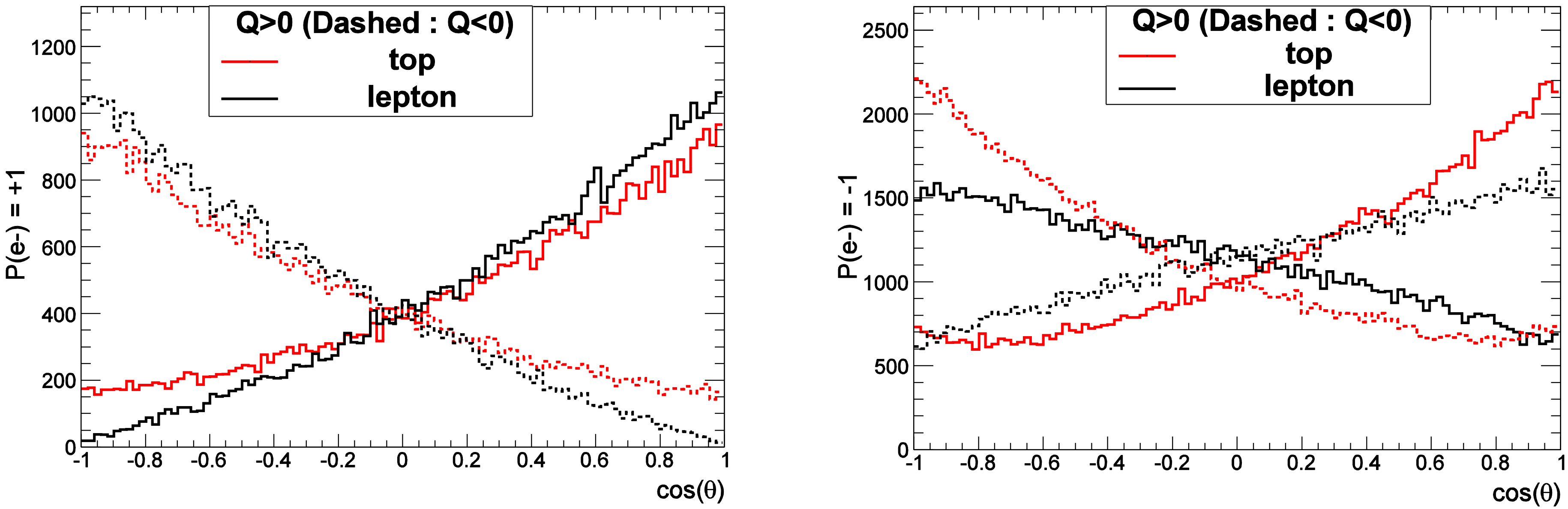
Top physics : LHC and ILC

- LC 1 pb, LHC 1nb but for gluon couplings only
- Very good s/b at ILC and energy/momentum conservation allows to reconstruct modes with a neutrino
- Mt and Γt with ≈50 MeV error, 0.4% on cross section
- LC unique to measure t_R and t_L Z couplings at % (ND>4) LHC > 10 times worse





Angular distribution : top vs lepton



- For $P(e^-) = +1$ (e^-_R) : correlation between directions of the lepton and its top
- For $P(e^-) = -1$ (e^-_L) : anticorrelation

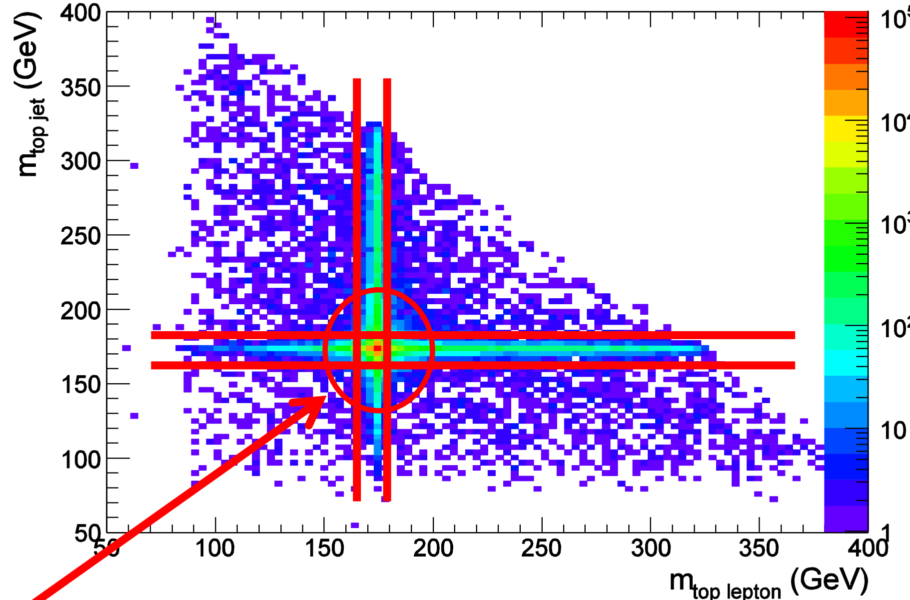
Finding ZWW in bbqqlv events

- Using the MC table of bbqqlv, t_1 = blv (top lepton) and t_2 = bqq (top jet) are reconstructed
- Tag : top or ZWW
- Top event is tagged if

$$|M_{t1} - M_{top}| < 5 \times \Gamma_{top} \quad \text{or}$$

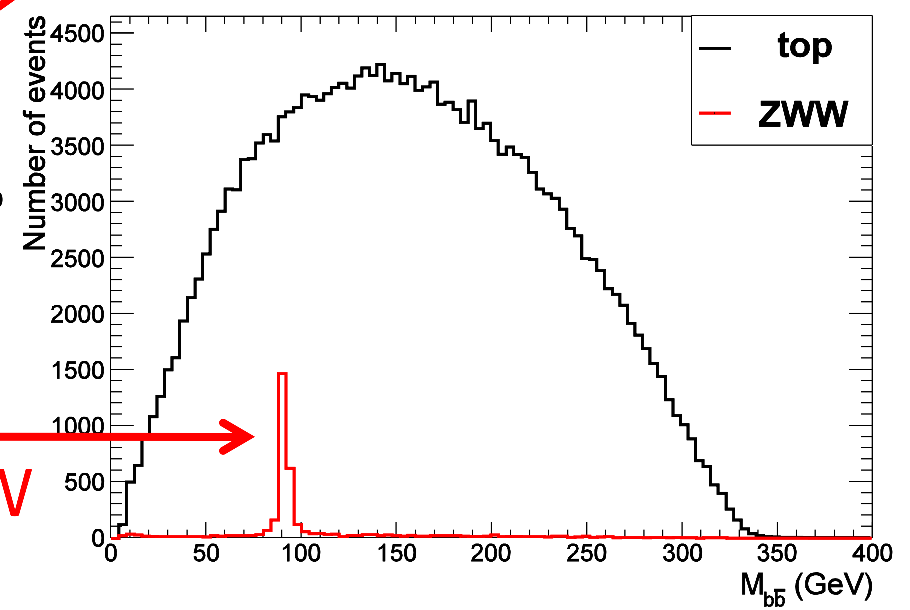
$$|M_{t2} - M_{top}| < 5 \times \Gamma_{top} \quad \text{or}$$

$$\sqrt{(M_{t1} - M_{top})^2 + (M_{t2} - M_{top})^2} < 15 \times \Gamma_{top}$$



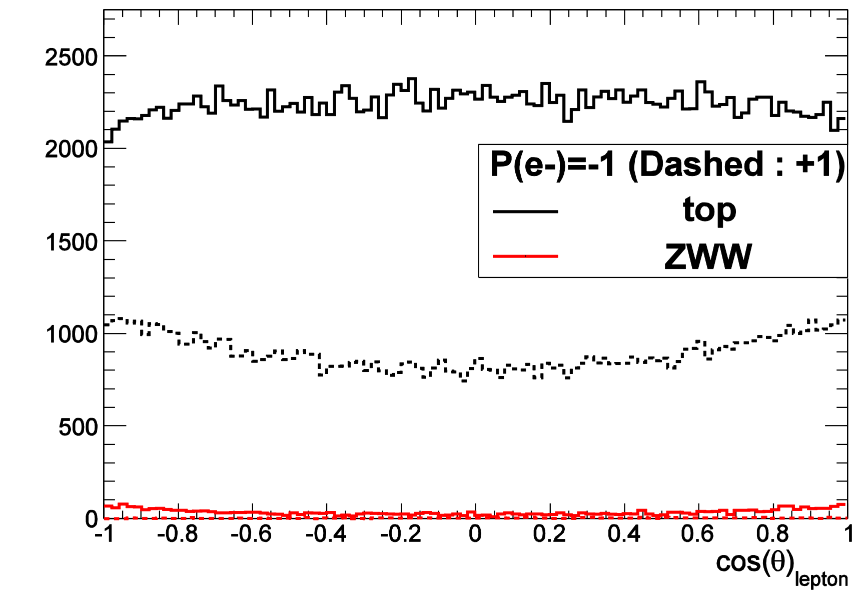
- Check on M_{bb}

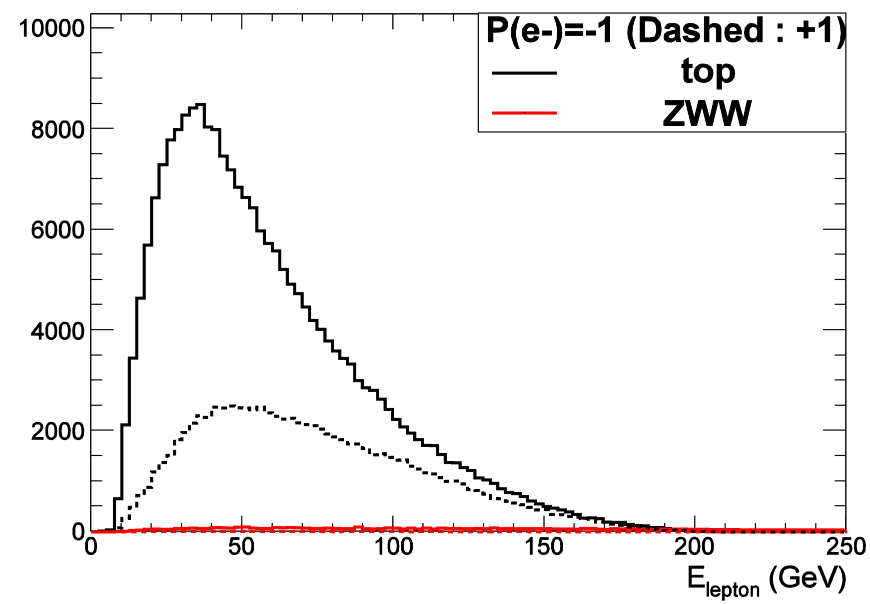
Z peak in ZWW events, < 2%



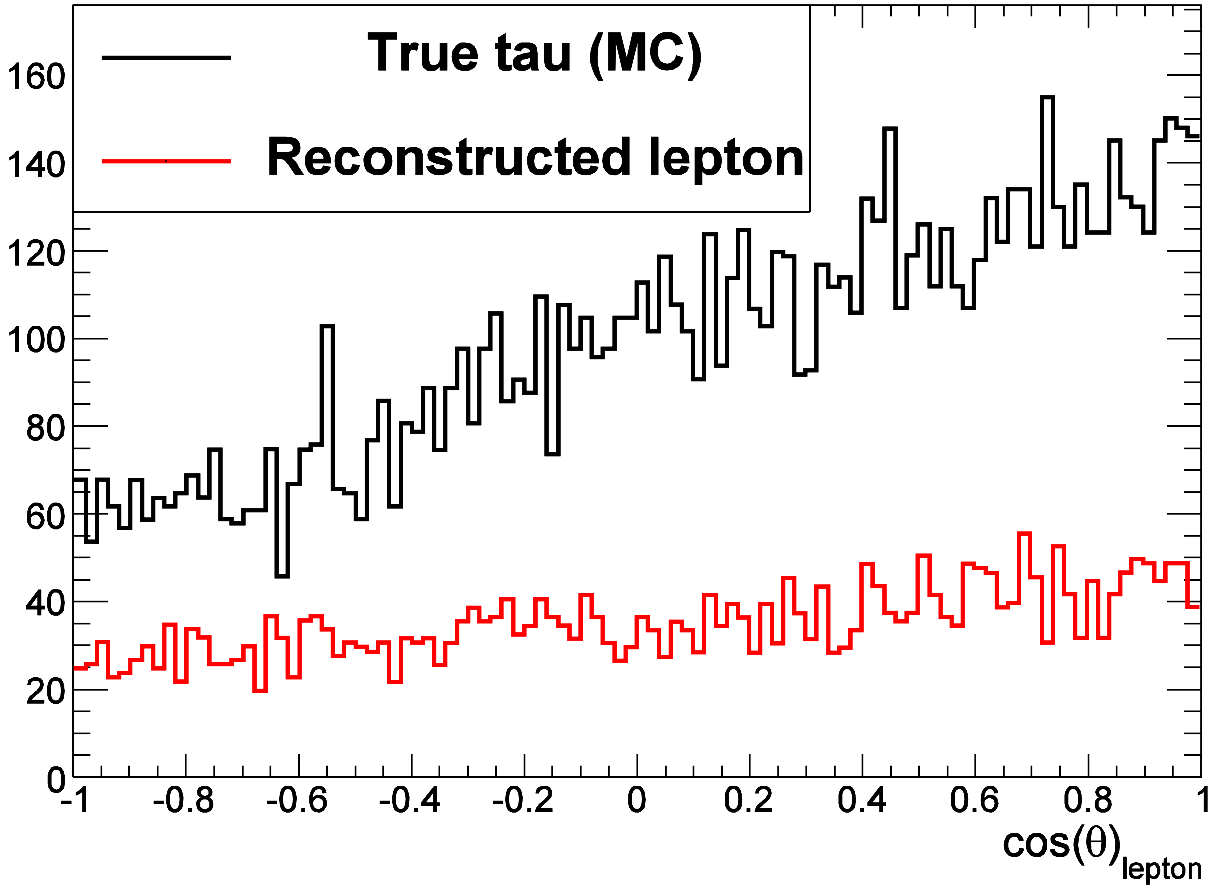
Comparative distributions : ZWW/tt

- At MC level, top and ZWW events are separated
- Lepton distributions :
  - Angular
  - Energetic
- ZWW clearly negligible
- Needs to be substracted to reach permil precision



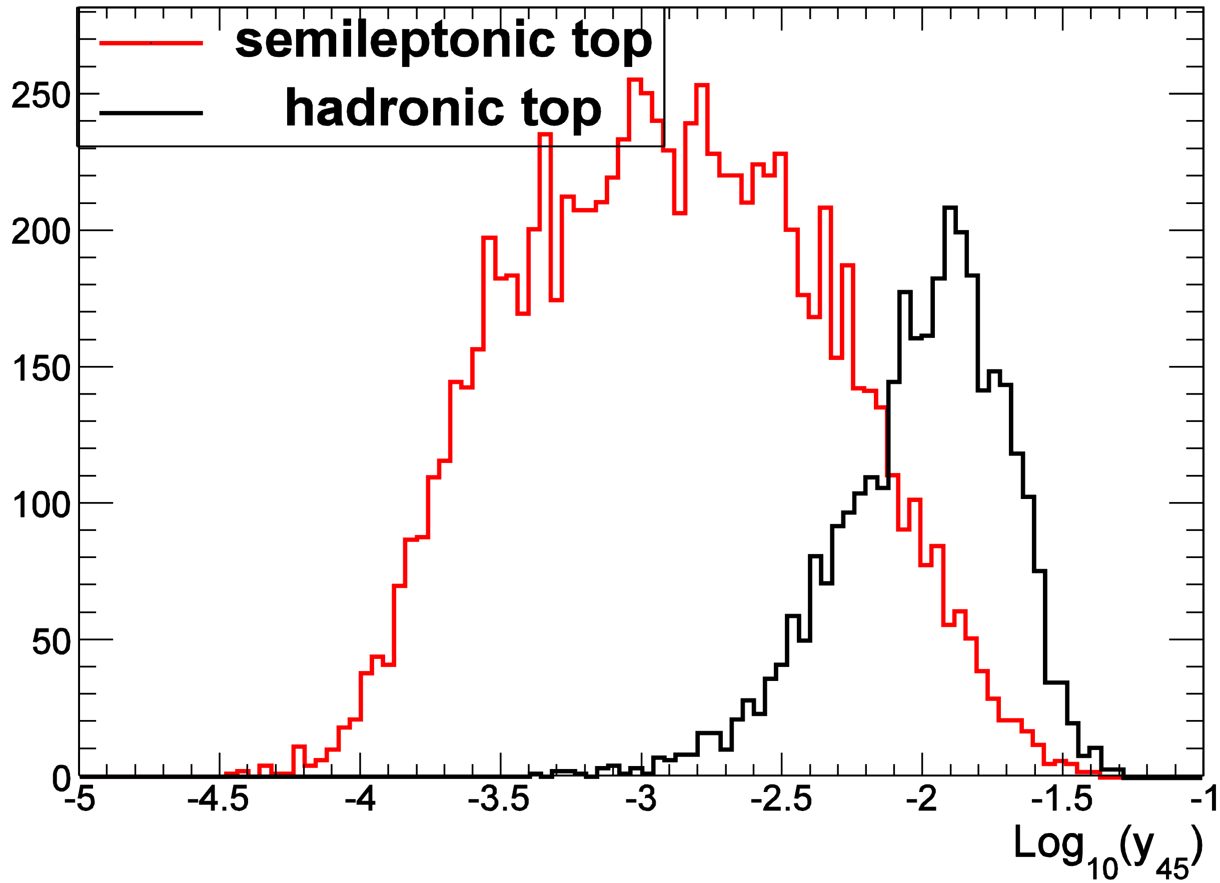


Semileptonic taus : tt → bbqqτν



- A lepton is found in 1/3 of semileptonic tau events
- Adds statistics for measurements but cannot use lepton

Full hadronic tops



• Ycut expected to be enough to separate semileptonic tops from hadronic ones… Maybe not enough. Try y_{56}.

Top couplings : bibliography

- [1] : Djouadi et al., Nuclear Physics B, Volume 773, Issues 1-2, 25 June 2007, Pages 43-64
- [2] : Hosotani et al., Prog. Theor. Phys. 123 (2010), 757-790
- [3] : Cui, Gherghetta et al., arXiv:1006.3322v1 [hep-ph]
- [4] : Carena et al., Nuclear Physics B Volume 759, Issues 1-2, 18 December 2006, Pages 202-227