Spin Correlations in top quark pair events

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- Top quark spin correlation
- Production at LHC
- At tevatron
- Analysis strategies
- Description of a new method

Importance of the spin correlation

Observation of the spin correlation would:

- **confirm that the top quark does indeed decay before its spin flip, thereby setting an upper limit bound on the top quark lifetime;**
- **place a lower bound on the top quark width, which is proportional to the CKM matrix element $|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2$. If there are just three generations of quarks this quantity equals unity, but it can be smaller if there are more than three generations.**

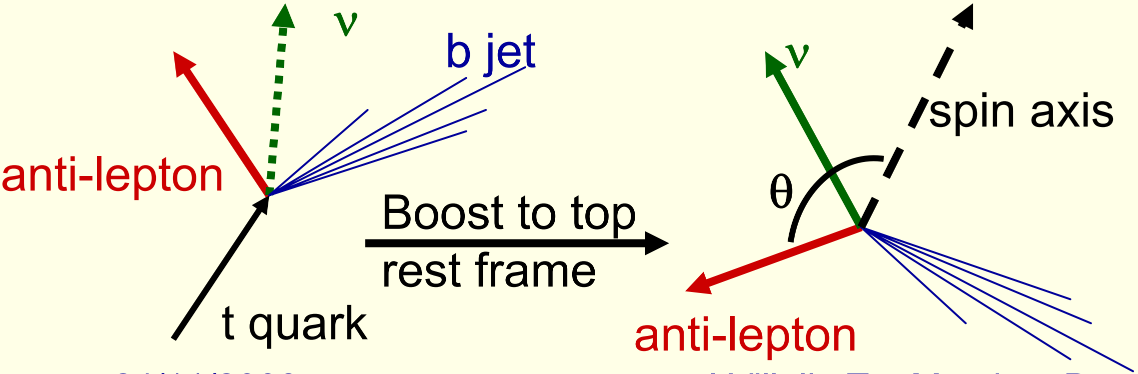
Unique feature of the top quark

Top quark is extremely short lived:

Γ_t **= 1.48 GeV →** τ_t **= 0.44 x 10^{-24} <** τ_{QCD} **≈ 3 x 10^{-24}**

The spin information is not diluted by hadronization but transferred to the decay products.

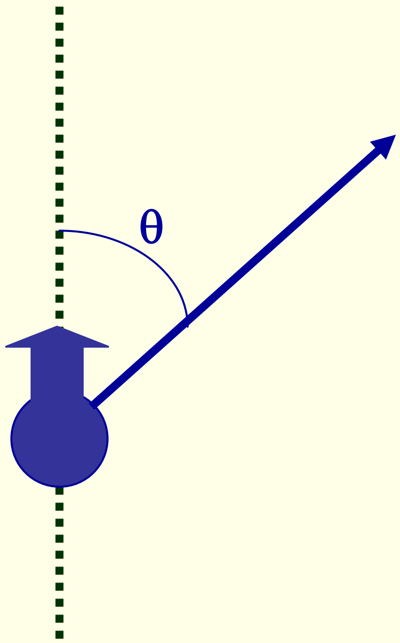
- Top and anti-top produced at hadron colliders are unpolarized, but their spins are *Correlated !!!*
- the spin of the top quark is reflected by its decay products



Helicity basis → spin axis = top direction of flight in the ttbar rest frame

Angular distribution

Angular distribution of the daughter particle:



$$\frac{1}{\Gamma}\frac{d\Gamma}{d(\cos\theta_{\pm})} = \frac{1}{2}(1+\kappa_f \cos\theta_{\pm})$$

θ = angle between the direction of motion of the daughter particle and the chosen spin axis.

κ = spin analyzer quality of top quark daughter defined as the degree to which the daughter is correlated to the top spin.

Spin analyzer quality κ of the top quark daughter particle (semileptonic decay)

i	l^+, $\bar{d}$, $\bar{s}$	ν_l, u, c	b	W^+	lower energy q
κ	1	-0.31	-0.41	0.41	0.51

Top quark spin correlation

The spin correlation of top quark pairs:

$$A = \frac{N_{\parallel} - N_X}{N_{\parallel} + N_X} = \frac{N(t_L \bar{t}_L + t_R \bar{t}_R) - N(t_L \bar{t}_R + t_R \bar{t}_L)}{N(t_L \bar{t}_L + t_R \bar{t}_R) + N(t_L \bar{t}_R + t_R \bar{t}_L)}$$

$N_{\parallel}$ N_x =number of events with parallel and anti-parallel top quark spin

The spin correlation in the semileptonic decay channel can be measured in terms of double differential distribution:

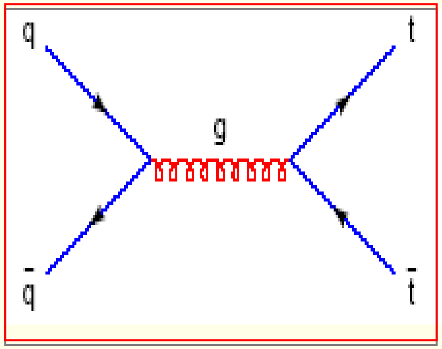
$$\frac{1}{N}\frac{d^2N}{d\cos\theta_l \, d\cos\theta_q} = \frac{1}{4}(1 - A\kappa_l\kappa_q \cos\theta_l \cos\theta_q)$$

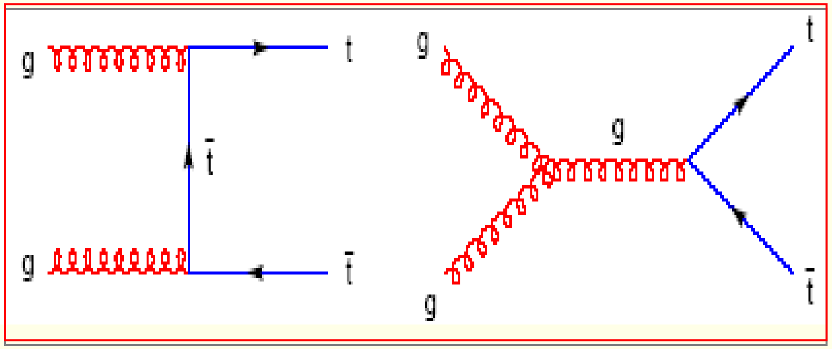
θ_l / θ_l = angle between the decay particle momentum in its parent (anti) top quark rest frame and the (anti) top quark momentum in the ttbar quark pair rest frame.

top pair production at LHC

At LHC the top quarks are mostly produced via gluon fusion (87.5%) and quark-antiquark annihilation (12.5%)

~ 12%





~ 87%

Spin correlations distinguish between the two main ttbar production mechanisms

@LHC the Standard Model prediction is: $A = 0.311^{+0.034}_{-0.035}(stat) \pm 0.028(syst)$

@Tevatron

The dominant production mechanism for t quark pair at the Tevatron is the quark – antiquark annhilation and the Standard Model prediction of the correlation is A ~ -40%.

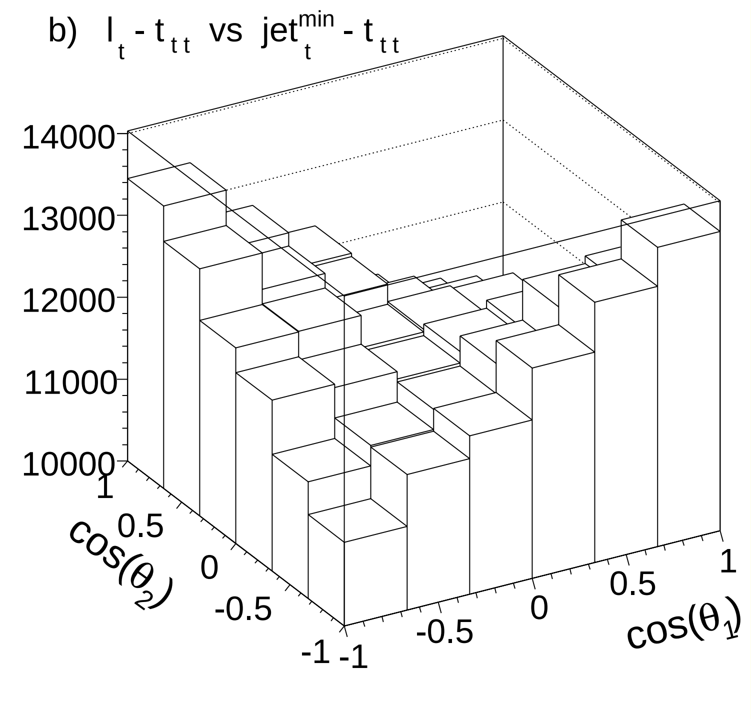
The present measurement of spin correlation performed at Tevatron is limited

by the small sample of top quarks collected.

The Spin Correlation in the top quark pair

has never been observed!!!

Double differential distribution



Double differential distribution

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_l\, d\cos\theta_q} = \frac{1}{4}(1 - A\kappa_l\kappa_q \cos\theta_l \cos\theta_q)$$

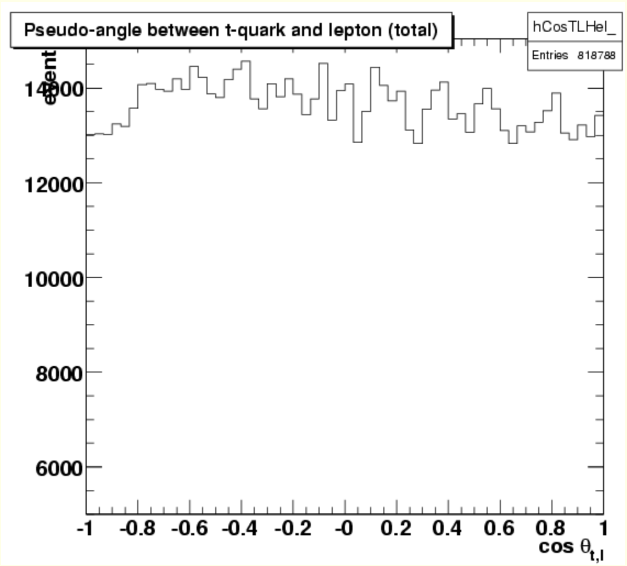
Generator level
before event selection.

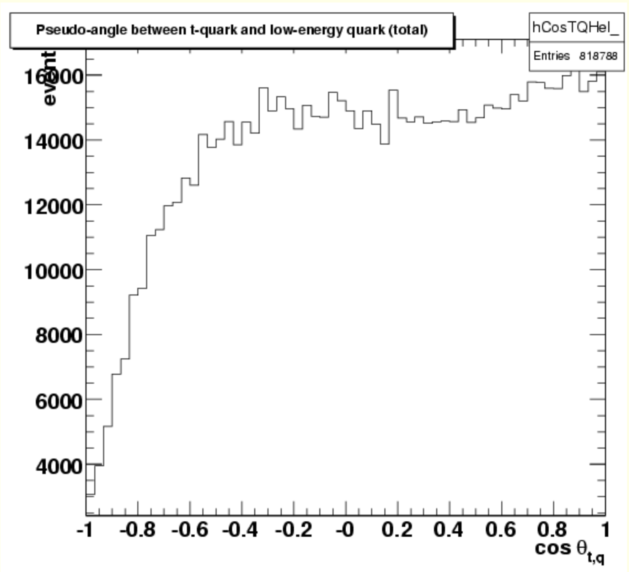
The event selection modifies significantly the shape of the double differential distribution meanly in the corners.

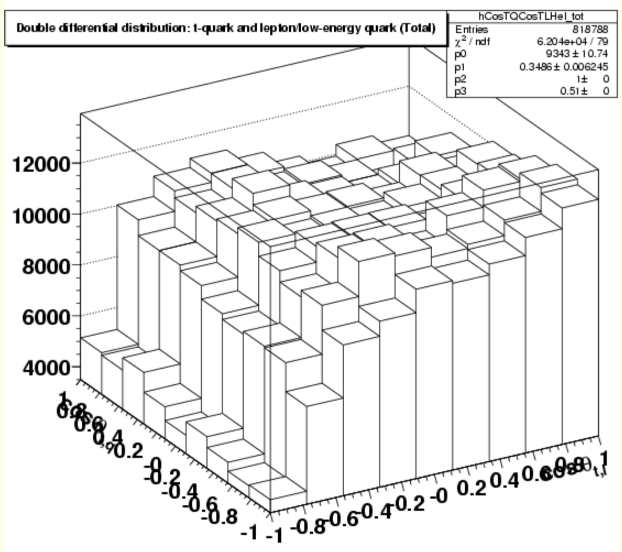
Sample

1M private ttbar semileptonic muon events using

- **MadGraph,**
- **FastSimulation CMSSW_1_6_12.**

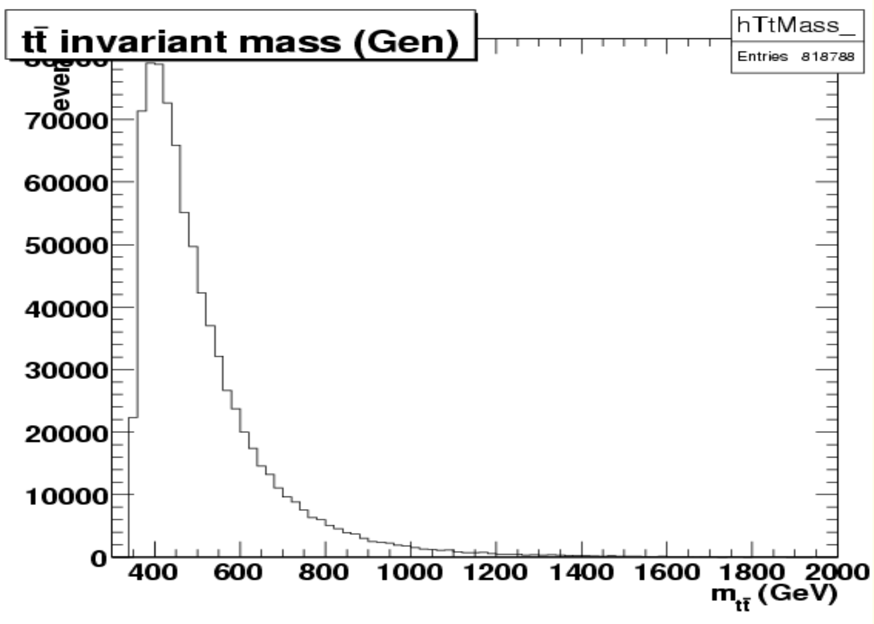






The differential distributions should be flat at generator level before event selection!!!

A new method (Jorgen's Method ;))



In several bins of m_{ttbar} the double differential distribution is fitted to obtain the magnitude of the spin correlations A:

$$f = 1/N\,(1 - \kappa_l\,\kappa_q\,A\cos\theta_l\cos\theta_q)$$

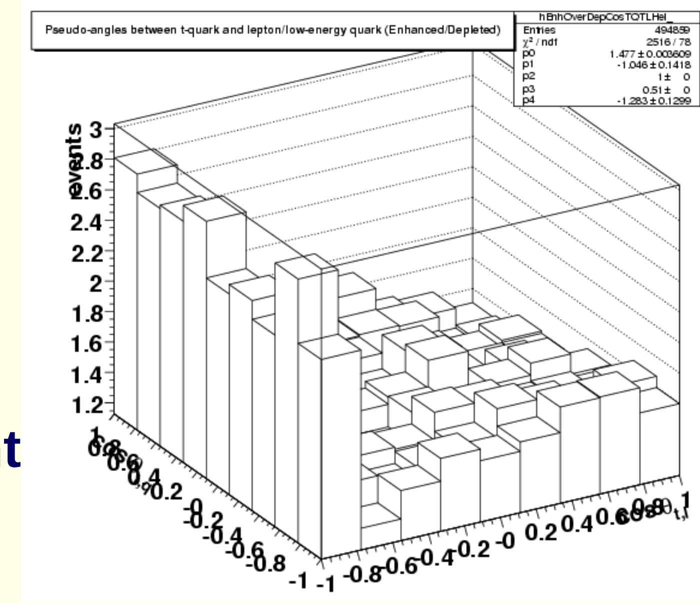
- For low masses m_{ttbar} the spin correlations are enhanced, while for higher masses they are depleted.
- The inclusive sample can be divided into two subsamples with a threshold of m_{ttbar} = 500 GeV/c^2
- The spin correlation magnitude A can be obtained from the fit
- The effect of non-zero spin correlations becomes visible making the ratio between two exclusive distributions.

Estimation of the spin correlation

The fit function becomes:

$$f = R\,(1 - kl\, k_q\, A^+ \cos\theta_l \cos\theta_q) \,/\, (1 - k_l\, k_q\, A^- \cos\theta_l \cos\theta_q)$$

The values A^+ and A^- have a well determined relation in the SM. It can be used as a constraint on the fit function.



The difference of A+ and A- is visible as an offset of the correlation axis with respec to the origine of the two dimensional plane (A+, A-).
This offset becomes measurable and can be compared with SM prediction.

Analysis Strategy

- Generator level analysis:
  - Look at A vs mttbar,
  - Check the effects of the event selection on A vs mttbar,
  - Effectiveness of the method;
- Reconstruction level analysis;
- Final event selection;
- Evaluation of the lower luminosity needed to observe the spin correlation.

Conclusions

The observation of the spin correlations in the top quark pair needs a very pure selected sample and a very high statistic.

We need to know very well the b-tagging procedure and the JES.

We have to understand very well the sample we are using and to design the analysis in order to study the properties of the observables.