WORKSHOP 2012

Status of ttbar analysis

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CNRS/IN2P3/LAL Orsay

... on behalf of groups at

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

UNIVERSITAT DE BARCELONA

ICCUB

SIC Sistemes d'Instrumentació i Comunicacions

IFIC INSTITUT DE FÍSICA CORPUSCULAR

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

Disclaimer:

Will concentrate today mostly on studies at 500 GeV

There are studies at 1 TeV going on with fast simulations

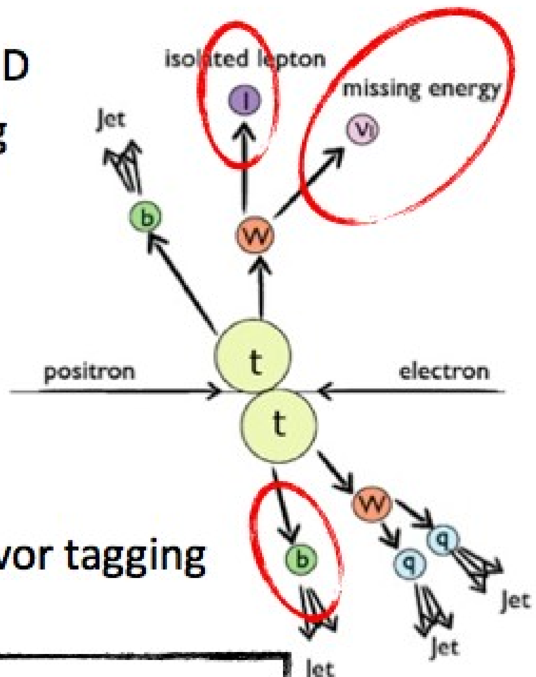
1. motivation

... left for Jenny's talk later this afternoon
... or look at the slides of last week's
top physics workshop

http://events.lal.in2p3.fr/conferences/Top-Quark-Physics/Contacts.html

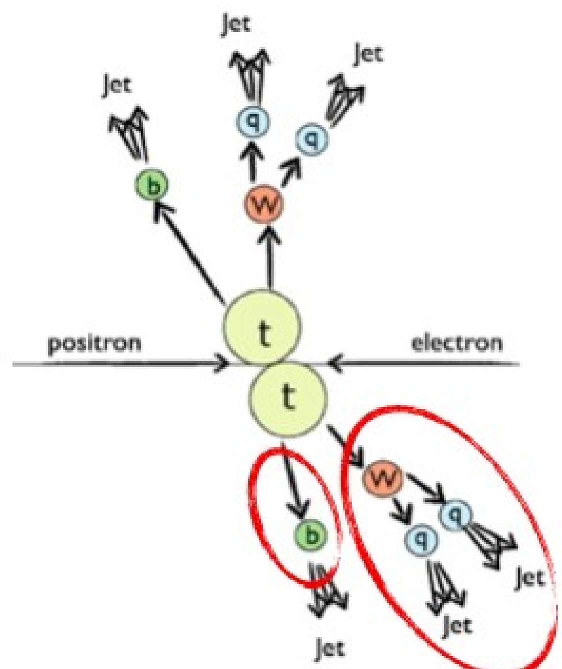
- By far dominating decays: All-hadronic (46%), semi-leptonic / lepton+jets (45%, 30% w/o τ)
  - try to avoid decays into τ, increased uncertainties from additional neutrino

lepton ID
tracking



flavor tagging

4 jets, isolated lepton



6 jets

jet energy reconstruction, global event reconstruction

Uses all aspects of LC detectors!

Nice illustration stolen from Frank

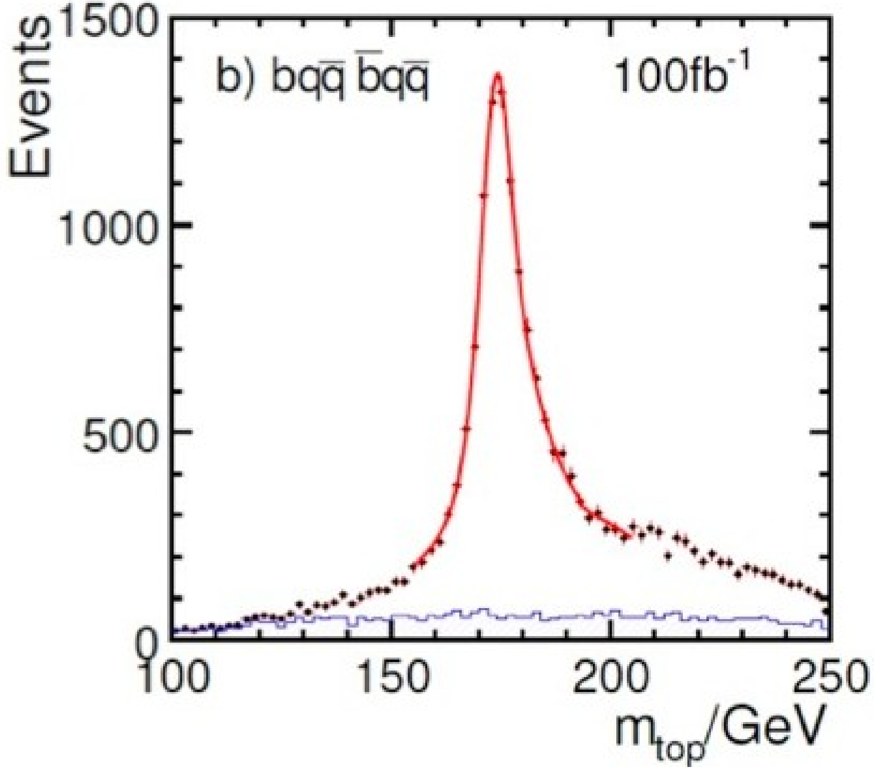
2. Top mass

Will be taken in charge by MPI group for DBD

New information and result of meeting at KILC12

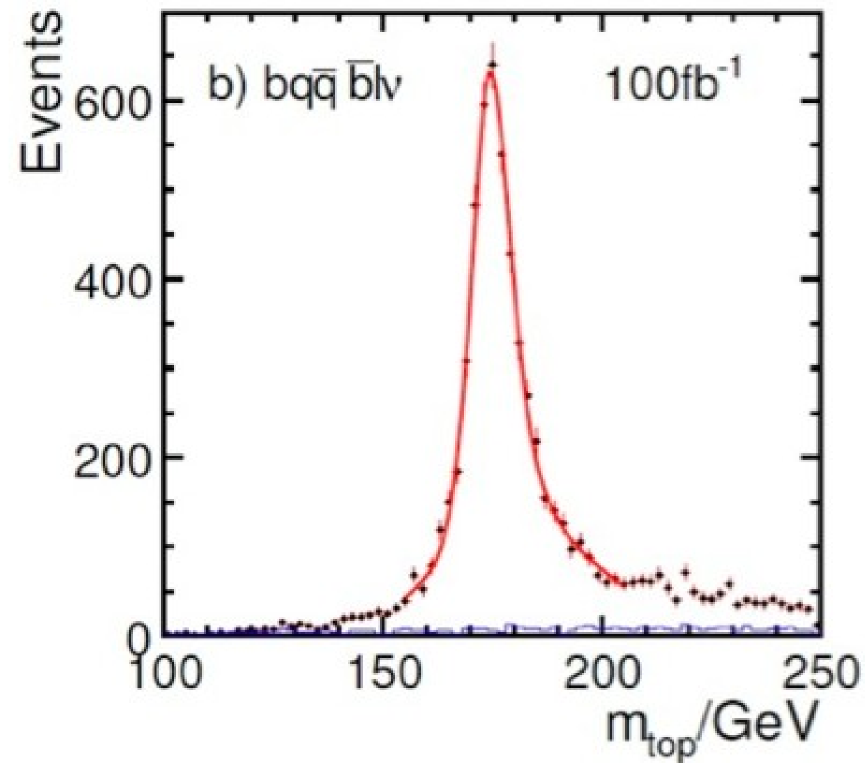
Reminder: Top mass LOI

Chi2Fit over limited mass range



$$m_{top} = 175.00 \pm 0.11\, GeV$$

$$\Gamma_{top} = 1.58 \pm 0.07\, GeV$$



$$m_{top} = 175.25 \pm 0.14\, GeV$$

$$\Gamma_{top} = 1.56 \pm 0.09\, GeV$$

Errors are statistical only

Cleaning the tt sample – Analysis as conducted for CLIC(_ILD) CDR

Kinematic Fit

- Powerful Background Rejection for qq, WW, ZZ
- Rejection of unwanted signal events: full-leptonic events, tau- events

Overall background rejection: > 99%

Overall signal selection:

Full-Hadronic: 35%

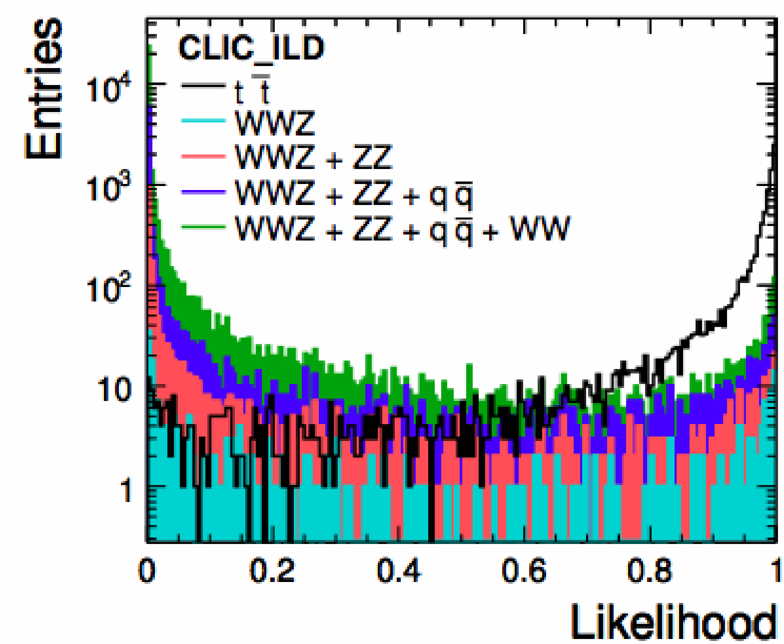
Semi-Leptonic: 56%

- Signal efficiency could be improved
- Analysis goal: clean events, not maximized statistics

Binned likelihood rejection

- Seven input variables (Number of particles in event, value of b-tags, sphericity, ...)
- Likelihood cut of 0.6 chosen
- Training with independent sample

Full-Hadronic

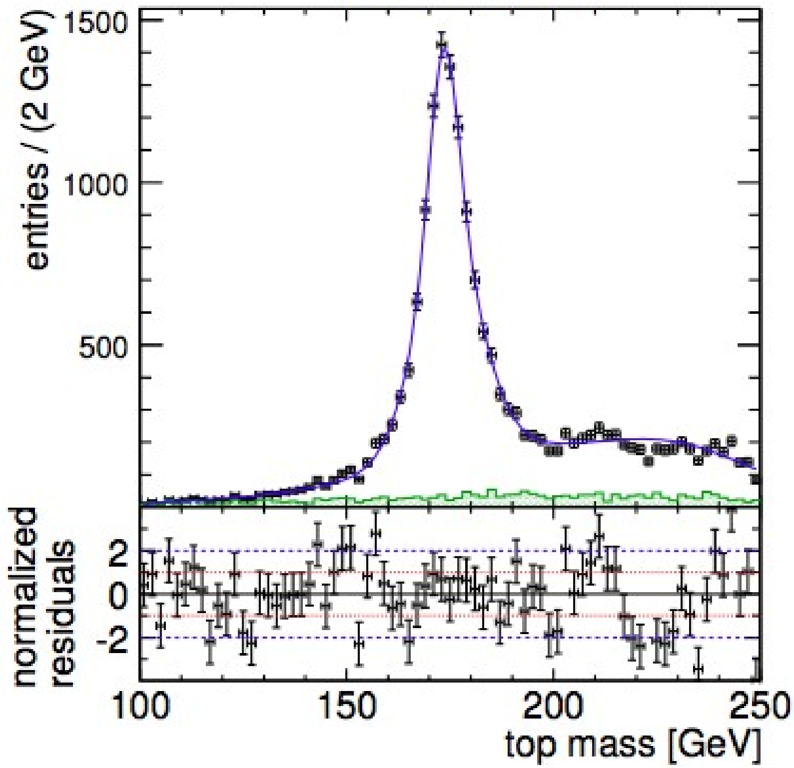


CLIC_ILD CDR result (for CLIC_500)

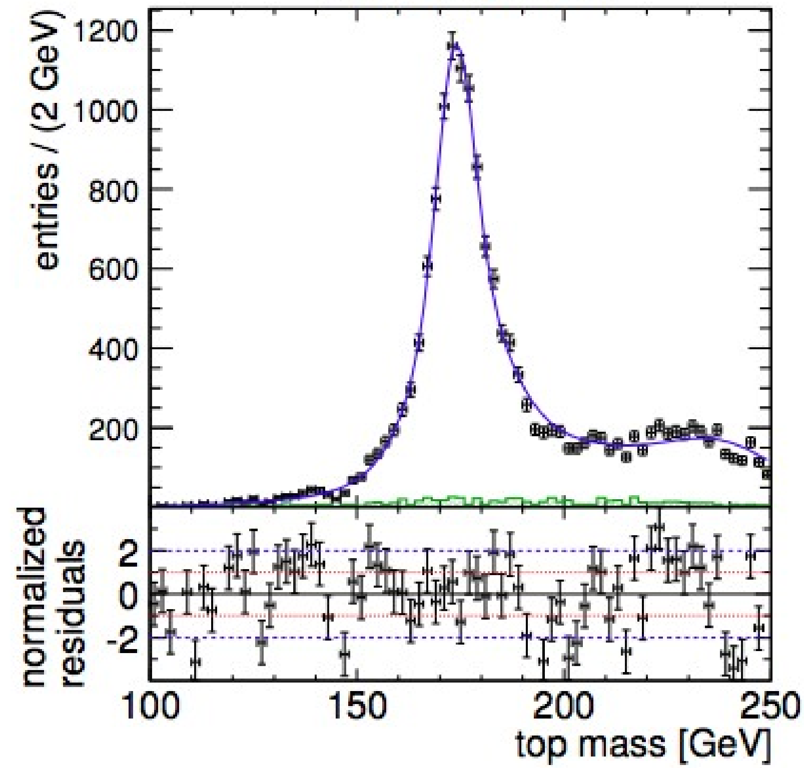
Unbinned maximum likelihood fit over **full** range
- Combination of signal and background pdf
- Signal pdf is convolution of a Breit-Wigner and a (multi-gaussian) detector resolution function

Full-Hadronic

100 fb^{-1}



Semi-Leptonic



$m_{top} = 174.07 \pm 0.08\, GeV$

$\Gamma_{top} = 1.33 \pm 0.21\, GeV$

Errors are statistical only

$m_{top} = 174.28 \pm 0.09\, GeV$

$\Gamma_{top} = 1.55 \pm 0.26\, GeV$

Important: Analysis needs large enough statistics to determine detector resolution function with independent sample

3. Asymmetries

French and Spanish groups for DBD

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 :

  $t\bar{t} \rightarrow (bW)(bW) \rightarrow (bqq)(bl\nu)$

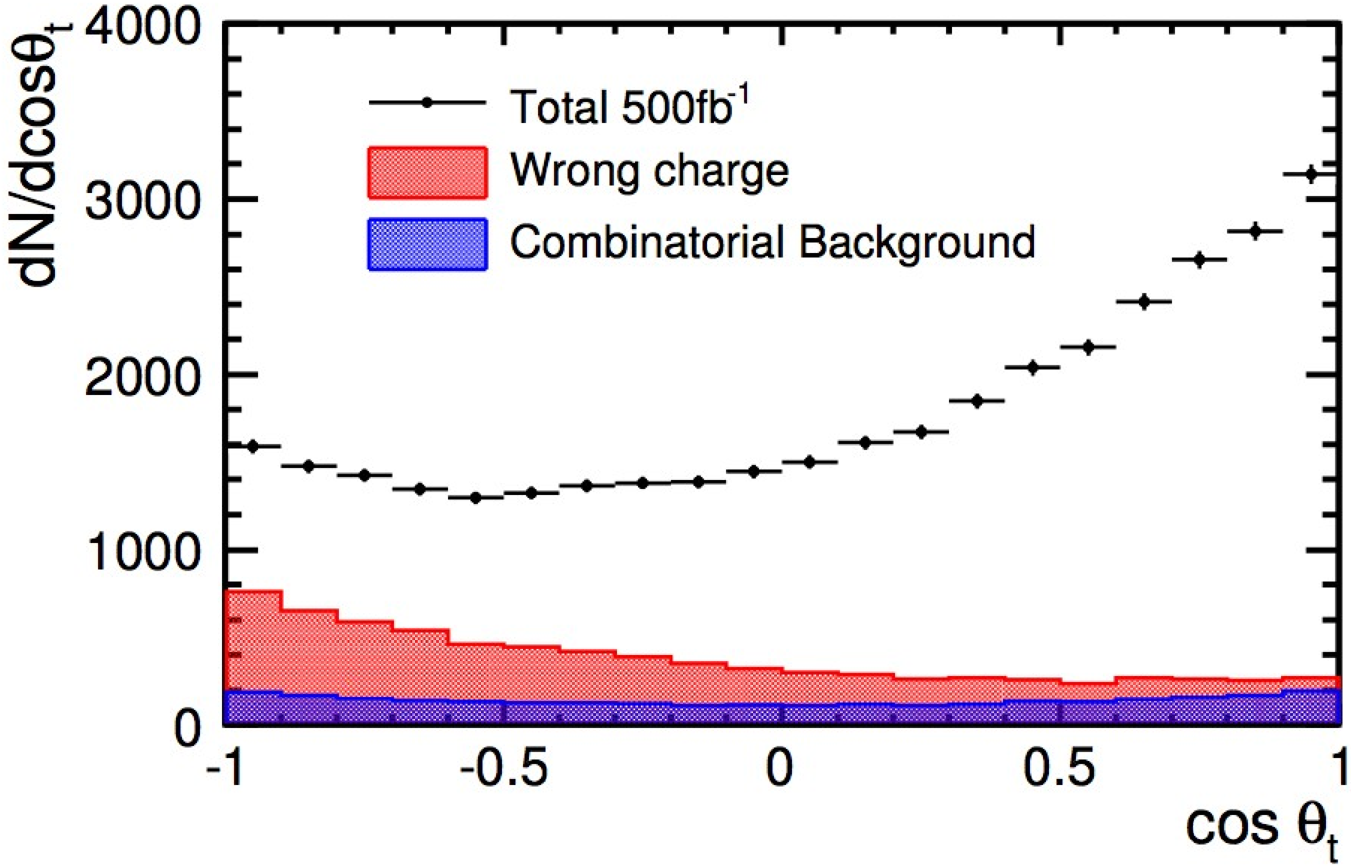
  Allows reconstruction of the top quark (from (bqq))

  $l = e, \mu$ → Gives top charge

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

Reminder on A_{FB} in LOI

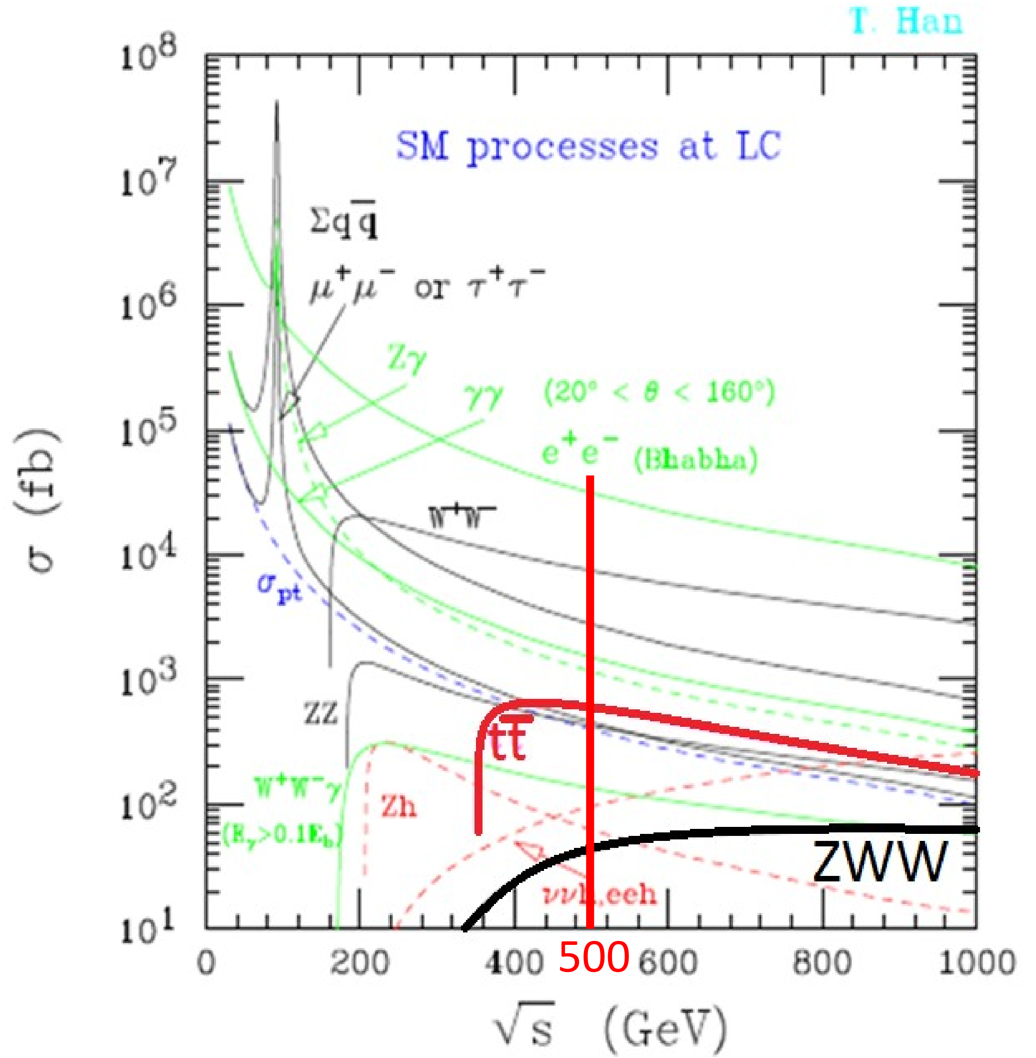
Fully hadronic channel, only one polarisation mode $P(e^+, e^-) = (+30\%, -80\%)$



$$A_{FB}^t = 0.334 \pm 0.008$$

Top quark cross section

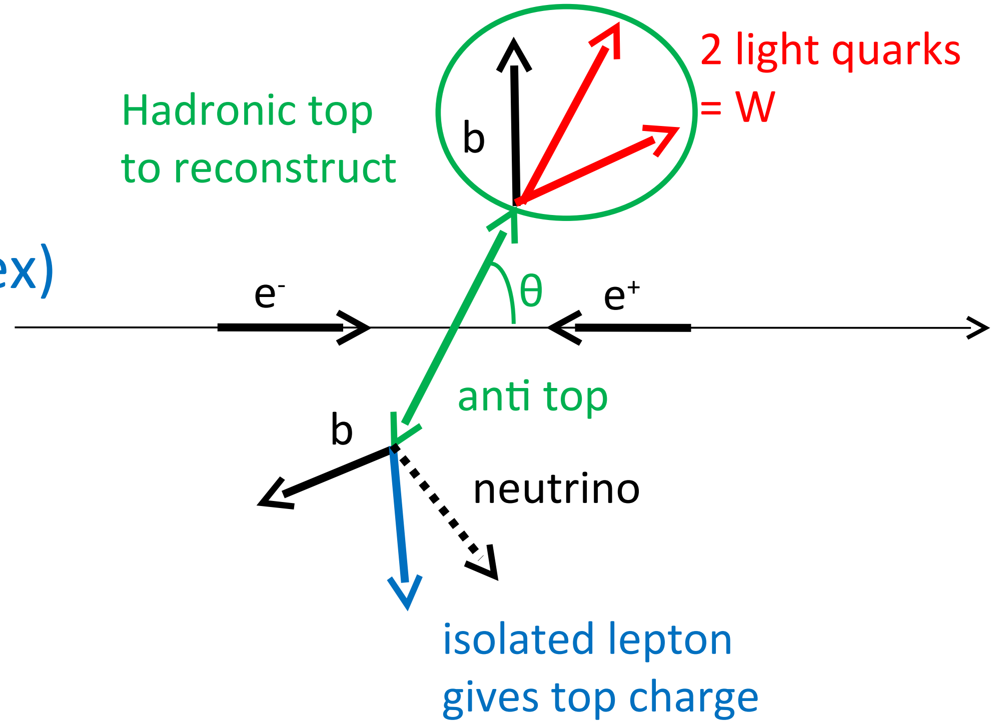
- σ(tt) ≈ 600 fb at 500 GeV with 500 fb^{-1}
  - Ntotal ~ 570k events
  - Semileptonic ~ 34%
- Almost background free ?
  - Major background = other top channels → find 1 isolated lepton
  - WW → no b quark
  - bb → simple topology
- Major background : ZWW (Z→bb) ≈ 8 fb, same topology
  - Small but needs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



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

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



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

Top reconstruction

Cross section and A_{LR}

Problem with the top reconstruction

Origin of the problem

Precisions reached

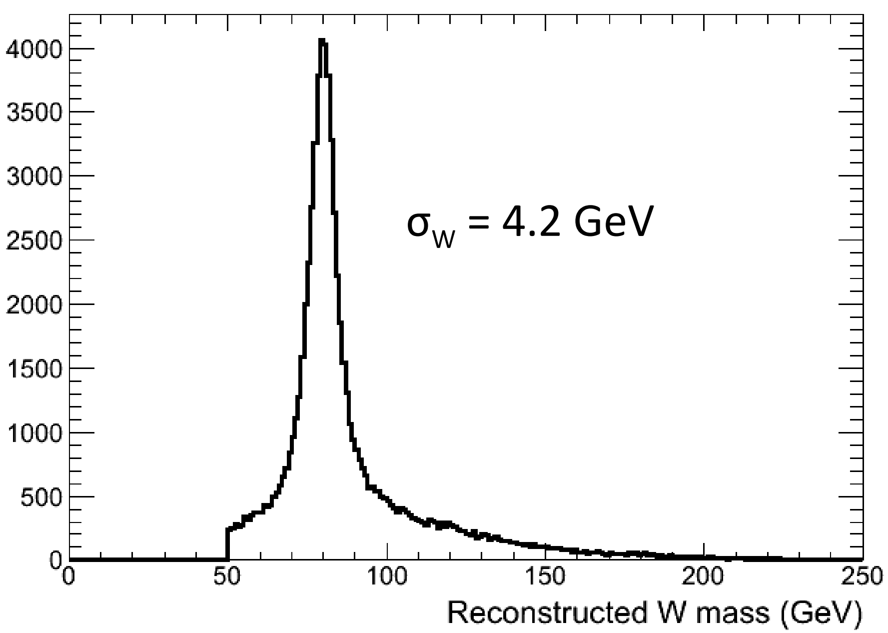
Conclusions and prospects

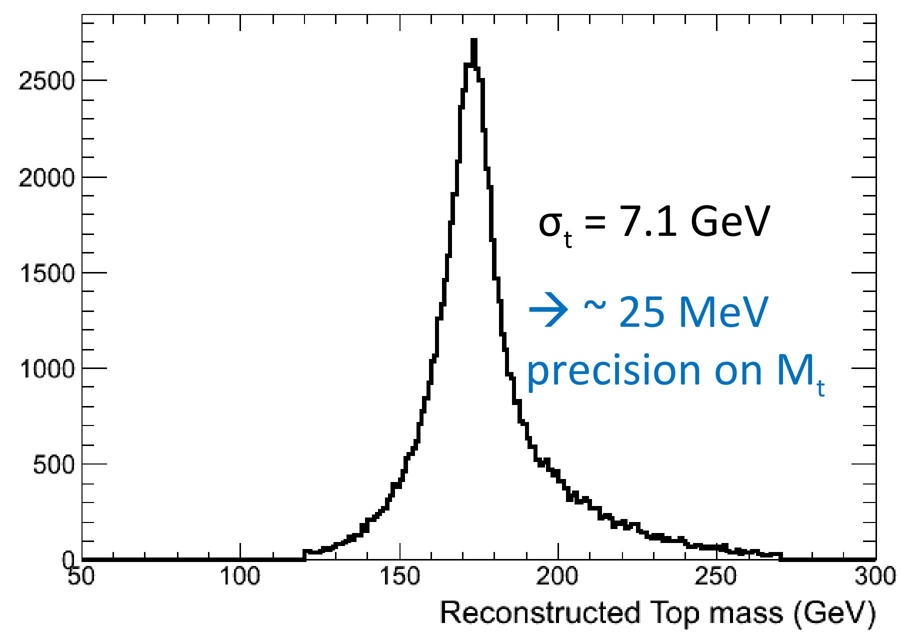
4. Results and further systematic studies

Top reconstruction

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

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





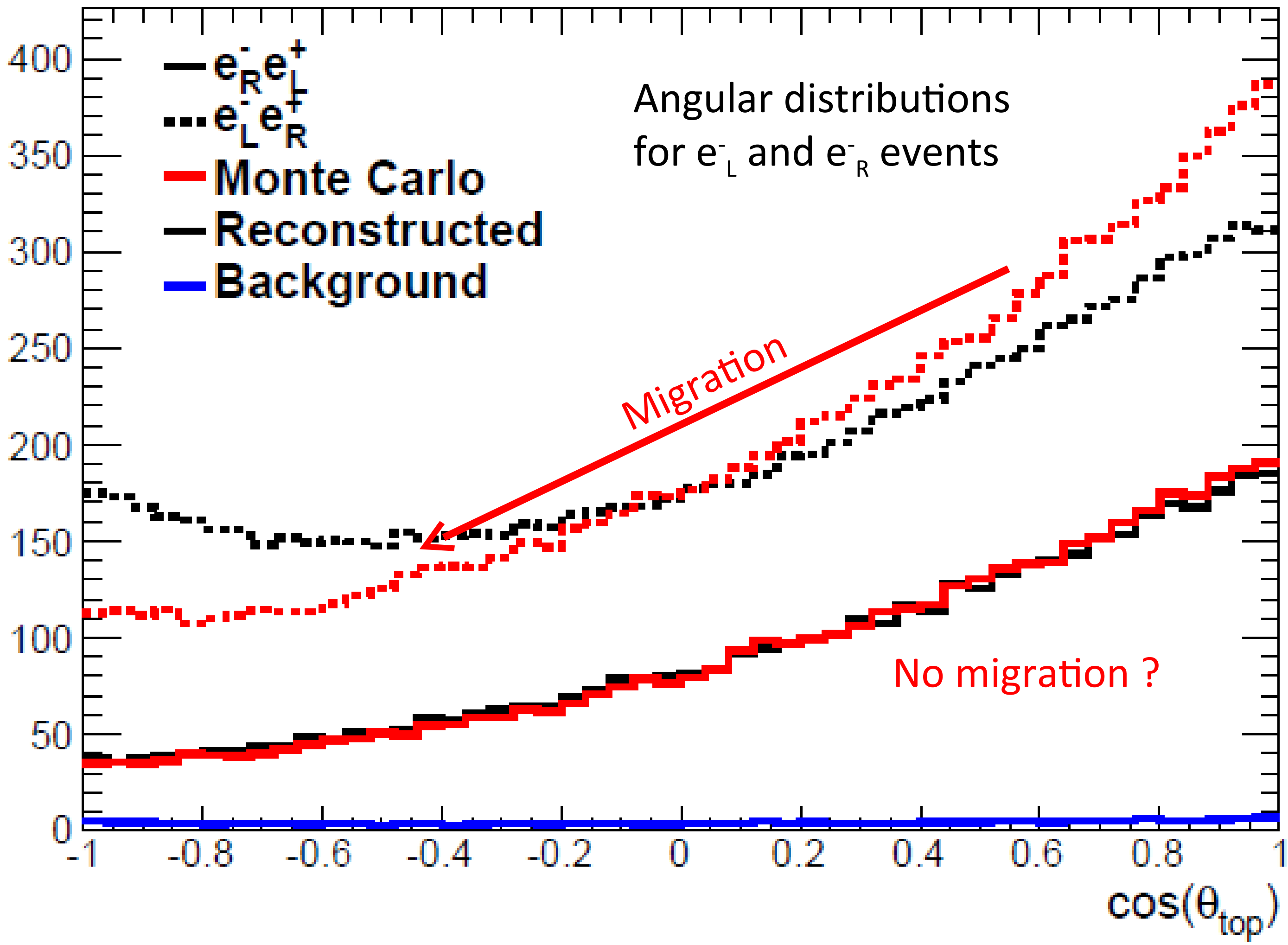
Cross-section and A_{LR}

- $\sigma = N/(\varepsilon L)$, $L = 500 fb^{-1}$
- 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%)
  - $P(e^- e^+)$= (±80%, 0) → $\Delta\sigma/\sigma$ = 0.39% (stat.)
- A_{LR} = 0.435
  - A_{LR} = 0.37 expected… Whizard problem ?
  - However, interest lies in relative uncertainty
  - $P(e^- e^+)$= (±80%, 0) → $\Delta A_{LR}/A_{LR}$ = 1.24% (stat.)

Problem with the top reconstruction



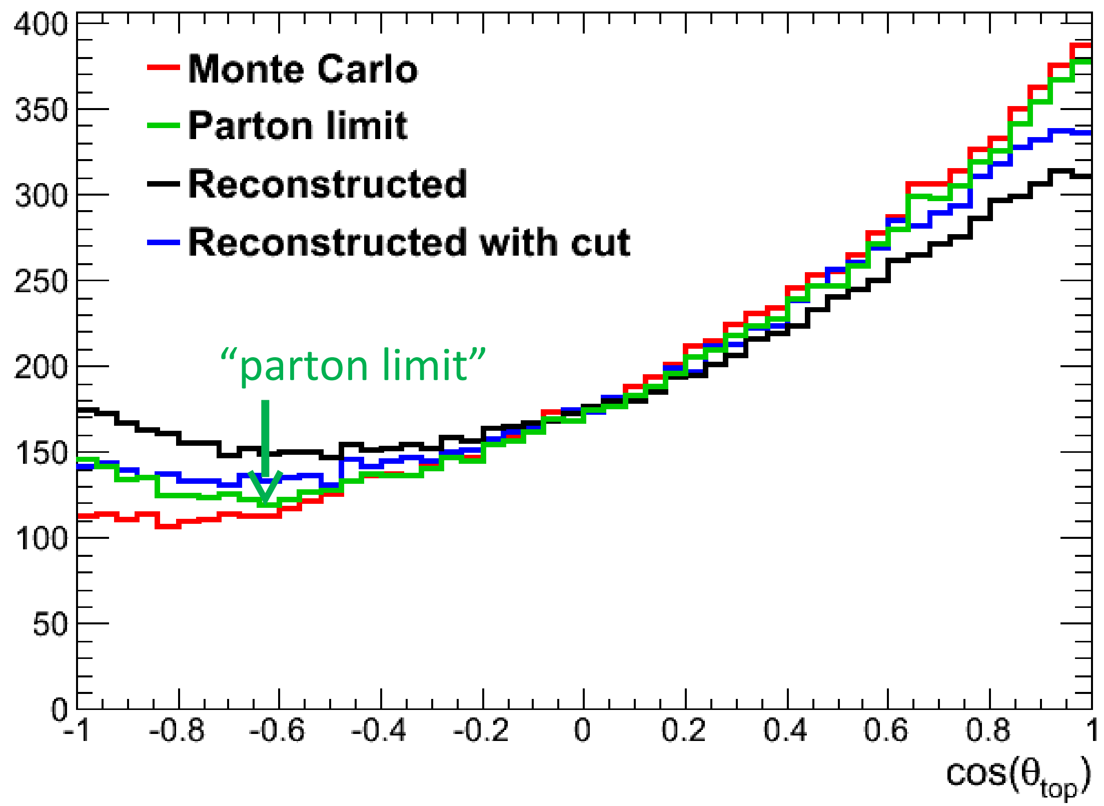
Migration : -5.2% ($A_{FB}{}^{t}{}_{R}$) -40.4 % ($A_{FB}{}^{t}{}_{L}$) 1.1 % (stat.)

Solving the problem

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

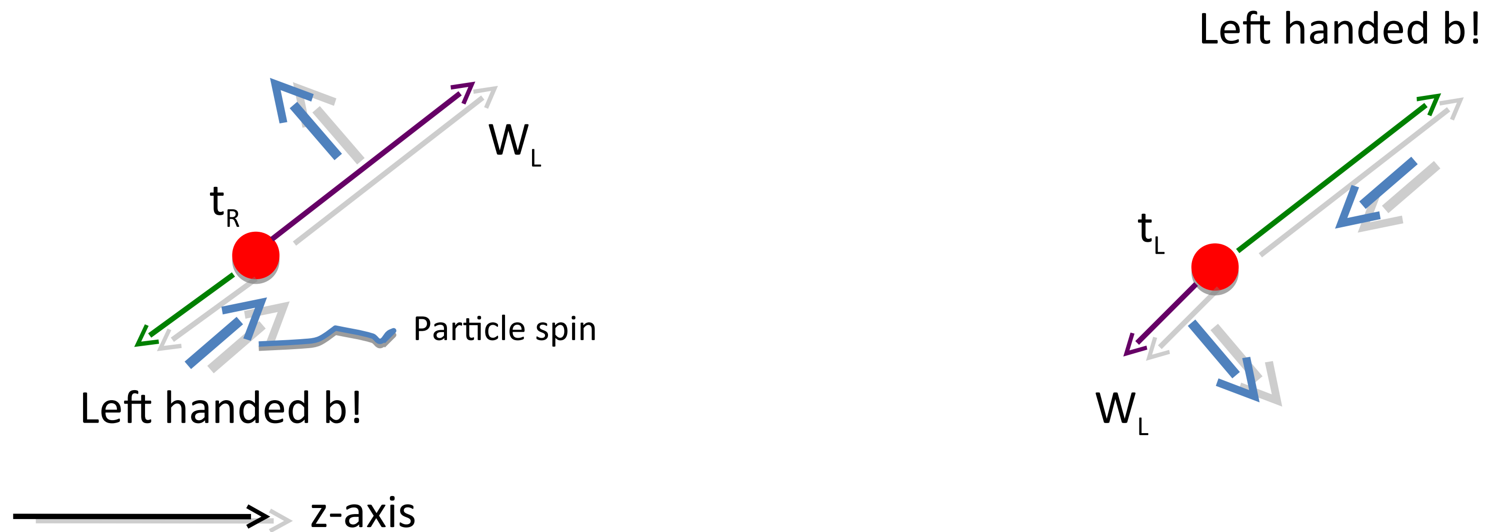
→ quality of the candidate

1. Is it due to the reconstruction ?
   - → Cut on the quality of the candidate (particle flow)
   - → Efficiency in e^-_L : x60%
   - → Migration : 40% → 20 %
1. 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

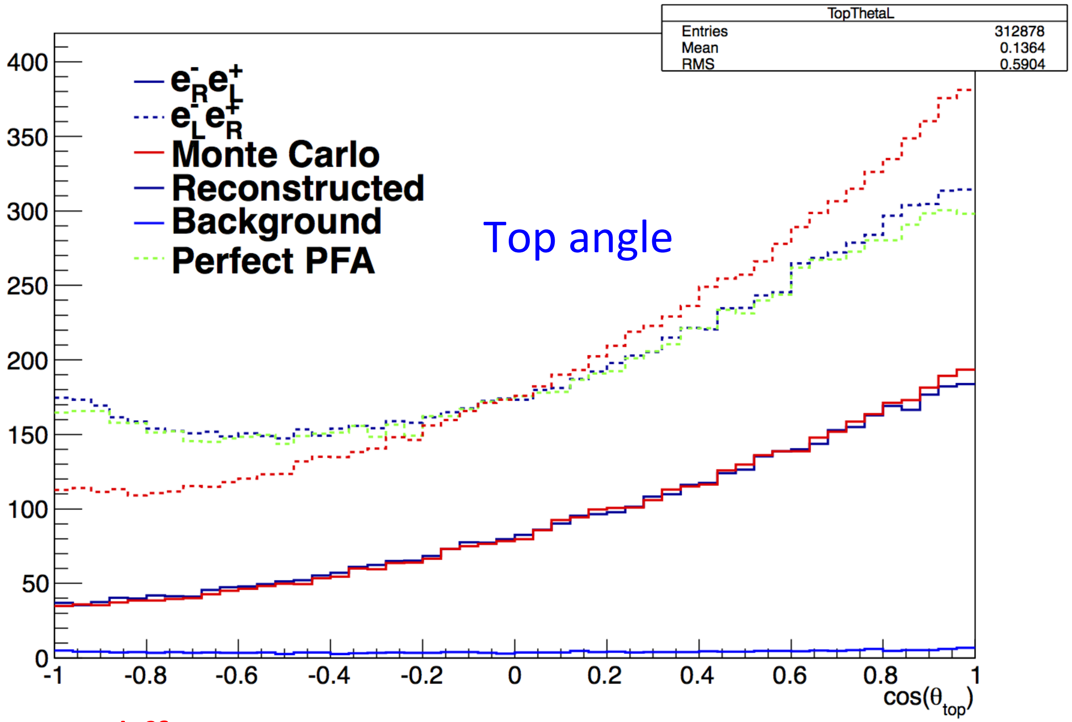
- Correction on $A_{FB}^{t}{}_{L}$ = dominant systematic (reco. + intrinsic)
  - Good PFA + b tagging are essential
  - 20% correction on $A_{FB}^{t}{}_{L}$ requires a well tuned MC

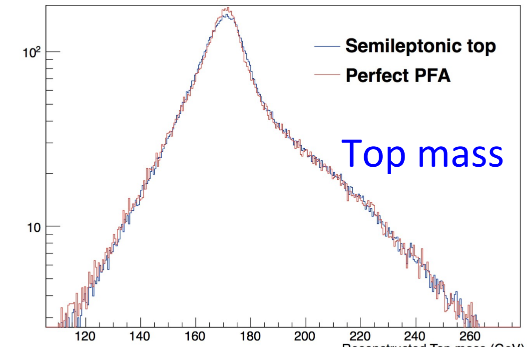
P_{e-} / P_{e+} (80% / 0)	A_{LR}	$A_{FB}^{t}{}_{R}$	$A_{FB}^{t}{}_{L}$		$Q^{Z}{}_{tL}$	$Q^{Z}{}_{tR}$
stat. error	1.3%	1.2 %	1.4 %		1.0 %	1.9 %

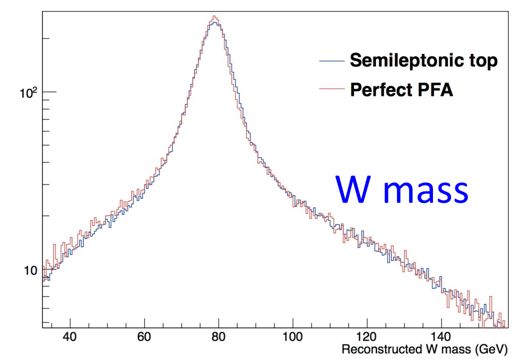
- Possible to probe some RS models with M_{KK} ~ 2.8 TeV and up to 25 TeV in case of presence of Z' boson

Systematic study with 'Perfect PFA'

... or at least with what we think would be Perfect PFA,
ILCSoft v01-10, TrackCheater, ClusterCheater







No difference ...

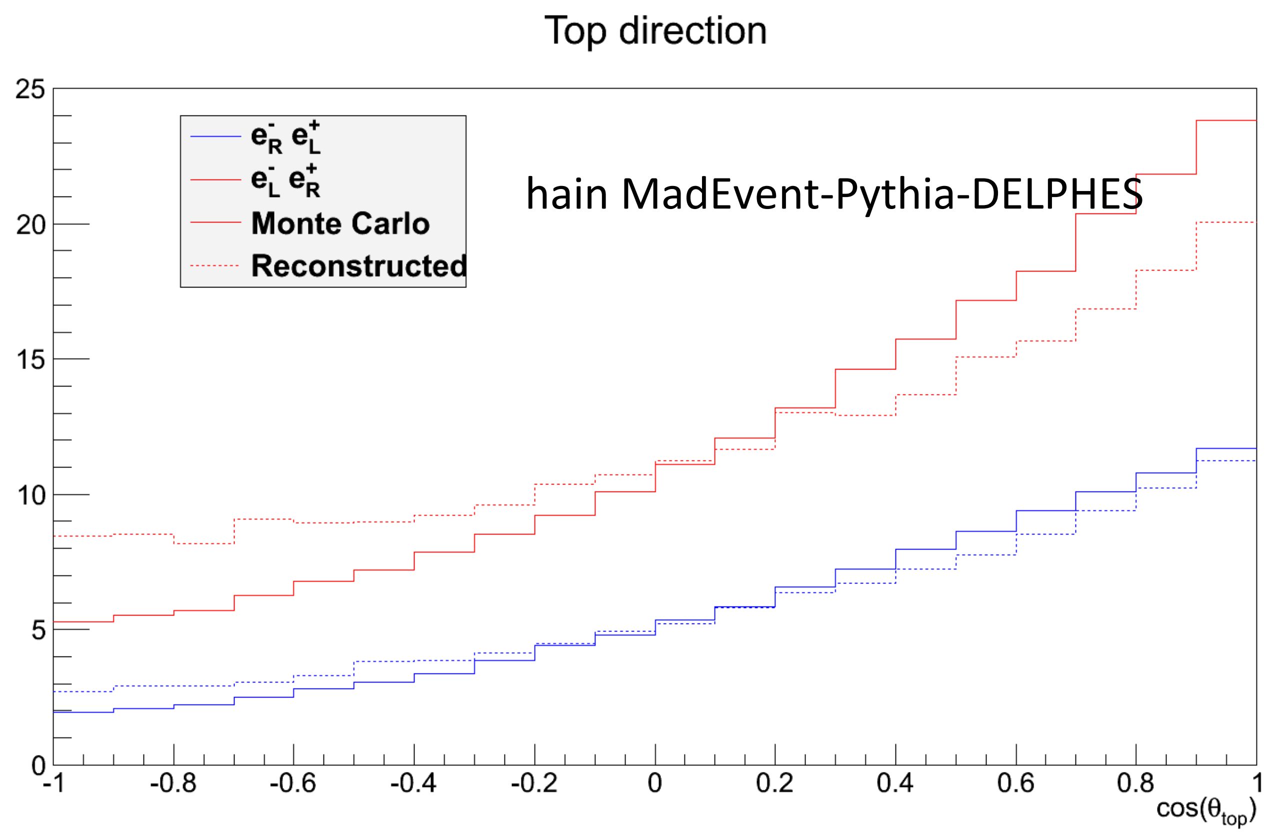
- Either no effect due to improvement of PFA
- ... or wrong application of PFA

N.B. I : A perfect PFA as reference would be a powerful tool to improve PFA

N.B. II: LLR and LAL do have a PostDoc position to work on particle separation in calorimeters
Collaboration with group(s) of Applied Mathematics

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.



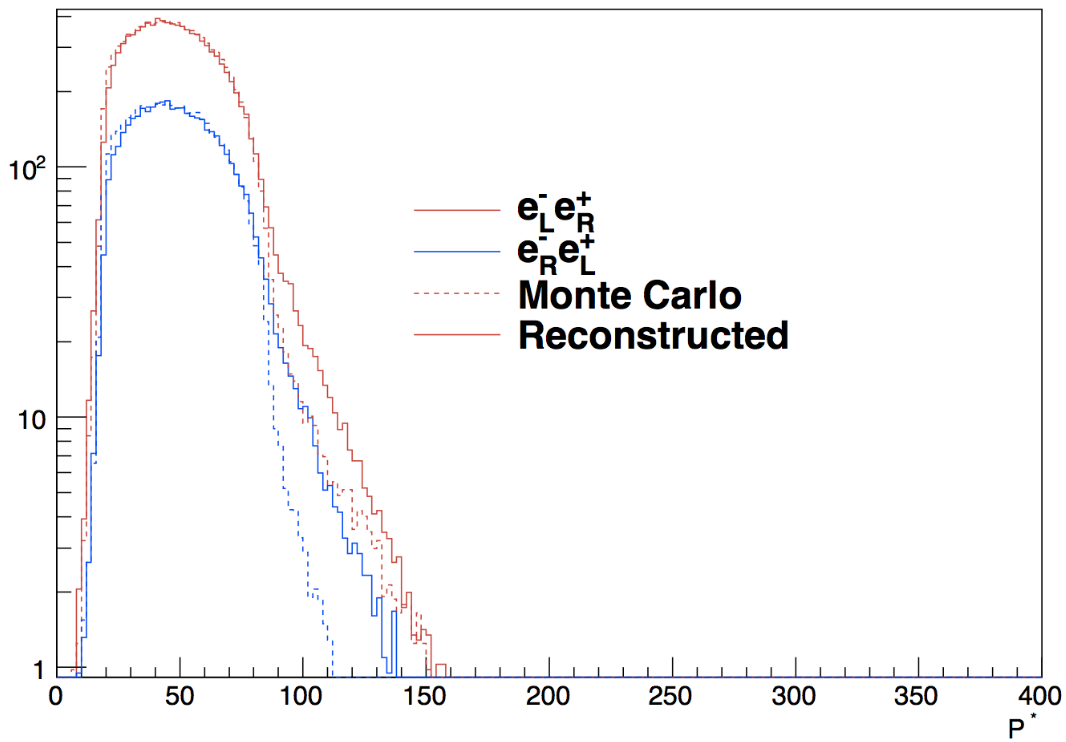
DELPHES matches full simulation reasonably well

Migrations of same order than with full simulation puts influence of PFA into question

Further ideas to control migrations

- Work in top restframe and reconstruct p* of decay lepton and b jet

Example: p* of decay lepton



Distribution peaks around p*=50 Gev (as expected)

- Discrepencies in tails
- However present for eL and eR -> to be better understood (at least by me)

Introduction of observable

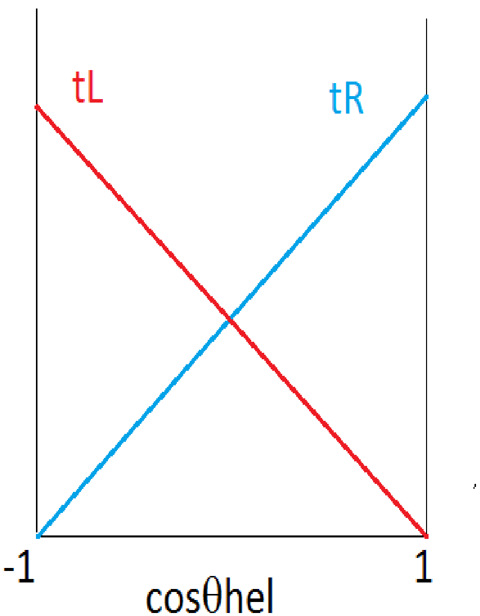
First studies

5. New Observable A_{hel}

New observable A_{hel} Proposal by F. Richard

Differential decay rate in <u>top rest frame:</u>

$$\frac{1}{\Gamma}\frac{d\Gamma}{dcos\theta_\ell} = \frac{1+\lambda_t cos\theta_\ell}{2} \quad \text{with } \lambda_t = 1 \text{ for } t_R \text{ and } \lambda_t = 1 \text{ for } t_L$$



Forward backward asymmetry **Ahel**

Slope measures fraction of tR,L in sample
=>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 $e_R^- e_L^+$

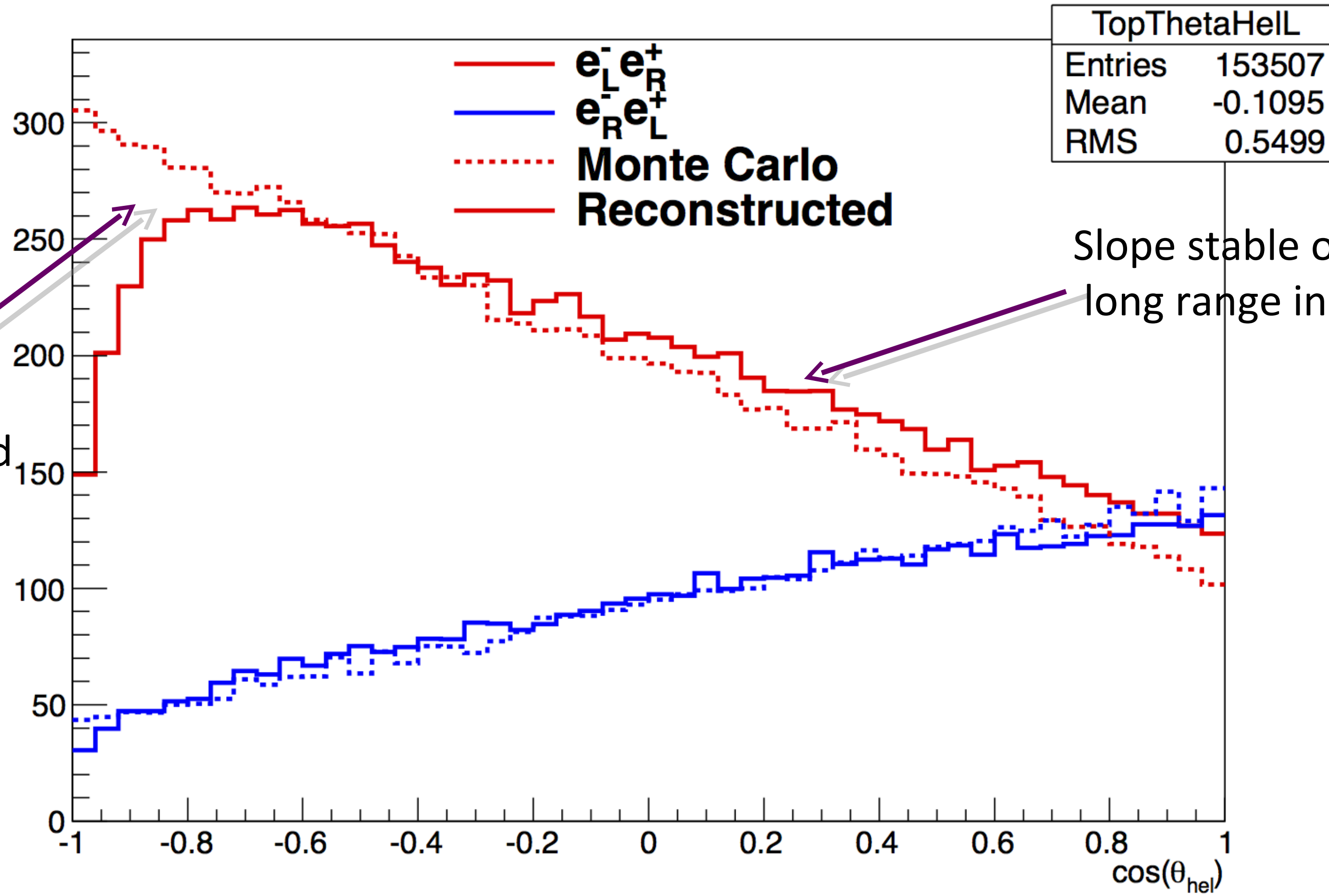
$\Rightarrow$ Set of four observables
σ_L, σ_R instead of A_{LR} $A_{hel,R}$, $A_{hel,L}$
to determine unknowns $g_\gamma(t_L), g_\gamma(t_R), g_Z(t_L), g_Z(t_R)$

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

Studies on A_{hel} I

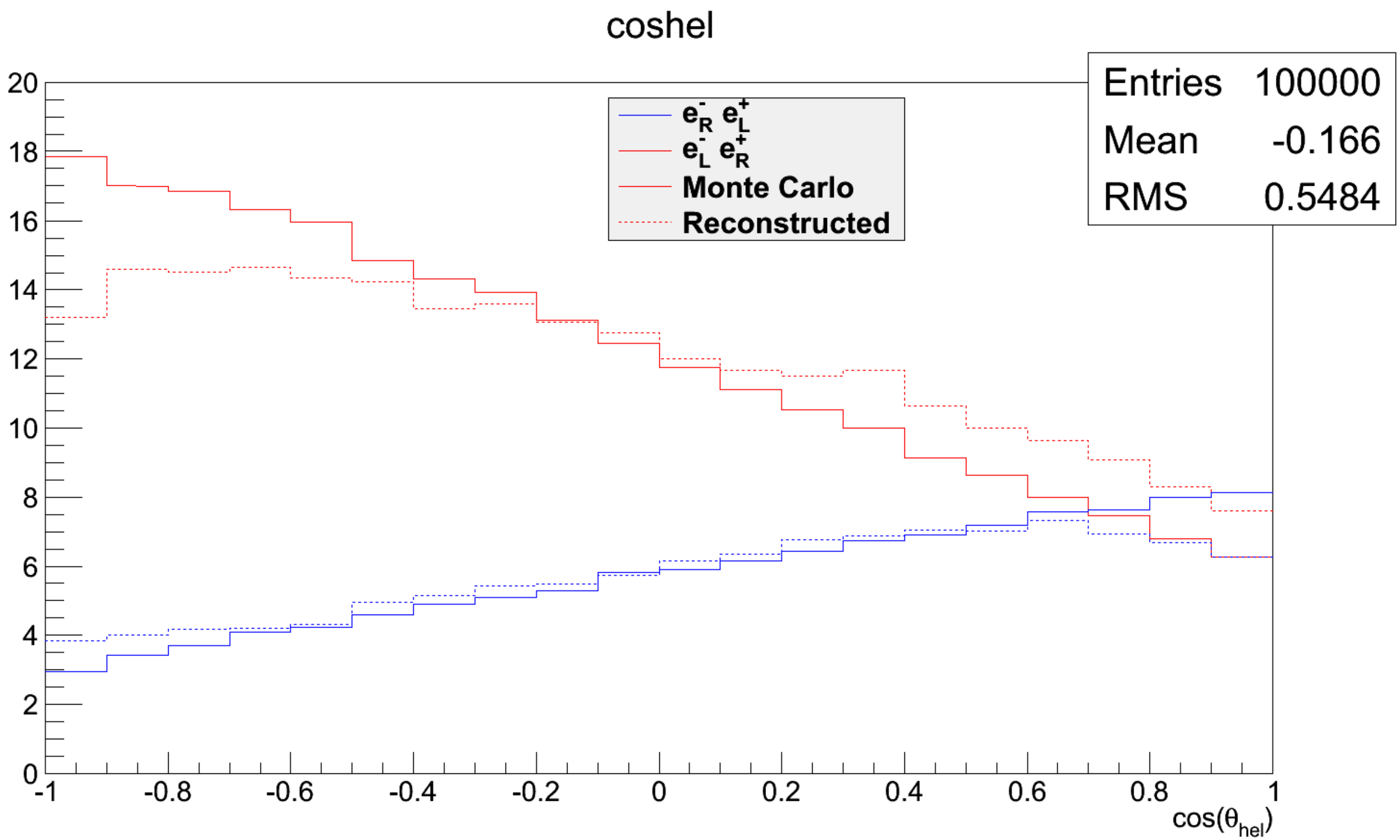
Results with Whizard and full ILD simulation at √s = 500 GeV
Selection as above but fully polarised beams

Region affected
by ambiguities
'Wrong boost'
+
Soft leptons
from Taus



Slope stable over
long range in cos θ

Studies on A_{hel} II - DELPHES



Migrations less prominent – Reduced polarisation flattens out

Conclusion and prospects

- Established procedure to determine top mass from LOI and CLIC study. Can expect improvement w.r.t. LOI
- Top mass is utmost relevant parameter for physics BSM

  What about threshold scan? → See also Jenny's talk
- σ and A_{LR} can be known at 0.4% and 1.3% statistical uncertainty (systematics 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

  500 GeV and 1 TeV
- New observable A_{hel}, more robust than traditional asymmetries

=> precise couplings of t to γ and Z

Summary of MC-requests include tt bar sample – Tomohiko 9/5/12

- nunuh [1 TeV]:
  - nunuh signal: ~1M (2ab-1) [-0.8/+0.3]
  - 2f+4f: ~60M (2ab-1): pre-selection being studied
  - 6f: ~0.5M (1ab-1)
- WW [1 TeV]:
  - WW->qqlnu signal ~ 4.3M (not all needed, systematics limited)
  - background: 2f, 4f = ?
- tth [1 TeV]:
  - tth + ttz + ttbb: total 50k (4ab-1)
  - 6f: ~1M (2ab-1)

2f & 4f sharing may not be an option due to pre-selections

could be shared

- tt [500 GeV]:
  - all 6f: ~ 2M
- Zhh [500 GeV]:
  - Zhh signal: < 1M
  - ZZh, ZZZ, ttqq, bbbb, Zh bkg: < total 1M
  - 6f: ~10M, probably require more stdhep!!

to be simulated at KEK/CC

could be shared

9

Question: Ok for top mass analysis as training sample is needed? Maybe yes

Work in the next months

… for asymmetry studies

- Testing of ilcsoft v01-13 (DBD release) against existing results
- Inclusion of background (although can assumed to be negligible)
- Study the influence of PFA on the migration effects. What in case of perfect PFA? Already answered ?
- 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
- AFB fully hadronic (as required for DBD), LAL Student will start in June with exactly repeating the LOI analysis
- Extension of studies to 1 TeV
- (Naturally) derivation of couplings
- Alternative jet algorithms (lower priority, DBD analysis has to be ready for early autumn)

Question to ILD on asymmetries:

What weight between pure repetition of LOI analysis and integration of 'new' knowledge?

- Semi-leptonic asymmetries more precise
  (and open new requirements to detector capabilities)
  e.g. B-charge, influence of PFA to be better understood
- About to establish new (better?) set of observables

In principle similar question applies also to top mass:

-> Improved fitting method
-> Discussion of threshold scan?

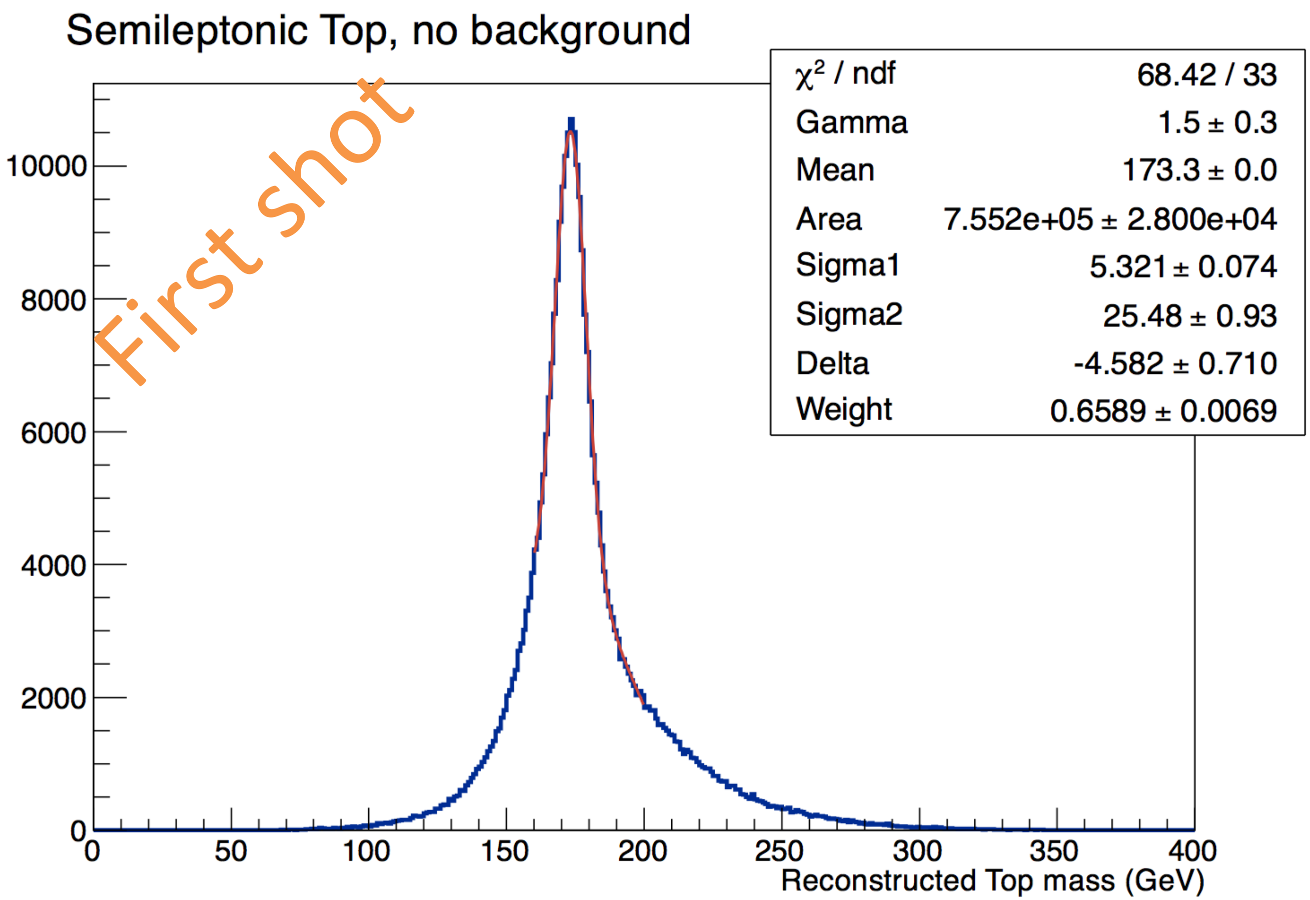
5. Additional material

Plan

1. Motivation
2. Measurement method
3. Top mass
4. Asymmetries
5. New observable Ahel
6. Conclusions and outlook

Top mass reloaded

(First analysis steps by Jeremy)



Fit of Breit-Wigner with two gaussians

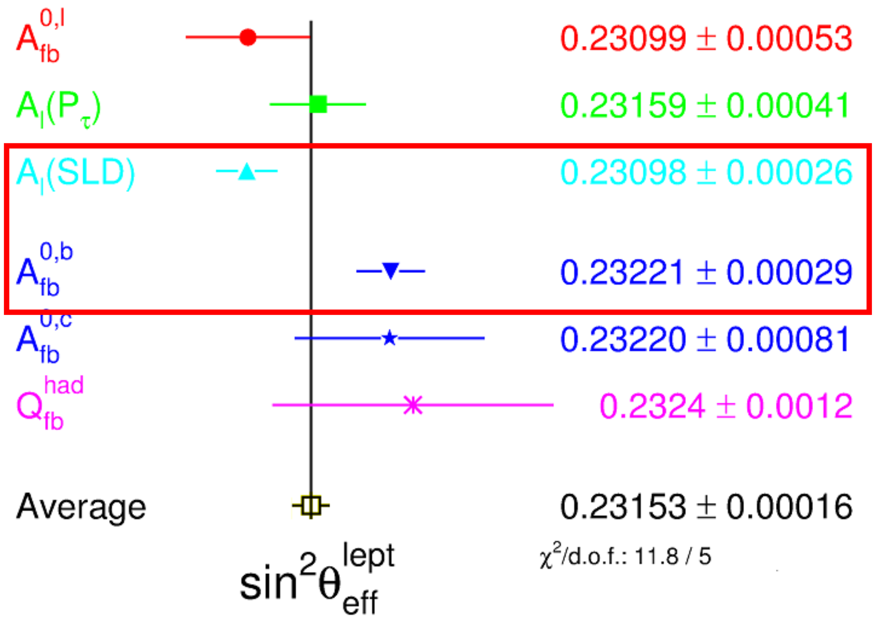
Top parameters from BW function:

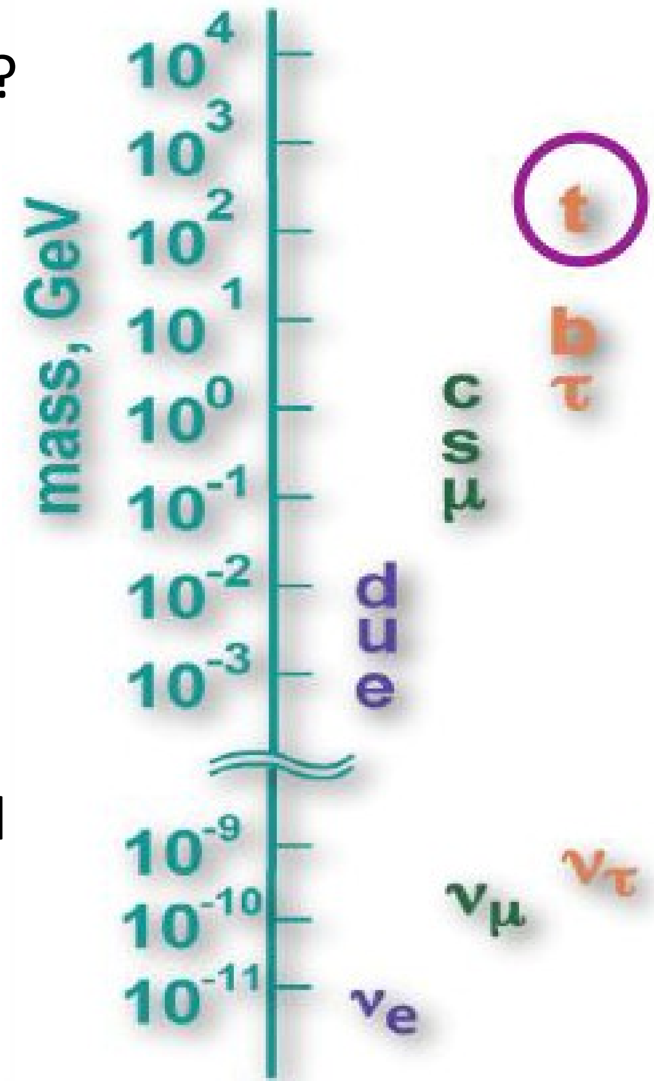
m_t=173.35 ±0.05 GeV

Γ_t = 1.5 ±0.3 GeV

The top quark and flavor hierarchy

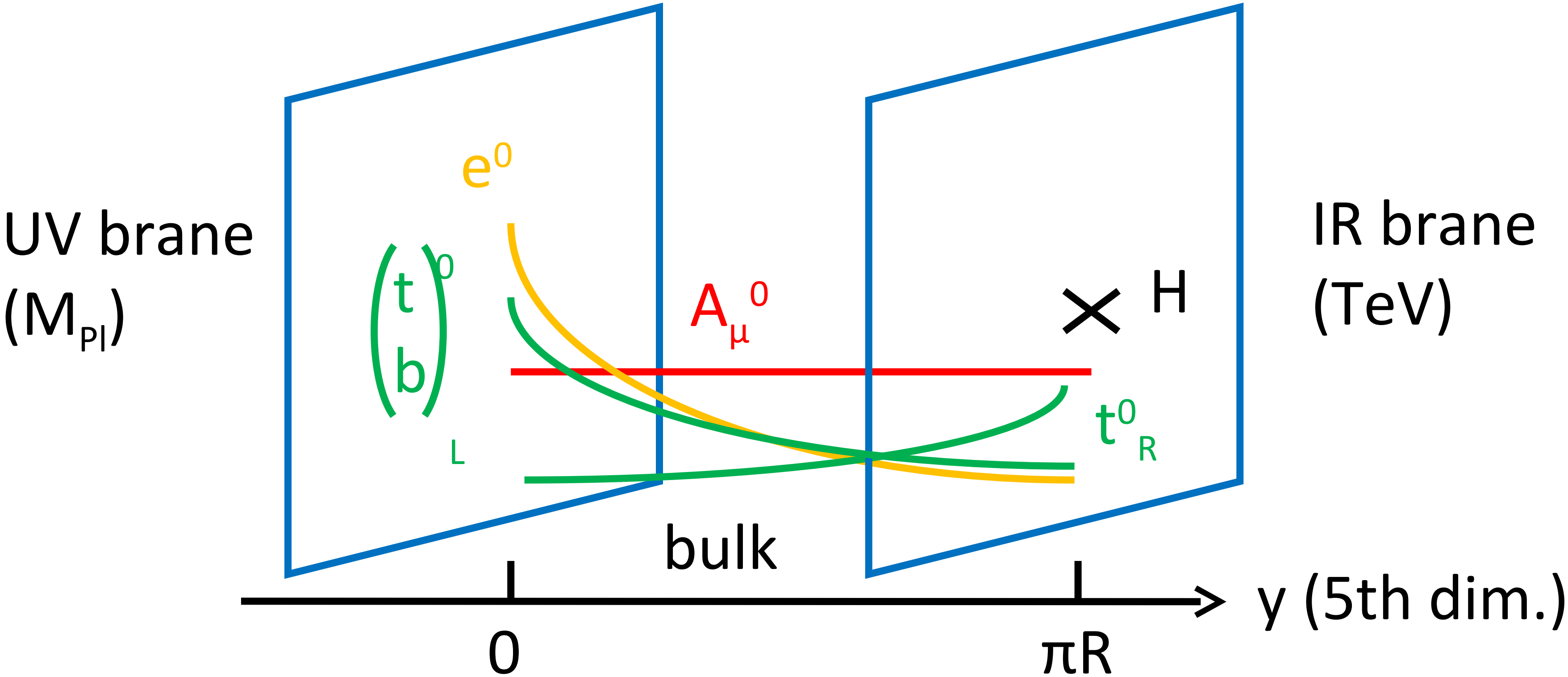
- Flavor hierarchy ? Role of 3rd generation ?





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

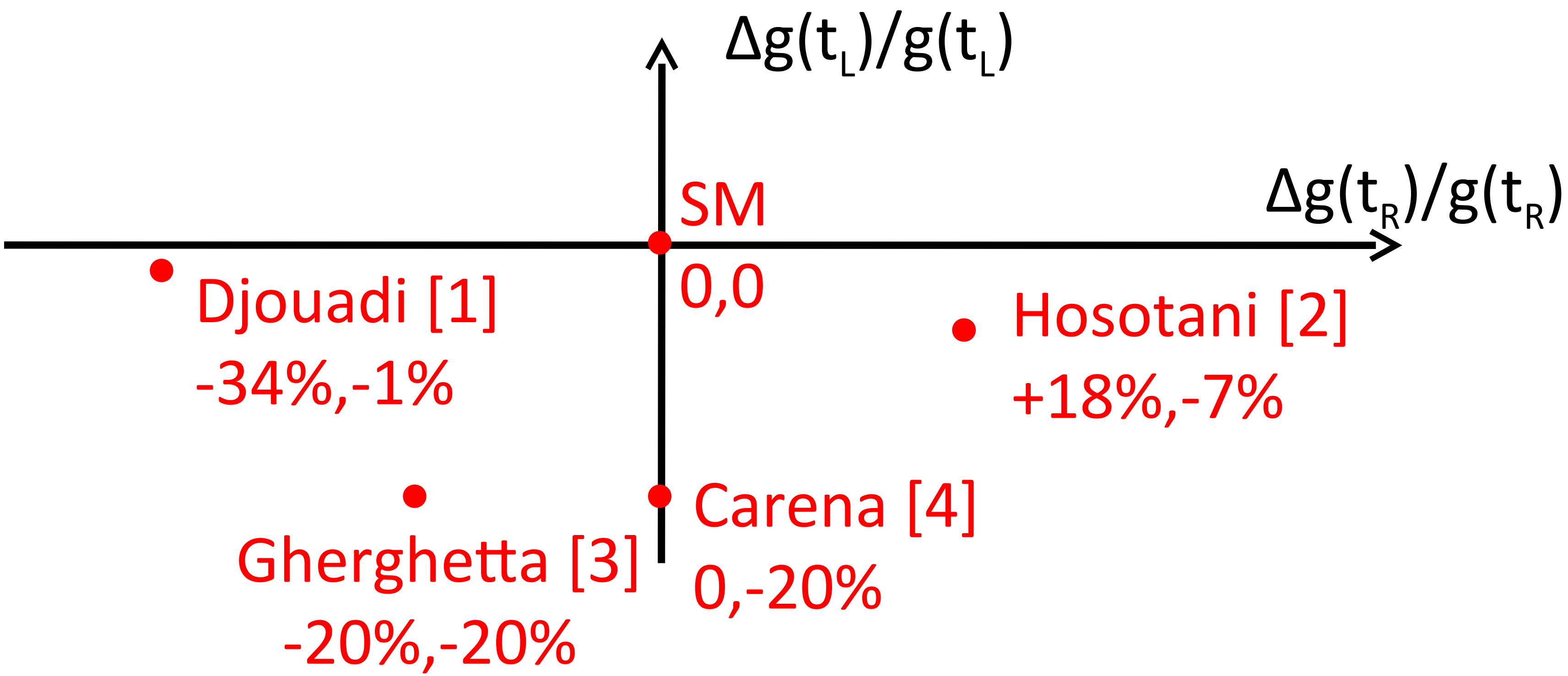
Geography in Randall-Sundrum models



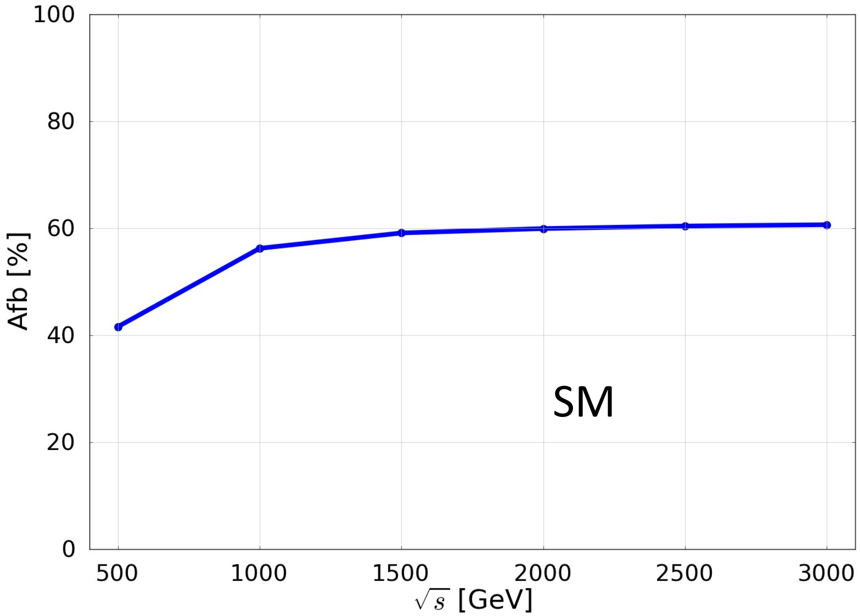
- Higgs on IR brane for gauge hierarchy problem
- SM fermions have different locations along the 5th dimension
- Overlaps leptons – Higgs in the 5th dimension generate good Yukawa couplings with O(1) localisation parameters

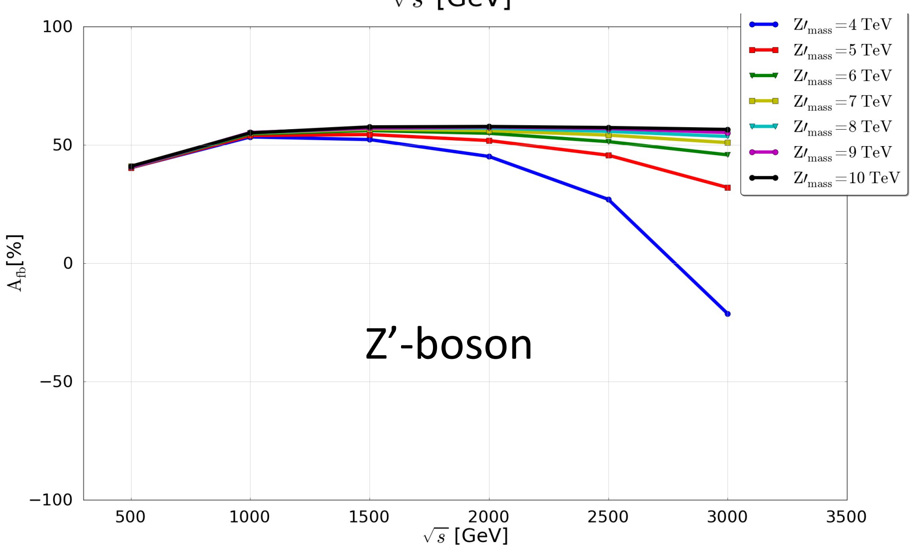
Top to Z couplings

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



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

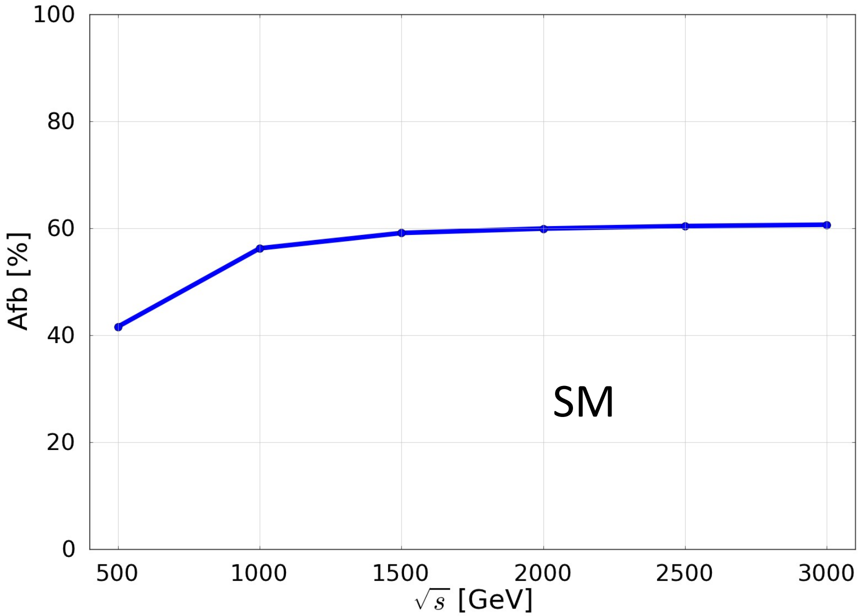




- Results obtained with MadGraph/MadEvent.
- 400.000 events by point to obtain 1‰ of statistical dispersion.
- m(t) = 173.2 ± 0.9GeV

New physics will alter asymmetries
More discriminative at higher energies

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



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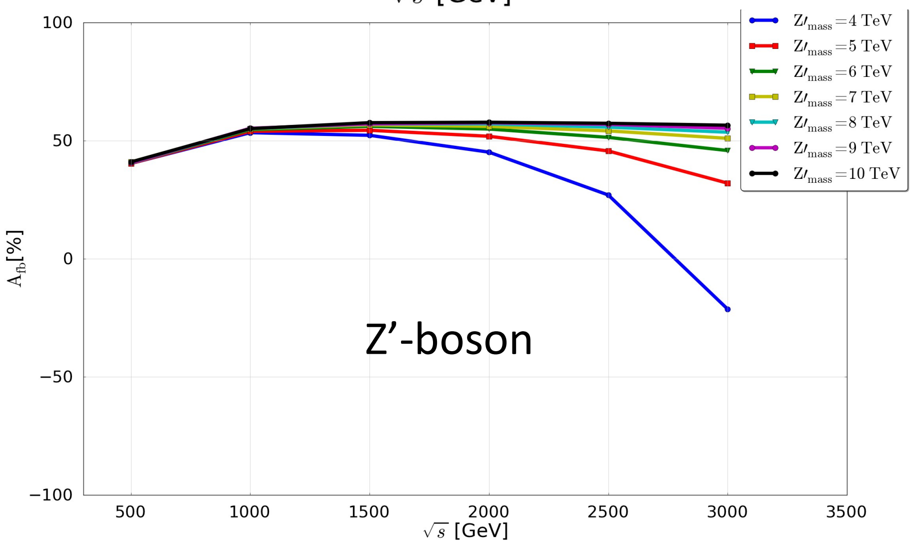

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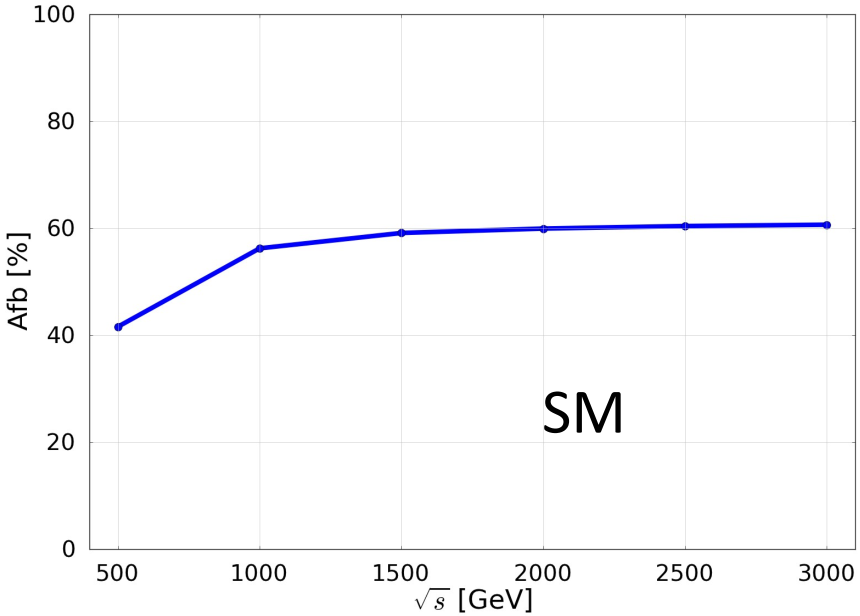

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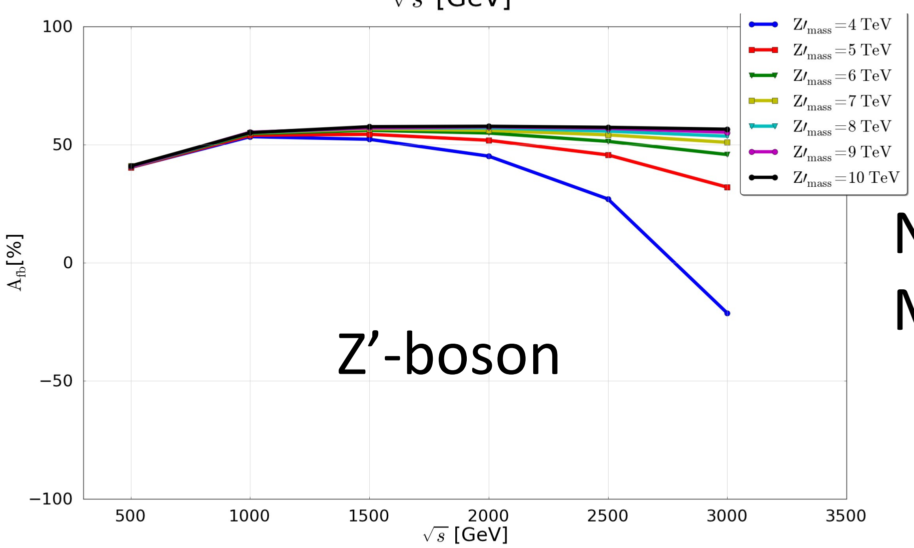
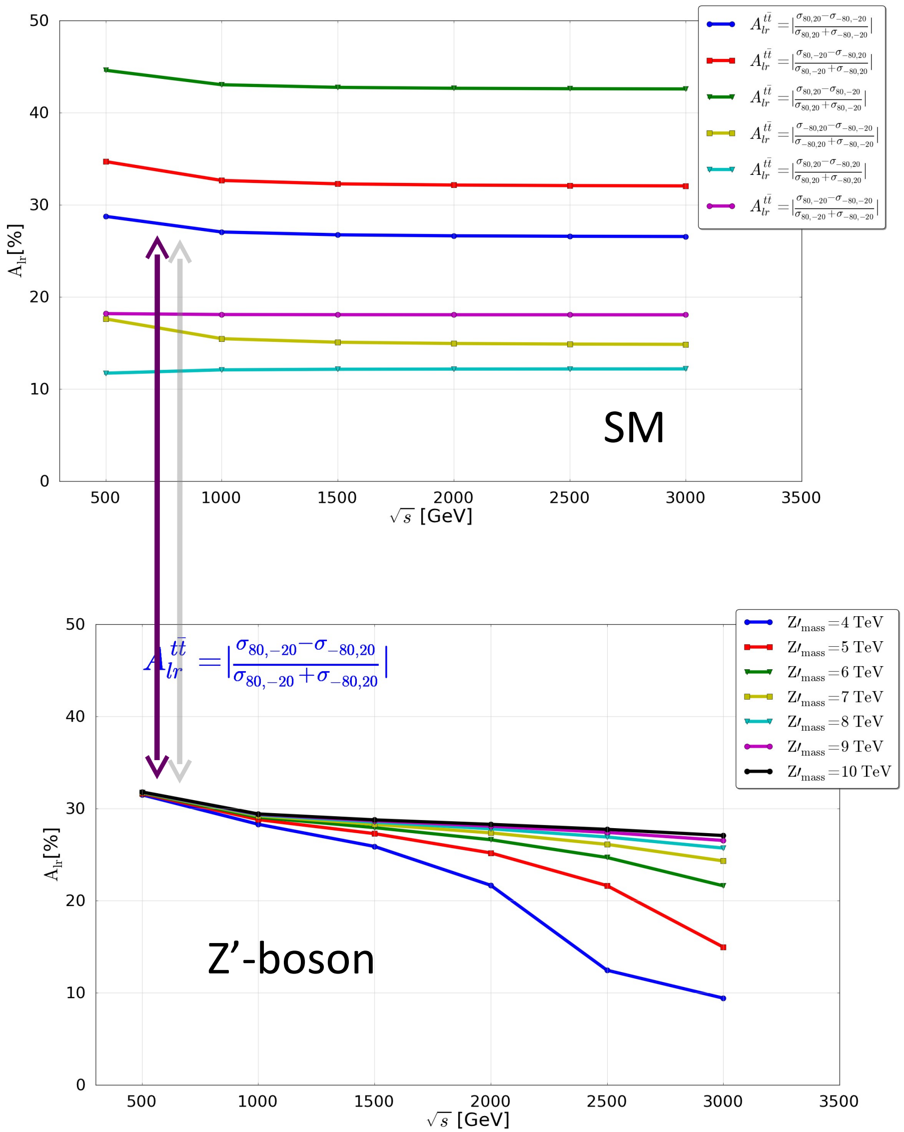


New physics will alter asymmetries
More discriminative at higher energie

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



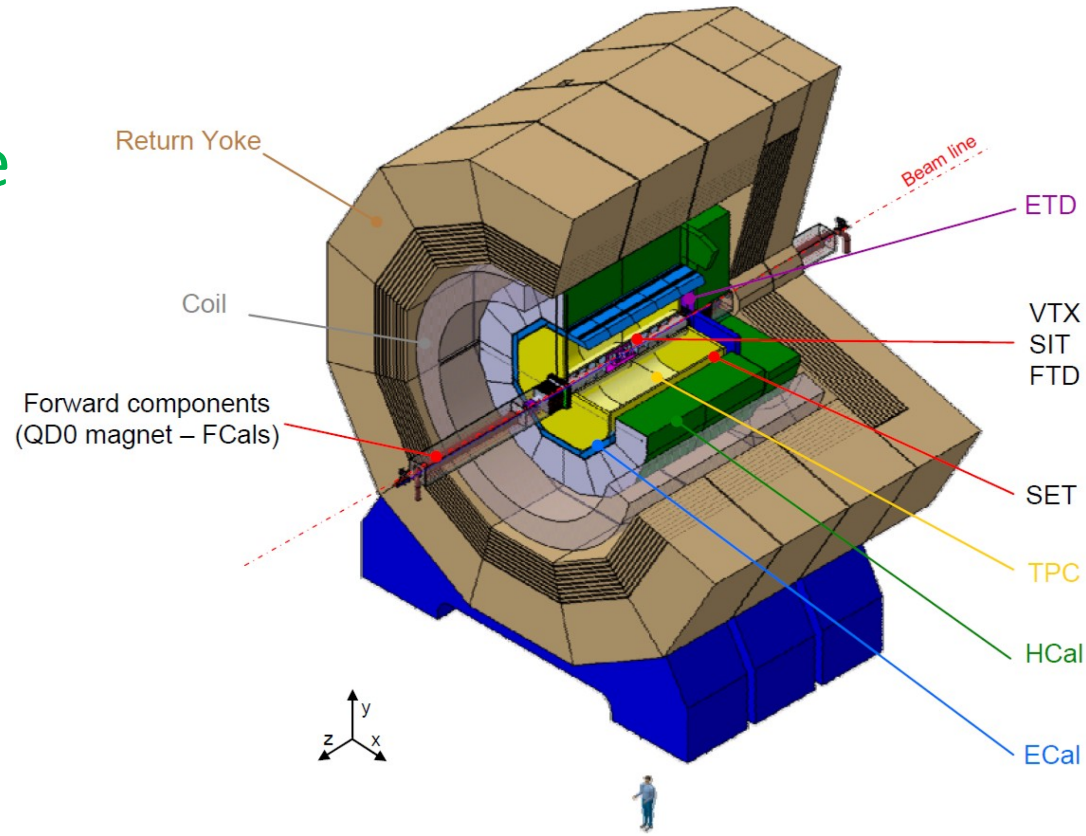
- e^- beam polarization: ±80%
- e^+ beam polarization: ±20%

New physics will alter asymmetries
More discriminative at higher energies

2. Measurement method

Measurement with the ILD detector

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

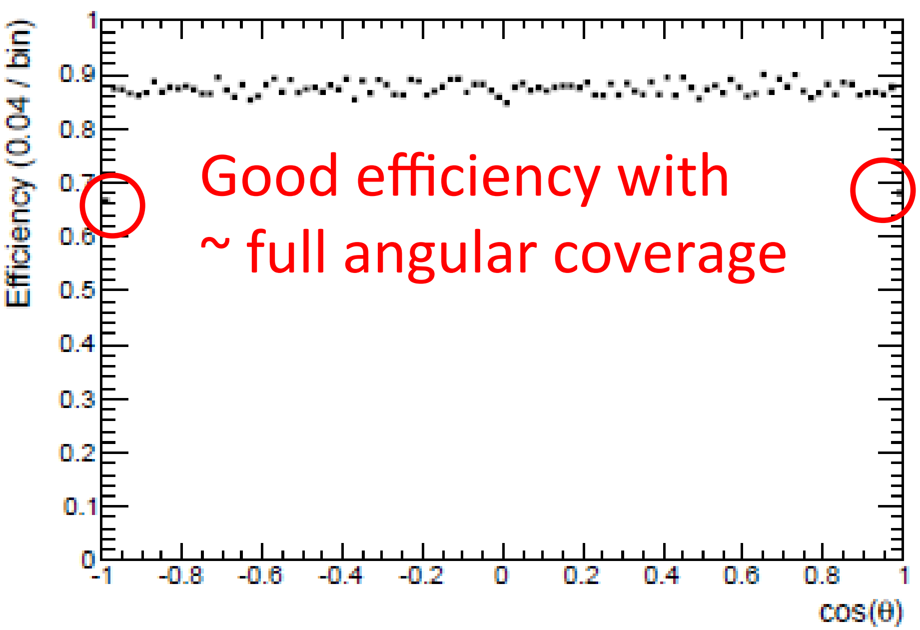


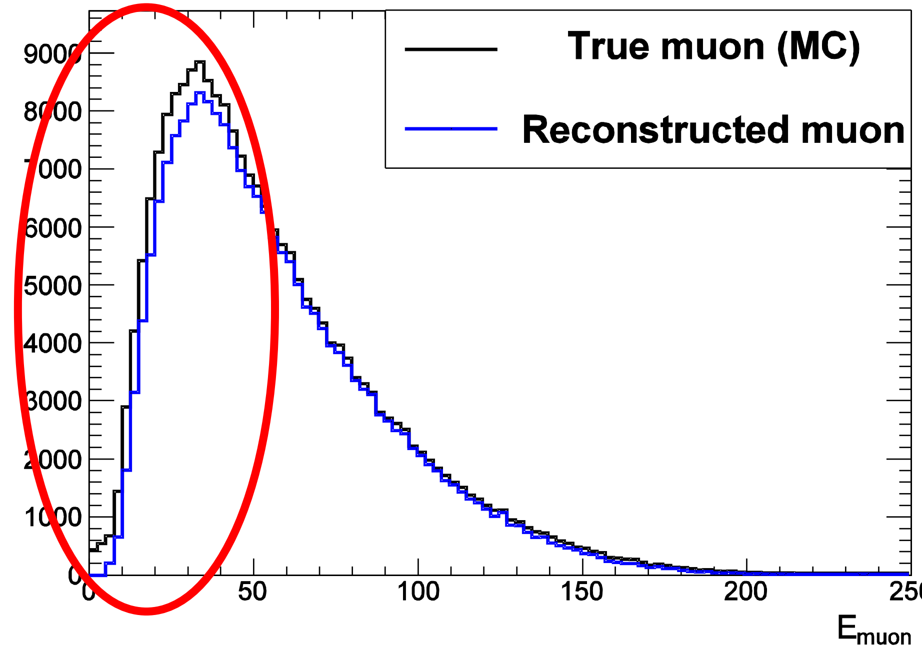
- 3.5 T B-field
- Performances :
  - Vertexing : σ_{IP} = 5 µm (+) 10 µm/p(GeV)$\sin^{3/2}\theta$
  - Tracking : $\sigma(1/p_T) < 5.10^{-5}$ GeV^{-1}
  - Granular calorimetry : $\sigma_E/E \sim 30\%/\sqrt{E}$

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

Efficiencies : angular and energetic



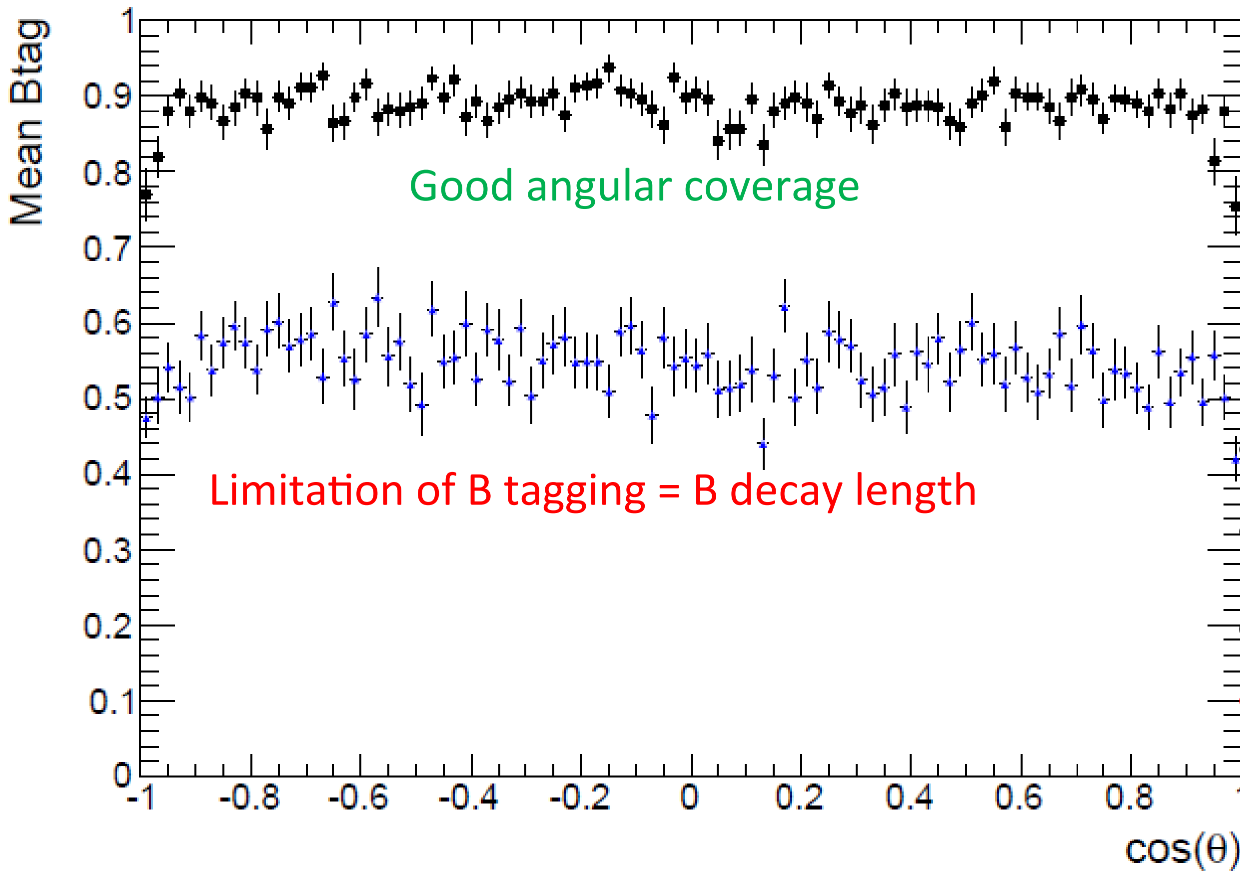


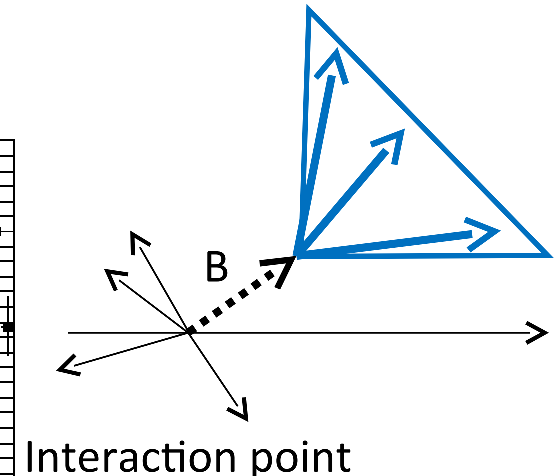
- Effiencies under control :
  - Tracking worse in very forward regions
  - Leptons with small energies are suppressed by isolation cuts

Efficiency = 87.9%
Contamination = 0.3%

B tagging

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





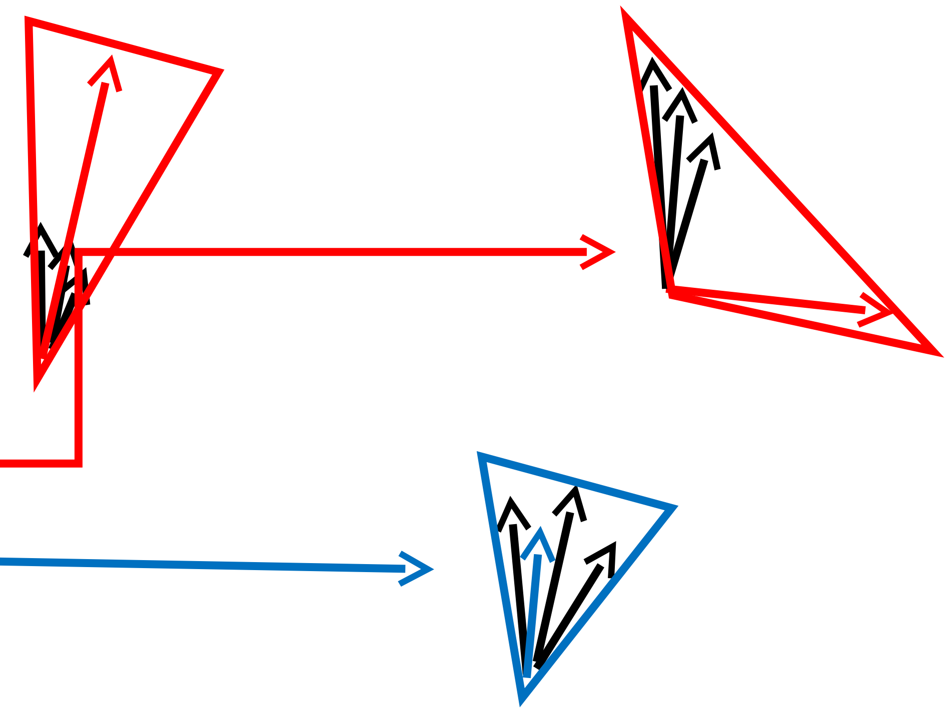
- 4 jets
- 2 highest Btag = b_1 & b_2
- 2 “light” jets = W

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

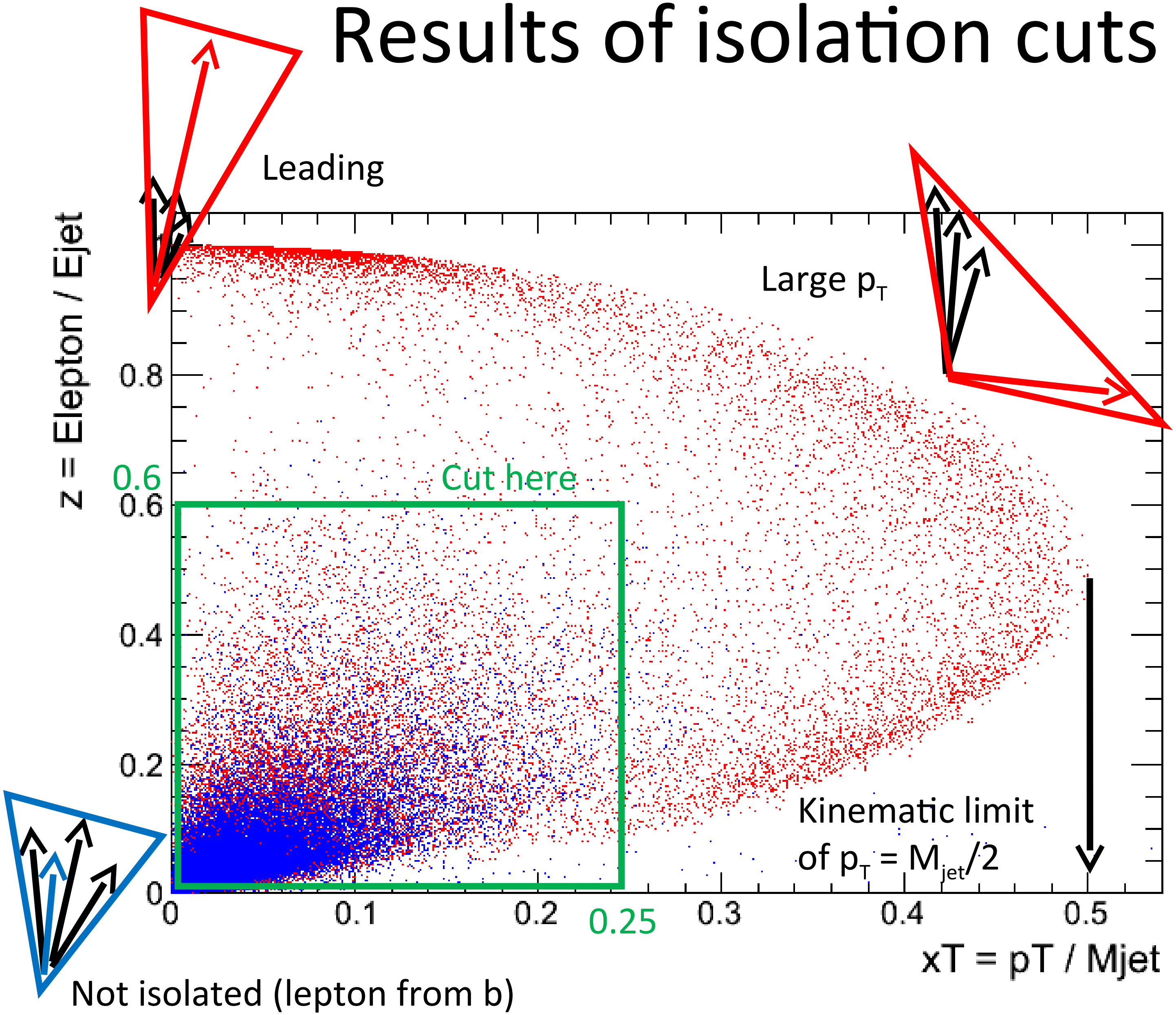
- Define :
  - $z = E_{lepton}/E_{jet}$
  - $x_T = p_T/M_{jet}$
- Lepton is :
- Leading (high z)
- At high p_T
- Not isolated



→ 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

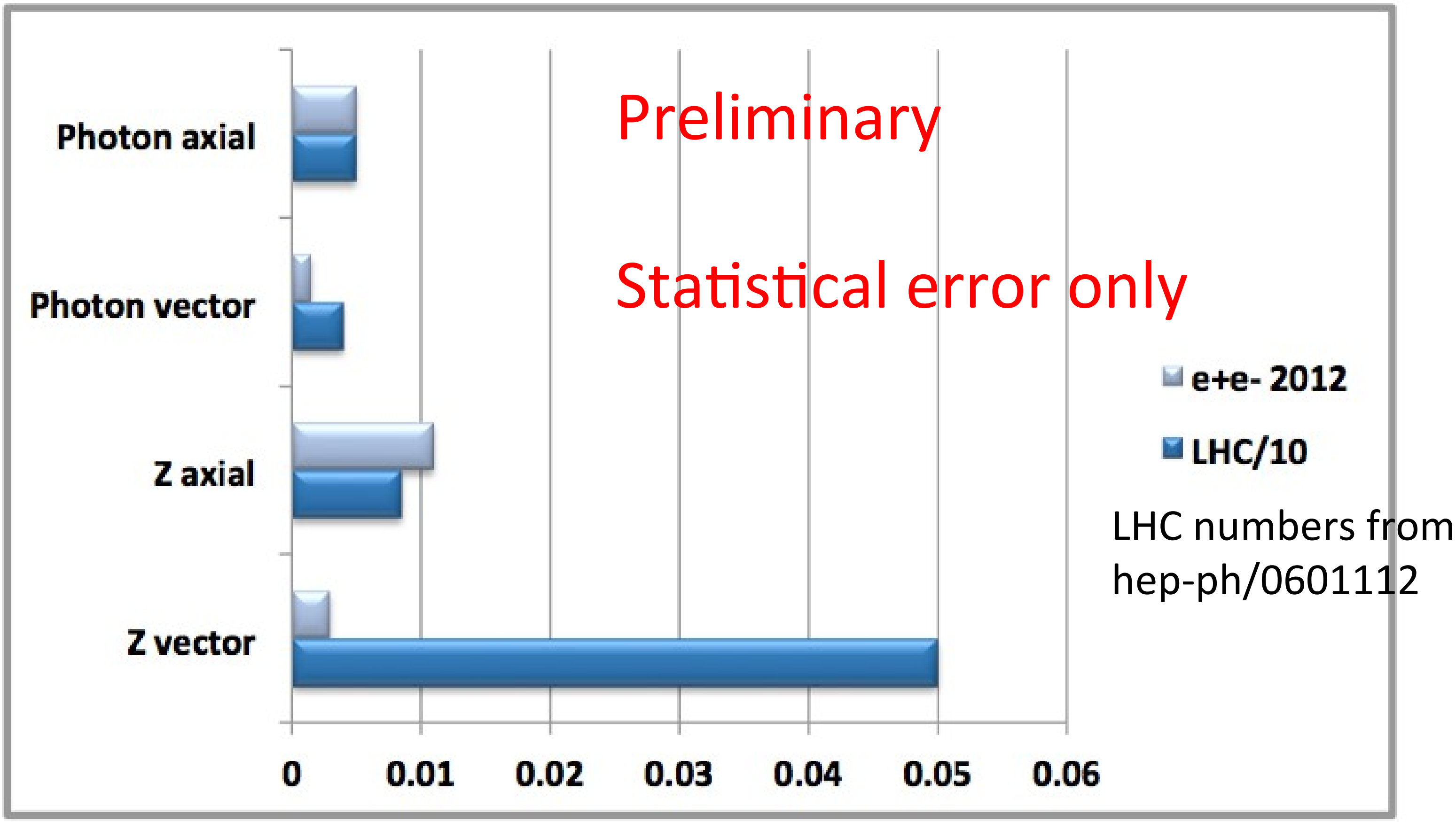


Red = leptons in semileptonic top events

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

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}



Dramatic differences

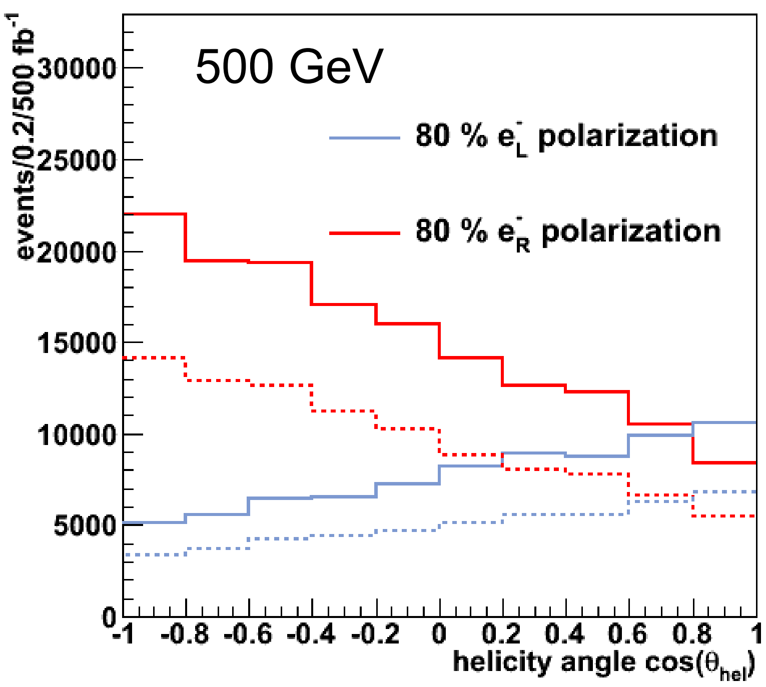
Study based on calculations using corresponding event numbers expected at ILC

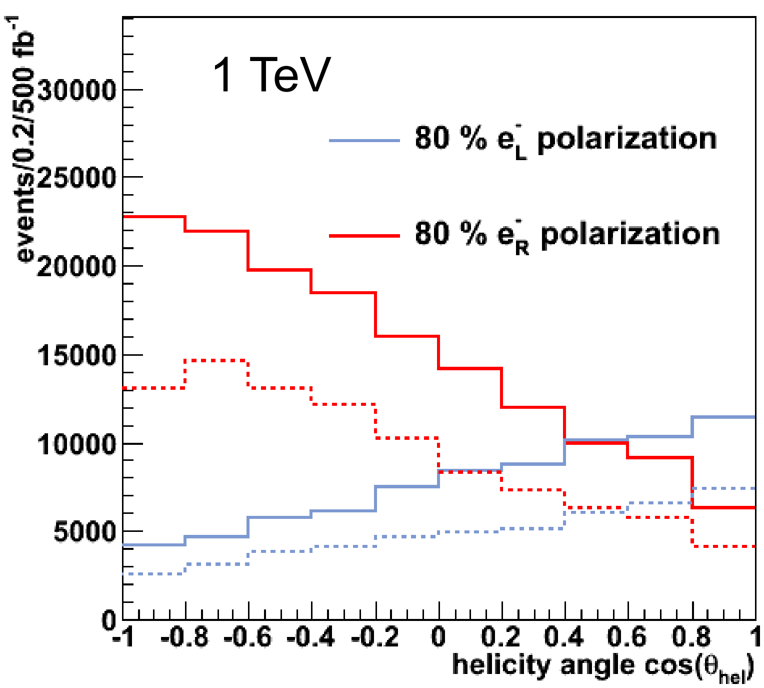
Spectacular improvement by use of 'optimal' observables!?

Studies to concentrate on systematic effects and theoretical uncertainties

Studies on A_{hel} II

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





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