ECFA Study

Physics and Detectors
for a Linear Collider

Measuring the asymmetries of the top quark at the ILC

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Plan

1. Motivation
2. Measurement method
3. Efficiencies
4. Results

The top quark and flavor hierarchy

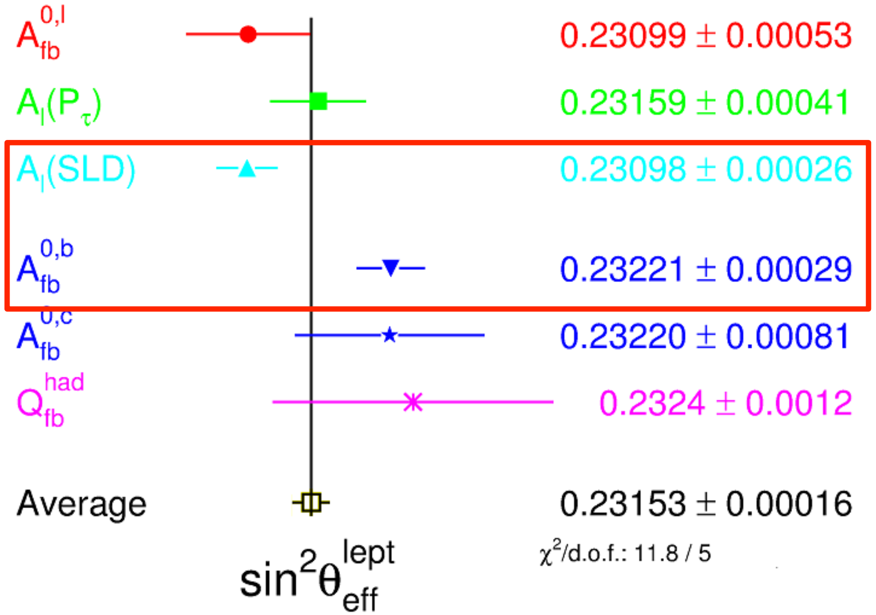
Geography in Randall-Sundrum models

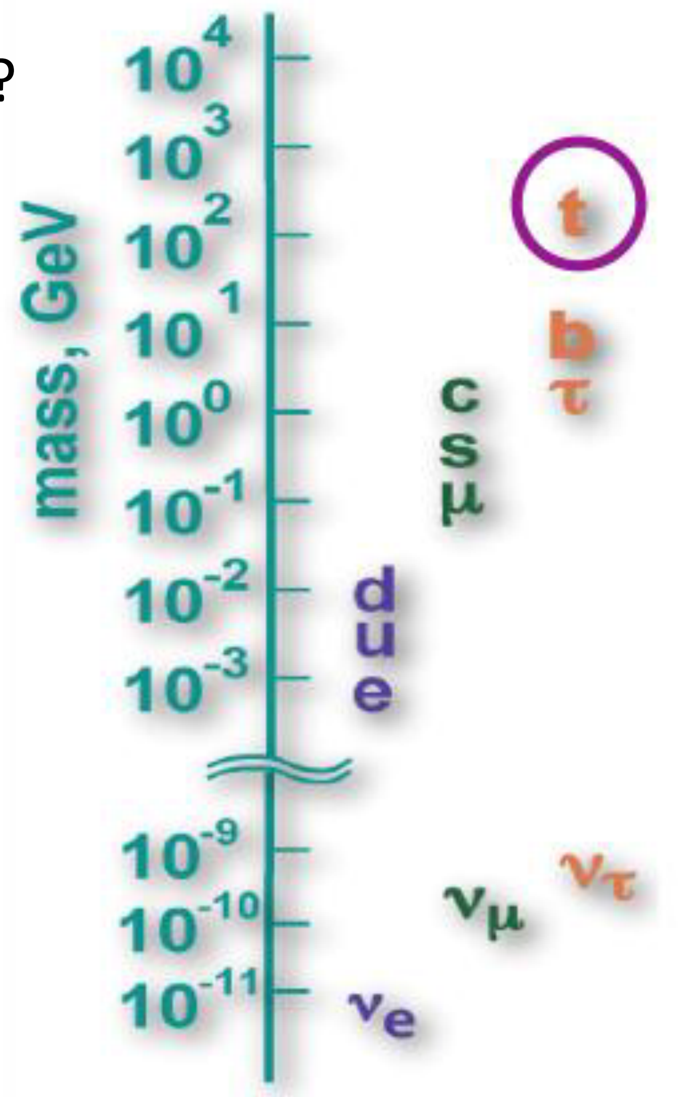
Top to Z couplings

1. MOTIVATION

The top quark and flavor hierarchy

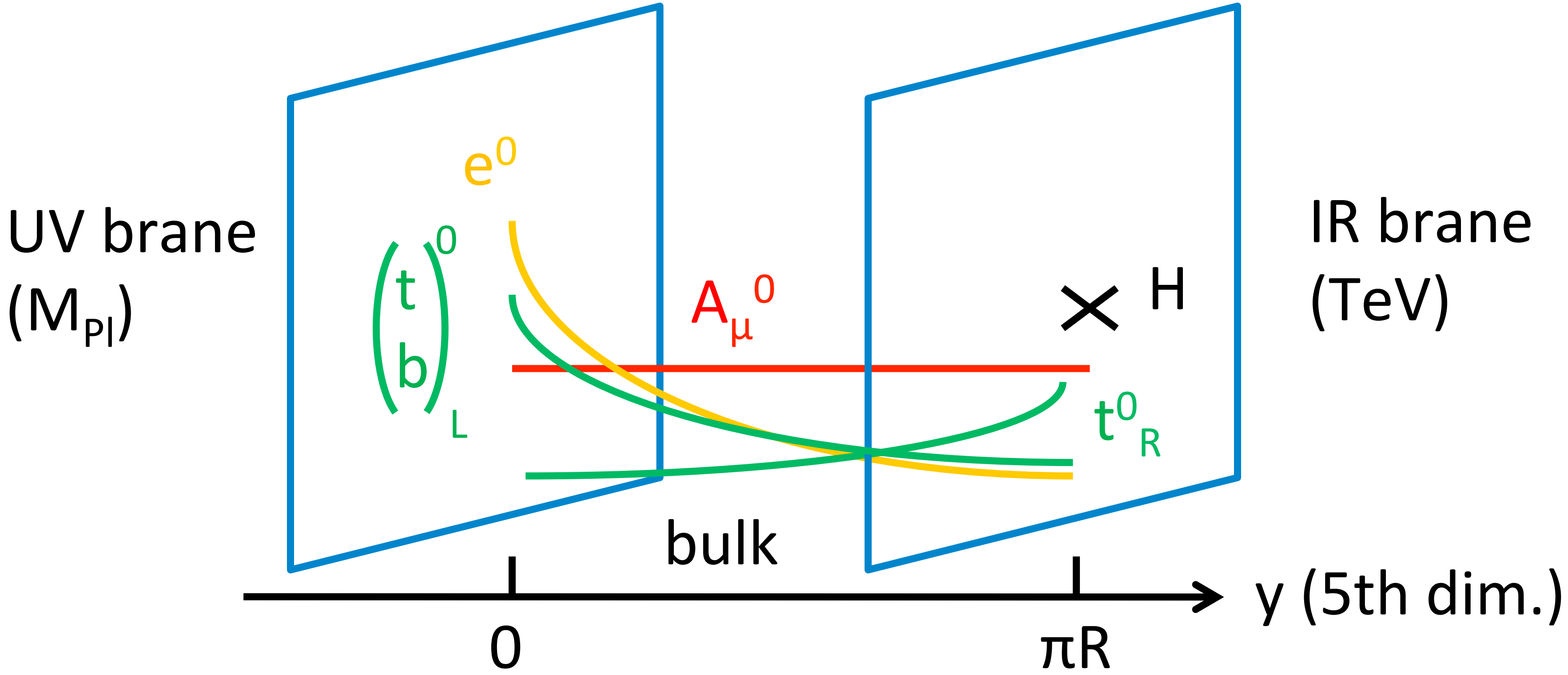
- Flavor hierarchy ? Role of 3rd generation ?





- Top quark : no hadronisation → clean and detailed observations
- Redo measurements of A_{LR} and A_{FB} with the top

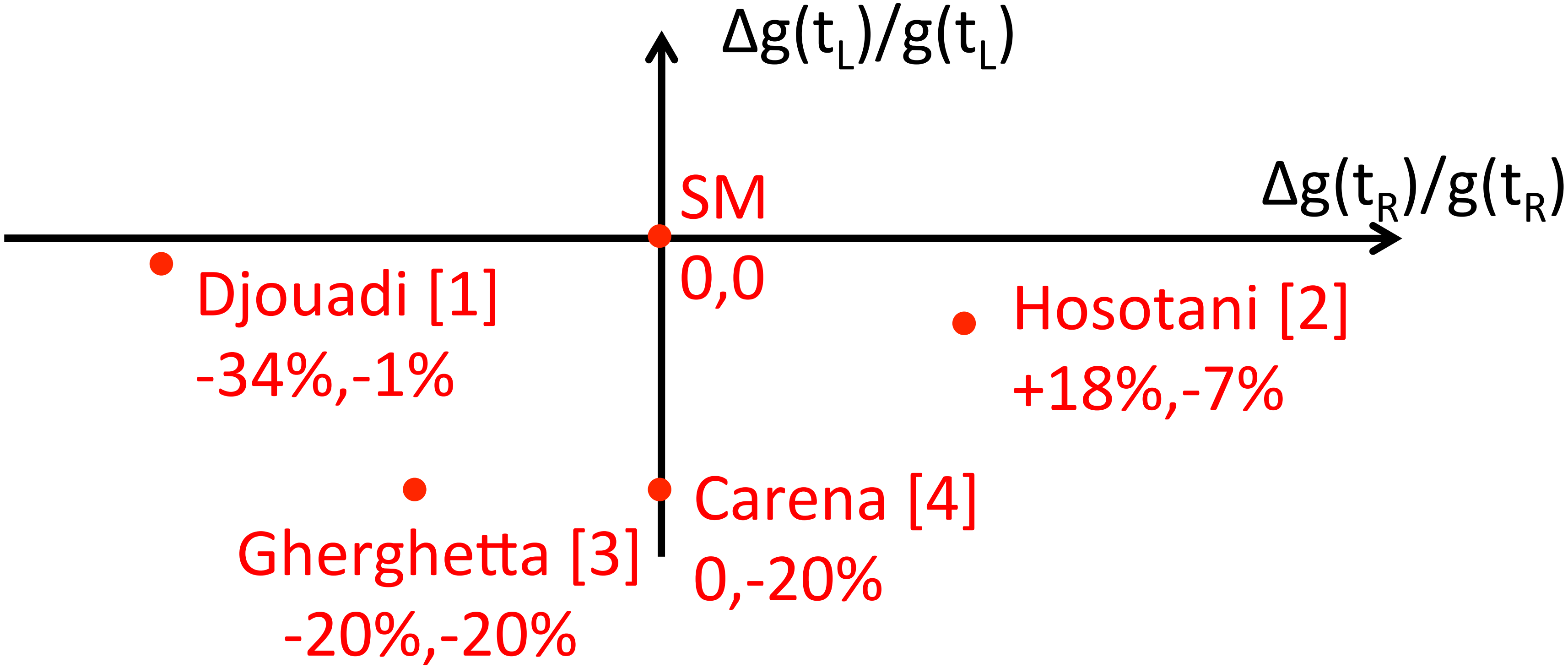
Geography in Randall-Sundrum models



- 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 to Z couplings

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



Observables

Top quark cross section

Measurement with the ILD detector

Reconstruction within the ILD framework

Requirements

2. MEASUREMENT METHOD

Observables

- σ(tt), A_{LR} and A_{FB} :

$$A_{LR} = \frac{N_{top}(e_L^-) - N_{top}(e_R^-)}{N_{top}(e_L^-) + N_{top}(e_R^-)}$$ (e⁻ polar flip)

$$A_{FB} = \frac{N_{top}(\cos\theta > 0) - N_{top}(\cos\theta < 0)}{N_{top}(\cos\theta > 0) + N_{top}(\cos\theta < 0)}$$ (top direction)

- Semileptonic decay mode :

  tt→(bW)(bW)→(bqq)(blν)

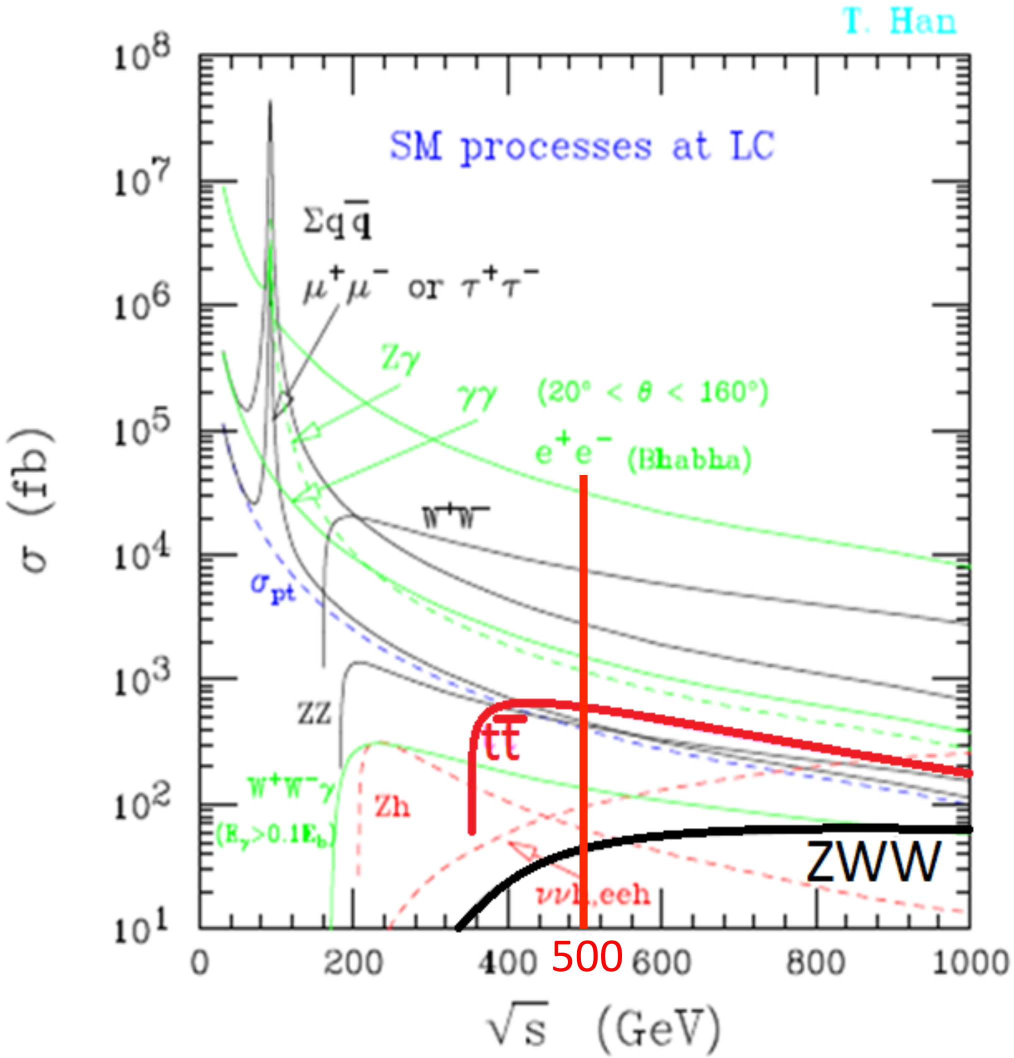
  Allows reconstruction of the top quark

  l = e, μ → Gives top charge

- From A_{LR} and A_{FB}, one deduces $g_Z(t_L)$ and $g_Z(t_R)$ couplings

Top quark cross section

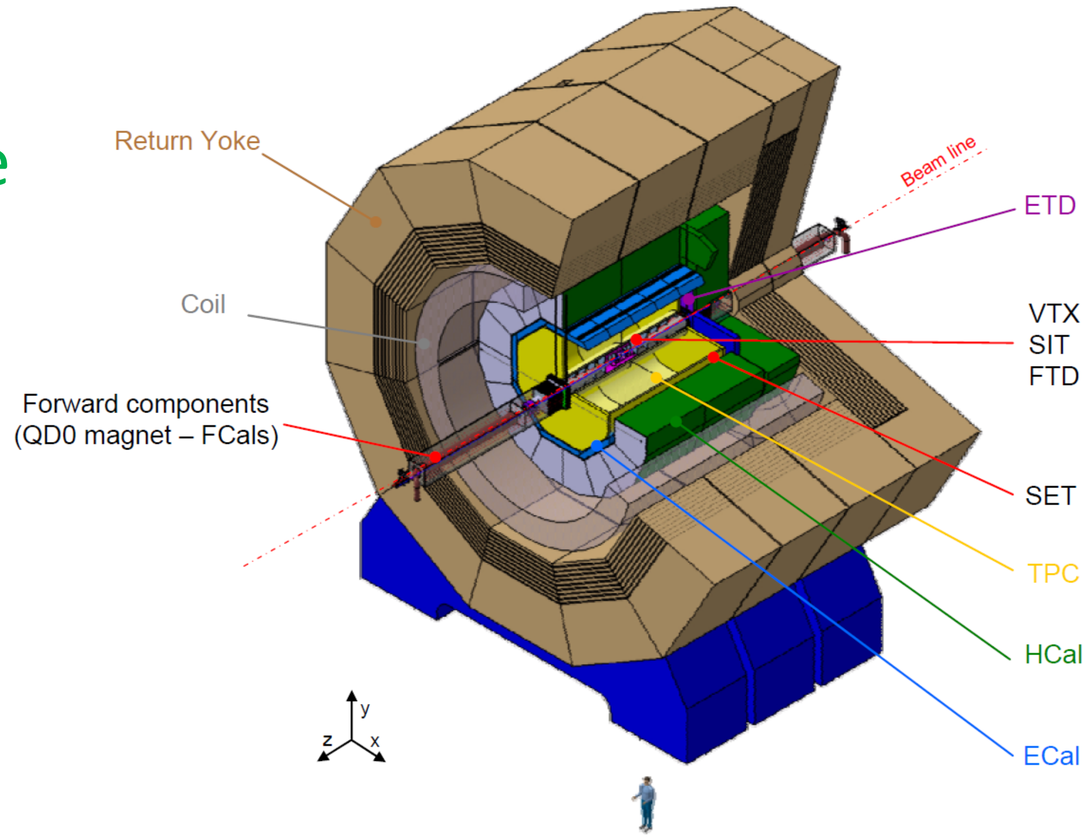
- σ(tt) ≈ 600 fb at 500 GeV with 500 fb^{-1}
  - Ntotal ~ 570k events
  - Semileptonic ~ 34%
- Almost background free ?
  - Major background = other top channels → find 1 isolated lepton
  - WW → no b quark
  - bb → simple topology
- Major background : ZWW (Z→bb) ≈ 8 fb, same topology
  - Small but needs to be subtracted



Process	tt	bb	WW	ZZ	ZWW
A_{LR} (%)	36.7	62.9	98.8	31.0	89

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 : $\sigma_E/E \sim 30\%/\sqrt{E}$

Analysis within the ILCsoft framework

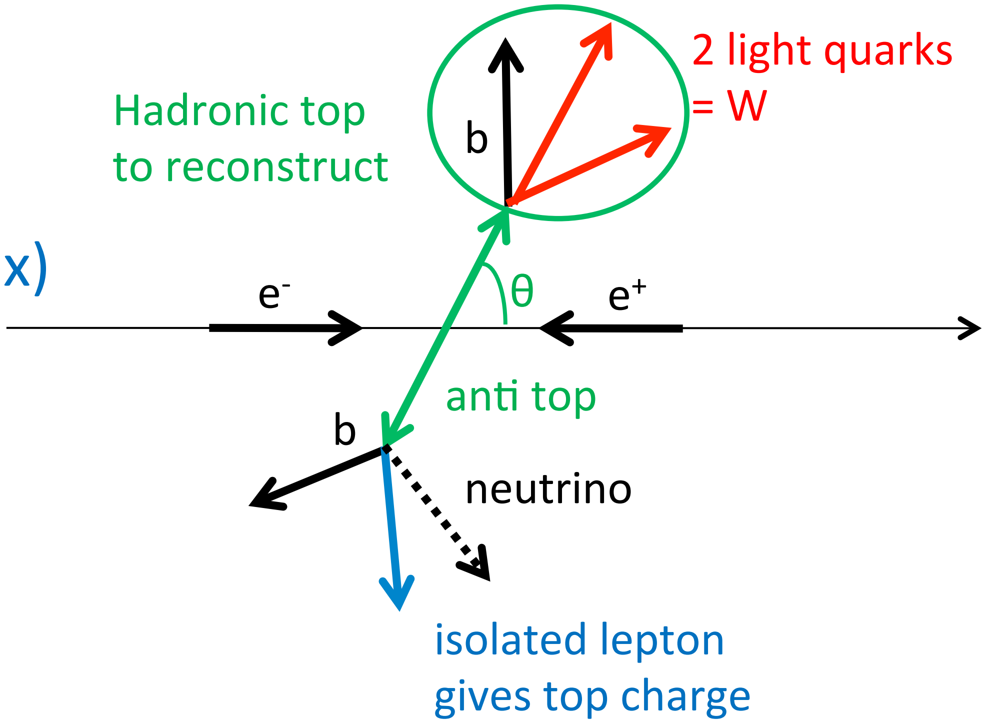
- Full simulation is done with the ILD detector under GEANT4 (Mokka software)

- « 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



Identification of leptons

Isolation

Efficiencies and purities of the selected lepton

Efficiencies : angular and energetic

B tagging

3. EFFICIENCIES

Isolation

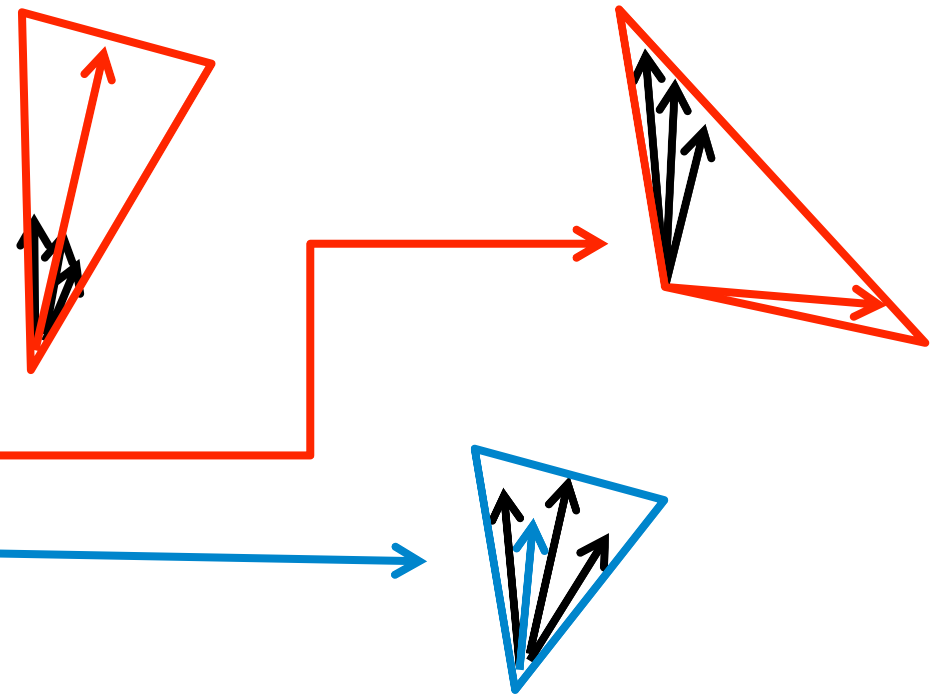
- In reconstructed events, look at the true (MC) lepton :
  - Events forced to 4 jets
  - $t\bar{t} \rightarrow bbqql\nu$: 4 jets + 1 lepton

  } True lepton embedded inside a jet

- Define :
  - $z = E_{lepton}/E_{jet}$
  - $x_T = p_T/M_{jet}$
- Lepton is :

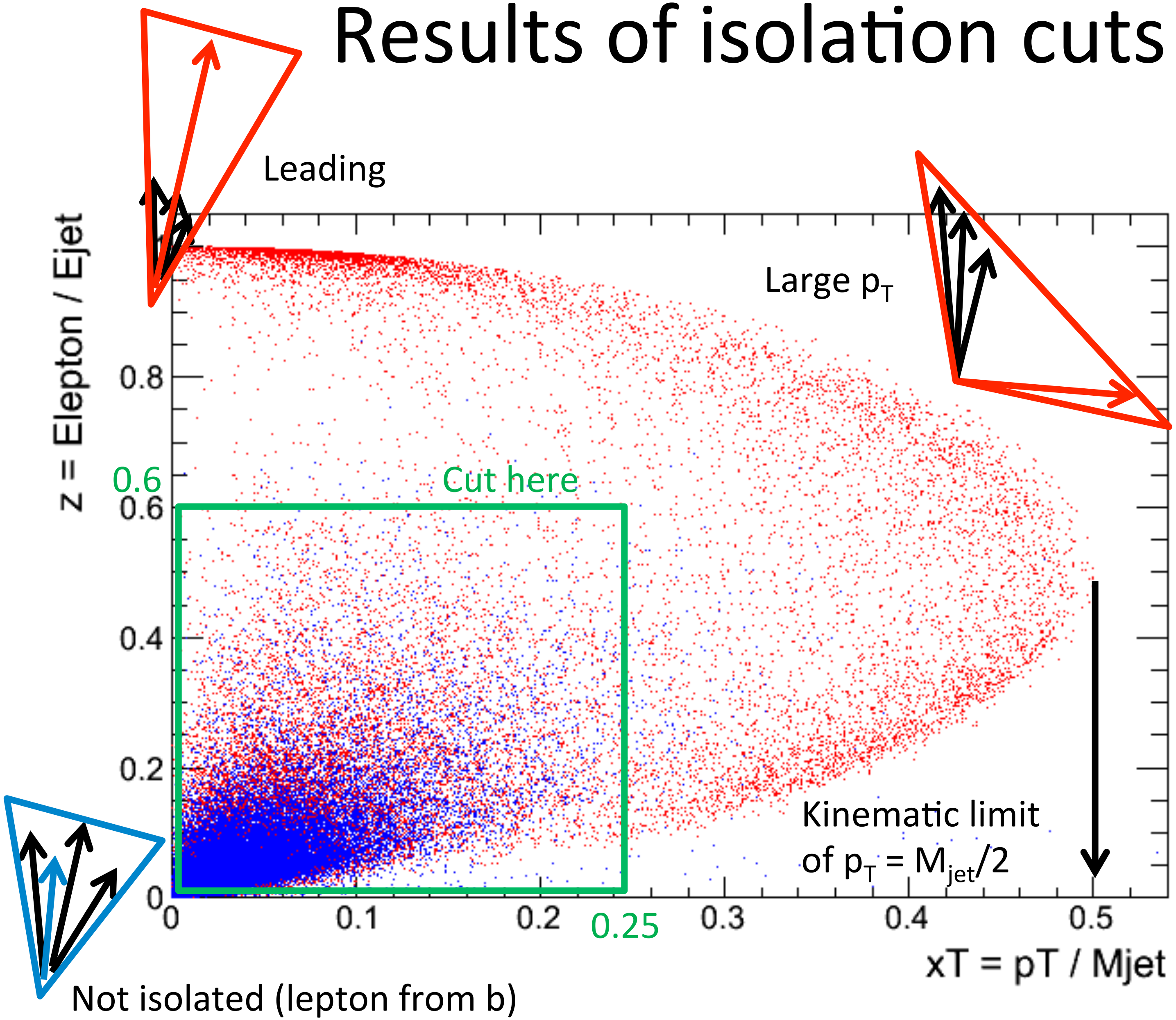
1. Leading (high z)
2. At high p_T
3. Not isolated

→ optimise cuts on z and x_T



N.B.: Note that this is based on old reconstruction flow, new s/w version allows to isolate lepton before jet finding also on DST

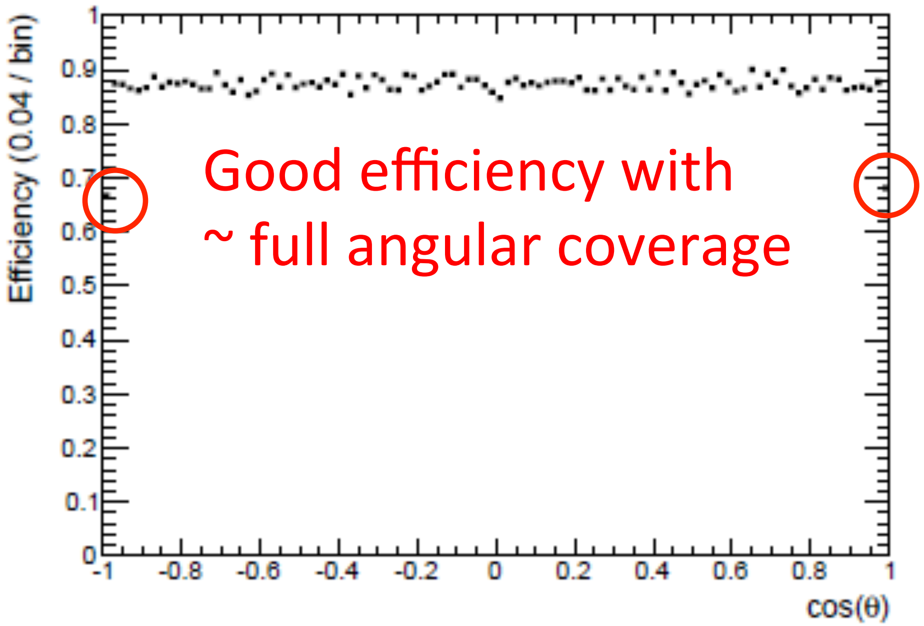
Results of isolation cuts

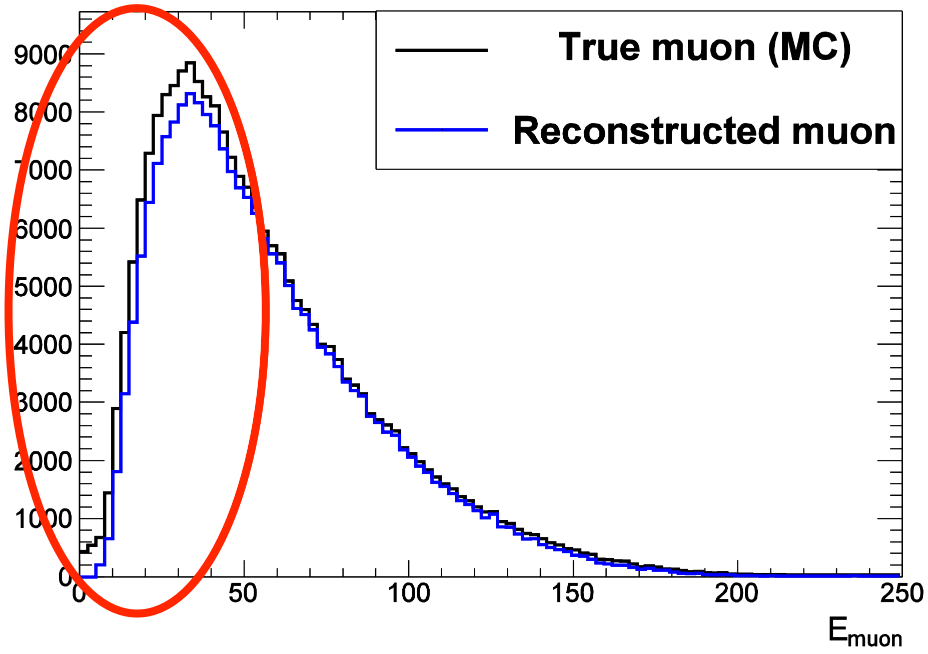


Red = leptons in semileptonic top events

Blue = leptons in full hadronic top events = leptons from b

Efficiencies : angular and energetic



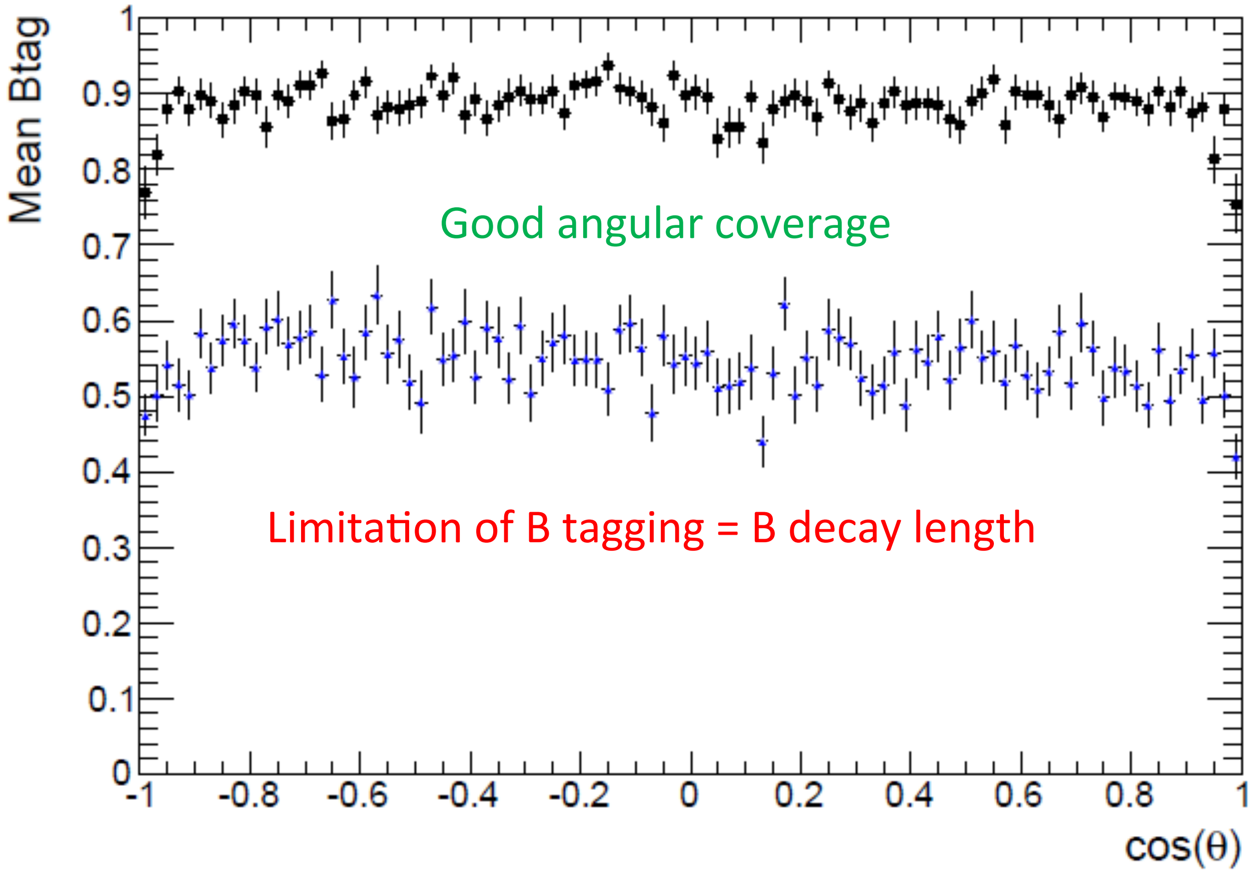


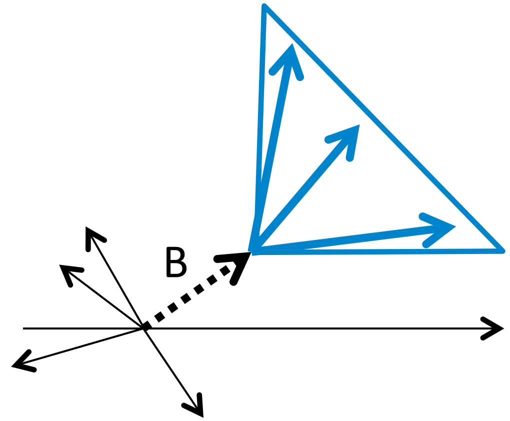
- Effiencies under control :
  - Tracking worse in very forward regions
  - Leptons with small energies are suppressed by isolation cuts

Efficiency = 87.9%
Contamination = 0.3%

B tagging

- Vertex detector → measure offset, multiplicity and mass of jets to separate b from c decays





- 4 jets
- 2 highest Btag = b_1 & b_2
- 2 "light" jets = W

Top reconstruction

Cross section and A_{LR}

Problem with the top reconstruction

Origin of the problem

Precisions reached

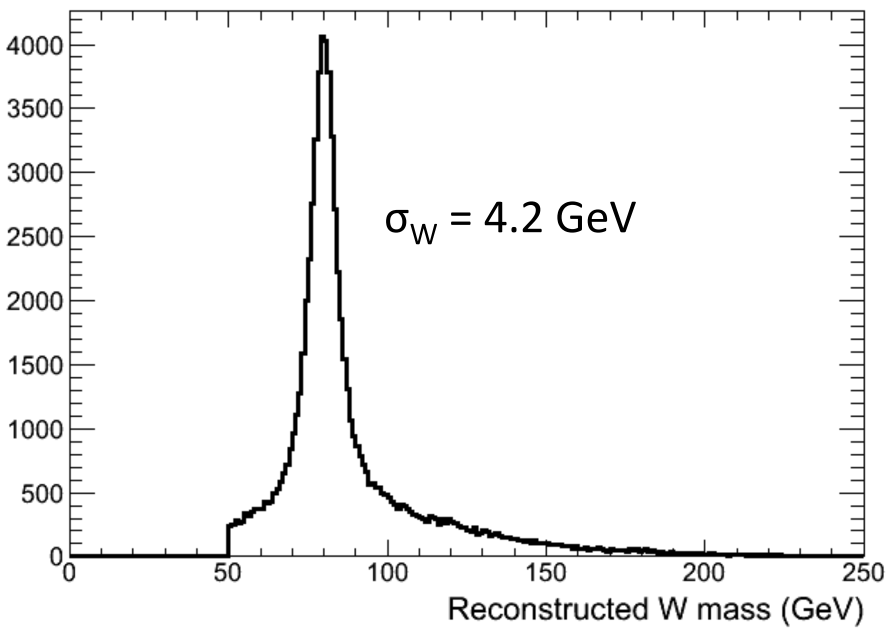
Conclusions and prospects

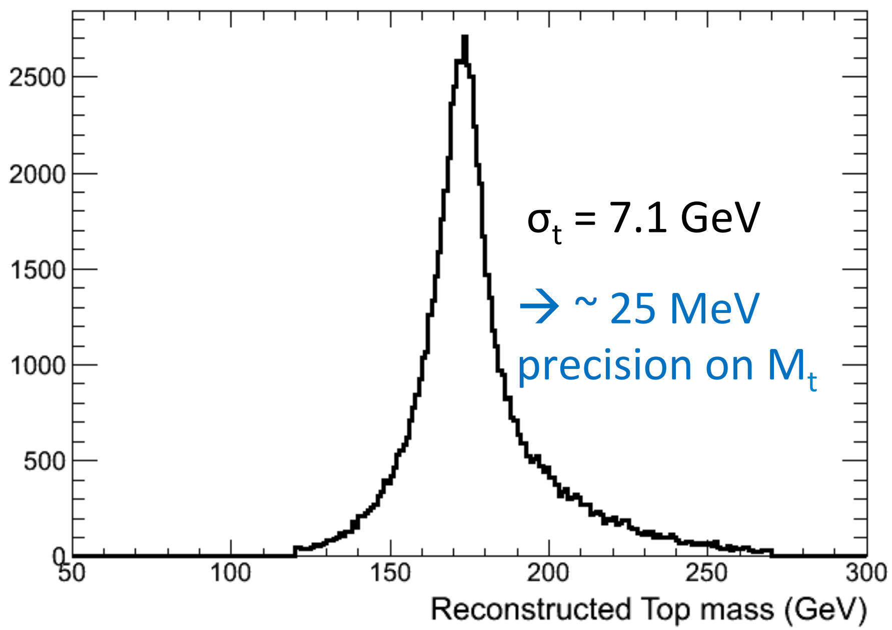
4. RESULTS

Top reconstruction

- 2 top candidates : $(b_1 + W)$ or $(b_2 + W)$
- Retain candidate with minimal

$$d^2 = (M_{cand}-M_t)^2/\sigma_{mt}^2 + (E_{cand}-E_{beam})^2/\sigma_{Et}^2 + (M_W^{rec}-M_W)^2/\sigma_{mw}^2$$





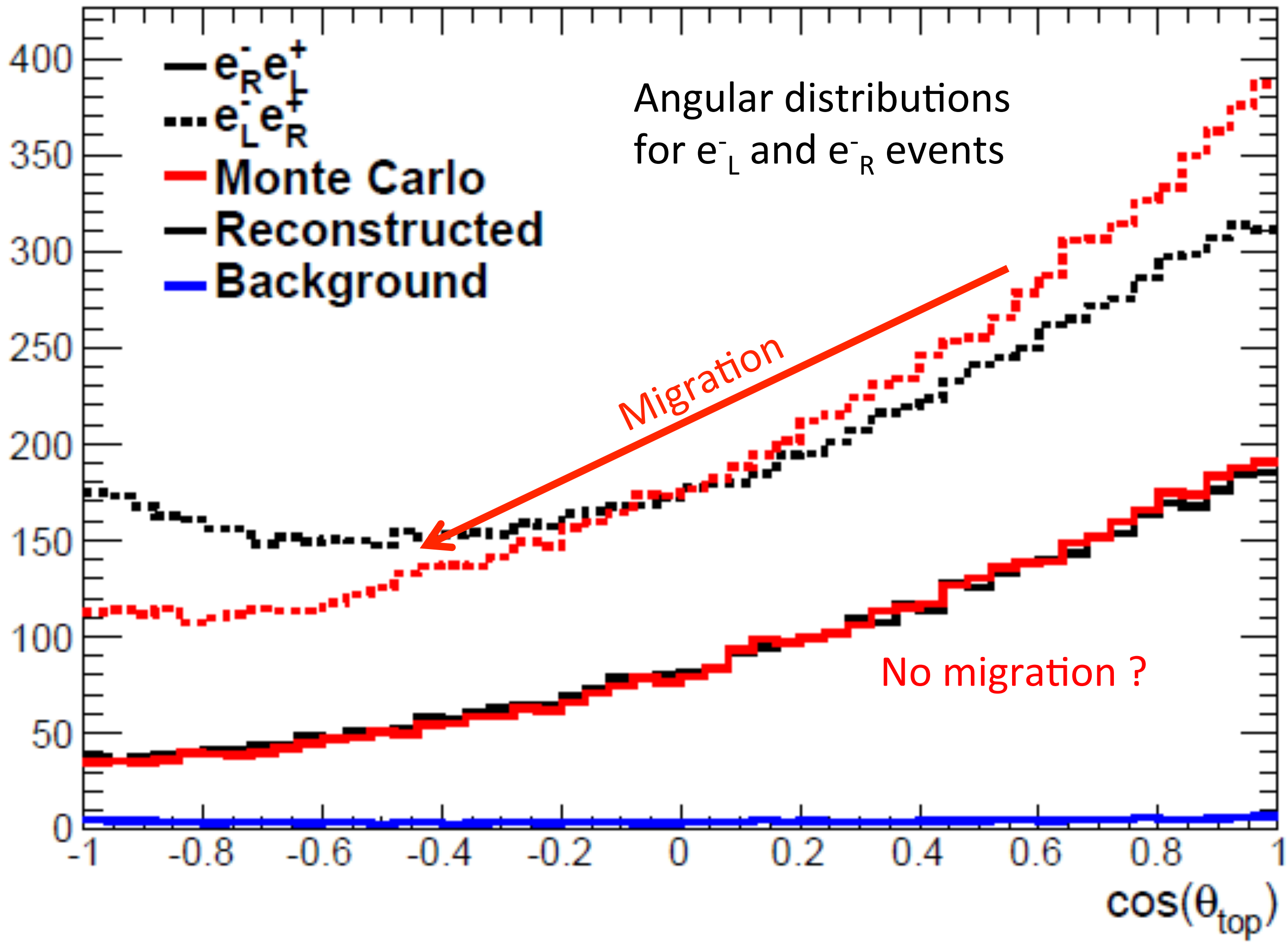
Cross-section and A_{LR}

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

  Efficiency = 72.7 % + Contamination = 4.6 % (mostly full hadronic top pairs)

- $\sigma(tt \rightarrow SL)_{unpol.} = 159.4$ fb
  - Whizard : $\sigma(tt \rightarrow SL)_{unpol.} = 159.6$ fb (-0.1%)
  - $P(e^- e^+) = (\pm 80\%, 0) \rightarrow \Delta\sigma/\sigma = 0.39\%$ (stat.)
- $A_{LR} = 0.435$
  - $A_{LR} = 0.37$ expected… Whizard problem ?
  - However, interest lies in relative uncertainty
  - $P(e^- e^+) = (\pm 80\%, 0) \rightarrow \Delta A_{LR}/A_{LR} = 1.24\%$ (stat.)

Problem with the top reconstruction



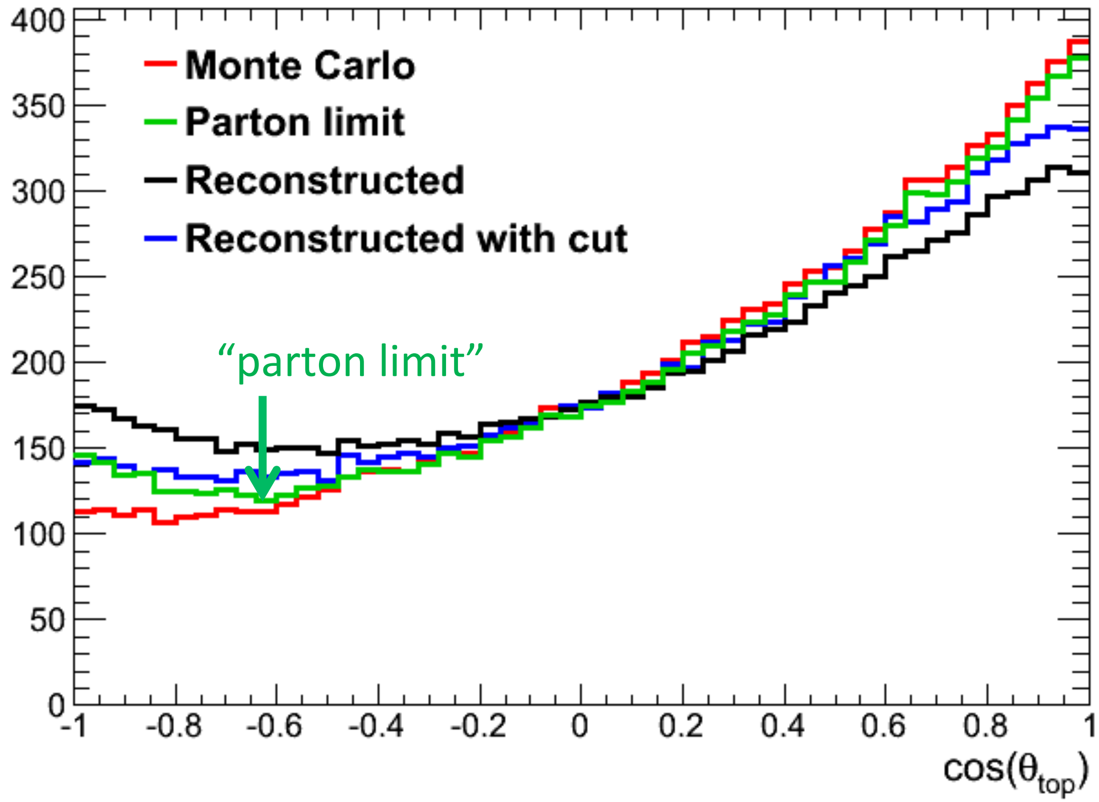
Relative errors : -5.2% ($A_{FB}{}^{t}{}_{R}$) -40.4 % ($A_{FB}{}^{t}{}_{L}$) 1.1 % (stat.)

Solving the problem

$d^2 = (M_{cand}-M_t)^2/\sigma_{mt}^2 + (E_{cand}-E_{beam})^2/\sigma_{Et}^2 + (M_W^{rec}-M_W)^2/\sigma_{mw}^2$

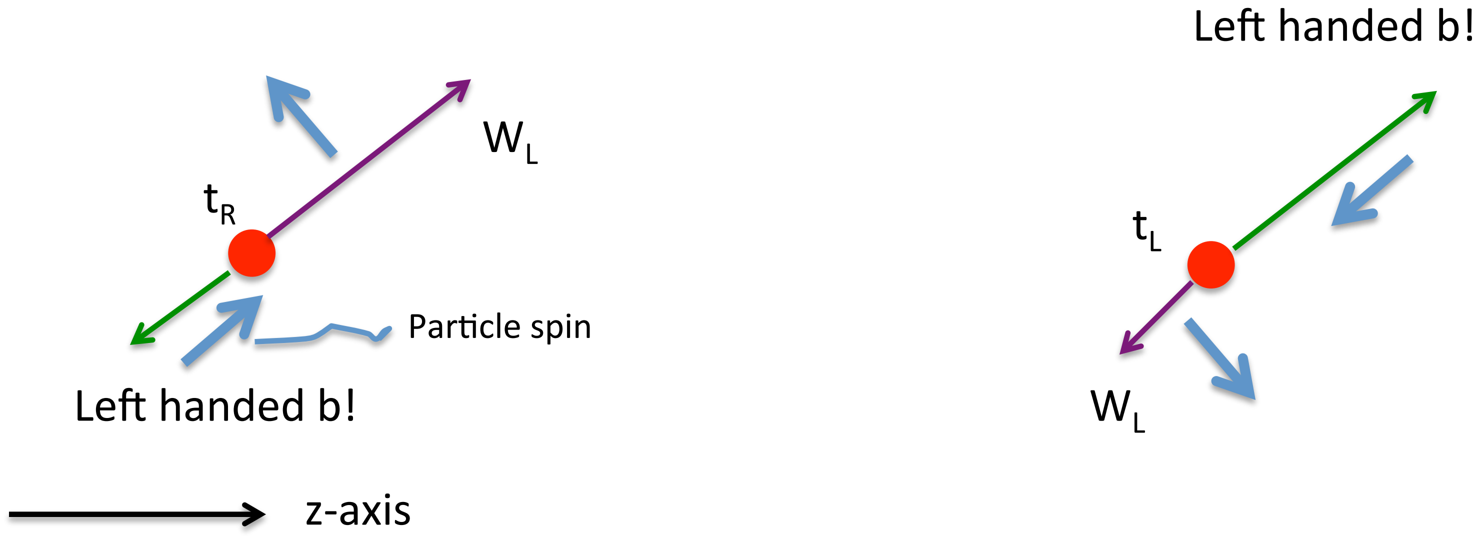
→ quality of the candidate

1. Is it due to the reconstruction ?
   - → Cut on the quality of the candidate (particle flow)
   - → Efficiency in e^-_L : x60%
   - → relative systematics : 40% → 20 %
2. Is is intrinsic ?
   - → Effect of helicity structure of the decays
   - → Ambiguous solutions
   - → Seen with partonic reco.



On ambiguities

Ambiguities are (partially) result of V-A structure of (electro)weak interaction



- Fermions participate only via left handed component of wave function to weak interaction
- Therefore hemisphere of b and thus of W_L emission varies as a function of top polarisation
- For t_R W_L gets boosted into top direction, for t_L it is emitted opposite to top direction and is nearly at rest (for small centre-of-mass energies)
  e.g. for $\sqrt{s} = 500$ GeV, $E_{WL} \approx 81$ GeV for t_L
- The « resting » W gives rise to ambiguities in reconstruction of top angle!!!

Precisions reached

- Correction on $A_{FB}{}^{t}{}_{L}$ = dominant systematic (reco. + intrinsic)
  - Good PFA + b tagging are essential
  - 20% correction on $A_{FB}{}^{t}{}_{L}$ can be done on a well tuned MC

P_{e-} / P_{e+} (80% / 0)	A_{LR}	$A_{FB}{}^{t}{}_{R}$	$A_{FB}{}^{t}{}_{L}$		$Q^{Z}{}_{tL}$	$Q^{Z}{}_{tR}$
stat. error	1.3%	1.2 %	1.4 %		1.0 %	1.9 %

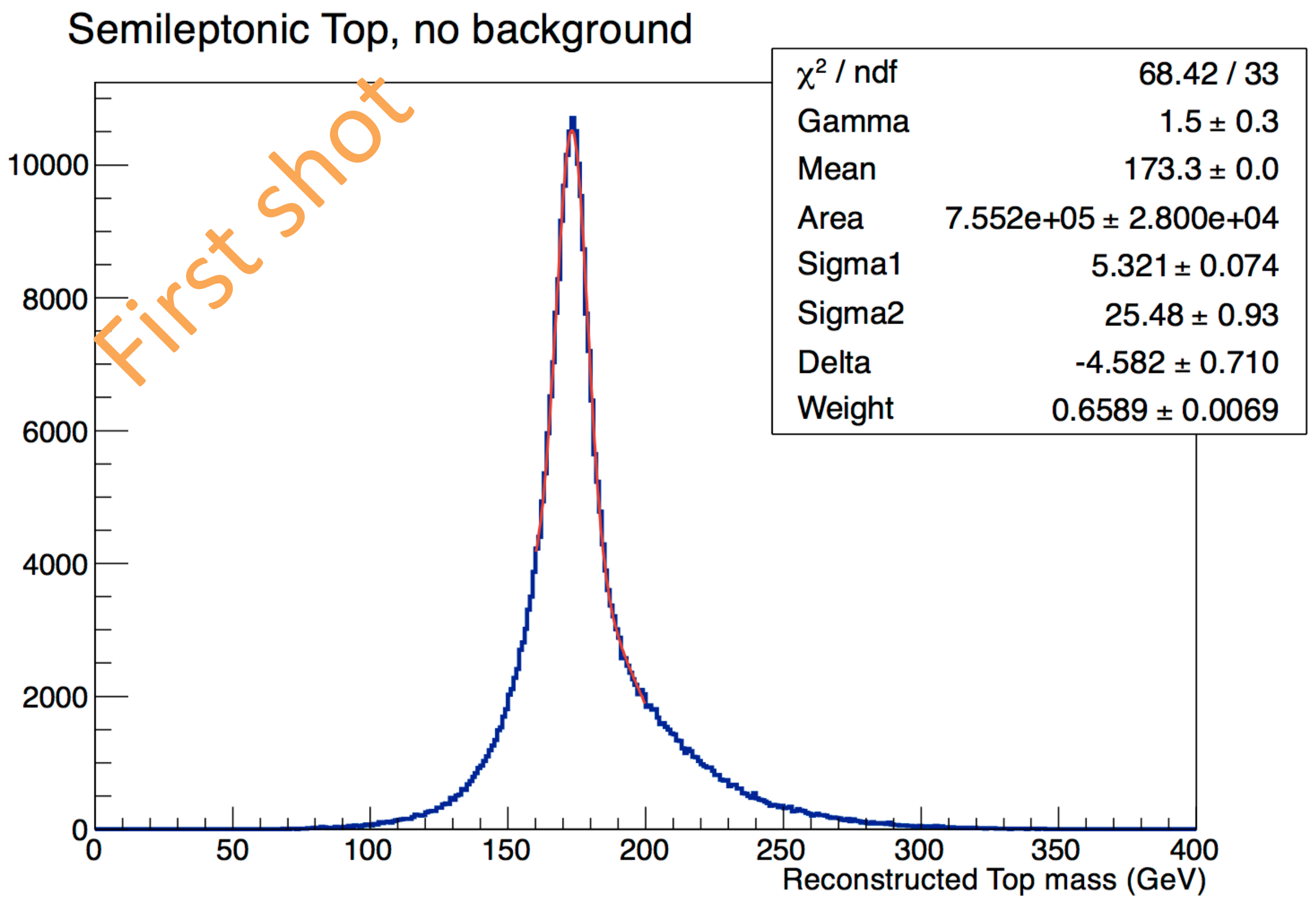
- Possible to probe some RS models with M_{KK} ~ 2.8 TeV
  up to 25 TeV

Conclusion and prospects I

- Impact of detector & reconstruction performances on a complex channel : lepton + 4 jets with 2 b jets
- Final efficiency = 72.7%
- Contamination = 4.6% (Major backgrounds are other top channels)
- σ and A_{LR} can be known at 0.4% and 1.3% statistical uncertainty (systematics guaranteed small due to large purity)
- Problem in reconstructing the direction of the top
  - Reconstruction needs improvements or leads to efficiency losses
  - Intrinsic problem with $A_{FB}{}^{t}{}_{L}$ needs excellent Monte Carlo
  - $A_{FB}{}^{t}{}_{R/L}$ known with 1.2/1.4% statistical uncertainty
- Study of A_{FB} to enter the DBD for the ILD in 2012 (work has been resumed by Jeremy Rouene)

Top mass reloaded

(First analysis steps by Jeremy)



Fit of Breit-Wigner with two gaussians

Top parameters from BW function:

m_t=173.35 ±0.05 GeV

Γ_t = 1.5 ±0.3 GeV

Work in the next months

Let me remind that also we have only one PhD student working on it who has also hardware committments

- Testing of ilcsoft v01-13 (DBD release) against existing results
- Inclusion of background
- Study the influence of PFA on the migration effects. What in case of perfect PFA?
- Alternative jet algorithms
- The hard case: Tame migration effect by reconstruction of charge of b-quarks, Need collaboration with other groups (Valencia, University of Tokio)

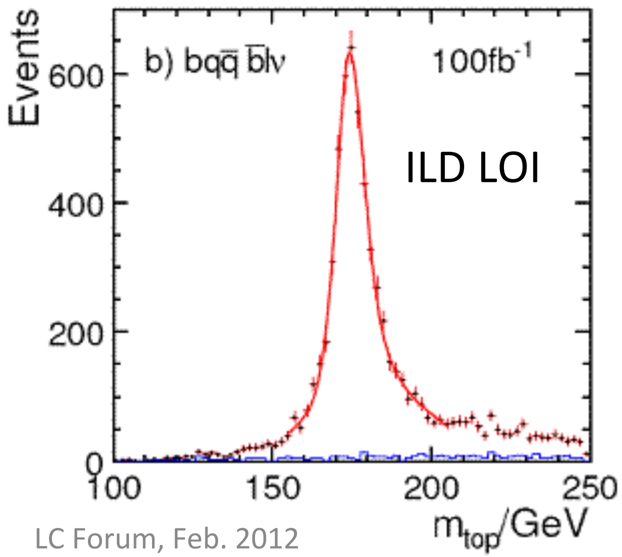
Top physics : LHC and ILC

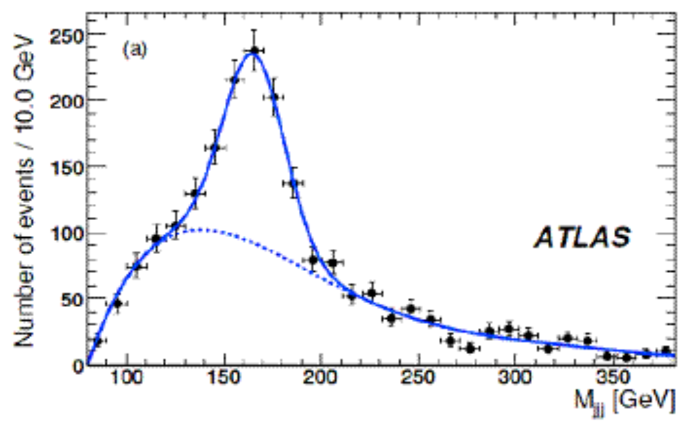
Top couplings : bibliography

5. ADDITIONAL MATERIAL

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





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