Asian Committee for Future Accelerators

KILC12 – Daegu/Korea

Top quark asymmetries at the LC

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Plan

1. Motivation
2. Measurement method
3. Efficiencies
4. Results
5. New observable Ahel
6. Conclusions

The top quark and flavor hierarchy

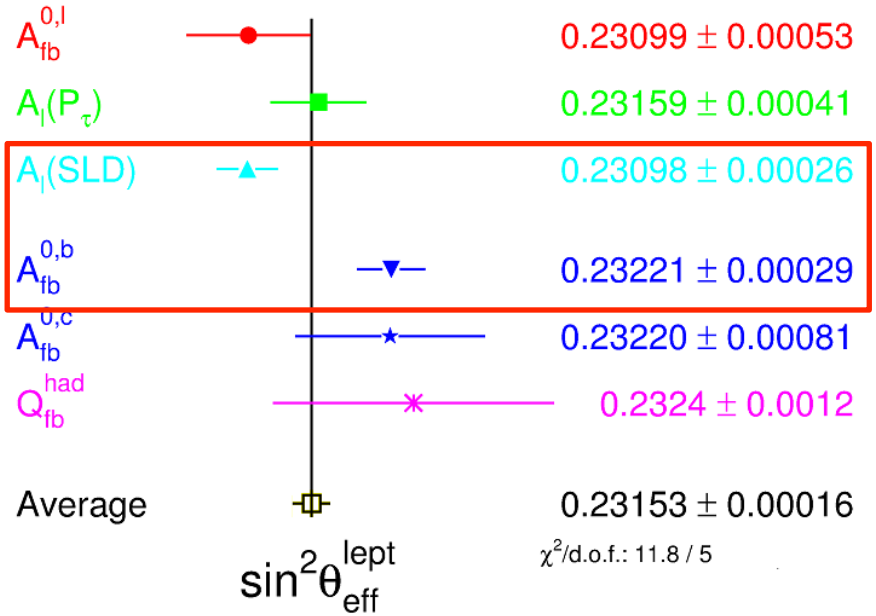
Geography in Randall-Sundrum models

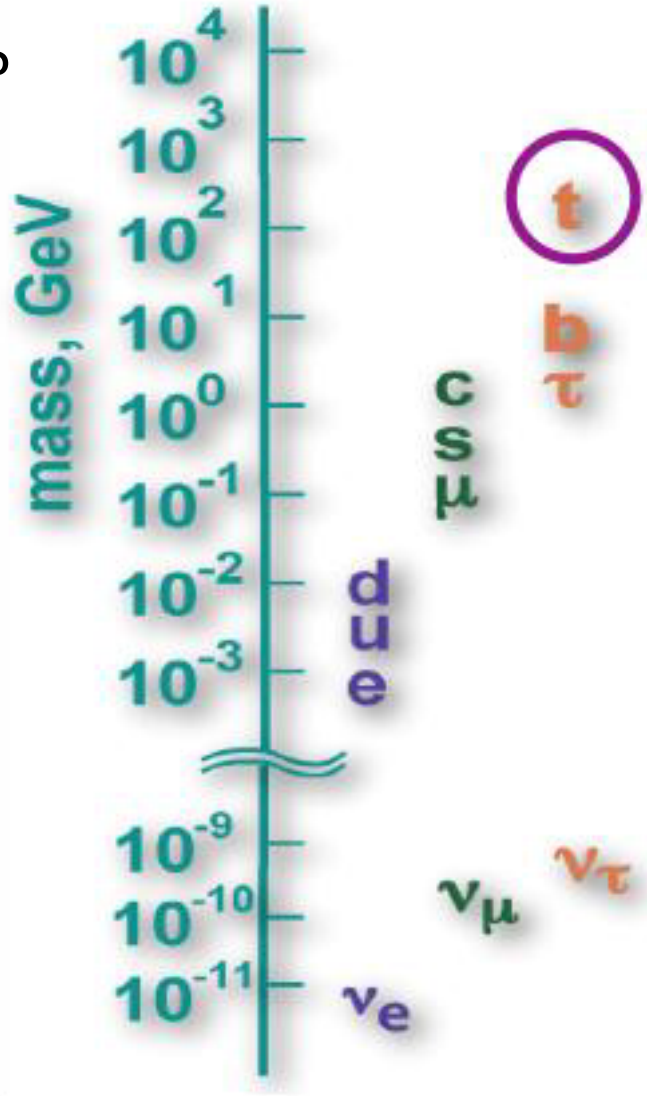
Top to Z couplings

1. MOTIVATION

The top quark and flavor hierarchy

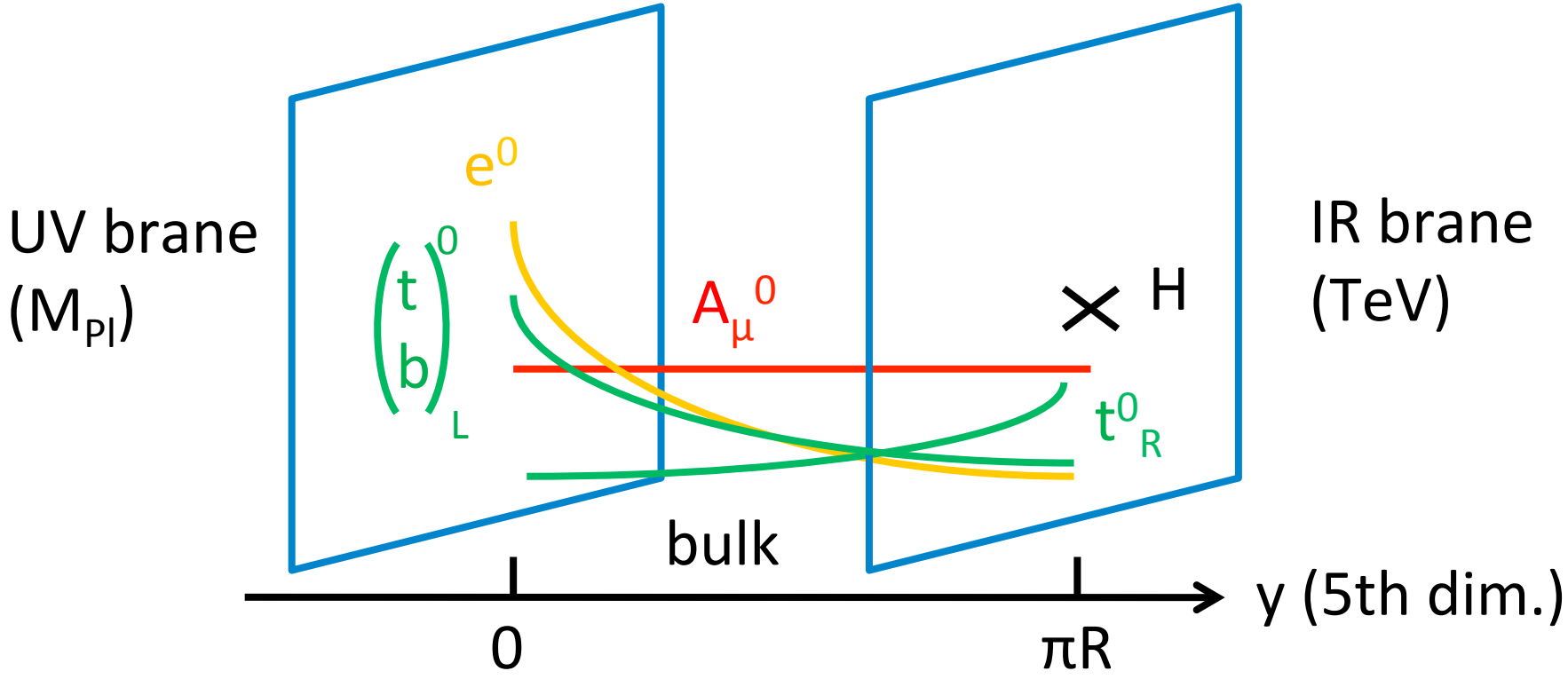
- Flavor hierarchy ? Role of 3rd generation ?





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

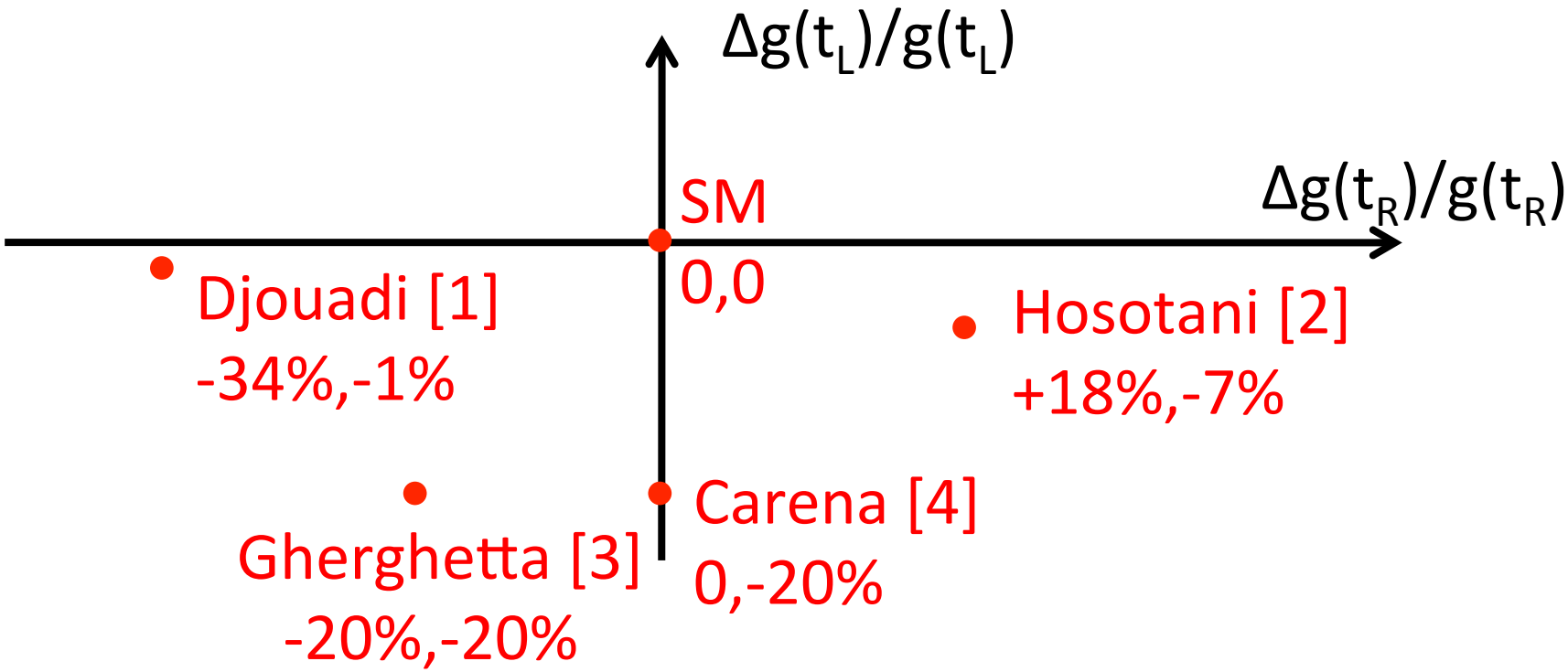
Geography in Randall-Sundrum models



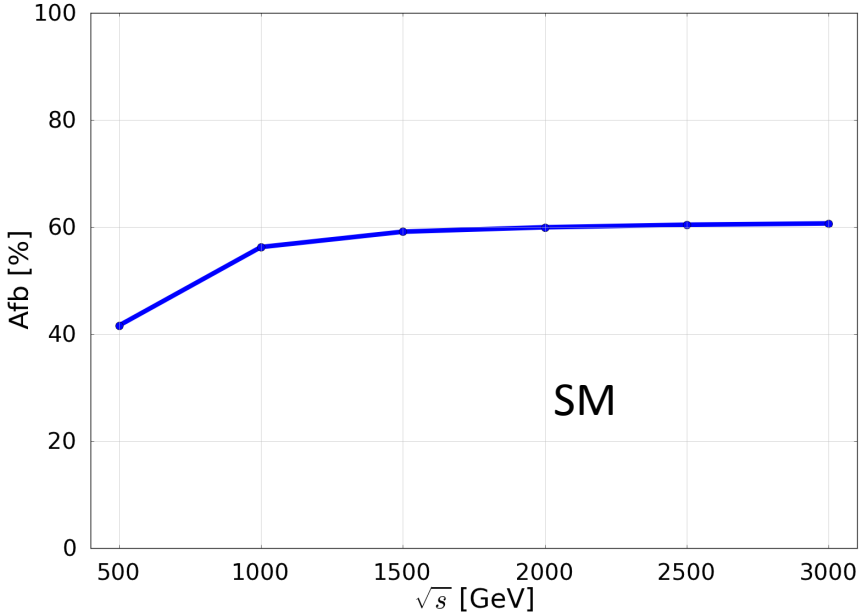
- Higgs on IR brane for gauge hierarchy problem
- SM fermions have different locations along the 5th dimension
- Overlaps leptons – Higgs in the 5th dimension generate good Yukawa couplings with O(1) localisation parameters

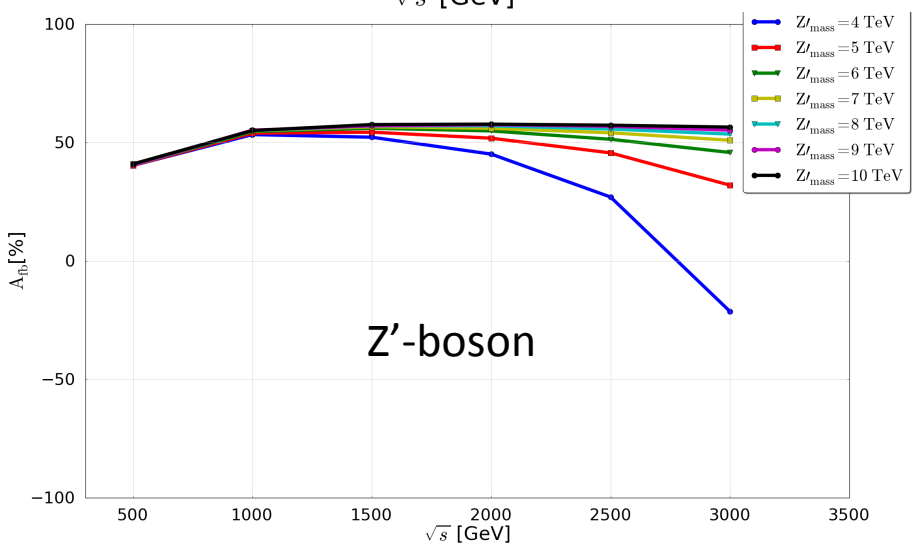
Top to Z couplings

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



Survey on expected results at different energies - A_{FB}

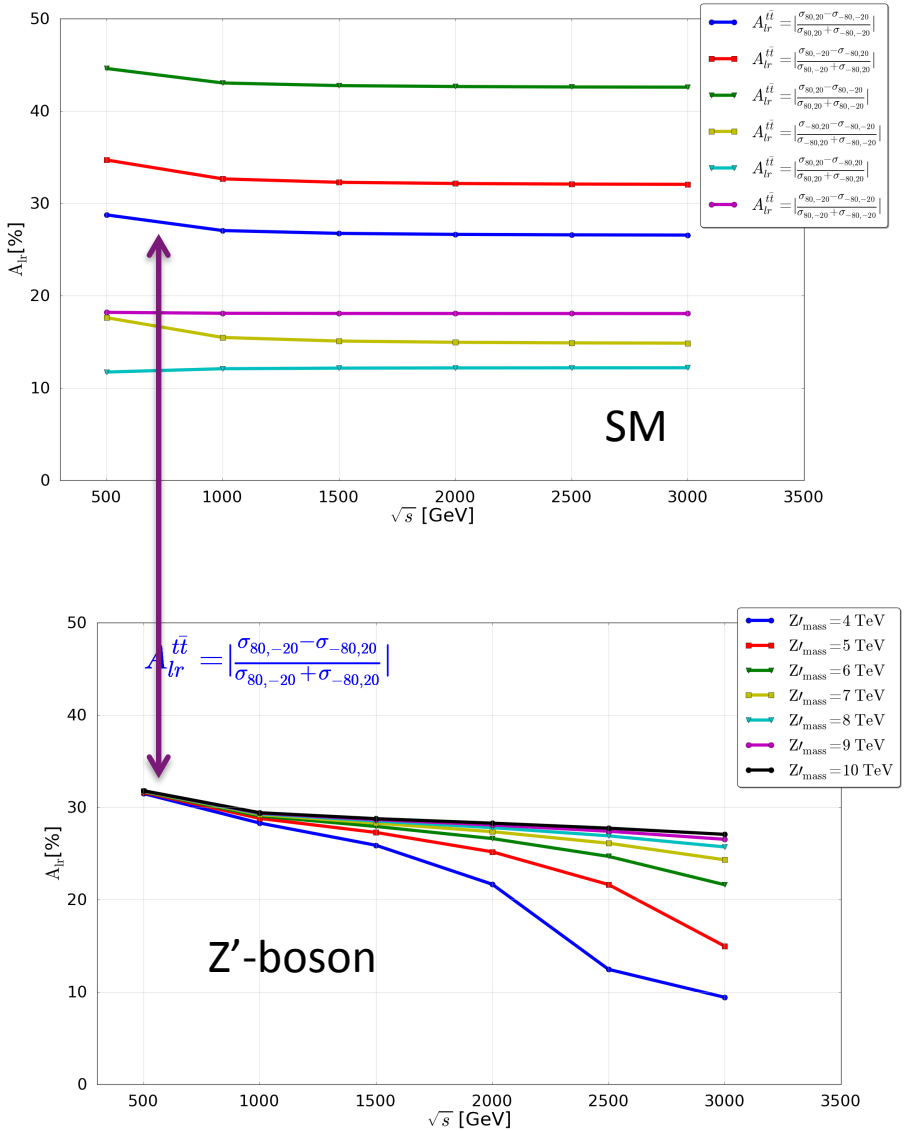




- Results obtained with MadGraph/ MadEvent.
- 400.000 events by point to obtain 1‰ of statistical dispersion.
- m(t) = 173.2 ± 0.9GeV

New physics will alter asymmetries
More discriminative at higher energies

Survey on expected results at different energies - A_{LR}



- e^- beam polarization: ±80%
- e^+ beam polarization: ±20%

New physics will alter asymmetries
More discriminative at higher energies

Observables

Top quark cross section

Measurement with the ILD detector

Reconstruction within the ILD framework

Requirements

2. MEASUREMENT METHOD

Traditional observables

- $\sigma(t\bar{t})$, 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 :

  $t\bar{t} \rightarrow (bW)(\bar{b}W) \rightarrow (bqq)(\bar{b}l\nu)$

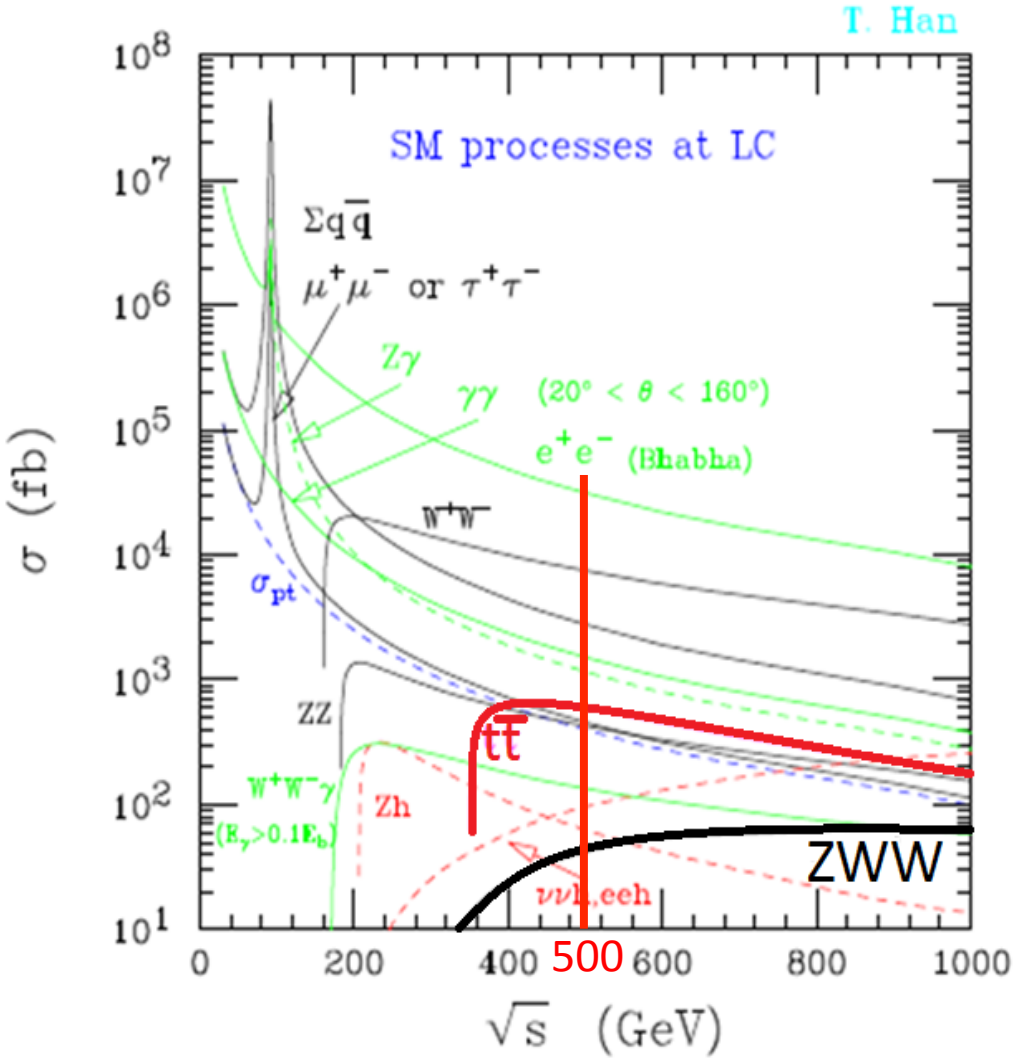
  Allows reconstruction of the top quark

  $l = e, \mu$ → 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

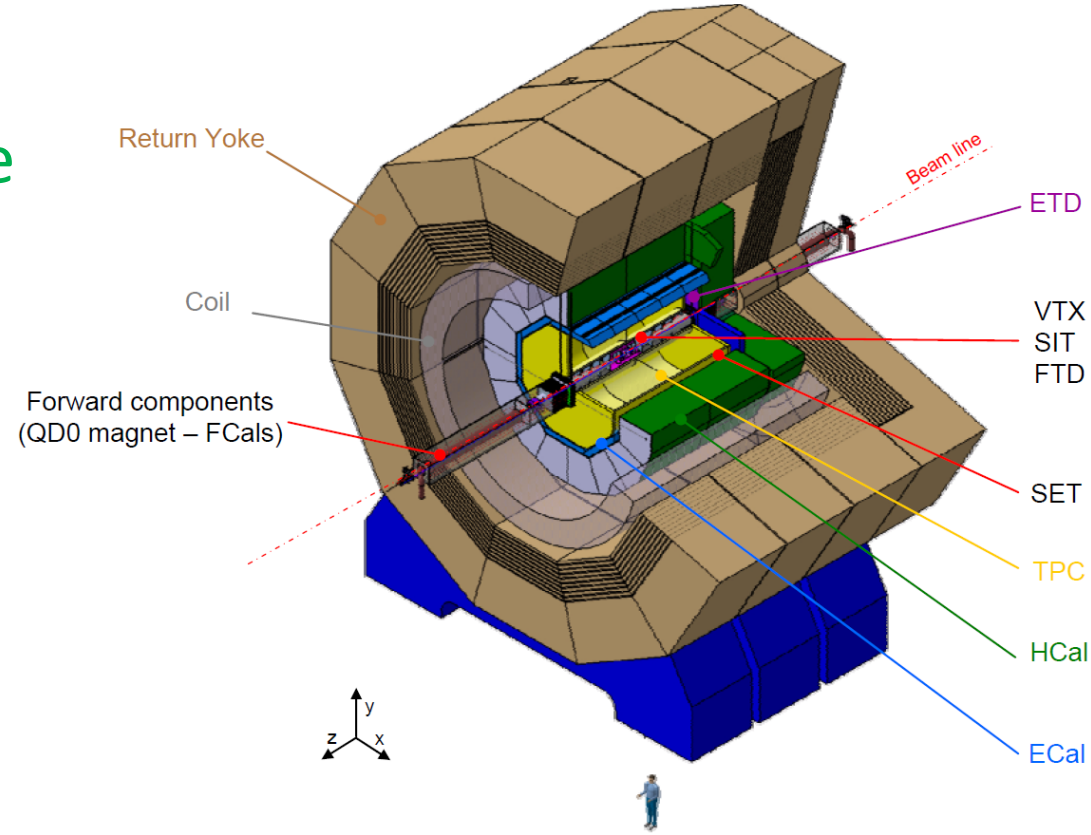
- σ(tt) ≈ 600 fb at 500 GeV with 500 fb^{-1}
  - Ntotal ~ 570k events
  - Semileptonic ~ 34%
- Almost background free ?
  - Major background = other top channels → find 1 isolated lepton
  - WW → no b quark
  - bb → simple topology
- Major background : ZWW (Z→bb) ≈ 8 fb, same topology
  - Small but needs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

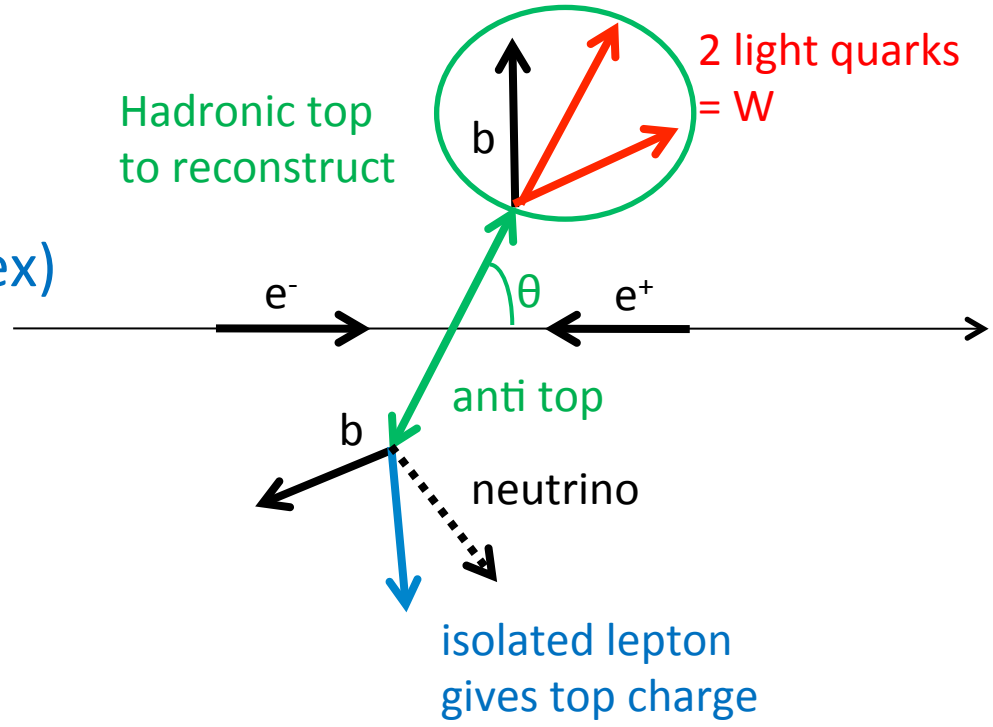
- Performances :
  - Vertexing : σ_{IP} = 5 µm (+) 10 µm/p(GeV)$\sin^{3/2}\theta$
  - Tracking : $\sigma(1/p_T) < 5.10^{-5}$ GeV^{-1}
  - Granular calorimetry : $\sigma_E/E \sim 30\%/\sqrt{E}$

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

- $tt \rightarrow bbqq l\nu$ ($l=e,\mu$)
  - 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

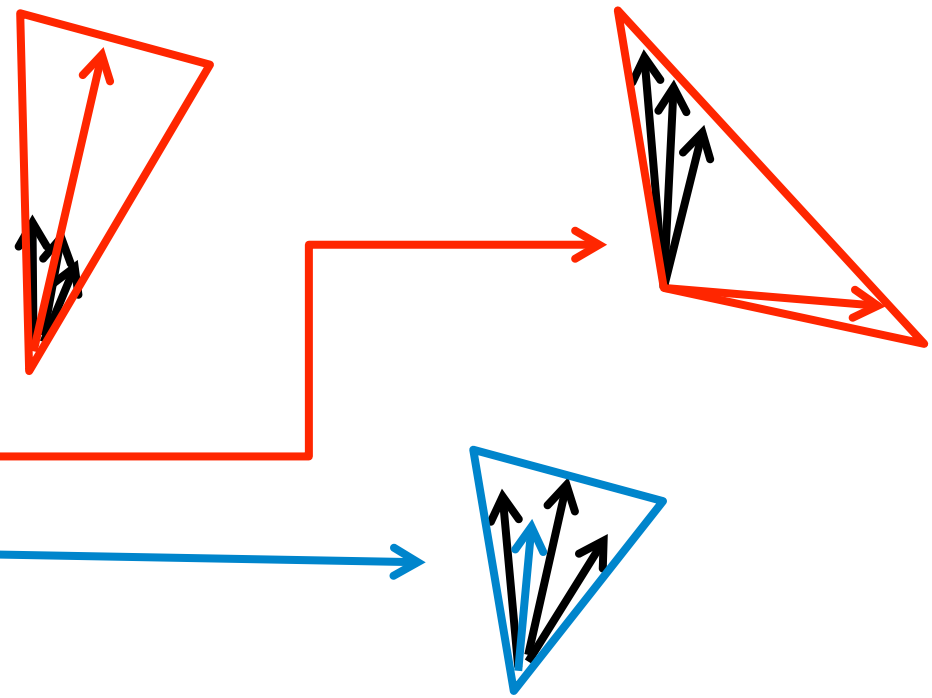
Isolation

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

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

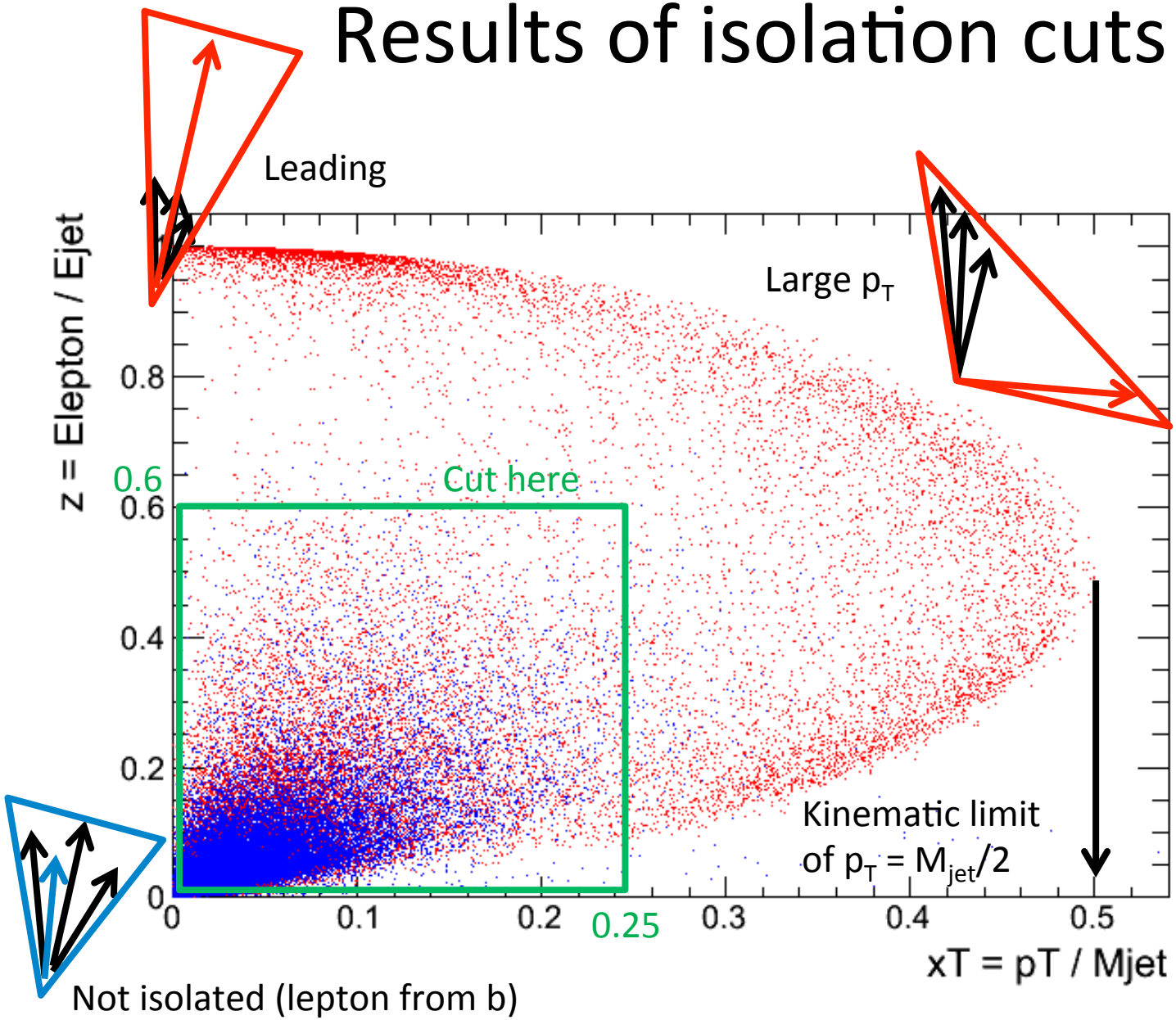
1. Leading (high z)
2. At high p_T
3. Not isolated

→ 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

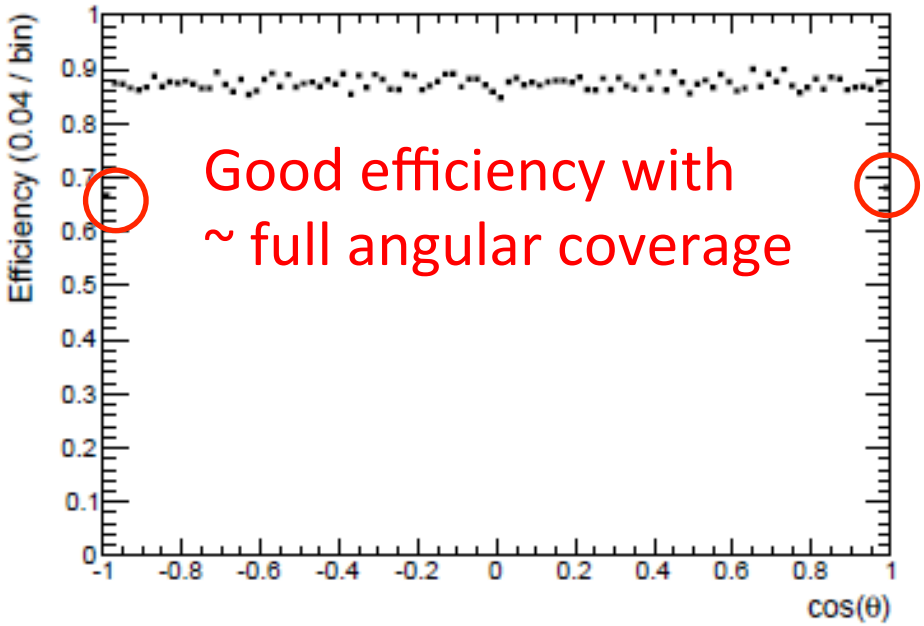
Results of isolation cuts

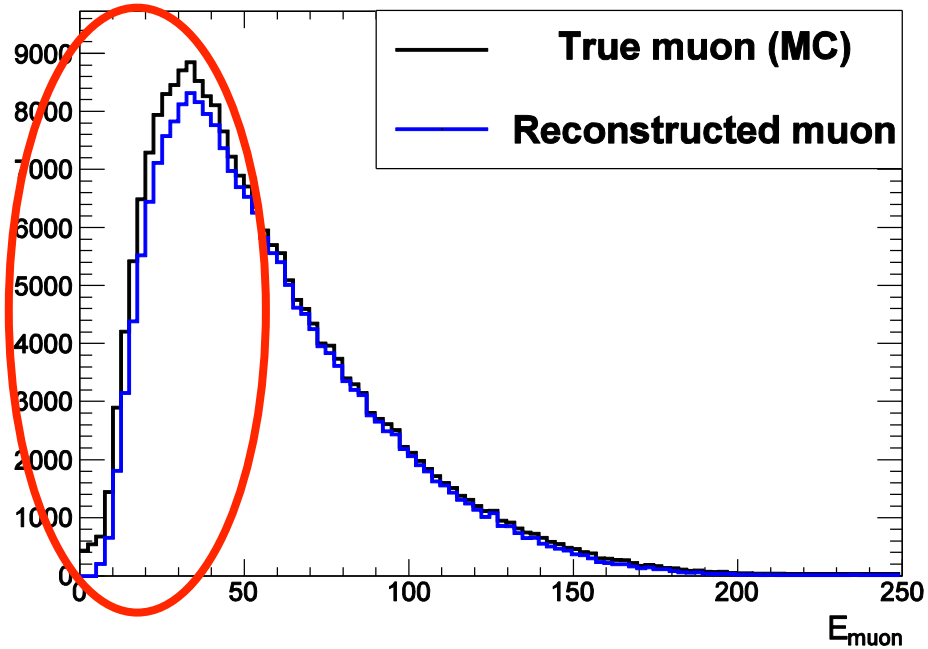


Red = leptons in semileptonic top events

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

Efficiencies : angular and energetic



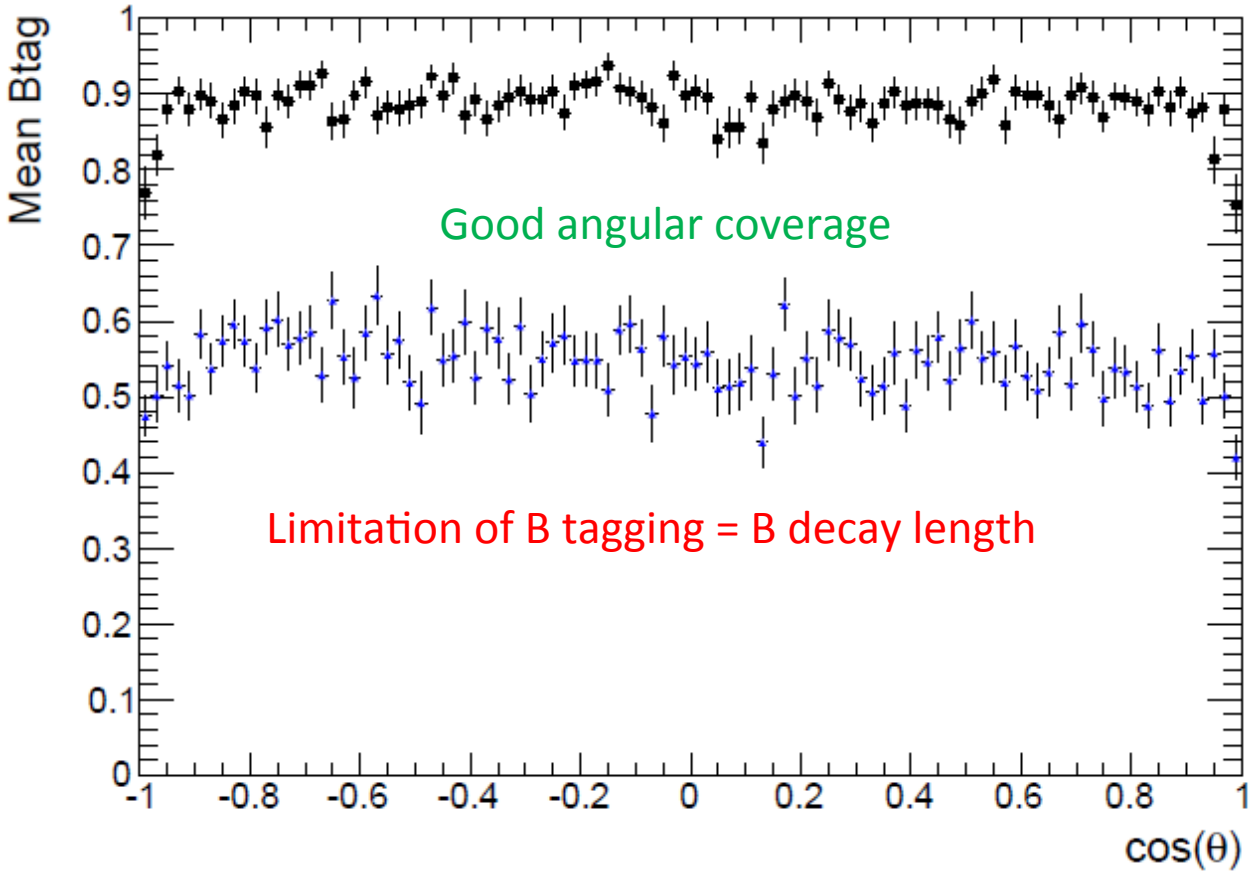


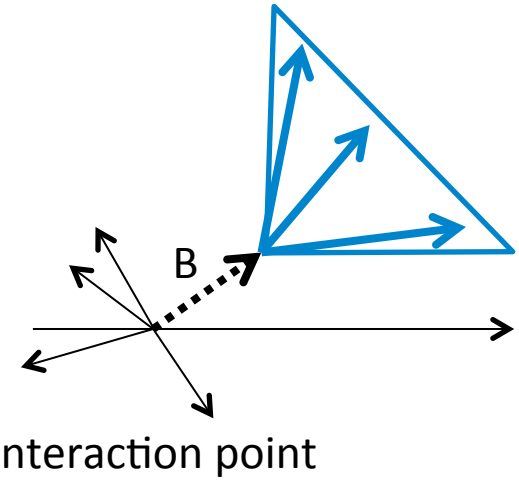
- Effiencies under control :
  - Tracking worse in very forward regions
  - Leptons with small energies are suppressed by isolation cuts

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

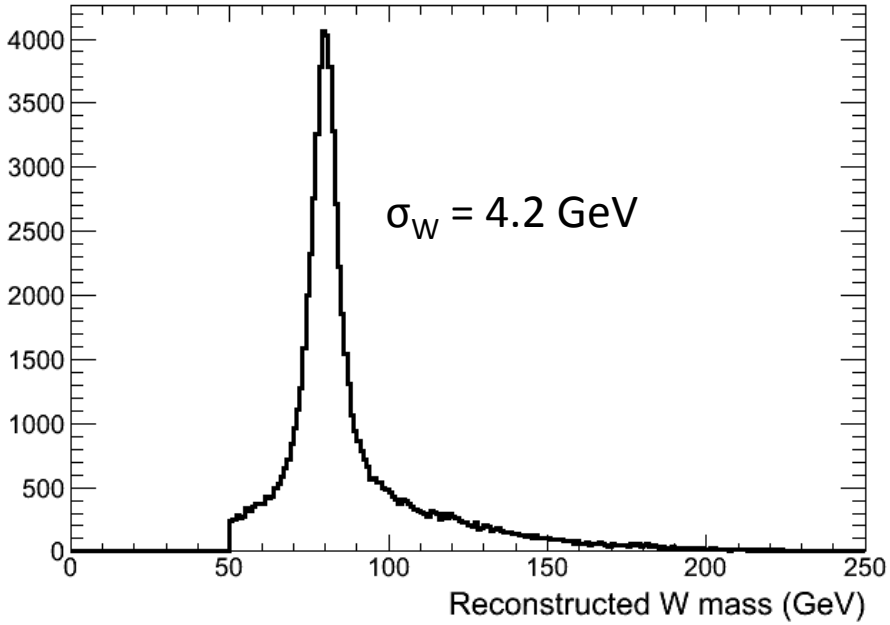
Conclusions and prospects

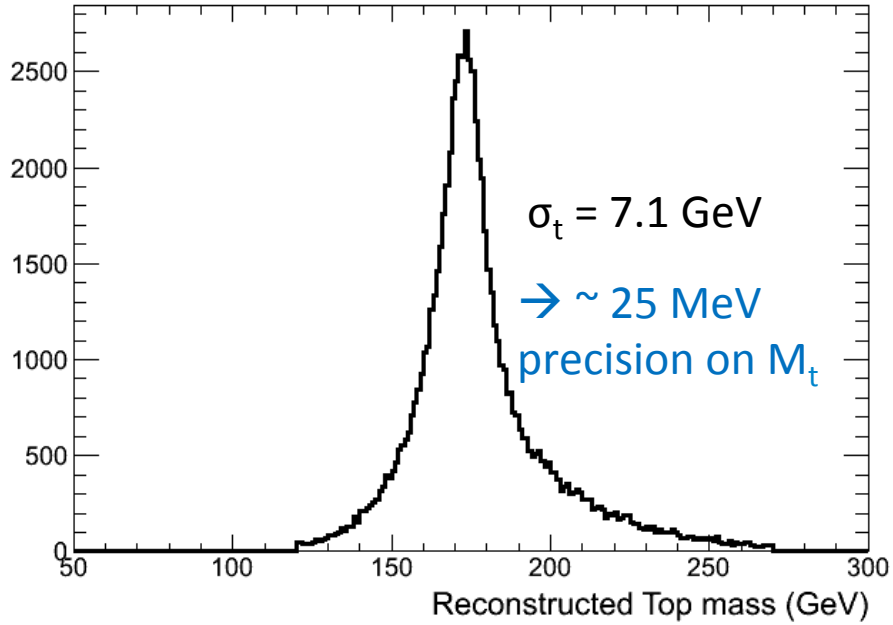
4. RESULTS

Top reconstruction

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

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





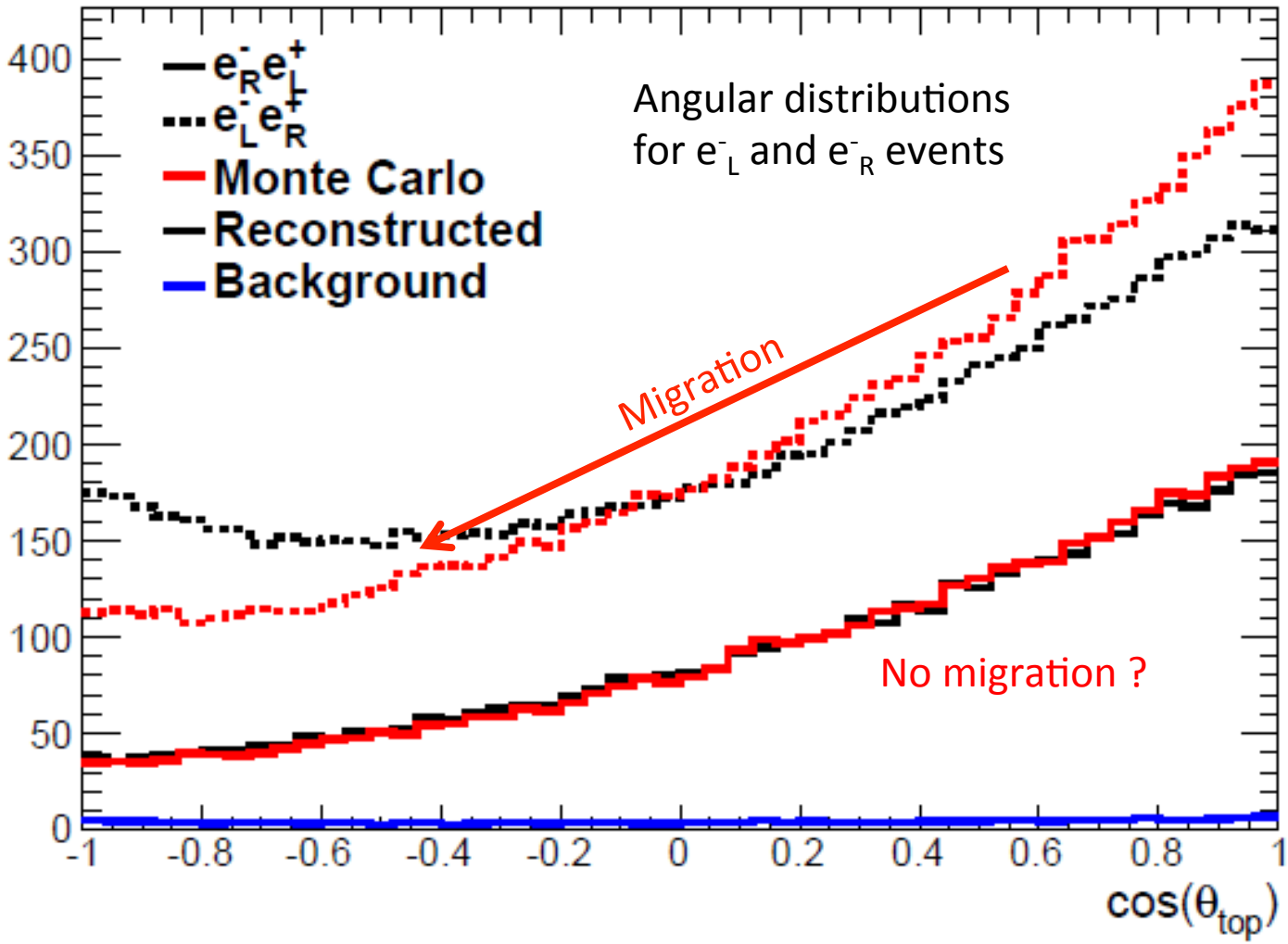
Cross-section and A_{LR}

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



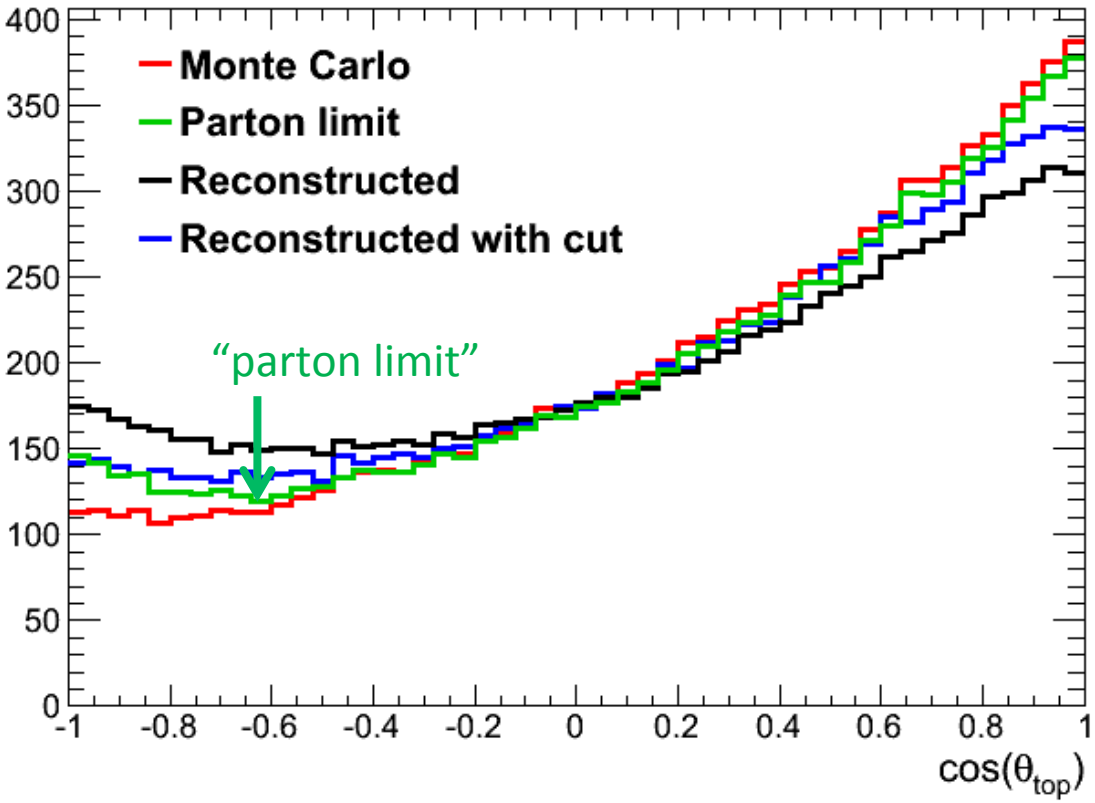
Relative errors : -5.2% ($A_{FB}{}^{t}{}_{R}$) -40.4 % ($A_{FB}{}^{t}{}_{L}$) 1.1 % (stat.)

Solving the problem

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

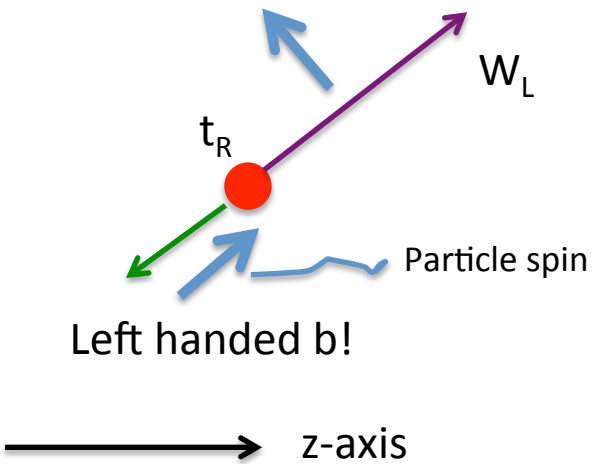
→ quality of the candidate

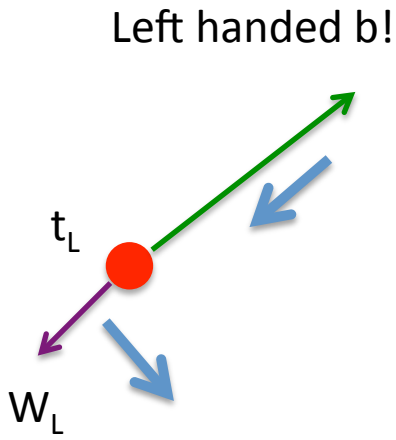
1. Is it due to the reconstruction ?
   - → Cut on the quality of the candidate (particle flow)
   - → Efficiency in e^-_L : x60%
   - → relative systematics : 40% → 20 %
2. Is is intrinsic ?
   - → Effect of helicity structure of the decays
   - → Ambiguous solutions
   - → Seen with partonic reco.



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!!!
- Remark: Vos at LCForum at DESY: Migrations less severe at $\sqrt{s}$ = 1 TeV

Precisions reached

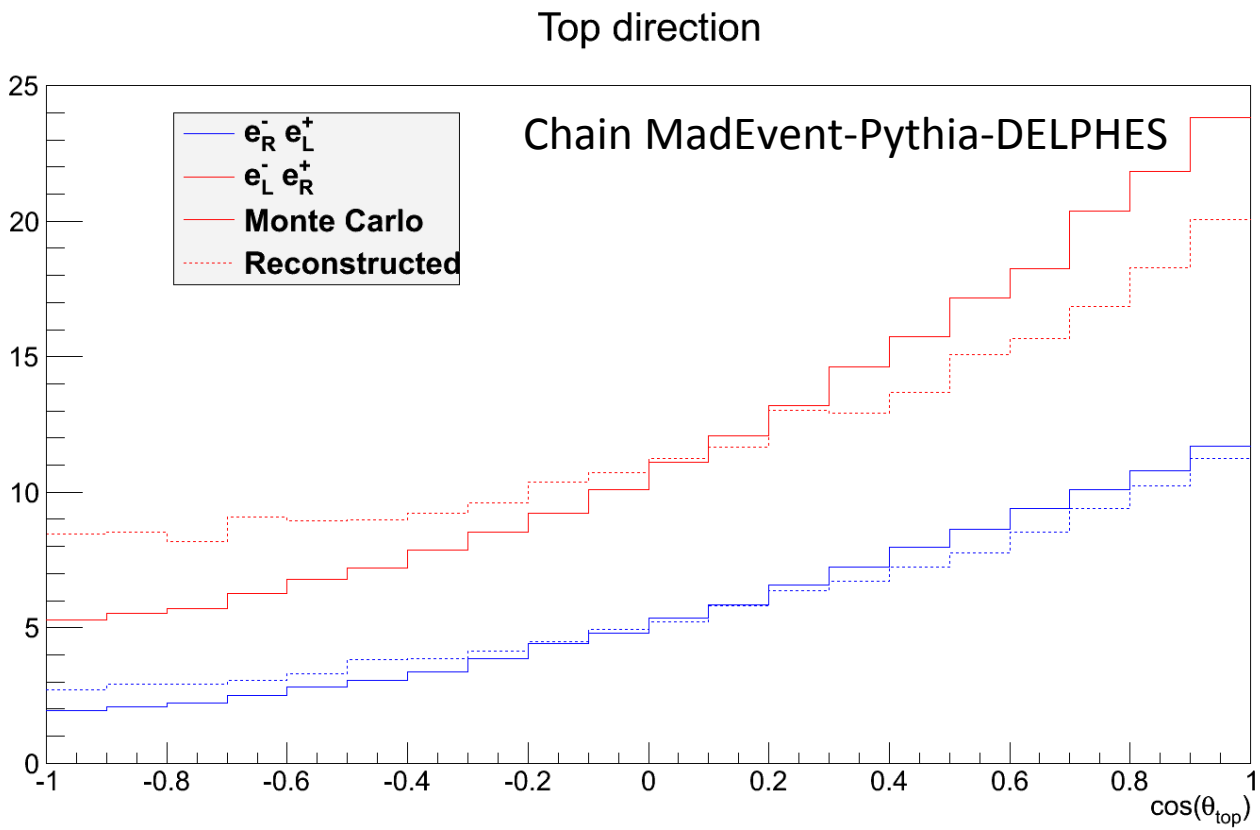
- Correction on $A_{FB}{}^{t}{}_{L}$ = dominant systematic (reco. + intrinsic)
  - Good PFA + b tagging are essential
  - 20% correction on $A_{FB}{}^{t}{}_{L}$ can be done on a well tuned MC

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 and up to 25 TeV in case of presence of Z' boson

Sanity check with fast simulation - DELPHES

DELPHES is a fast simulation tool, capable of producing results with a "perfect particle flow" algorithm. An ILD and SiD detector card are in preparation.



DELPHES matches full simulation reasonably well

Migrations of same order than with full simulation

puts influence of PFA into question

Introduction of observable

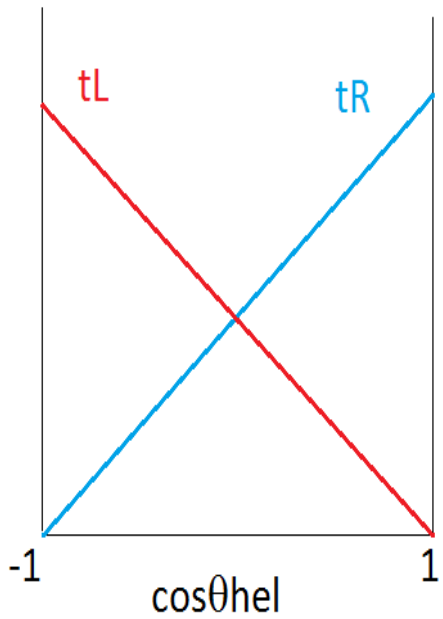
First studies

5. NEW OBSERVABLE A_{hel}

New observable A_{hel} Proposal by F. Richard

Differential decay rate in top rest frame:

$$\frac{1}{\Gamma}\frac{\partial\Gamma}{\partial\cos\theta_h} = \frac{1+\lambda_t\cos\theta_h}{2} \quad \text{with } \lambda_t = 1 \text{ for } t_R \text{ and } \lambda_t = -1 \text{ for } t_L$$



Forward backward asymmetry **Ahel**

Slope measures fraction of tR,L in sample
$\Rightarrow$ Couplings of top quarks to vector bosons

Slope more robust to migration effects (to be proven!!!)

Define: $A_{hel,L}$ for $e_L^- e_R^+$ and $A_{hel,R}$ for $e_R^- e_L^+$

$\Rightarrow$ Set of four observables:

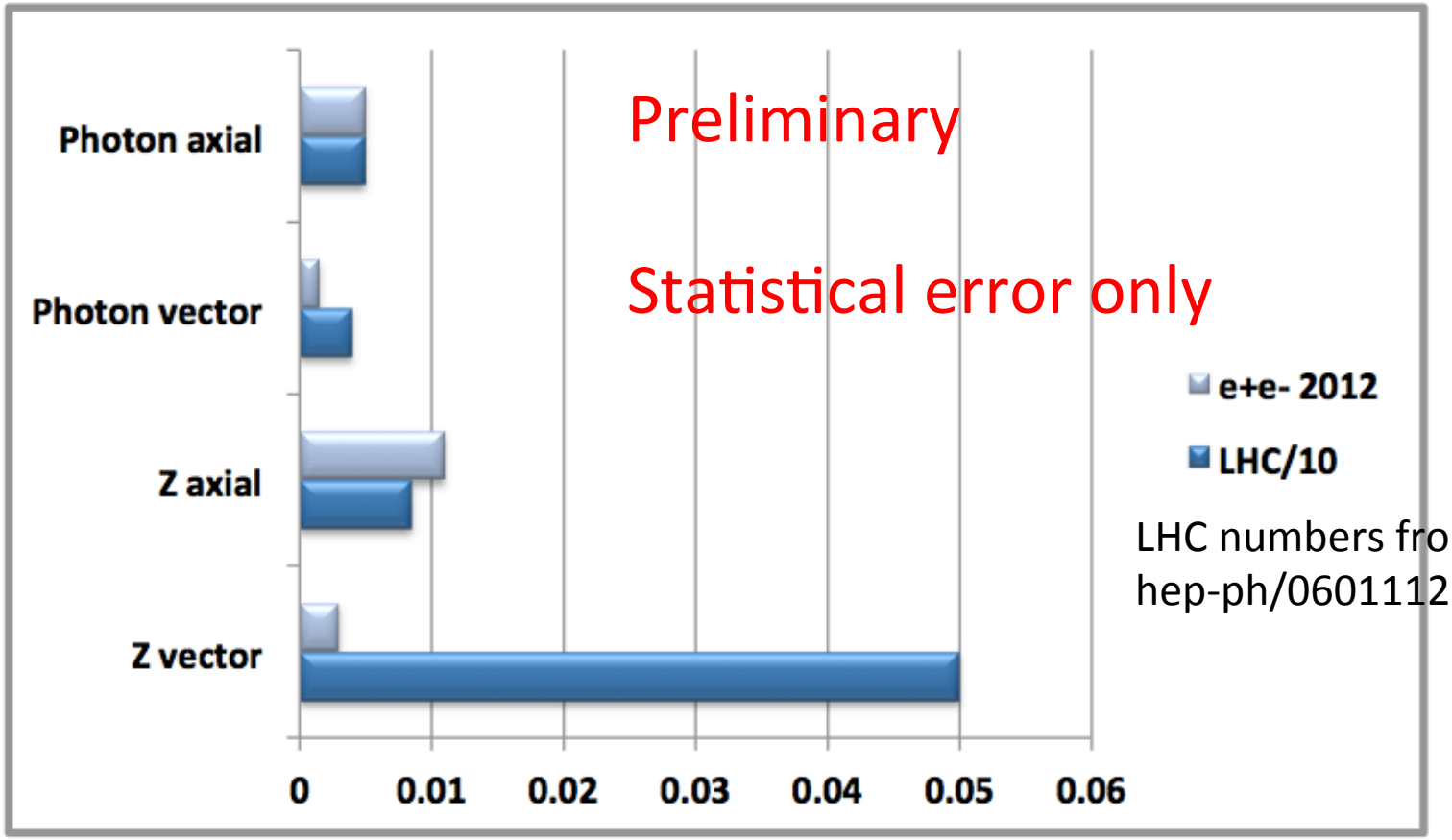
σ_L, σ_R (instead of A_{LR}), $A_{hel,R}$ and $A_{hel,L}$

to determine unknowns $g_\gamma(t_L), g_\gamma(t_R)$, $g_Z(t_L), g_Z(t_R)$

Current result (Richard): Couplings will be much more precise than LHC300
Work in progress

Estimation of precisions – Study by F. Richard

$\sqrt{s}$ = 500 GeV, Pe- = ±80%, Pe+ = ±30%, L_{ILC} = 250 + 250 fb^{-1}. L_{LHC} = 300 fb^{-1}



LHC numbers from hep-ph/0601112

Dramatic differences

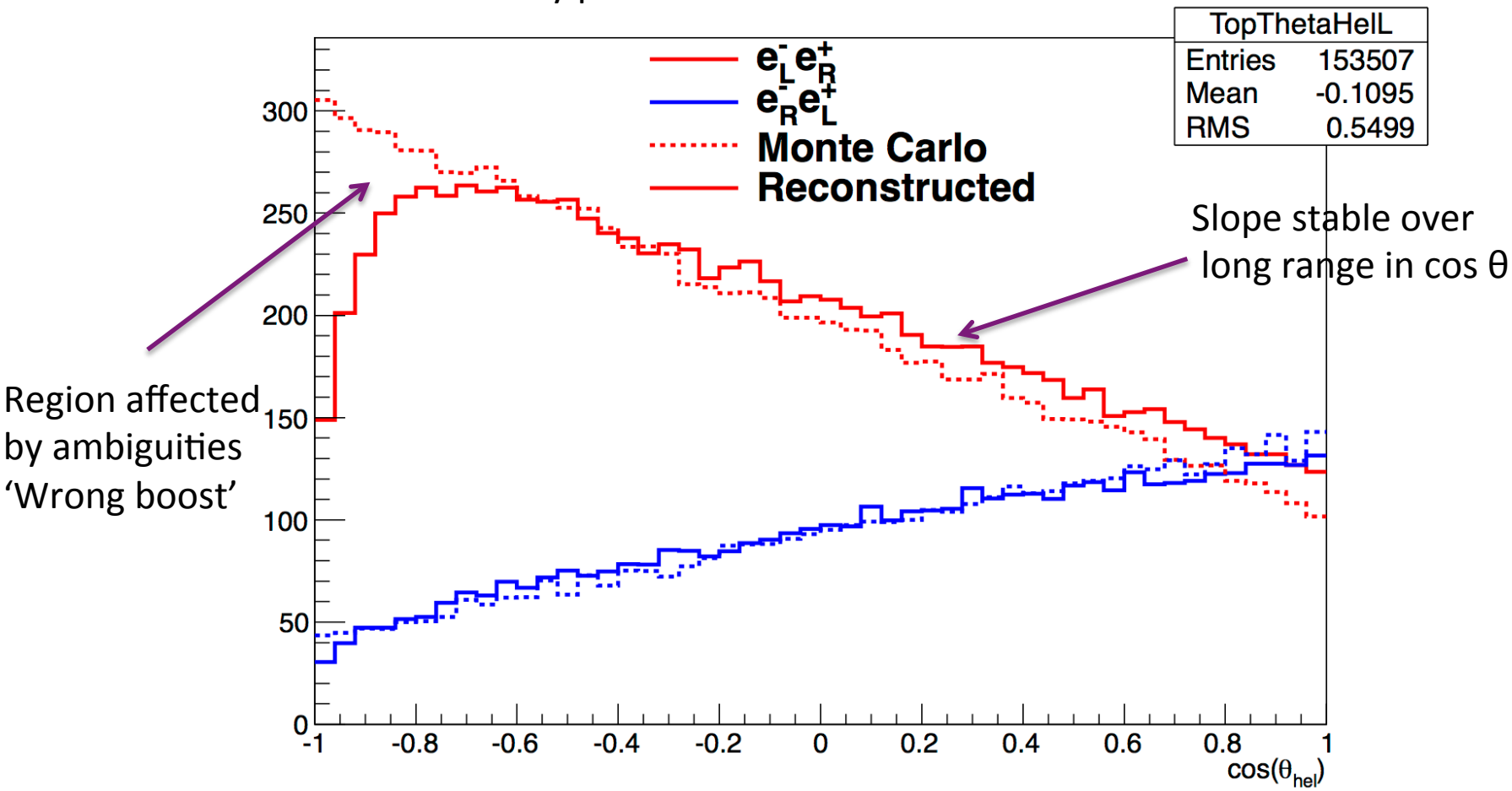
Study based on calculations using corresponding event numbers expected at ILC

Spectacular improvement by use of 'optimal' observables!?

Studies to concentrate on systematic effects and theoretical uncertainties

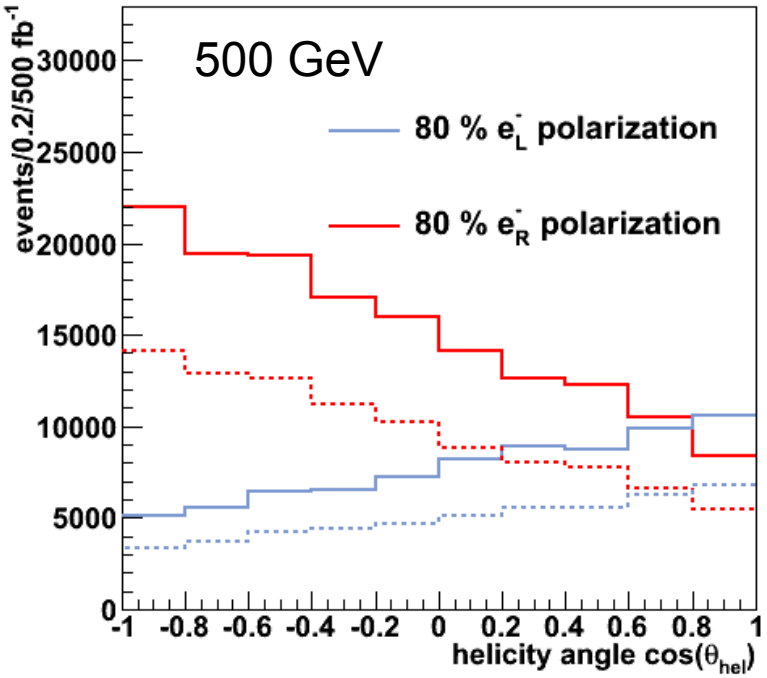
Studies on A_{hel} I

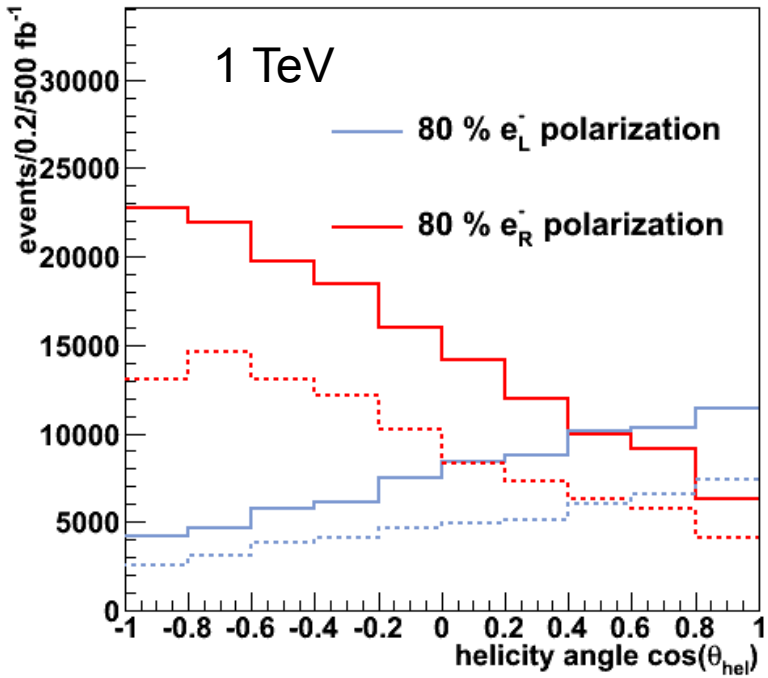
Results with Whizard and full ILD simulation at √s = 500 GeV
Selection as above but fully polarised beams



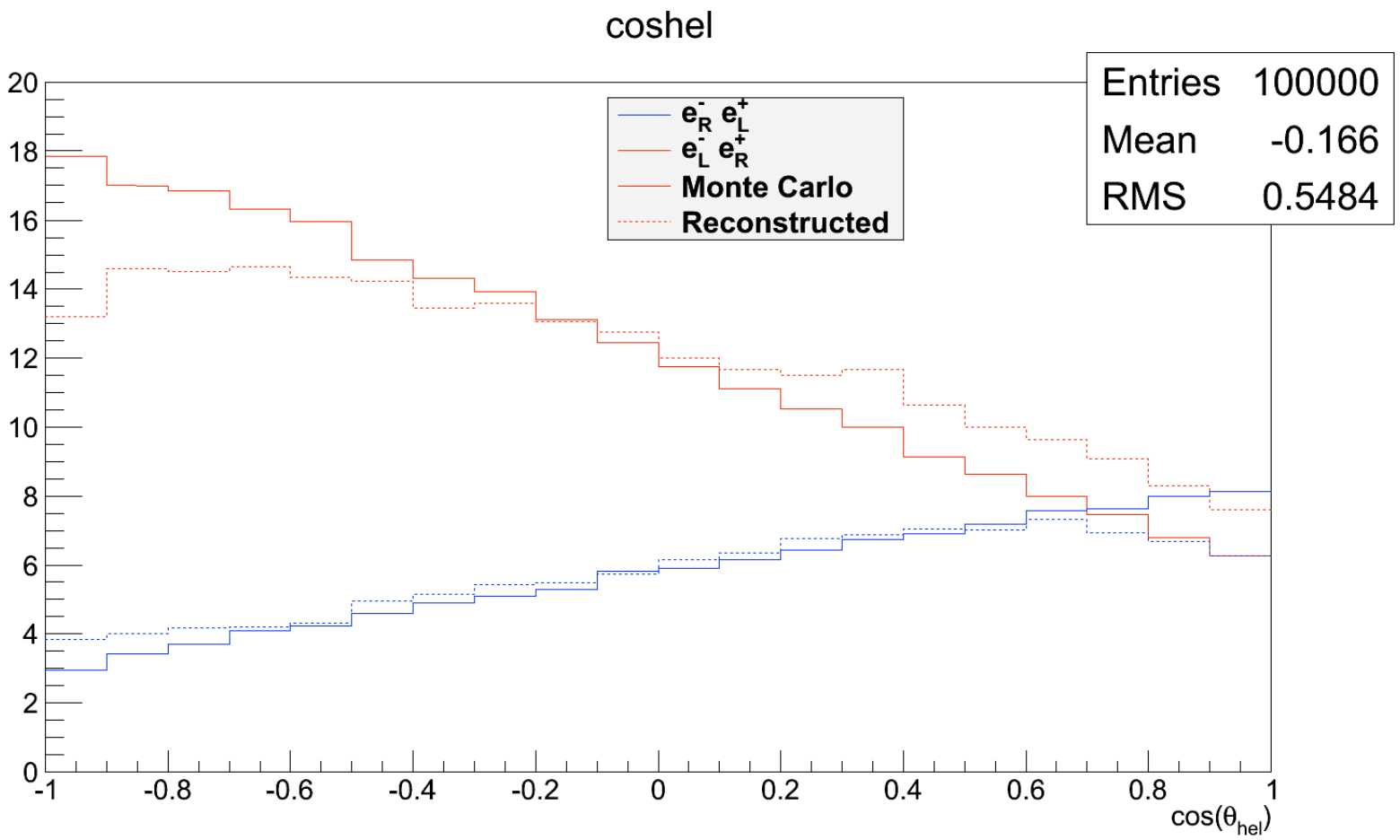
Studies on A_{hel} II

- Impact of selection
  - E (lepton) > 10 GeV
  - abs(cos(theta_l)) < 0.996
  - E_miss > 20 GeV





Studies on A_{hel} II - DELPHES



Migrations less prominent – Reduced polarisation flattens out

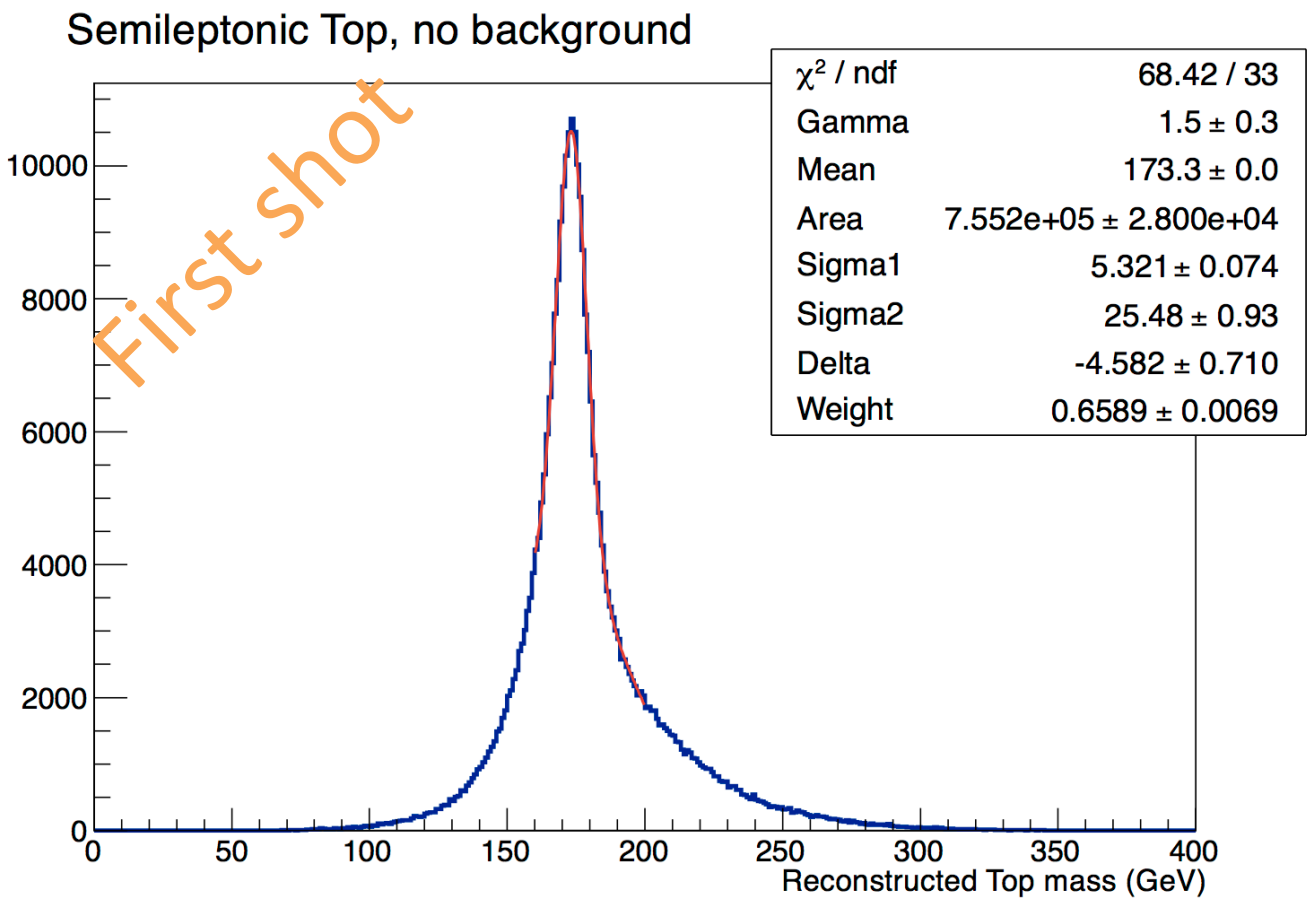
Conclusion and prospects

- 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}, A_{LR} to enter the DBD for the ILD in 2012
- New observable A_{hel}, more robust than traditional asymmetries

=> precise couplings of t to γ and Z

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

Three groups: LAL, IFIC Valencia, Univ. De Barcelona

- 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? Partially answered with DELPHES
- Alternative jet algorithms
- The hard case: Tame migration effect by reconstruction of charge of b-quarks, Need collaboration with other groups of experts
- More on A_{hel} if variable turns out to be as robust as expected
- Extension of studies to 1 TeV
- (Naturally) derivation of couplings

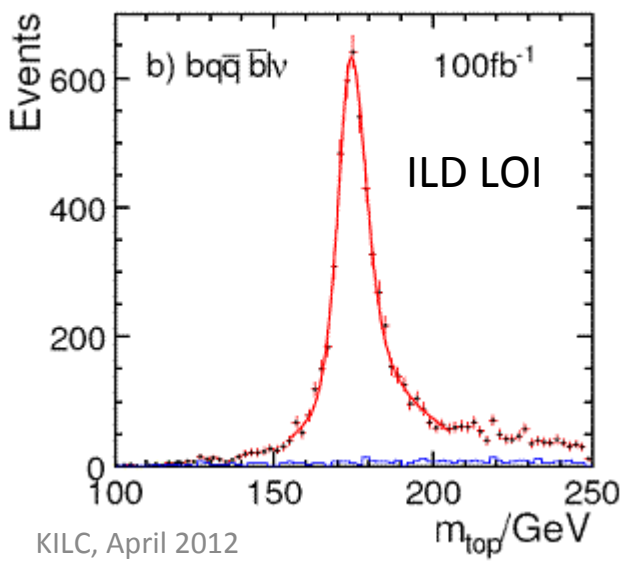
Top physics : LHC and ILC

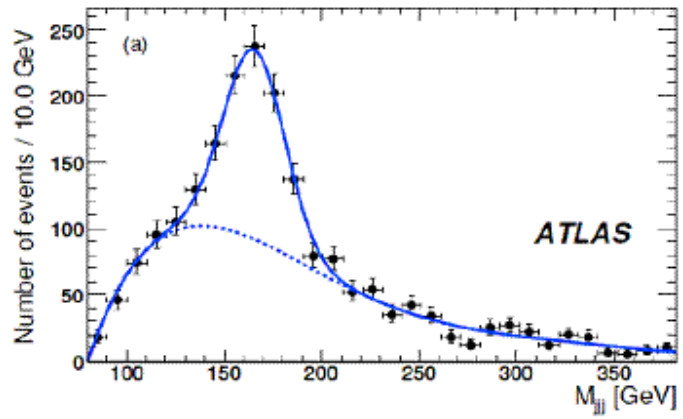
Top couplings : bibliography

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

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- [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