Top polarization studies in ATLAS

W polarization and spin correlation as a probe to new physics

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Top Workshop – from DØ to ATLAS, Grenoble

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Motivation: test top production and decay

Top production

Weak Interaction
→ single top

LHC	Tevatron
σ ~300 pb	σ ~3 pb

Strong Interaction
$gg, q\bar{q} \rightarrow t\bar{t}$ pairs

LHC	Tevatron
σ ~850 pb	σ ~7 pb

Top decay

- **BR(t→Wb)~100%, no top hadronization**

$t\bar{t}$ final states (10 fb^{-1})

- **Full hadronic (3.7M)**: jets
- **Dileptonic (0.4M)**: 2 l + 2 b + 2 ν
- *Semileptonic (2.5M):* l + ν + 2b + jets

Top polarization
- → **Test top production**
- → **Search $gt\bar{t}$ anomalous couplings**

W polarization
- → **Test SM weak decay**
- → **Search tWb anomalous couplings**

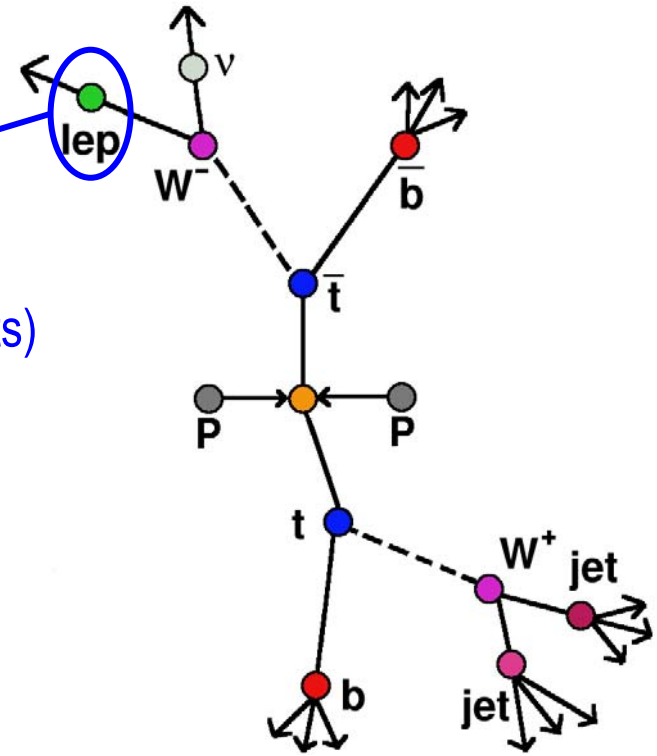
Simulation used for this study

- MC generators used
  - TopReX 4.09, AcerMC 3.2, AlpGen 1.33, MC@NLO 2.31
  - Pythia 6.2 or Herwig 6.5
  - Tauola + Photos
- Simulation of Atlas detector
  - "Fast" simulation: rough parameterization of detector performances
  - "Full" simulation: GEANT4 simulation of each sub-system
  - ➔ Good kinematic agreement between both (ATL-PHYS-PUB-2006-017)
- Working hypotheses:
  - 1 year ~ 10 fb^{-1} ~ 2.5M signal events
  - Assume well tuned MC, ideal and well understood detector

Selection and reconstruction

- Event selection for semileptonic $t\bar{t}$
  - **1 isolated lepton**, p_T>20 GeV, $|\eta|$<2.5
  - p_T^{miss} > 20 GeV
  - **≥ 4 jets,** p_T > 40 GeV
  - **≥ 2 b-tagged jets** → reject SM background (W+4 jets)

trigger



- Event reconstruction

t → W(→jj)b
- Light jet pair with M_{jj} closest to M_W
- b-jet with M_{jjb} closest to M_t

t → W(→lν)b
- $P_T^{miss} = P_T^{\nu}$; P_z^{ν} by constraining $M_{l\nu} = M_w$
- b-jet closest to lepton
- ν with $M_{l\nu b}$ closest to M_t

- Efficiency ~ 3%, background dominated by combinatorics

S / B = 11	signal (LO)	$t\bar{t}$ → τ+X (LO)	W + 4 jets	Single top	Others
Selected events (10 fb^{-1})	85000	6200	[200,500]	1000	300

W polarization in top decay

- Test top weak decay…
  - Polarization depends only on M_t et M_W (1st order)

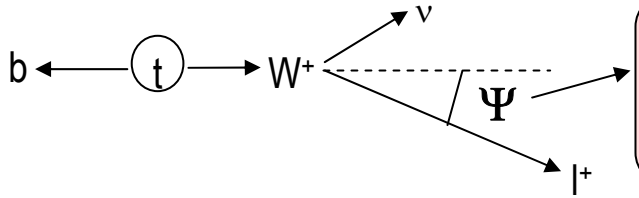
	Longitudinal W^+ (F_0)	Left-handed W^+ (F_L)	Right-handed W^+ (F_R)
Standard Model (M_{top}=175 GeV) *NLO*	**0.703** $\left(=\frac{M_t^2}{M_t^2+2M_W^2}\right)$ 0.695	**0.297** $\left(=\frac{2M_W^2}{M_t^2+2M_W^2}\right)$ 0.304	**0.000** 0.001

Electroweak tests

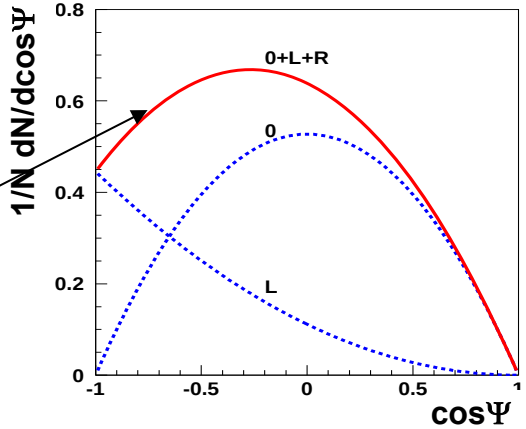
Test of V-A structure

- …through lepton angular distribution in W rest frame

$$\frac{1}{N}\frac{dN}{d\cos\Psi}=\frac{3}{2}\left[F_0\cdot\left(\frac{\sin\Psi}{\sqrt{2}}\right)^2+F_L\cdot\left(\frac{1-\cos\Psi}{2}\right)^2+F_R\cdot\left(\frac{1+\cos\Psi}{2}\right)^2\right]$$



Angle between :
- lepton in W rest frame
- W in top rest frame



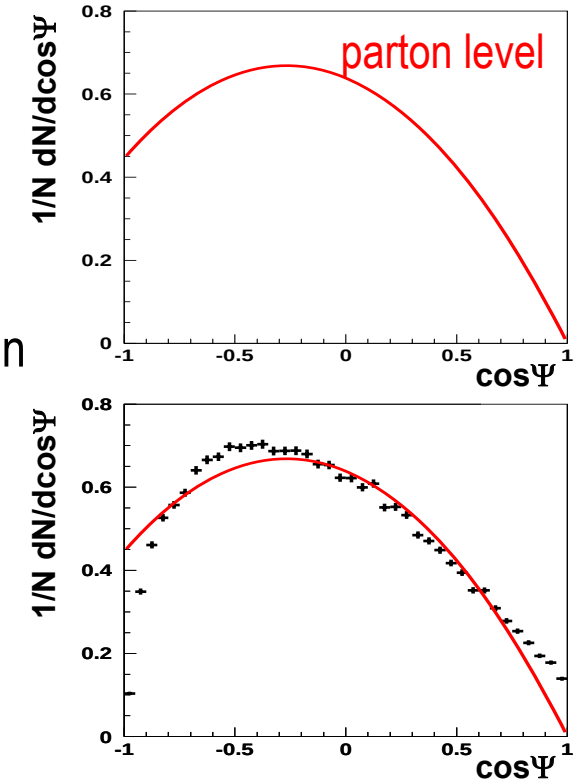
Measurement method

- Bias from acceptance and reconstruction effects

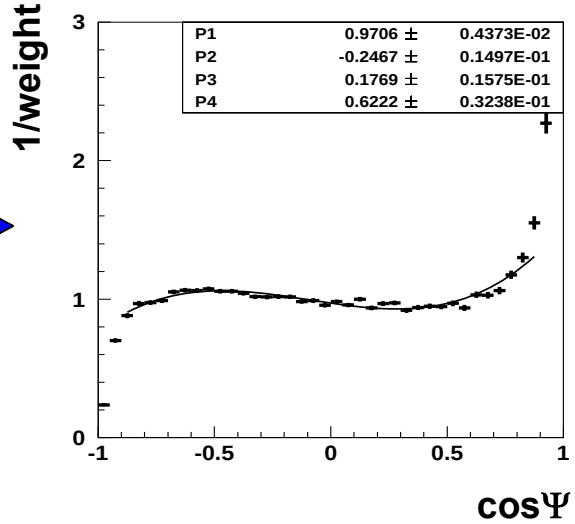
→ **Use ratio reco / theory (MC)** from a single independent sample

Fast simulation (high statistics)

Reconstruction and cuts



Correction function :

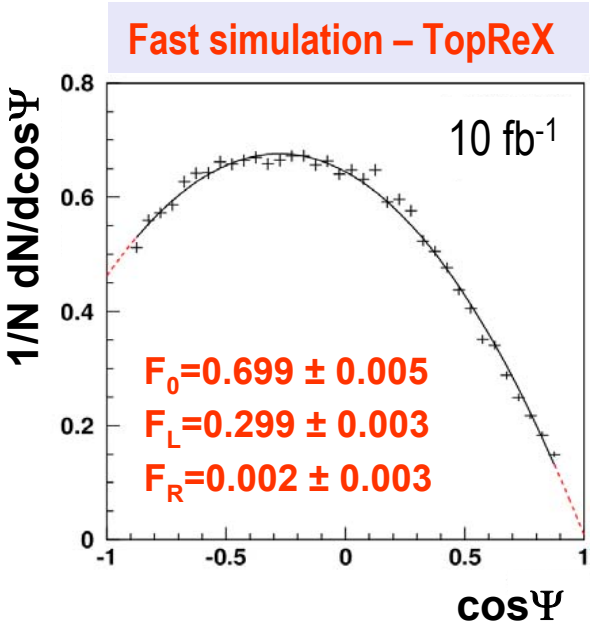


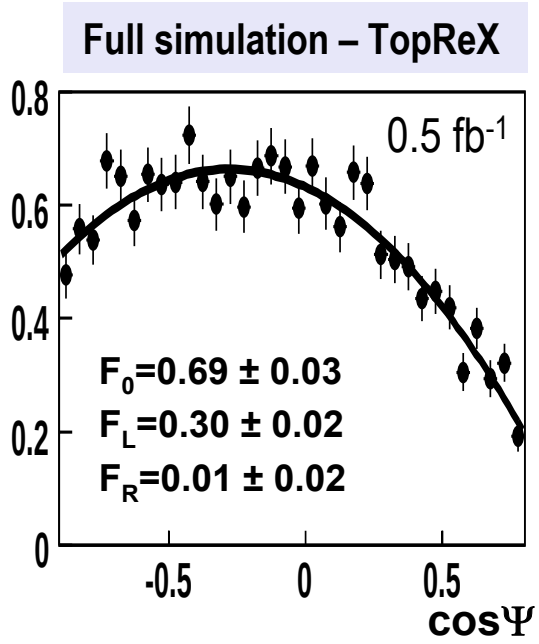
apply weights event by event

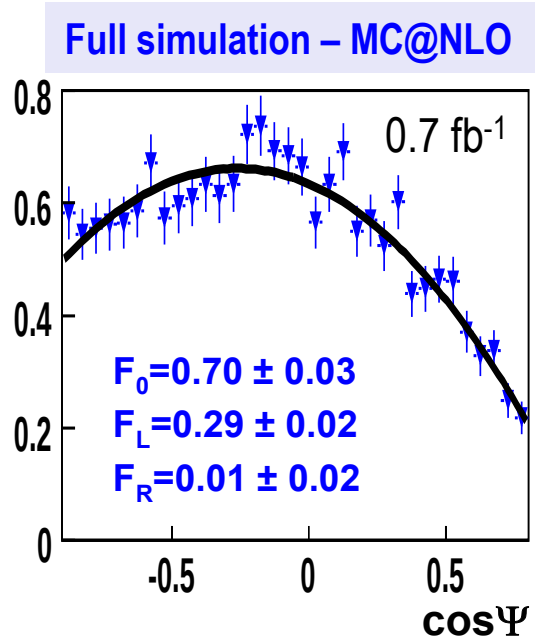
Apply this method for W polarization and spin correlation

Values after correction

- Single correction function from **fast simulation**
  - Motivation : very good kinematic agreement with full simulation



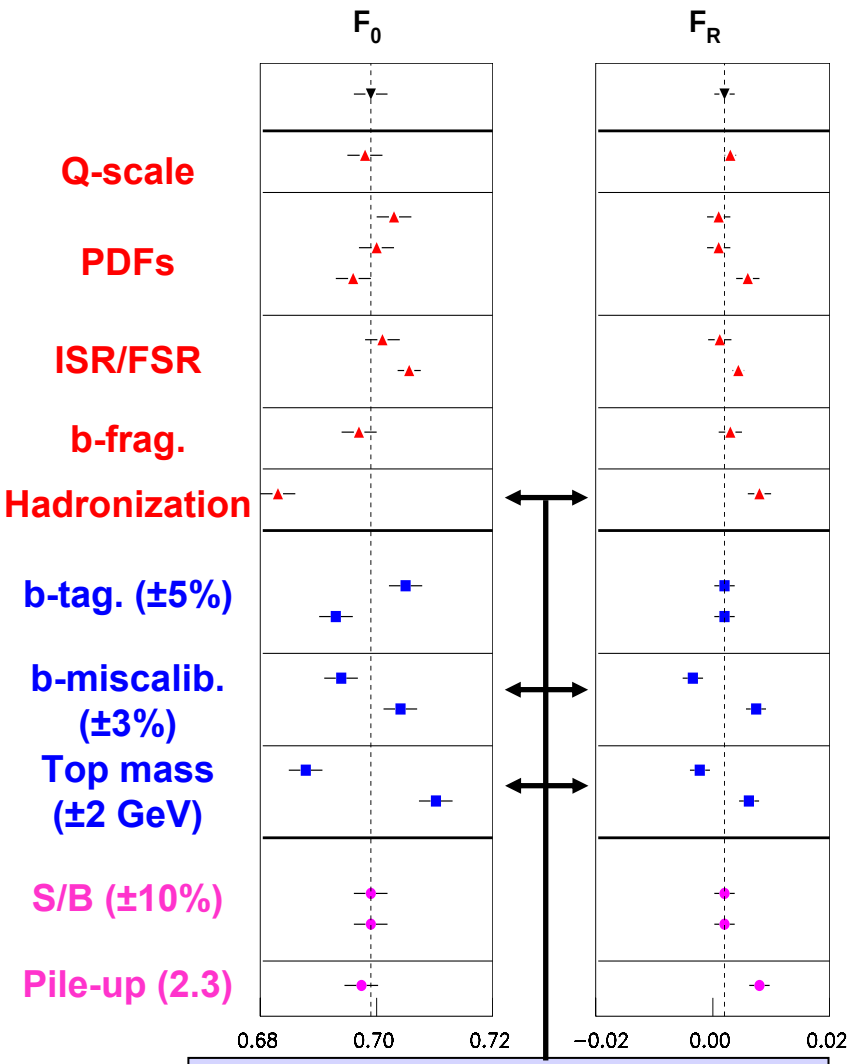




➔ **SM values retrieved : no bias**

➔ Method validated and robust

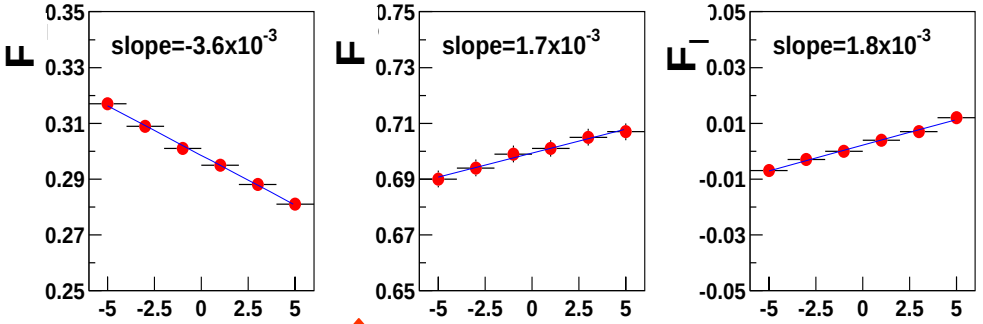
Study of systematics



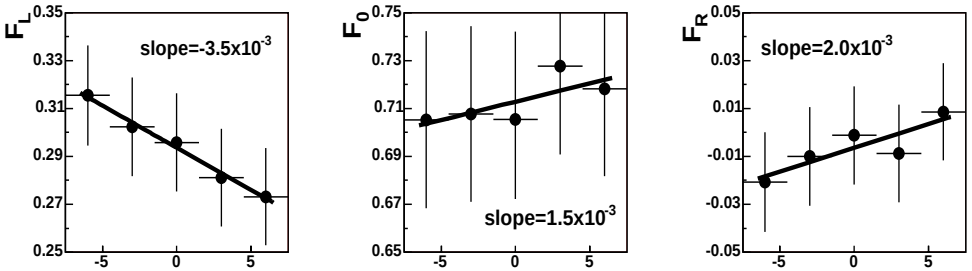
Main contributions (semilep)

- Calculated with fast simulation
- Confirmed with full simulation

➔ ex.: b-jet energy calibration



fast simulation ⬆ **b-jet miscalibration** ⬇ full simulation



➔ Same dependence

Results – W polarization

Ref .: EPJC 44 S2 (2005) 13
ATL-PHYS-PUB-2006-022

- Study using semileptonic channel

SM values	F_0	F_R
	0.703	0.000
Fast simulation (10 fb^{-1})	0.699 ± **0.005** ± **0.023**	0.001 ± **0.003** ± **0.012**
Full simulation (0.5 fb^{-1})	0.71 ± **0.04**	0.00 ± **0.02**

statistic error / systematic error

➔ **Precision between 1% et 2%** dominated by systematics

➔ Statistic error expected at TeVatron (2 fb^{-1}): $\delta F_0^{stat} \sim 0.09$

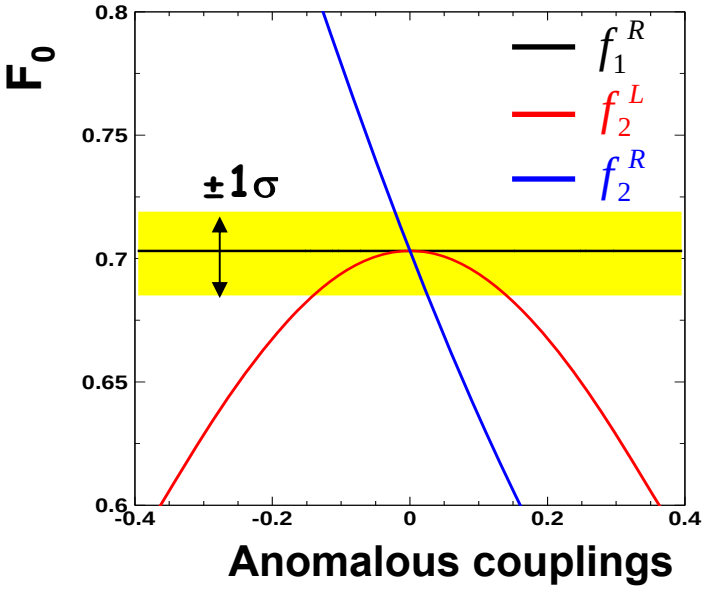
$\delta F_R^{stat} \sim 0.03$

Sensitivity to new physics

- W polarisation → deduce sensitivity to anomalous tWb couplings
  - → Generic approach with an effective Lagrangian

$$L = \frac{g}{\sqrt{2}} W_\mu b \gamma^\mu (f_1^L P_L + f_1^R P_R) t - \frac{g}{\sqrt{2}\Lambda} \partial_\nu W_\mu b \sigma^{\mu\nu} (f_2^L P_L + f_2^R P_R) t + h.c.$$

$P_{R/L} = \frac{1}{2}(1 \pm \gamma_5)$ and 4 couplings (SM at 1st order, $f_1^L = V_{tb} \approx 1,\ f_1^R = f_2^L = f_2^R = 0$)



- Limit at 2σ (stat⊕syst) on f_2^R = 0.04
- 3 times better than indirect limits (B factories, LEP)
- Less sensitive to f_1^R and f_2^L already highly constrained by B factories

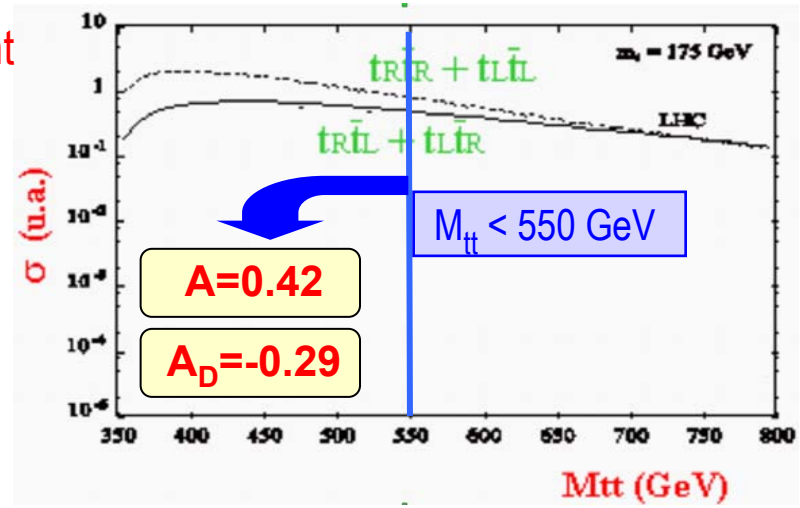
Polarization in $t\bar{t}$ pairs

- Test $t\bar{t}$ pair production…
  - Tops not polarized, but like-spin pairs more abundant

$$A = \frac{\sigma(t_L\bar{t}_L)+\sigma(t_R\bar{t}_R)-\sigma(t_L\bar{t}_R)-\sigma(t_R\bar{t}_L)}{\sigma(t_L\bar{t}_L)+\sigma(t_R\bar{t}_R)+\sigma(t_L\bar{t}_R)+(t_R\bar{t}_L)} \neq 0$$

$$A_D = A_X + A_Y + A_Z$$

look for spin ≠1/2, anomalous couplings



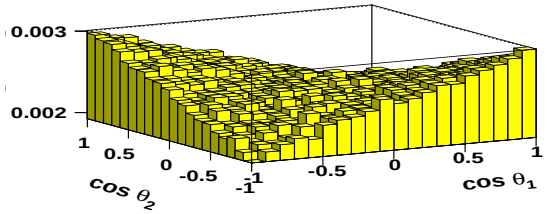
- …through angular distribution of daughters in t / $\bar{t}$ rest frame

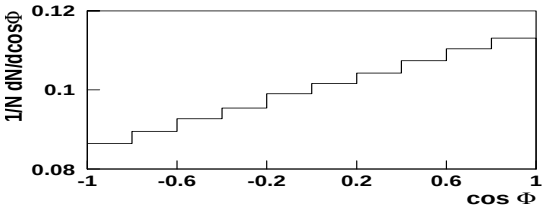
$$\frac{1}{N}\frac{d^2N}{d(\cos\theta_1)d(\cos\theta_2)} = \frac{1}{4}(1 - A\alpha_1\alpha_2\cos\theta_1\cos\theta_2)$$

Angle between t($\bar{t}$) and spin analyzers

$$\frac{1}{N}\frac{dN}{d\cos\Phi} = \frac{1}{2}(1 - A_D\alpha_1\alpha_2\cos\Phi)$$

Angle between spin analyzers





Results – $t\bar{t}$ spin correlation

Ref .: EPJC 44 S2 (2005) 13
ATL-PHYS-PUB-2006-022

- Study using semileptonic channel

SM values	A	A_D
	0.422	-0.290
Fast simulation (10 fb^{-1})	0.422 ± **0.020** ± **0.081**	-0.288 ± **0.012** ± **0.036**
Full simulation (0.7 fb^{-1})	0.67 ± **0.10**	-0.33 ± **0.06**

statistic error / systematic error

➔ Precision of the order of 10 % dominated by systematics

➔ With dileptonic channel, **precision between 3% and 6%**

Conclusion

- Study on top and W polarization in $t\bar{t}$ pairs performed
  - New study (with relation to 1999 physics TDR)
- Fast simulation results confirmed in full simulation
  - Encouraging : sensitivity at 1 to 6 % with 10 fb^{-1}

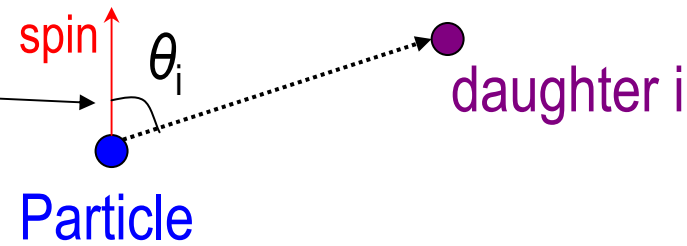
  ➔ With an ideal and well-understood detector
  - Comparison between MC generators → good agreement
- Next steps before data
  - Use "as-built" detector description in simulation
    - Global effort to estimate performances with non-perfect detector

Spare slides

Spin and polarization studies

- Top decay faster than hadronization timescales
  - Spin information transmitted to Wb → jjb / lνb
  - ➔ Test SM couplings with clean probe
  - Polarization from angular distributions of daughters :

$$\frac{d\Gamma}{d\cos\theta_i} \propto 1 + P\alpha_i \cos\theta_i$$

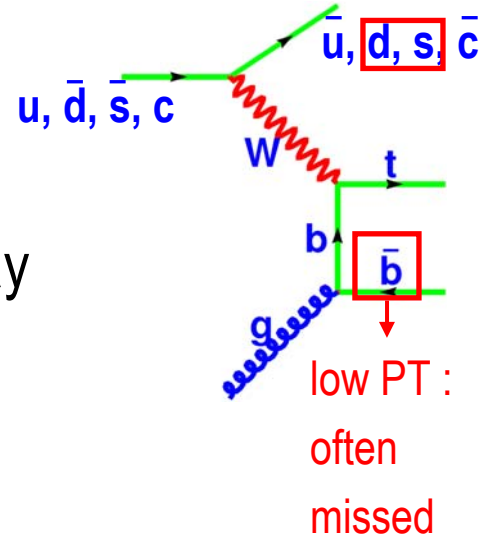


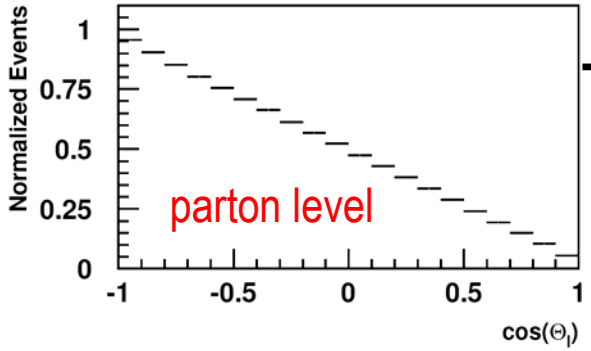
α_i : spin analyzing power of daughter particle i (-1 to 1)

Top spin with single tops

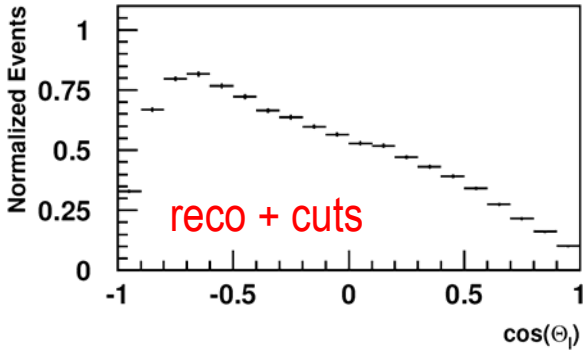
ref : ATL-PHYS-2000-017

- Polarization > 90% along d-type quark direction
  - Spectator basis used (if b missed, ~ helicity basis)
  - θ angle between top direction and lepton in top decay





→ Theory : mostly left-handed top



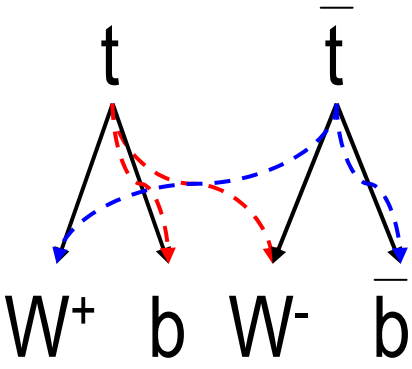
→ Deformation corrected through a χ^2

Minimize a set of $f_{th}(\cos\theta, P) - f_{data}(\cos\theta)$

Extract P with uncertainties

selected events	S/B	polarization (%)		statistical precision	
		parton	reco	2 pb^{-1}	10 fb^{-1}
3500	2.6	94.6	95.8	4 %	1.6 %

Top charge



- Motivation : confirm $Q_{top} = 2/3$
  - Exotic $Q_{top} = -4/3$ could be hidden in $t\bar{t}$ pair
- Two methods for direct measurement :
  - Study of radiative top processes
    - Production of γ in $t\bar{t}$ event depends on Q_{top}
    - Low statistics, high background
  - Charge of decay products (lepton and b)
    - Good measurement of Q_{lep} with LHC detectors
    - $Q_{b\text{-}jet}$ more challenging

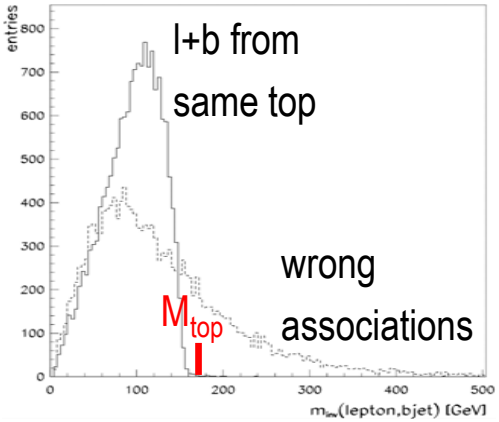
Top charge through decay products

ref : ATL-PHYS-2003-035

Charge of decay products : $t \rightarrow Wb \rightarrow l\nu b$; $Q_{top} = Q_b + Q_{lep}$

→ Correctly assign lepton to b-jet : $M_{lb} < M_{top}$

- → Semilep : 1 good matching, others wrong
- → Dilep : only one lepton may match both b's

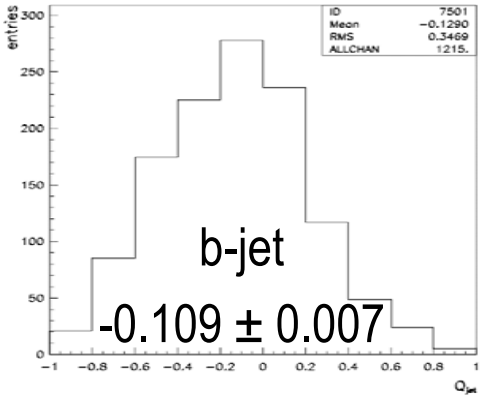


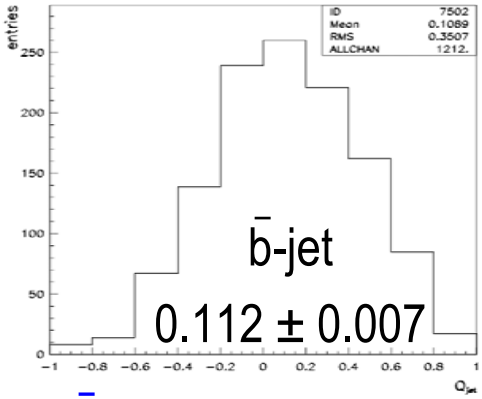
→ Estimate b-jet charge :

$$Q_{bjet} = \frac{\sum_i q_i \left| \vec{j} \cdot \vec{p}_i \right|^{\kappa}}{\sum_i \left| \vec{j} \cdot \vec{p}_i \right|^{\kappa}}$$

Results :

	eff (%)	S/B	nb of evts
lepton+jets	0.7	65	1200
dilepton	5.4	10	1200





→ Results could arrive rapidly (5σ separation between b and $\bar{b}$ with 24 pb^{-1})

→ Systematics to be done