

# Phenomenologic Studies @ the LHC

António Onofre

LIP/UM, onofre@fisica.uminho.pt



LIP 2016, Fevereiro 19

Universidade do Minho, Campus de Gualtar, Braga

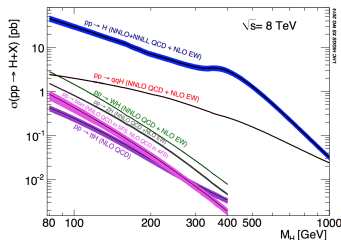
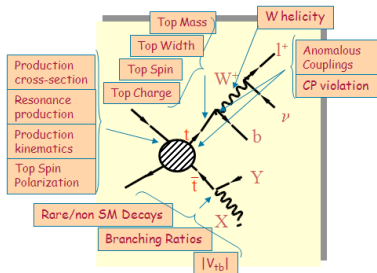


Governo da República  
Portuguesa



## Top quark and Higgs Phenomenology @ LHC

- $t\bar{t}$  production
  - $\sigma_{t\bar{t}}$
  - Mass
  - Charge
  - $W$  polarization and the  $t \rightarrow bW$  decay
  - Anomalous couplings
  - $t\bar{t}$  Spin correlations
  - $t\bar{t}$  resonances
- Single top production
  - Cross section
  - FCNC
- Higgs physics
  - $t\bar{t}H$
  - $pp \rightarrow H + X$



# 1- The $Wtb$ vertex and global fitter TopFit

The  $Wtb$  vertex is determined by a global fit to several observables:

- Several, theoretically equivalent, observables studied for  $t\bar{t}$  production at LHC (not all explored yet @ LHC)
- Single top cross section usefull (sensitive to  $V_{tb}$  and anomalous couplings)
- Indirect limits from  $b \rightarrow s\gamma$  available (not used)
- All couplings are allowed to vary freely in TopFit, i.e. the global fitter developed by the team to find the allowed regions for the anomalous couplings for a given wanted CL

# $t\bar{t}$ Production: Anomalous couplings at the $Wtb$ vertex

## General $Wtb$ vertex

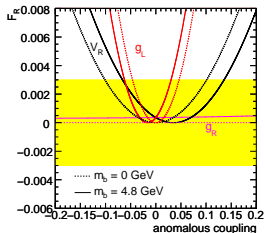
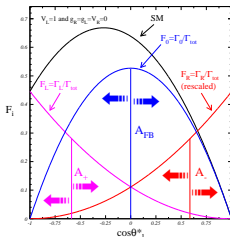
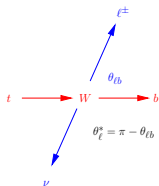
Eur.Phys.J. C50 (2007) 519-533

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

- New **angular asymmetries** and **helicity ratios** were introduced to probe anomalous couplings:

$$A_t = \frac{N(\cos \theta_\ell^* > t) - N(\cos \theta_\ell^* < t)}{N(\cos \theta_\ell^* > t) + N(\cos \theta_\ell^* < t)}$$

$V_R, g_L$  and  $g_R$   
change  $F_R, F_L$  and  $F_0$   
( $\rho_R = F_R/F_0, \rho_L = F_L/F_0$ )

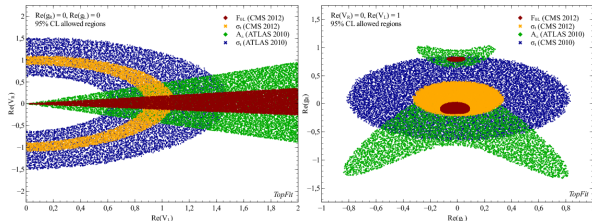


(NLO)  $A_{FB} = -0.2269$ ,  $A_+ = 0.5429$ ,  $A_- = -0.8402$ ,  $\rho_L = -0.8402$  and  $\rho_R = -0.8402$

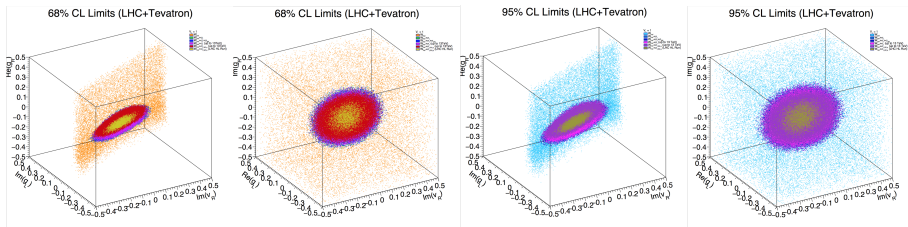


# Constraints from LHC and Tevatron data

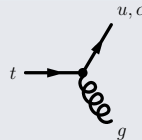
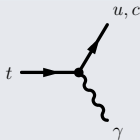
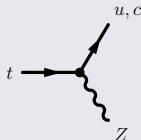
Phys.Rev. D90 (2014) 11, 113007



in preparation (all anomalous couplings with both real and imaginary parts)



## Several top quark FCNC Vertices Studied:



## Enhanced Branching Ratios for several models:

BR( $t \rightarrow \text{FCNC}$ ) in several models:

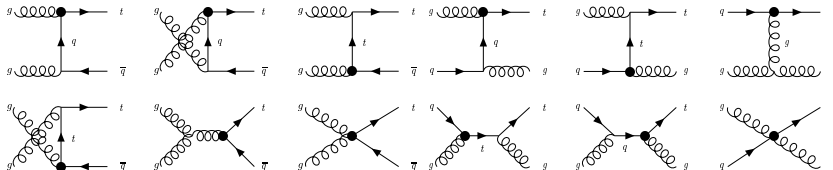
	SM	QS	2HDM	FC 2HDM	MSSM	$\mathcal{R}$ SUSY
$t \rightarrow q\gamma$	$\sim 10^{-14}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-6}$
$t \rightarrow qZ$	$\sim 10^{-14}$	$\sim 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$\sim 10^{-6}$	$\sim 10^{-5}$
$t \rightarrow qg$	$\sim 10^{-12}$	$\sim 10^{-7}$	$\sim 10^{-4}$	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-4}$

[Acta Phys. Polon. B 35 (2004) 2695]

- Effects of FCNC may manifest at **top quark production** and **decay** and indicates the existence of New Physics beyond the Standard Model

## What was the contribution from the project?

- A new NLO generator is now available (MTop) to the community and it has been used by the LHC Collaborations
- It includes @ NLO single top + jet production ( $g g \rightarrow \bar{q} t + X$ ,  $g q \rightarrow g t + X$ )  
(many contributions from Strong and EW sectors)



- **Eur.Phys.J. C72 (2012) 2222**

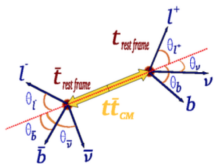
# 3-Spin Correlations in $t\bar{t}$ Events

Although produced unpolarised, the  $t$  spins are correlated in  $t\bar{t}$  events

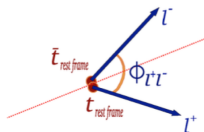
Two spin correl. parameters studied using angular distributions:  $A$  and  $A_D$

$$A = \frac{\sigma(t_{\uparrow}\bar{t}_{\uparrow}) + \sigma(t_{\downarrow}\bar{t}_{\downarrow}) - \sigma(t_{\uparrow}\bar{t}_{\downarrow}) - \sigma(t_{\downarrow}\bar{t}_{\uparrow})}{\sigma(t_{\uparrow}\bar{t}_{\uparrow}) + \sigma(t_{\downarrow}\bar{t}_{\downarrow}) + \sigma(t_{\uparrow}\bar{t}_{\downarrow}) + \sigma(t_{\downarrow}\bar{t}_{\uparrow})}$$

$$\frac{1}{N} \frac{d^2 N}{d \cos \theta_1 d \cos \theta_2} = \frac{1}{4} (1 - A |\alpha_1 \alpha_2| \cos \theta_1 \cos \theta_2), \quad \alpha_i = \text{spin analysing power of } i$$



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



$$A^{\text{SM}} = 0.326^{+0.003}_{-0.002}(\mu)^{+0.013}_{-0.001}(\text{PDF}), \quad A_D^{\text{SM}} = -0.237^{+0.005}_{-0.007}(\mu)^{+0.000}_{-0.006}(\text{PDF})$$

$$A^{\text{SM}} = 0.422, \quad A_D^{\text{SM}} = -0.290 \quad (m_{t\bar{t}} < 550 \text{ GeV})$$

Nucl.Phys.**B690** (2004) 81, Eur.Phys.J.**C44** (2005) s13-s33

# 3-Spin Correlations in $t\bar{t}$ Events

## Talk @ ICNFP2015, Greece, on behalf of ATLAS+CMS

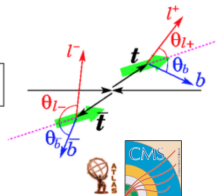
- **Top Spin Correlations are a powerful test of the SM:**
  - ☞  $t\bar{t}$ : top quarks are produced unpolarised but their spins are correlated in the SM
  - ☞ Different BSM predict different spin correlations, 1) and 2)
- **Measure angular distributions of decay products:**

$$\frac{1}{\sigma} \frac{d^2\sigma}{d[\cos(\theta_i)]d[\cos(\theta_j)]} = \frac{1}{4} [P\alpha_i \cos(\theta_i) + P\alpha_j \cos(\theta_j) + A\alpha_i\alpha_j \cos(\theta_i) \cos(\theta_j)]$$

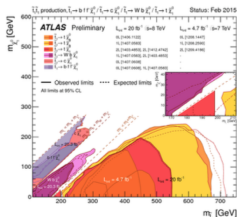
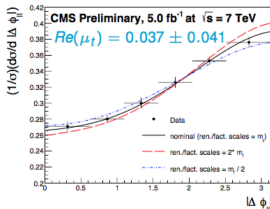
$$A = \frac{N_{\text{like}} - N_{\text{unlike}}}{N_{\text{like}} + N_{\text{unlike}}}$$

Spin analyser power of particles:

	$b$	$\ell$	$d$	$u$
$\alpha$ (NLO)	-0.39	0.998	0.93	-0.31



### 1) CMS @ 7 TeV Chromo-magnetic anomalous couplings: CMS PAS TOP-14-005



### ATLAS@7 TeV:

PRD 90 112016 (2014)

☞ easiest observable,  $\Delta\phi_{\ell\ell}$

☞ but there are others,

$$S = \frac{(|\mathcal{M}|_{RR}^2 + |\mathcal{M}|_{LL}^2)_{\text{corr}}}{(|\mathcal{M}|_{RR}^2 + |\mathcal{M}|_{LL}^2)_{\text{uncorr}}}$$

### CMS@7 TeV:

PRL 112 182001 (2014)

$A_{\Delta\phi}, A_{c_1 c_2}$  with  $c_i = \cos(\theta_i)$

$$\Delta f_{SM}/f_{SM} = 12\%$$

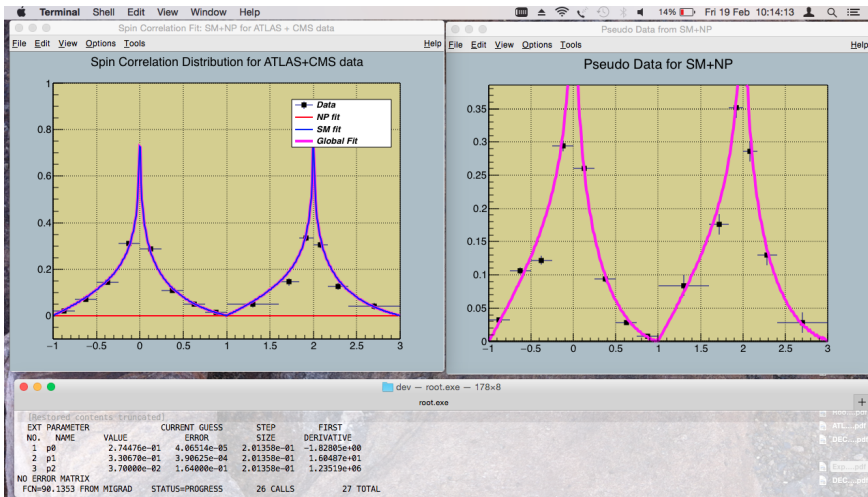
### 2) ATLAS @ 8TeV Spin Corr. can exclude $\tilde{t}$ masses from $m_{\tilde{t}} \rightarrow 191$ GeV @95% CL

ATLAS @ 8 TeV  $f_{SM} = 1.20 \pm 0.05(\text{stat}) \pm 0.13(\text{sys})$  PRL 114 142001 (2015)

CMS @ 8 TeV  $f_{SM} = 0.72 \pm 0.09(\text{stat})^{+0.15}_{-0.13}(\text{sys})$  CMS PAS TOP-13-015

# 3-Spin Correlations in $t\bar{t}$ Events

New fits of angular distributions from the project  
very, very, VERY Preliminary

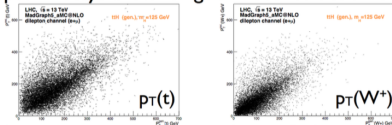




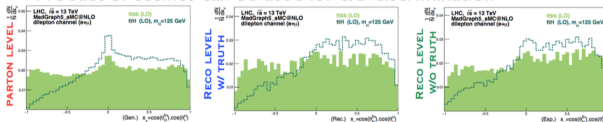
## Spin correlation in $t\bar{t}H$ : Improve S/B discrimination

Amor dos Santos et al. arXiv:1503.07787

- Use information from spin correlations to separate S and B ( $t\bar{t}b\bar{b}$ )
- Check robustness of variables against PS / detector simulation
- Dilepton decays allow for good reconstruction of top/W



- Product of cosines can be used for S/B discrimination



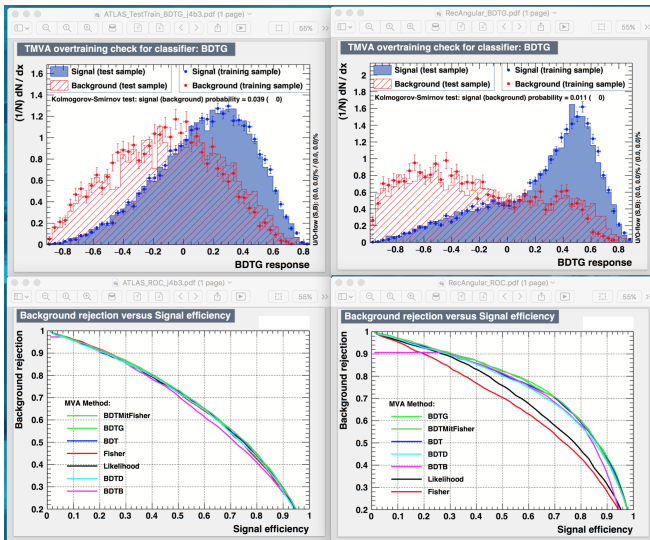
Marco Zaro, 17-09-2015

11

# 4-Higgs Physics

Loss of sensitivity @ 13TeV + Angular Dist.

👉 tough game





# Top Quark workshops

Next workshop TOP2016 @  
<https://indico.cern.ch/event/486433/overview>

**TOP 2006**  
International Workshop on Top Quark Physics  
January 12-15, 2006  
University of Coimbra, Portugal

**top2008**  
International Workshop on Top Quark Physics  
**Information and Registration**

**TOP 2010**  
3<sup>rd</sup> International Workshop on Top Quark Physics  
September 16-21, 2010  
Winchester, U.K.

**TOP 2012**  
5<sup>th</sup> International Workshop on Top Quark Physics  
September 16-21, 2012  
Winchester, U.K.

**TOP 2014**  
6<sup>th</sup> International Workshop on Top Quark Physics  
14-19 September 2013  
Durbach, Germany

**TOP 2016**  
9<sup>th</sup> INTERNATIONAL WORKSHOP ON TOP QUARK PHYSICS  
19 - 23 September 2016  
Olomouc, The Czech Republic

**TOP 2010**  
May 31 - June 4, 2010  
Bruges, Belgium

**TOP 2016**  
http://top2016.particle.cz

**International Advisory Committee**  
Matteo Cacciari, Fermilab  
Gordon Dorschner, Vrije Universiteit Amsterdam  
Michael Mangano, CERN  
Rolf Mertens, LBNL  
Roberto Morgante, INFN  
Alexander Peters, Cambridge  
Antonio Onofre, LBNL  
Frank Owe, Stockholm  
Juan Antonio Aguilar-Saavedra, Granada  
Vitaly Smirnov, CERN  
Pedro Silva, CERN  
Giovanni Stenlund, Stockholm  
Roberto Tanaka, INFN Pisa

**Local Organizing Committee**  
Jiri Kalin (chair), IPU Olomouc  
Renar Ali, CTU Prague  
Karel Augustin, CTU Prague  
Pavel Bartis, CTU Prague  
Lukáš Bělák, IPU Olomouc  
Jiri Franc, CTU Prague  
Miroslav Janáček, IPU Olomouc  
Pavel Hanel, IPU Olomouc  
Miroslav Hladký, IPU Olomouc  
Jiri Chvaloun, IPU Olomouc  
Ladislav Chvaloun, IPU Olomouc  
Katerina Chvalounová, IPU Olomouc  
Jana Jurek, SUDS CTU Prague  
Tereza Konečná, IPU Olomouc

**Advisory committee**  
Werner Burgard, DESY, Hamburg  
Tomas Dolezal, CTU Prague  
Stefano Frixione, CERN, EPFL

**Small organisation**  
Jana Jurek, SUDS CTU Prague  
Tomas Konecny, IPU Olomouc

**Past TOP Conferences**  
TOP 2011, Sant Feliu de Guindox, Spain  
TOP 2009, La Boccia, Italy

**Conferences**  
CTU Prague  
IPU Olomouc  
SUDS CTU Prague  
LBNL  
CERN  
EPFL  
FZJ

- **Immediate next steps: focus on global fitters for top quark and Higgs physics (angular distributions)**

- **(almost) Final thoughts:**

The project has been able to establish a good collaboration between Experimentalists and Theorists

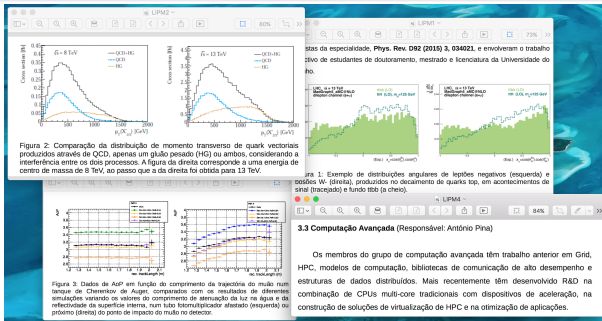
- Several tools have been developed and are available to the LHC community (several others are in the pipeline)
- Undergraduate, Master and PhD students have been trained
- .....financial issues are strongly limiting the activity

- **The activity is beeing extended to other fields (search for new particles 🖱️ ask Nuno)**

- at last but not the least....

## Structure of the LIP-Minho Group (26 members):

- A- Experimental Particle Physics Group with Accelerators
  - A1 Measurements (Antonio Onofre)
  - A2 Searches (Nuno Castro)
- B- Experimental Particle Physics Group without Accelerators, Astroparticles
  - B1 Auger (Raul Sarmento)
- C- Advanced Computing Group (Antonio Pina)
- D- Outreach, Advanced Education and Technology Transfer



### 3.3 Computação Avançada (Responsável: António Pina)

Os membros do grupo de computação avançada têm trabalho anterior em Grid, HPC, modelos de computação, bibliotecas de comunicação de alto desempenho e estruturas de dados distribuídos. Mais recentemente têm desenvolvido R&D na combinação de CPUs multi-core tradicionais com dispositivos de aceleração, na construção de soluções de virtualização de HPC e na otimização de aplicações.