studies of top quark decay asymmetries

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Flavour in the era of the LHC

CERN (3rd meeting), May 2006

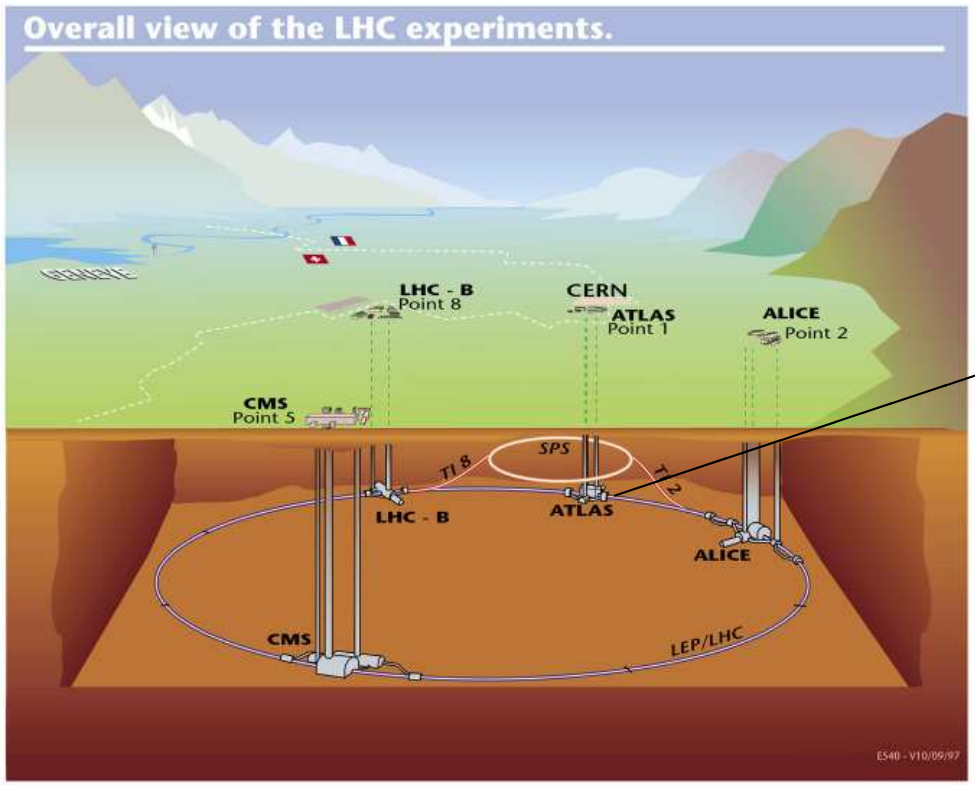
summary

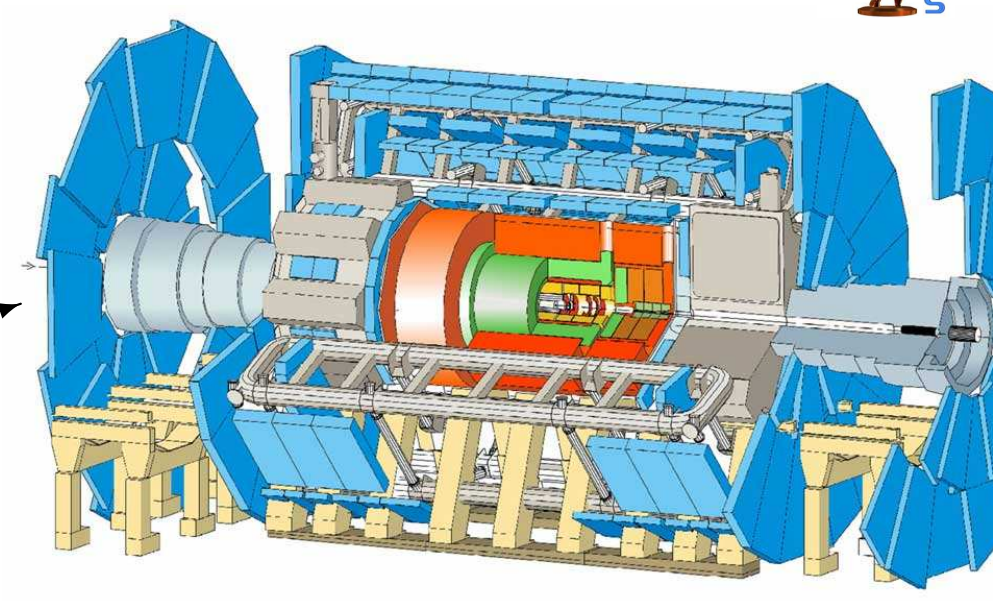
- ▷ introduction
  - anomalous couplings
- ▷ angular asymmetries
  - asymmetries in the W rest frame: A_{FB}, A_+ and A_-
  - W polarization: helicity fractions and ratios
  - spin asymmetries: A_{lj}, $\tilde{A}_{\ell j}$ and $A_{\nu j}$
- ▷ conclusions

introduction

- the LHC will be a top factory
  - $\sigma(pp \to t\bar{t}) \sim 800$ pb
  - $\sigma(\text{single top production}) \sim 300$ pb
- $t \to bW$ is the dominant decay mode
  - $BR(t \to sW) < 0.18\%$
  - $BR(t \to dW) < 0.02\%$
- top can be a window to physics beyond the SM
  - the anomalous couplings can be studied with angular asymmetries
- most of the definitions were given in Juan Aguilar's talk

the ATLAS experiment





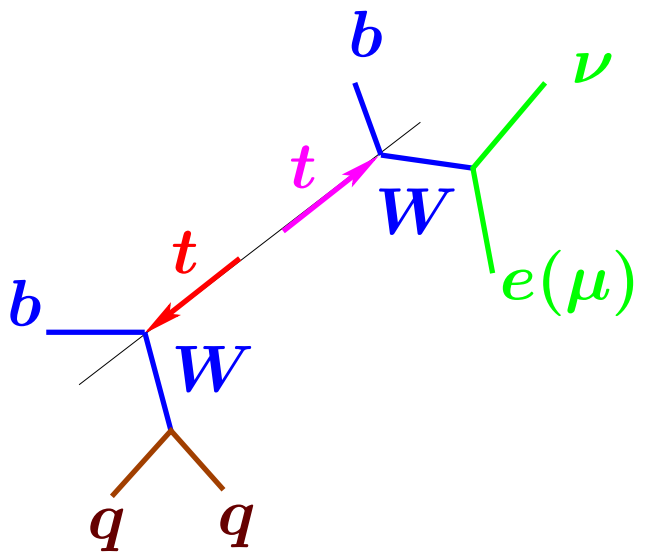
LHC: pp collisions at
$\sqrt{s} = 14$ TeV

anomalous couplings in the $t \longrightarrow bW$ decay

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\,(V_L P_L + V_R P_R)\,t\,W^{-}_{\mu}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\,(g_L P_L + g_R P_R)\,t\,W^{-}_{\mu} + \text{h.c.}$$

PRD45 (1992) 124:

$f_1^R \equiv V_R$
$f_2^L \equiv -g_L$
$f_2^R \equiv -g_R$



event selection ("semileptonic"$t\bar{t}$ decays):

- ≥ 4 jets with $p_T > 20$ GeV/c and $|\eta| < 2.5$
- = 2 b-tagged jets
- $= 1$ lepton with $p_T > 25$ GeV/c and $|\eta| < 2.5$
- $p_T^{missing} > 20$ GeV/c

signal efficiency: 8.7%

SM background: $\sim$ 40k events

($\sim$ 30k from $t\bar{t} \longrightarrow bqqb\tau\nu_\tau$ and $\sim$ 10k from single top)

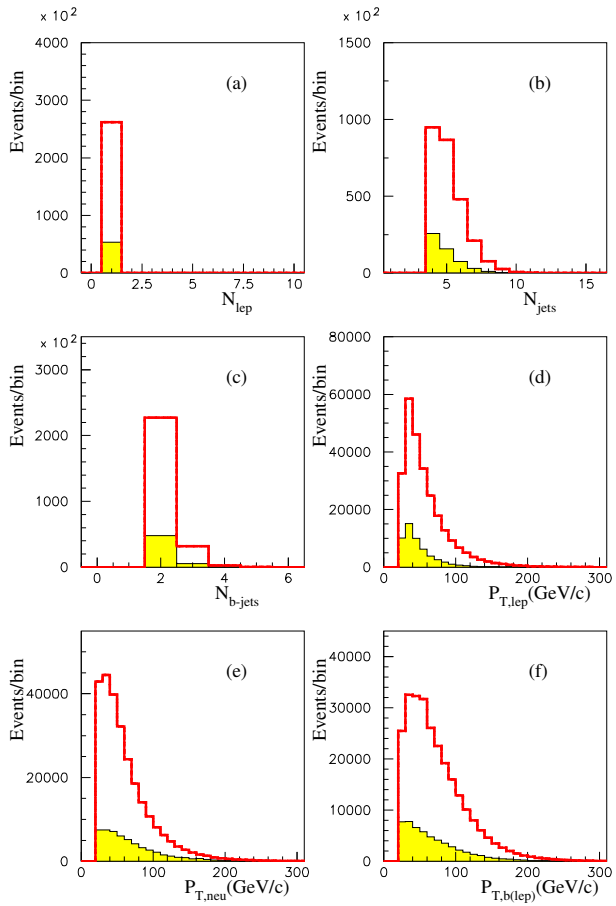
L=10 fb^{-1}

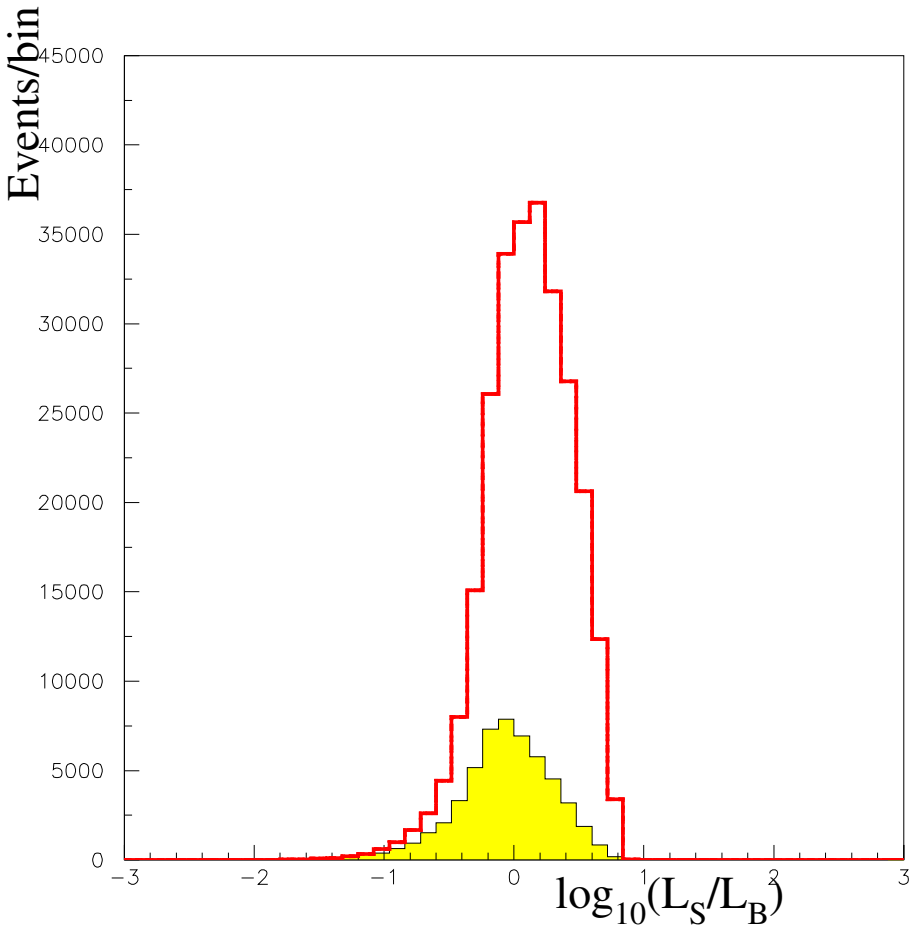
MC generation and simulation

- MC generation:
  - SM backgrounds:
    - QCD ($b\bar{b}$), W+jets, Z+jets, WW, ZZ, ZW (PYTHIA, HERWIG)
    - $t\bar{t}$, single t production (TopReX, ALPGEN, PYTHIA)
  - signal
    - $t\bar{t}$ production (TopReX, PYTHIA)
      - "semileptonic"$t\bar{t}$ decay:
        $t\bar{t} \rightarrow bW^{+}\bar{b}W^{-} \rightarrow b\bar{b}q\bar{q}'\ell\nu_{\ell}$ $(\ell = e, \mu)$
  - different versions of CTEQ PDFs sets used
- ATLAS simulation:
  - ATLFAST
  - ATLFASTB ($\varepsilon_{b-tag} = 60\%$)

distributions for the $t \to bW$ decay

- different kinds of analysis and sets of cuts tried: best results (lower systematics) for a probabilistic kind of analysis (no details given here)
- topological and kinematic distributions for the probabilistic analysis at the pre-selection level and the discriminant variable (semilep. decay)





signal and background for the $t \longrightarrow bW$ decay

number of background events, normalized to L=10 fb^{-1}, and signal efficiencies, for the probabilistic analysis:

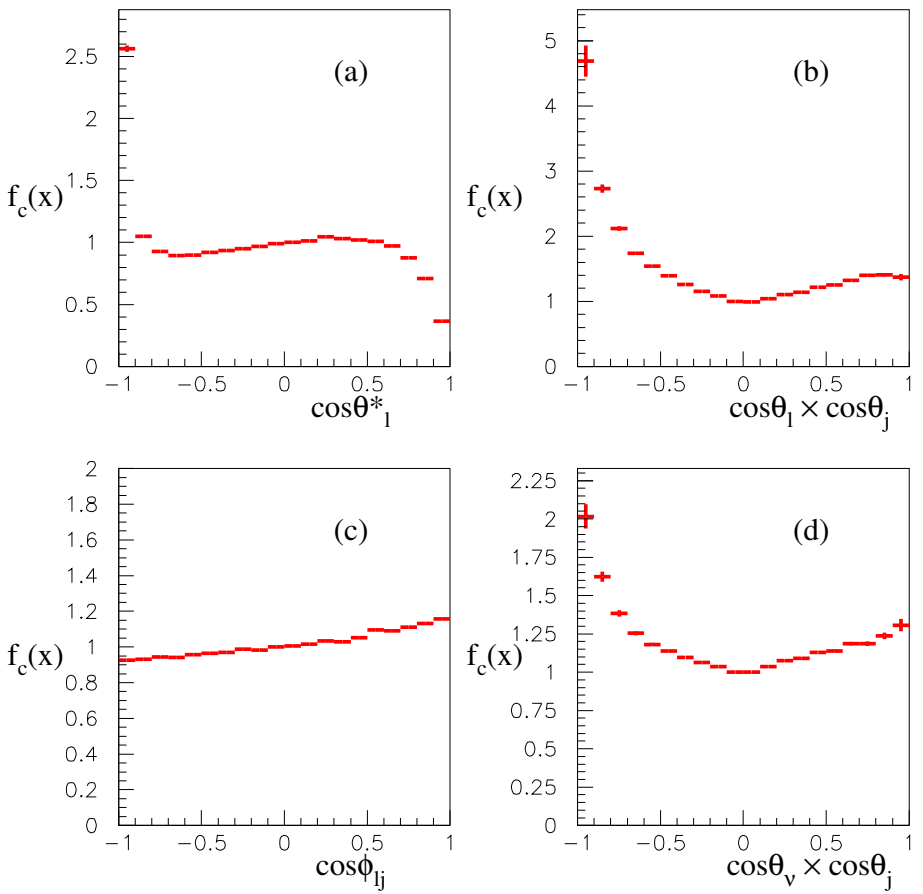
process	pre-selection	final selection
$t\bar{t} \rightarrow b\bar{b}q\bar{q}'\ell\nu_\ell$ $(\ell = e, \mu)$	262,111 (11%)	220,024 (9%)
$t\bar{t}$ (other)	36,745	27,060
single-t	12,410	7,600
Z+jets	566	253
W+jets	3,627	1,307
WW,ZZ,ZW	109	51
total SM bgd.	53,457	36,271

correction function

to correct the measured asymmetries, the MC sample is divided in two and the first one is used to correct the second one

corrected sample: $S = (S_2 + B_2 - B_1) \times (G/S_1)$

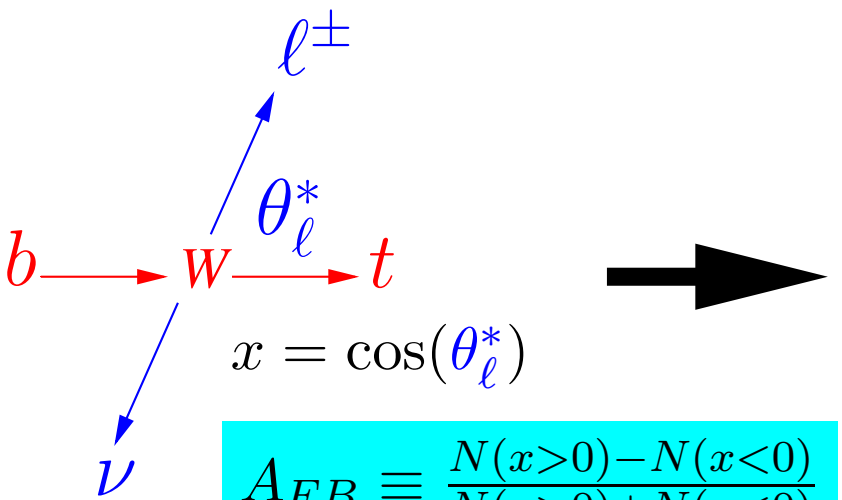
correction functions:



angular asymmetries in the W rest frame

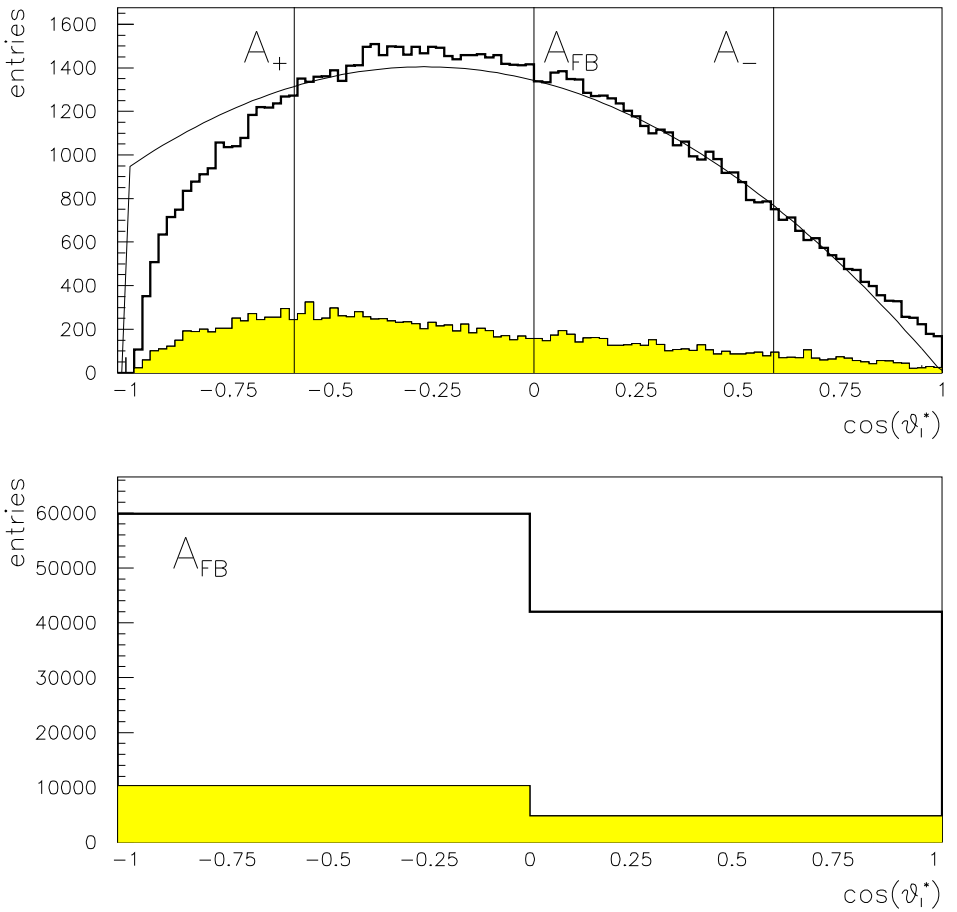
- angular asymmetries in $t \to bW \to b\ell\nu$ decay

$\cos(\theta^*_\ell)$ in W CMS



$$x = \cos(\theta^*_\ell)$$

$$A_{FB} \equiv \frac{N(x>0)-N(x<0)}{N(x>0)+N(x<0)}$$



L=10 fb^{-1}

precision in angular asymmetries

$$A_t = \frac{N(x>t)-N(x<t)}{N(x>t)+N(x<t)}$$

- $A_{FB} = -0.2237 \pm 0.0035$ (stat) ± 0.0144 (sys) $[\sigma/A_{FB} = 6.0\%]$
- $A_+ = 0.5472 \pm 0.0032$ (stat) ± 0.0099 (sys) $[\sigma/A_+ = 1.9\%]$
- $A_- = -0.8387 \pm 0.0018$ (stat) ± 0.0028 (sys) $[\sigma/A_- = 0.4\%]$

results obtained with "counting experiments"
(only two bins for each asymmetry, smaller dependence on the correction function shape), for L=10 fb^{-1}

systematic errors

sources of systematic errors considered in the evaluation of the top quark decays asymmetries (for the probabilistic analysis):

source	A_{FB}	$A_{\ell j}$	$\tilde{A}_{\ell j}$	$A_{\nu j}$
MC generator	0.0042	0.0026	0.0021	0.0025
PDFs	0.0030	0.0031	0.0026	0.0019
top mass	0.0038	0.0002	0.0003	0.0007
ISR+FSR	0.0044	0.0015	0.0019	0.0016
b-jet tag eff.	0.0042	0.0002	0.0001	0.0004
b-jet energy scale	0.0038	0.0011	0.0001	0.0020
light jet energy scale	0.0036	0.0003	0.0002	0.0005
background	0.0001	0.0003	0.0002	0.0001
pile-up	0.0084	0.0009	0.0011	0.0008
b-fragmentation	0.0056	0.0039	0.0028	0.0008
total syst. error	0.0144	0.0061	0.0049	0.0043

W helicity fractions and angular asymmetries

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l^*} = \frac{3}{8}\left(1+\cos\theta_l^*\right)^2 F_R + \frac{3}{8}\left(1-\cos\theta_l^*\right)^2 F_L + \frac{3}{4}\sin^2\theta_l^* F_0$$

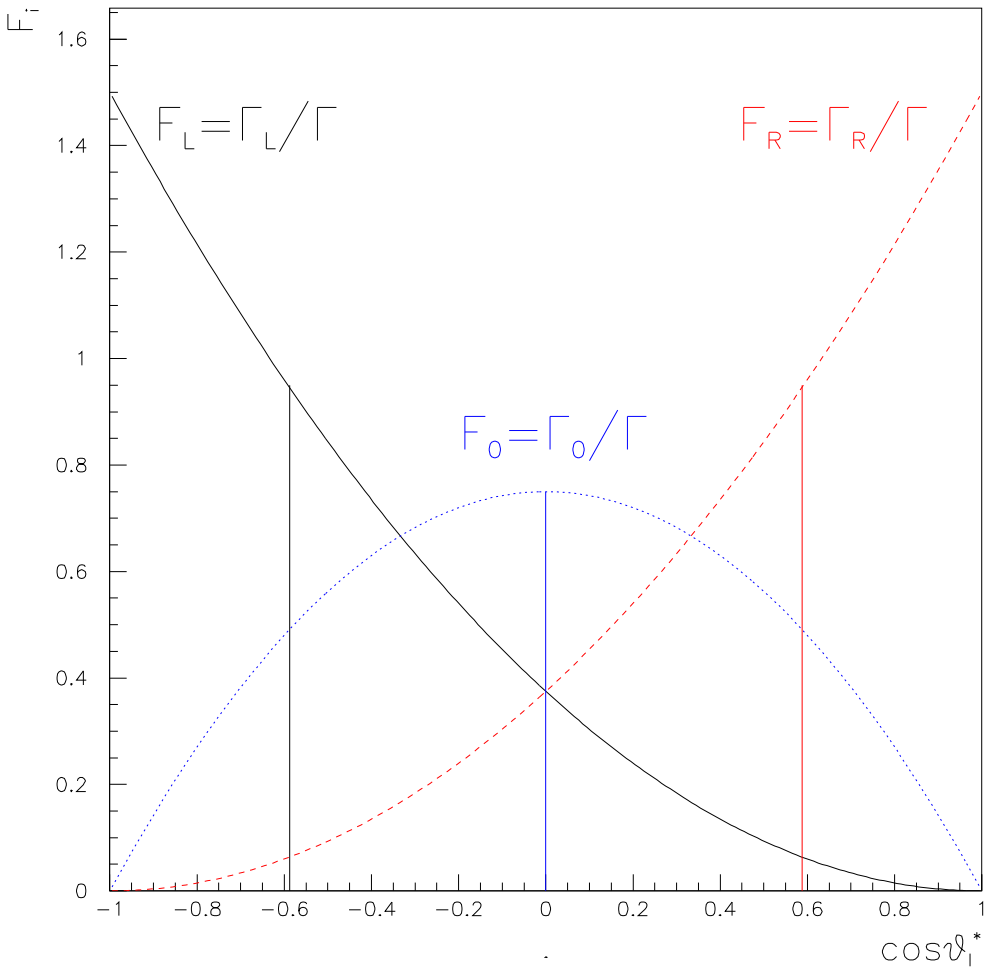
- W polarization is measured from the angular asymmetries in the W CMS:

$$A_{FB} = \frac{3}{4}(F_R - F_L) = -0.2226 \text{ (LO)}$$

$$A_+ = 3\beta\left[F_0 + (1+\beta)F_R\right] = 0.5482 \text{ (LO)}$$

$$A_- = -3\beta\left[F_0 + (1+\beta)F_L\right] = -0.8397 \text{ (LO)}$$

$$\beta = 2^{1/3} - 1$$



W helicity fractions and ratios

measurement of the W helicity fractions:

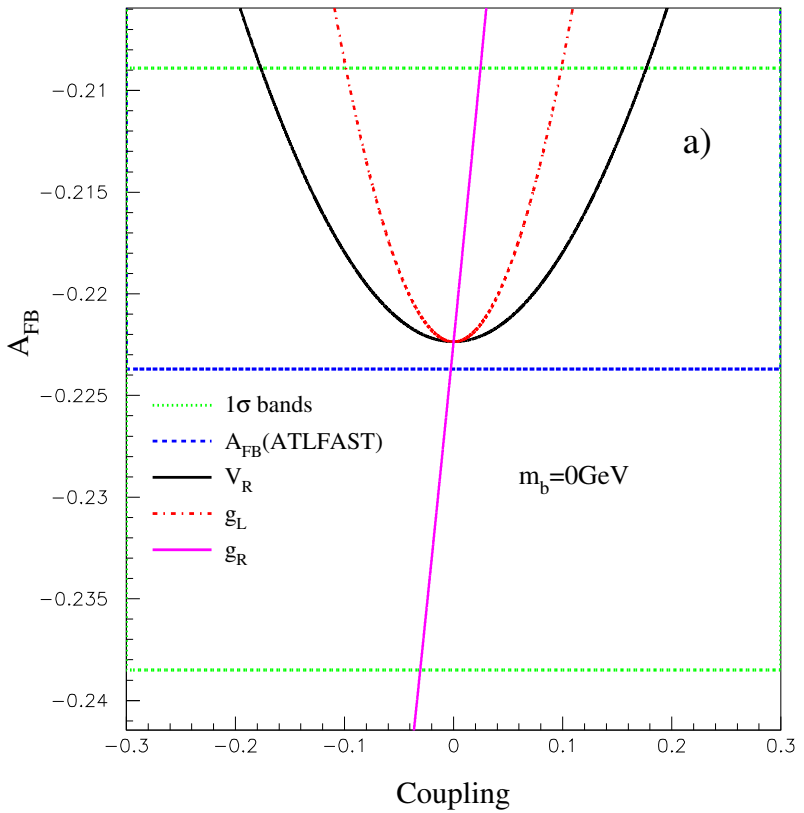
$$F_0 = 0.699 \pm 0.004 \text{ (stat.) } \pm 0.021 \text{ (syst.)} \quad \text{(LO: } 0.703\text{)}$$
$$F_L = 0.299 \pm 0.004 \text{ (stat.) } \pm 0.019 \text{ (syst.)} \quad \text{(LO: } 0.297\text{)}$$
$$F_R = 0.0021 \pm 0.0030 \text{ (stat.) } \pm 0.0033 \text{ (syst.)} \quad \text{(LO: } 0.00036\text{)}$$

and for the W helicity ratios:

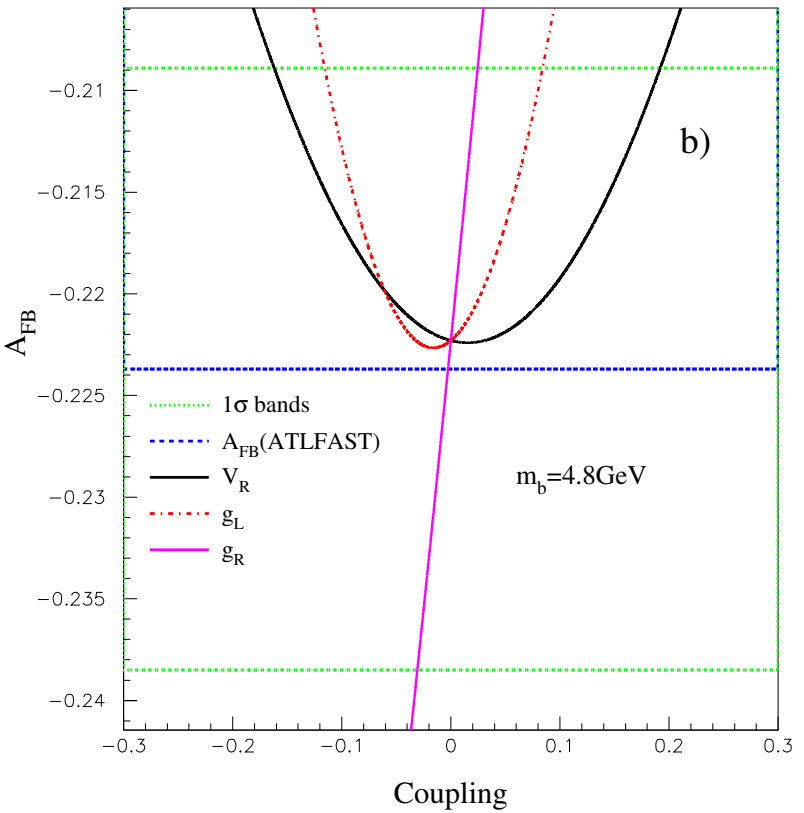
$$\rho_L = \frac{F_L}{F_0} = 0.423 \pm 0.0012 \text{ (stat.) } \pm 0.029 \text{ (syst.)} \quad \text{(LO: } 0.423\text{)}$$
$$\rho_R = \frac{F_R}{F_0} = 0.0033 \pm 0.0044 \text{ (stat.) } \pm 0.0084 \text{ (syst.)} \quad \text{(LO: } 0.00051\text{)}$$

effect of the b quark mass

- dependence of the angular asymmetry on the anomalous couplings



$m_b = 0$ GeV$/c^2$



$m_b = 4.8$ GeV$/c^2$

[PRD67 (2003) 014009]

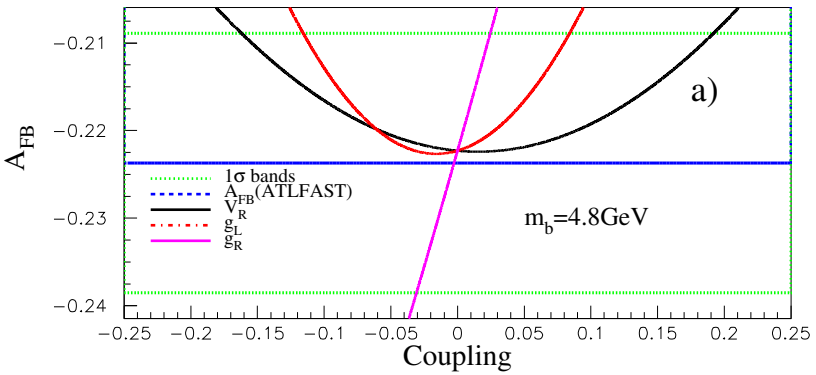
- differences up to 17% in g_L and up to 9% in V_R L=10 fb^{-1}

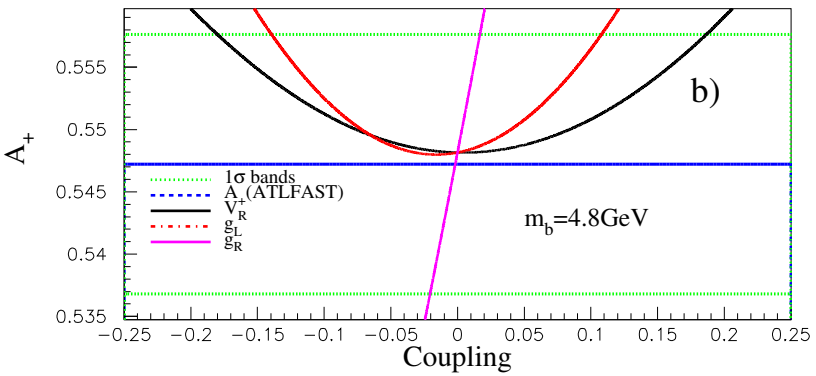
limits on the anomalous couplings

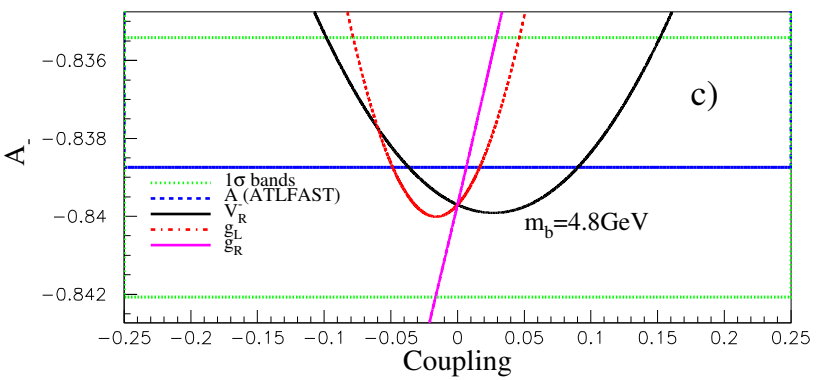
L=10 fb^{-1}

best 1σ limits on the anomalous couplings from the angular asymmetries, helicity fractions and helicity ratios (m_b taken into account):

1σ limits
$V_R \in [-0.05, 0.12]$
$g_L \in [-0.05, 0.02]$
$g_R \in [-0.021, 0.017]$

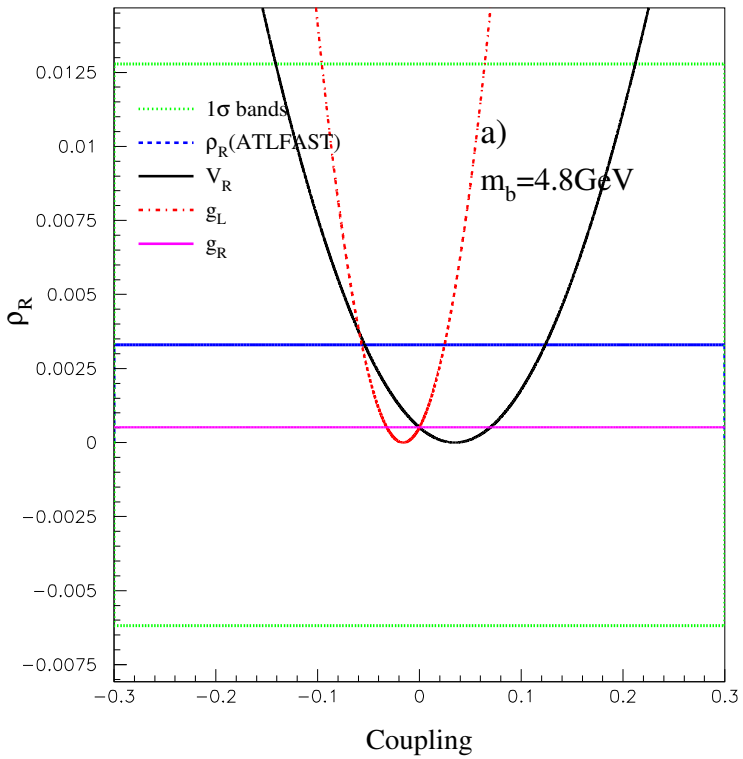


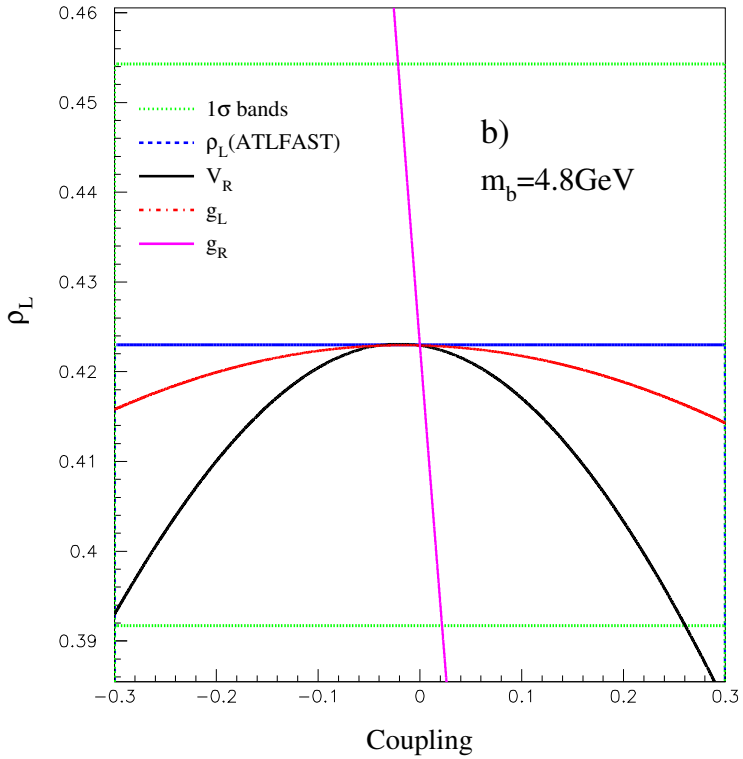




W helicity ratios - limits

1σ limits on the anomalous couplings from the helicity ratios:



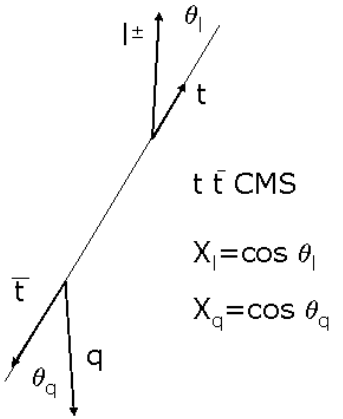


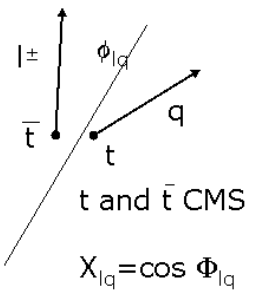
top spin asymmetries - angles

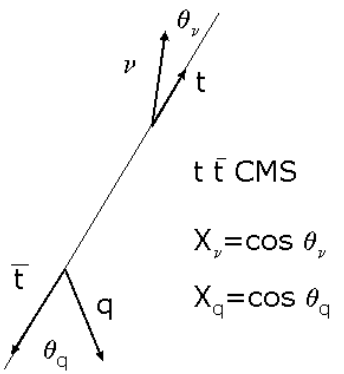
$$A_{X\bar{X}'} = A_{\ell j} = \frac{N(\cos\theta_X \cos\theta_{\bar{X}'} > 0) - N(\cos\theta_X \cos\theta_{\bar{X}'} < 0)}{N(\cos\theta_X \cos\theta_{\bar{X}'} > 0) + N(\cos\theta_X \cos\theta_{\bar{X}'} < 0)}$$

$$A_{X\bar{X}'} = \tilde{A}_{\ell j} = \frac{N(\cos\varphi_{X\bar{X}'} > 0) - N(\cos\varphi_{X\bar{X}'} < 0)}{N(\cos\varphi_{X\bar{X}'} > 0) + N(\cos\varphi_{X\bar{X}'} < 0)}$$

$$A_{X\bar{X}'} = A_{\nu j} = \frac{N(\cos\theta_X \cos\theta_{\bar{X}'} > 0) - N(\cos\theta_X \cos\theta_{\bar{X}'} < 0)}{N(\cos\theta_X \cos\theta_{\bar{X}'} > 0) + N(\cos\theta_X \cos\theta_{\bar{X}'} < 0)}$$

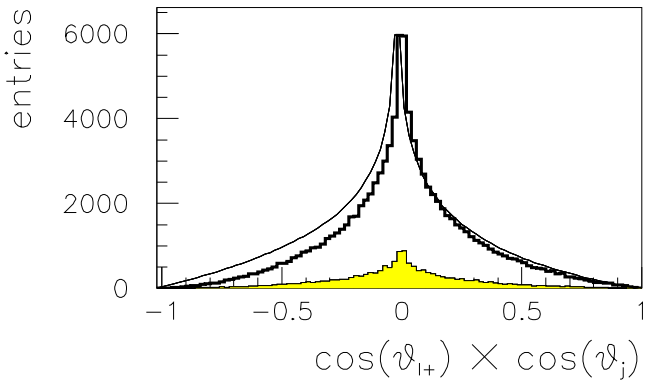


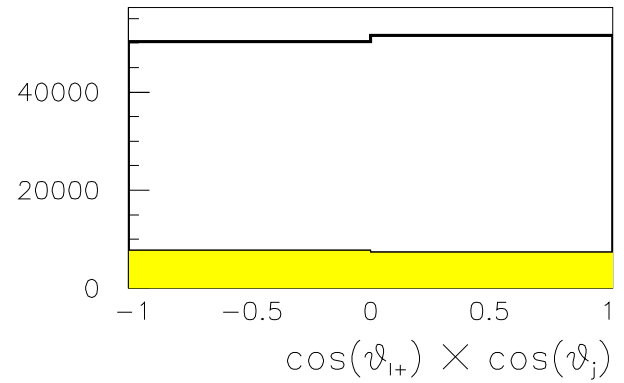




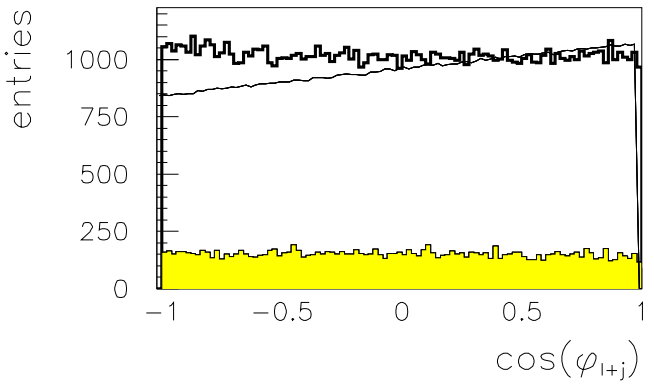
top spin asymmetries

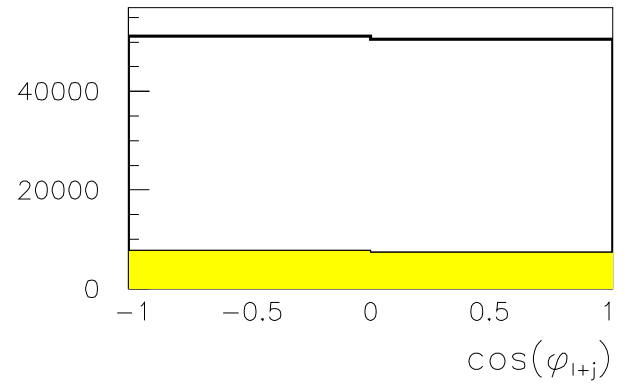
$A_{\ell j}$



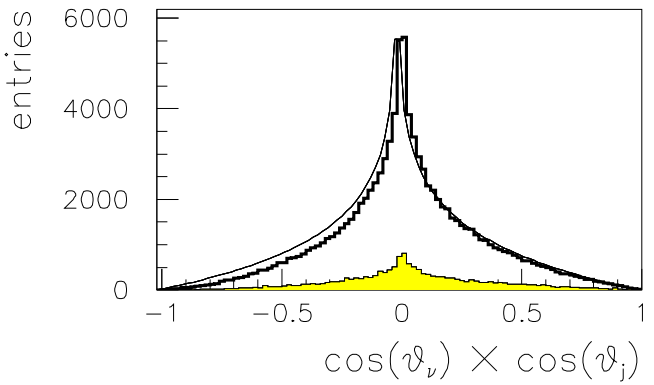


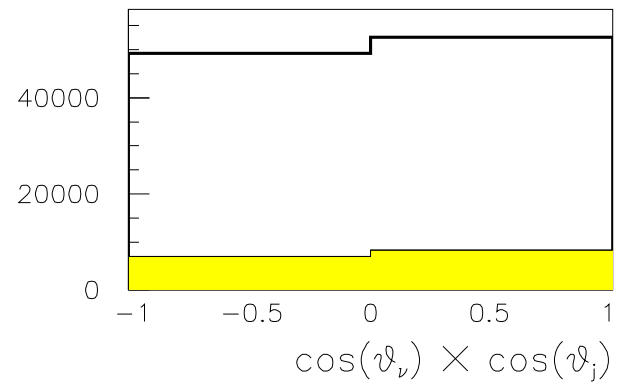
$\tilde{A}_{\ell j}$





$A_{\nu j}$





top spin asymmetries - precision

generated and corrected values of top spin asymmetries (normalized to $L = 10$ fb^{-1}):

	$A_{\ell j}$	$\tilde{A}_{\ell j}$	$A_{\nu j}$
generated	-0.0437 ± 0.0007	0.0606 ± 0.0007	0.0136 ± 0.0007
corrected	-0.0460 ± 0.0036	0.0613 ± 0.0036	0.0127 ± 0.0036
systematic error	0.0061	0.0049	0.0043

precison on the measurement of the anomalous couplings from the top spin asymmetries worse than from the W angular asymmetries or the helicity ratios

can instead be used to measure the $t\bar{t}$ spin correlation

conclusions

- ATLAS sensitivity to new physics in the $t \to bW$ decay (from angular asymmetries in the W rest frame and helicity ratios and fractions):
  - m_b should be taken into account
  - $g_R \in [-0.02, 0.02] \Rightarrow$ a factor 2-3 better than the present limits
  - further improvements expected from the combination of the semileptonic and the dileptonic channels
- as the spin asymmetries are less sensitive to the anomalous couplings, they can be used to measure the top spin correlations at the $t\bar{t}$ production
- after one year of low luminosity data taking, results already dominated by the systematic error (L=10 fb^{-1})
- preliminary tests with the full simulation give results similar to the fast simulation
- in the near future the CP asymmetries will also be tested