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March, 2nd 2015

$$e^+e^- \to t\,\bar{t} \to \mu^+\mu^- b\,\bar{b}\,\nu_\mu\bar{\nu}_\mu$$

The Matrix Element Method
Conjugate (optimal) variables
Results
Kinematics
Conclusion

D. Atwood and A. Soni : Phys. Rev. D45 (1992) (Pioneering work in that direction, among others)

The Matrix Element Method

$$| \mathcal{M} |^2$$

All information per event is used
(Petra->LEP->Tevatron->LHC)

H.J. Behrends et al., CELLO Collab. Z. Phys. C43 (1989)

Here, we are dealing with a rich 9-dimension Phase Space:

$$\mathrm{dLips} = \mathrm{d}\cos\theta_t \ \mathrm{d}\cos\theta_b \ \mathrm{d}\phi_b \ \mathrm{d}\cos\theta_{\bar{b}} \ \mathrm{d}\phi_{\bar{b}} \ \mathrm{d}\cos\theta_{\mu^+} \ \mathrm{d}\phi_{\mu^+} \ \mathrm{d}\cos\theta_{\mu^-} \ \mathrm{d}\phi_{\mu^-}$$

and $(2\text{x}16)^2$ amplitudes^2

$$| (t^\uparrow\bar{t}^\uparrow + t^\uparrow\bar{t}^\downarrow + t^\downarrow\bar{t}^\uparrow + t^\downarrow\bar{t}^\downarrow)_\gamma + (t^\uparrow\bar{t}^\uparrow + t^\uparrow\bar{t}^\downarrow + t^\downarrow\bar{t}^\uparrow + t^\downarrow\bar{t}^\downarrow)_Z |^2$$

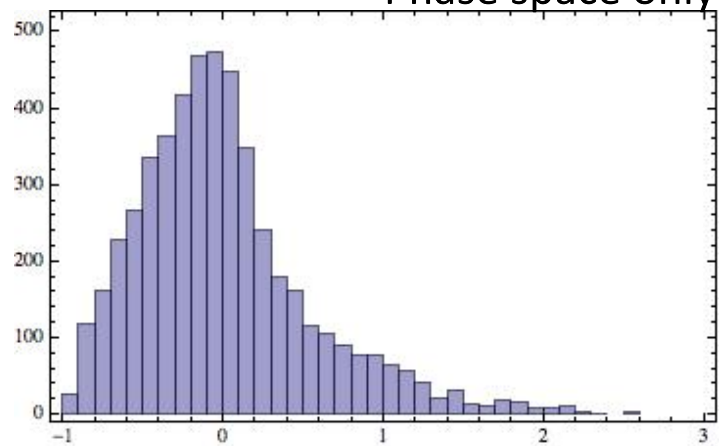
Example :

Correction term due to interferences between the helicity amplitudes

$$| t^\uparrow\bar{t}^\uparrow + t^\uparrow\bar{t}^\downarrow + t^\downarrow\bar{t}^\uparrow + t^\downarrow\bar{t}^\downarrow |^2 =$$

$$(| t^\uparrow\bar{t}^\uparrow |^2 + | t^\uparrow\bar{t}^\downarrow |^2 + | t^\downarrow\bar{t}^\uparrow |^2 + | t^\downarrow\bar{t}^\downarrow |^2) (1 + \rho)$$

Phase space only



ρ

NB:

Matrix Element Method is Optimal

BUT …

The Matrix Element should be as complete as possible (so far LO).

Things which are “trivial” to account for in other methods
using observables (eg. Forward Backward asymmetry et al.)
are no longer “trivial” if one wants to make use of them.

Example: ISR, NLO in general, etc.

$\Rightarrow$ One needs to use as complete as possible a Matrix Element

Or one should correct afterwards, but doing so thus dilute the
power of the method (how much? Maybe no big deal, maybe not)

$$\alpha \leftarrow \text{theoretical parameters}$$

$$\mathcal{L}(\alpha)$$

A likelihood analysis of events easily handle the 9-dimension analysis

It can be shown that, in effect, the Likelihood analysis implicitly makes use of "conjugate" kinematical variables defined by:

$$\omega_i = \frac{\partial \mid \mathcal{M} \mid^2 (\alpha)}{\partial \alpha_i}_{|\alpha^0} \frac{1}{\mid \mathcal{M} \mid^2 (\alpha^0)}$$

$$\Omega_i = \frac{\partial N(\alpha)}{\partial \alpha_i}_{|\alpha^0} \frac{1}{N(\alpha^0)}$$

Using only the distribution of events in Phase Space:

$$V_{ij}^{(-1)} \equiv \Lambda_{ij} = N \, \langle (\omega_i - \Omega_i)(\omega_j - \Omega_j) \rangle_0$$

Using also the yields:

$$V_{ij}^{(-1)} \equiv \Lambda_{ij} = N \, \langle \omega_i \omega_j \rangle_0$$

Simultaneous 10-parameter fit

$\mathcal{R}e\ \delta\tilde{F}^{\gamma}_{1V}$	$\mathcal{R}e\ \delta\tilde{F}^{Z}_{1V}$	$\mathcal{R}e\ \delta\tilde{F}^{\gamma}_{1A}$	$\mathcal{R}e\ \delta\tilde{F}^{Z}_{1A}$	$\mathcal{R}e\ \delta\tilde{F}^{\gamma}_{2V}$	$\mathcal{R}e\ \delta\tilde{F}^{Z}_{2V}$	$\mathcal{R}e\ \delta\tilde{F}^{\gamma}_{2A}$	$\mathcal{R}e\ \delta\tilde{F}^{Z}_{2A}$	$\mathcal{I}m\ \delta\tilde{F}^{\gamma}_{2A}$	$\mathcal{I}m\ \delta\tilde{F}^{Z}_{2A}$
0.0037	−0.18	−0.09	+0.14	+0.62	−0.15	0	0	0	0
	0.0063	+.14	−0.06	−0.13	+0.61	0	0	0	0
		0.0053	−0.15	−0.05	+0.09	0	0	0	0
			0.0083	+0.06	−0.04	0	0	0	0
				0.0105	−0.19	0	0	0	0
					0.0169	0	0	0	0
						0.0068	−0.15	0	0
							0.0118	0	0
								0.0069	−0.17
									0.0100

$$0.4 \rightarrow 1.7\%$$

$$500\ \mathrm{GeV}\ \&\ 500\ \mathrm{fb}^{-1}$$

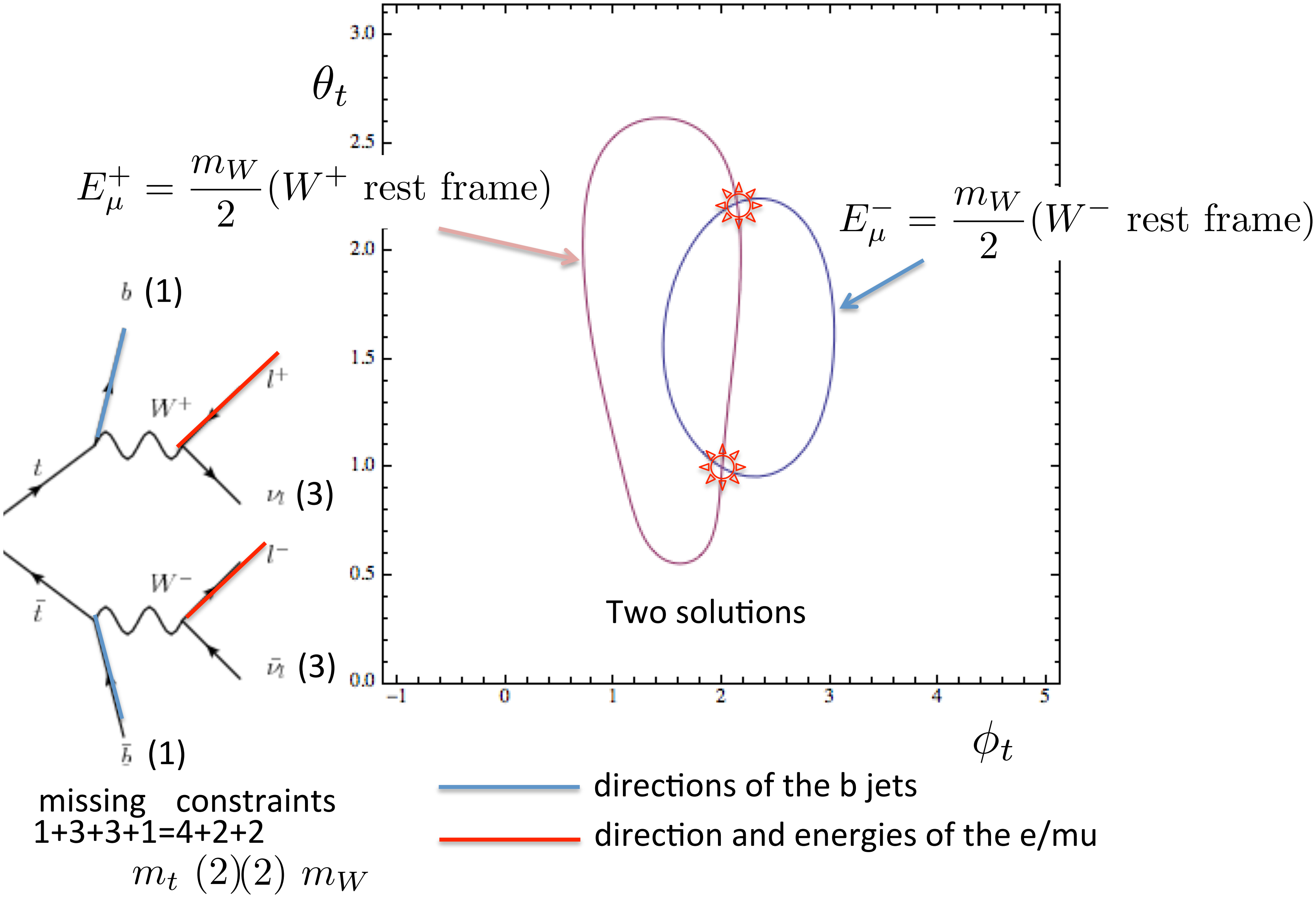
Luminosity split 50/50 between $\pm 80\% \mp 30\%$ beam polarizations

17 500 events produced

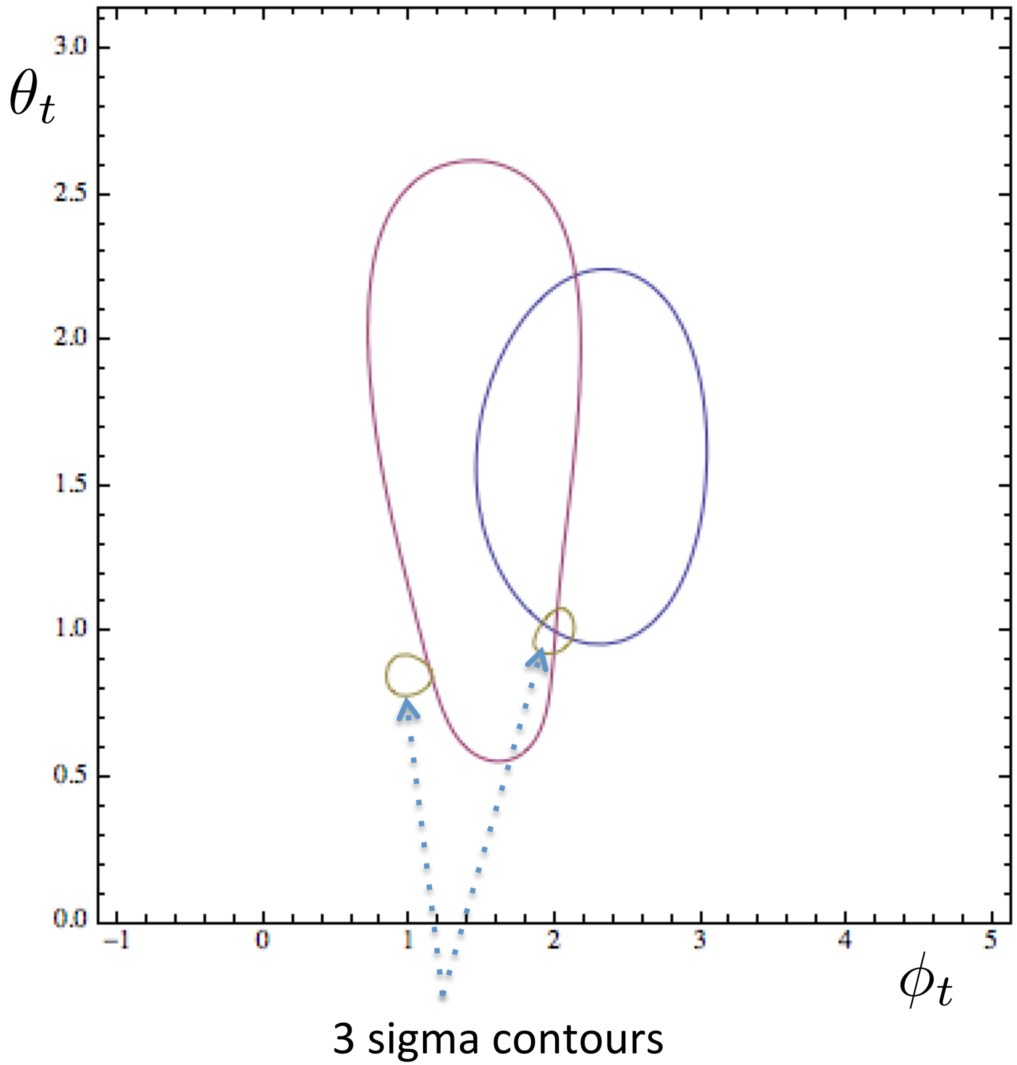
(no reconstruction & detector & background & **Physics effects** taken care of)

NLO, Hadronization

Kinematical reconstruction

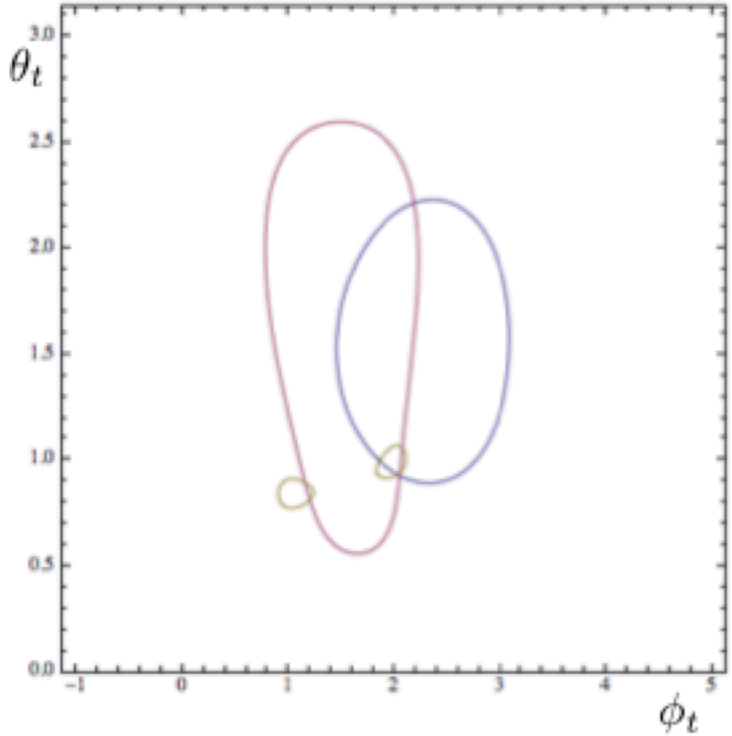


The energies of the b jets are used to select the right solution



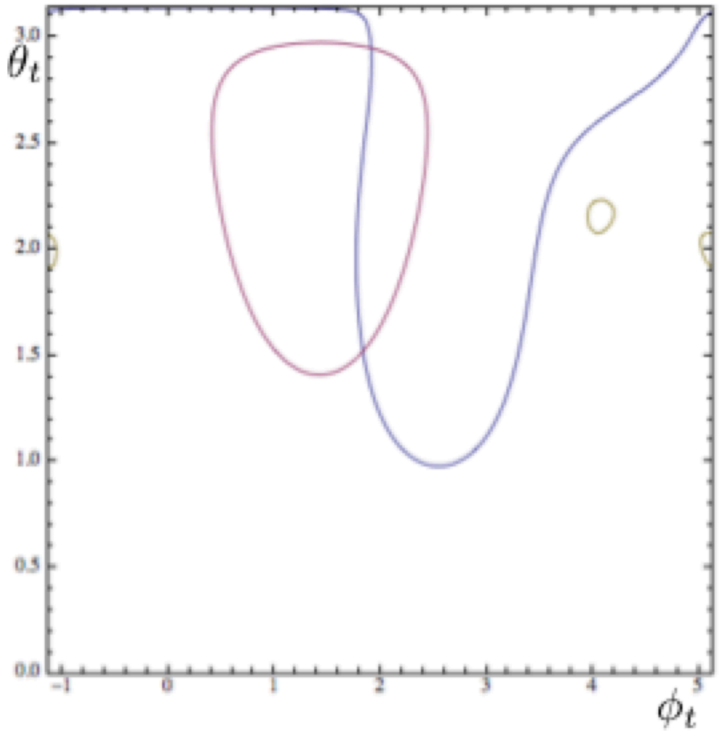
… and some complications.

The W and top widths do not help : remain manageable

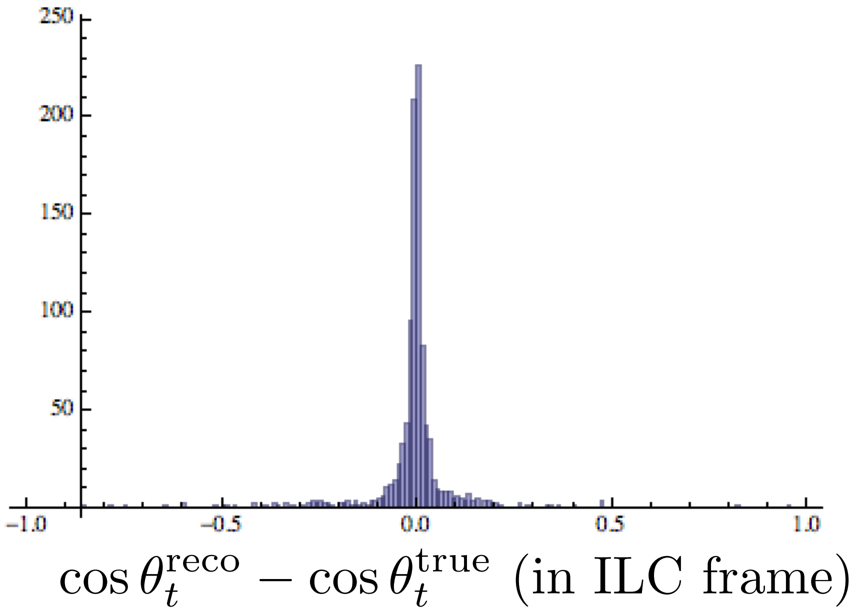


Picking up the best solution (unperfect) works

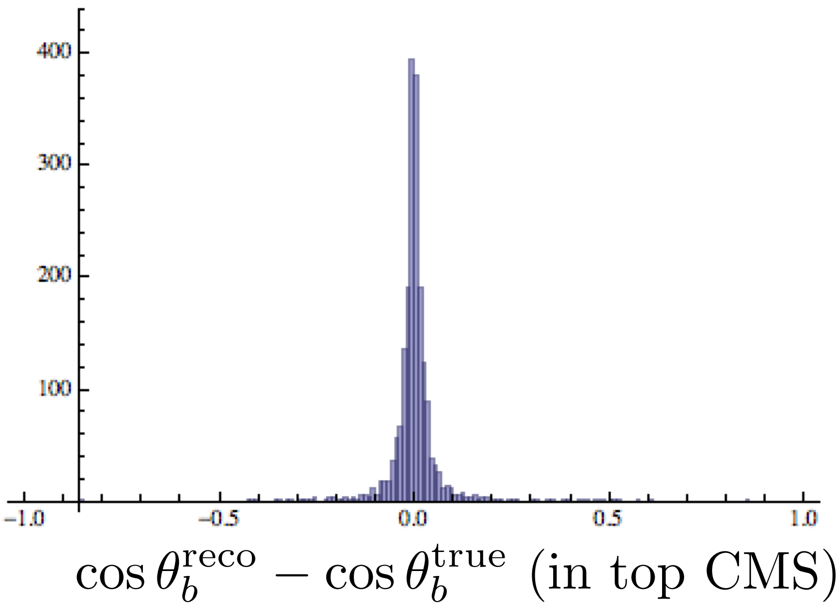
If one select the wrong b assignment : no solution



… in fact, 5% about manage to pass through



Using GRACE events, and letting the masses free to vary



Conclusion :

The final state

$$e^+e^- \to t\ \bar{t} \to \mu^+\mu^- b\ \bar{b}\ \nu_\mu \bar{\nu}_\mu$$

Appears promising for top studies :
The sensitivity to top couplings are similar to the semi-leptonic mode, but with different limitations.

A lot of work ahead

Higgs couplings

Top couplings