Phenomenologic Studies @ the LHC

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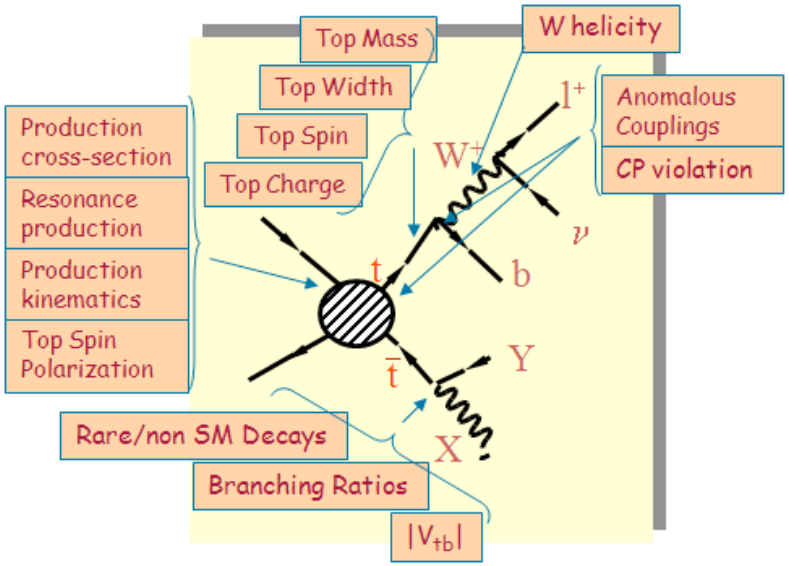
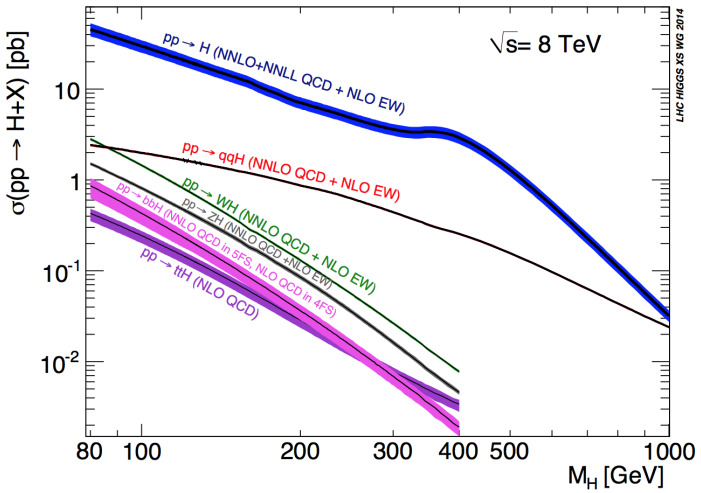
Top quark and Higgs Phenomenology @ LHC

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





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 $b \to s\gamma$ 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

General Wtb vertex

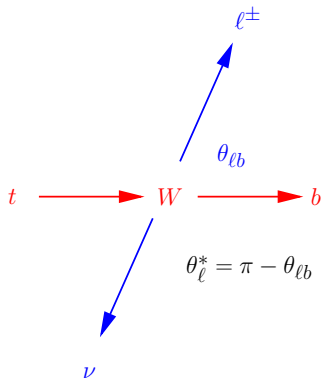
Eur.Phys.J. C50 (2007) 519-533

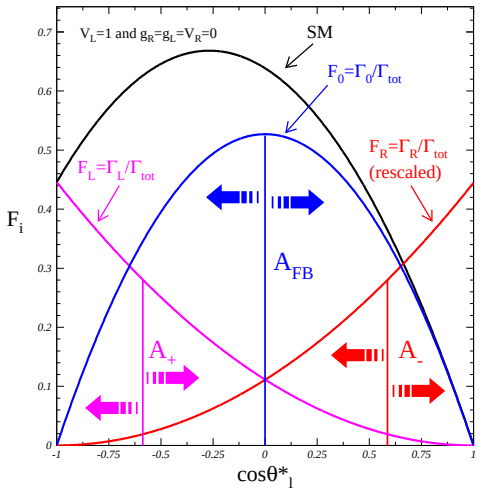
$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t\, W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(g_L P_L + g_R P_R\right) t\, W_{\mu}^{-}$$

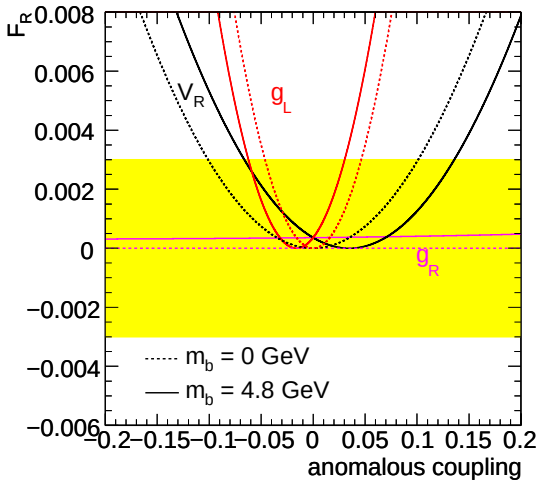
- New angular asymmetries and helicity ratios were introduced to probe anomalous couplings:

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

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



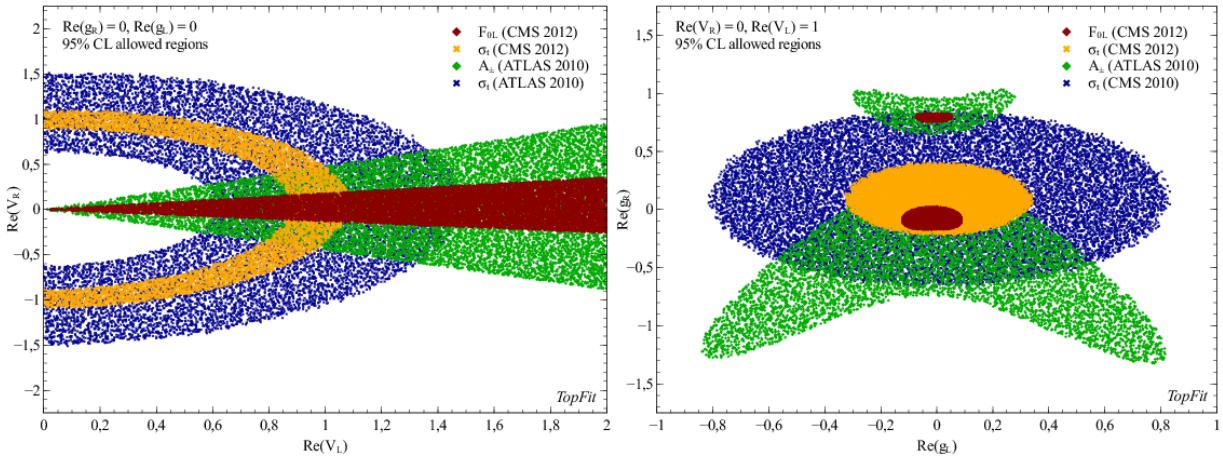




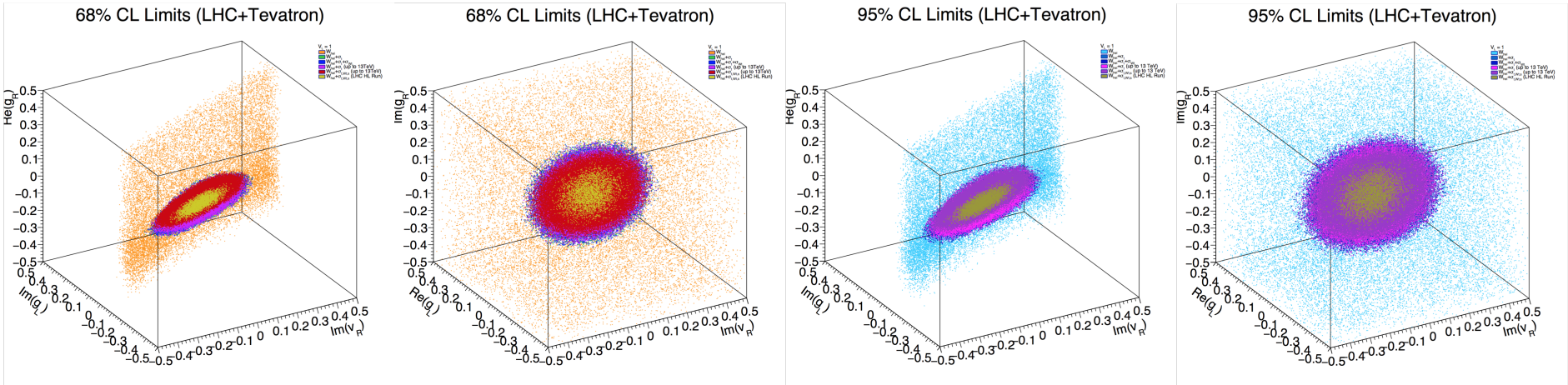
(NLO) A_{FB}=-0.2269, A_+=0.5429, A_-=-0.8402, ρ_L=-0.8402 and ρ_R=-0.8402

Constraints from LHC and Tevatron data

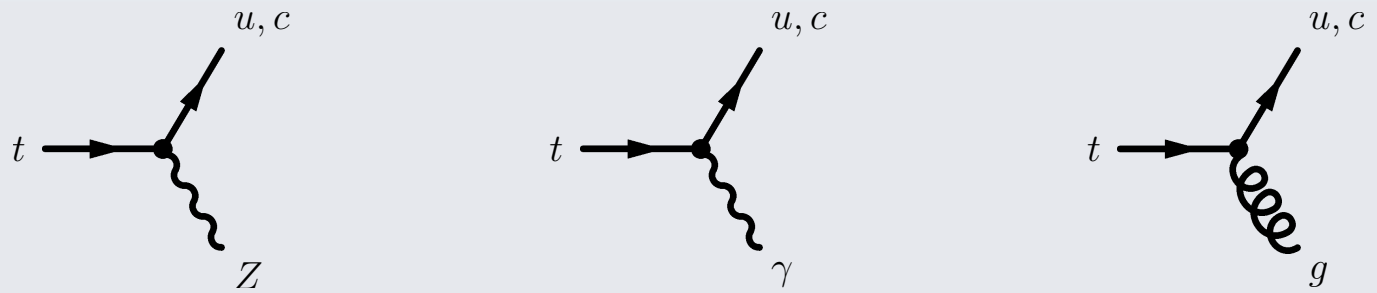
Phys.Rev. D90 (2014) 11, 113007



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



Several top quark FCNC Vertices Studied:



Ennhanced Branching Ratios for several models:

BR($t \to$ FCNC) in several models:

	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY
$t \to q\gamma$	$\sim 10^{-14}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-6}$
$t \to qZ$	$\sim 10^{-14}$	$\sim 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$\sim 10^{-6}$	$\sim 10^{-5}$
$t \to qg$	$\sim 10^{-12}$	$\sim 10^{-7}$	$\sim 10^{-4}$	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-4}$

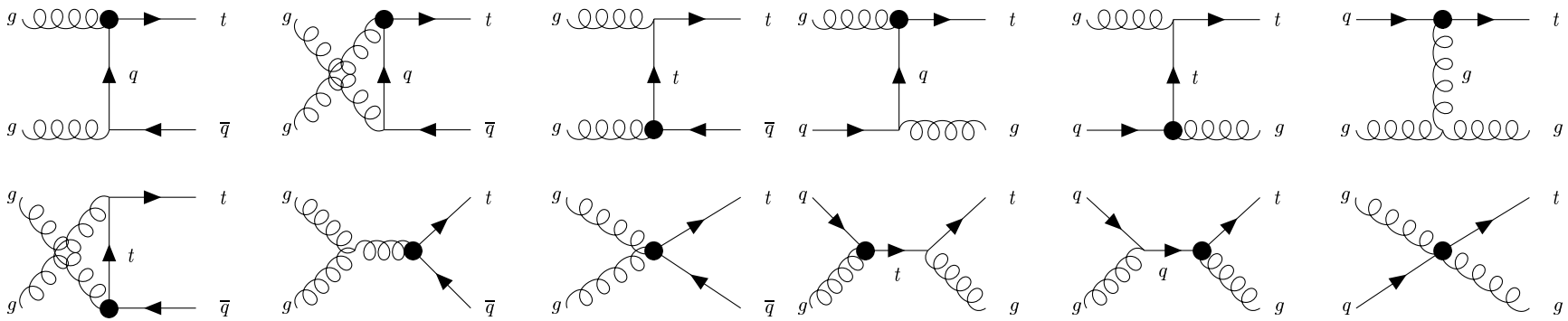
[Acta Phys. Polon. B 35 (2004) 2695]

- 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 (METop) to the community and it has been used by the LHC Collaborations
- It includes @ NLO single top + jet production
  ($g\,g \to \bar{q}\,t + X$, $g\,q \to g\,t + X$)

  (many contributions from Strong and EW sectors)



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

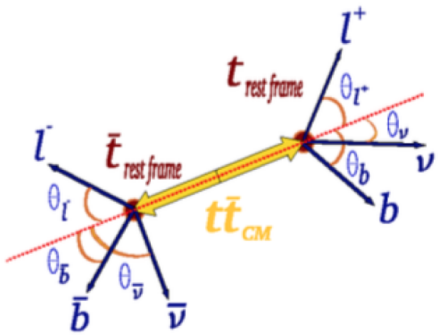
3-Spin Correlations in $t\bar{t}$ Events

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

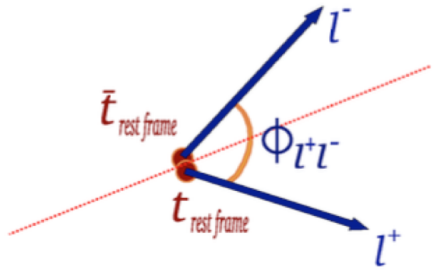
Two spin correl. parameters studied using angular distributions: A and A_D

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

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



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



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

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

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

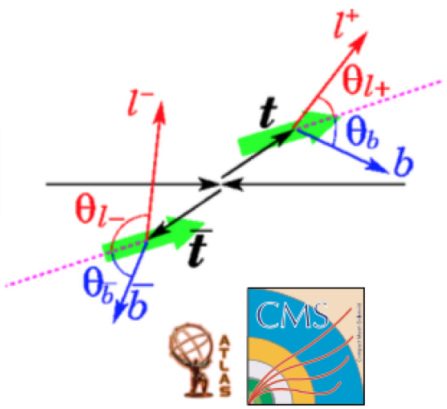
- **Top Spin Correlations are a powerful test of the SM:**
  - ☞ $t\bar{t}$: top quarks are produced unpolarised but their spins are correlated in the SM
  - ☞ Different BSM predict different spin correlations, 1) and 2)
- **Measure angular distributions of decay products:**

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

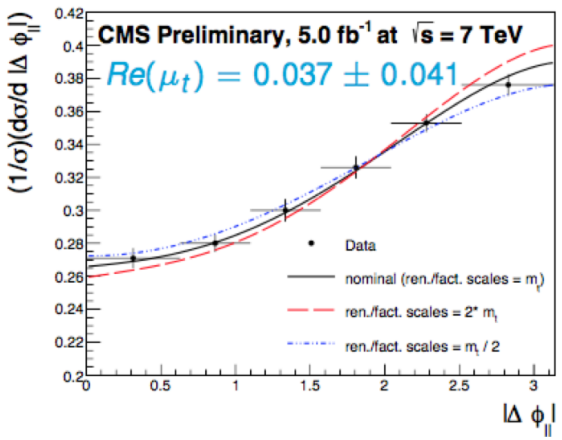
$$A = \frac{N_{like} - N_{unlike}}{N_{like} + N_{unlike}}$$

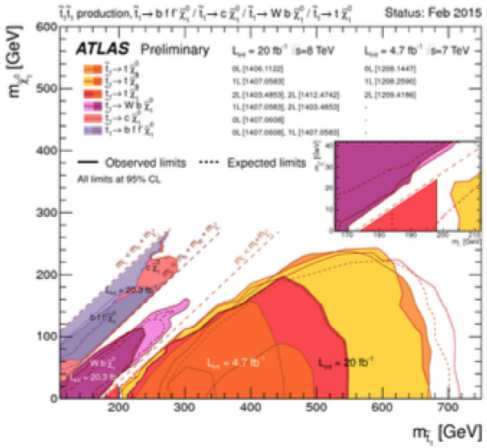
Spin analyser power of particles:

	b	ℓ	d	u
α (NLO)	-0.39	0.998	0.93	-0.31



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





2) ATLAS @ 8TeV Spin Corr. can exclude t̃ masses from m_t →191 GeV @95% CL

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

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

ATLAS@7 TeV:

PRD **90** 112016 (2014)

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

☞ but there are others,

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

CMS@7 TeV:

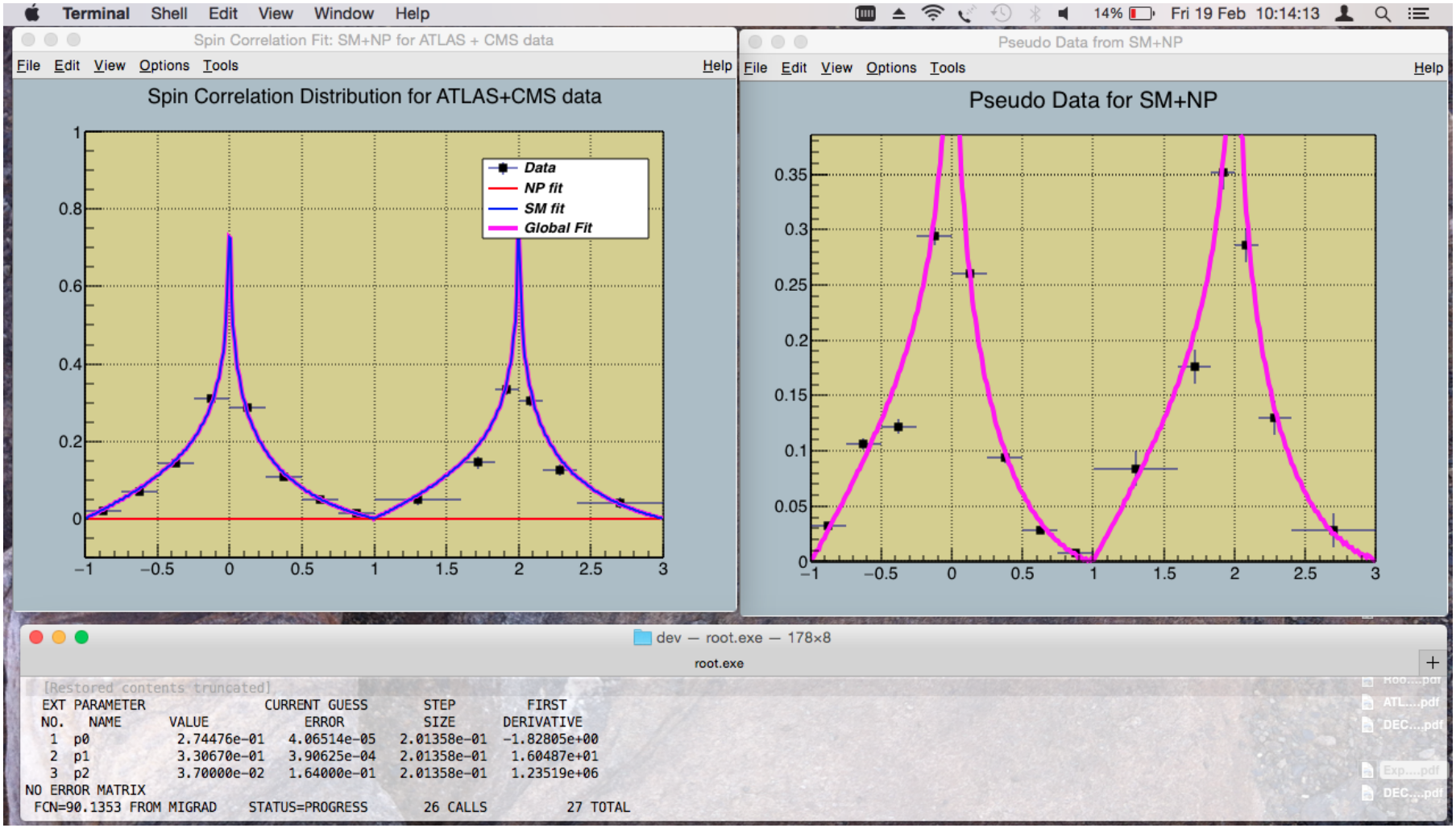
PRL **112** 182001 (2014)

$A_{\Delta\phi}$, $A_{c_1c_2}$ with $c_i = cos(\theta_i)$

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

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

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



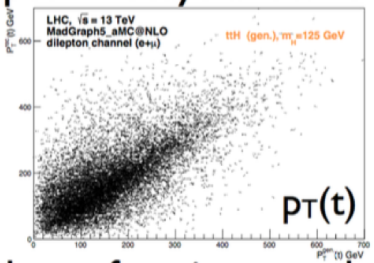
Presented by Zaro @ TOP2015

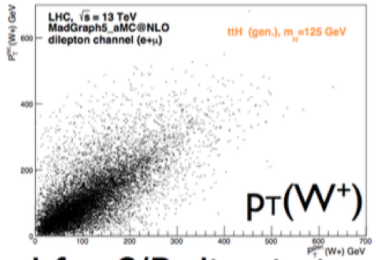
Higgs properties @ the LHC

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

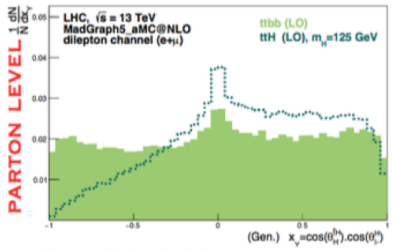
Amor dos Santos et al. arXiv:1503.07787

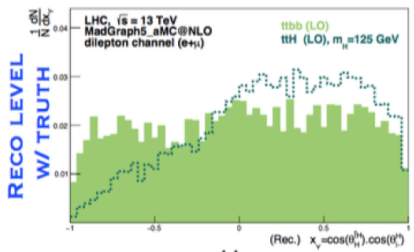
- Use information from spin correlations to separate S and B ($t\bar{t}b\bar{b}$)
- Check robustness of variables against PS / detector simulation
- Dilepton decays allow for good reconstruction of top/W

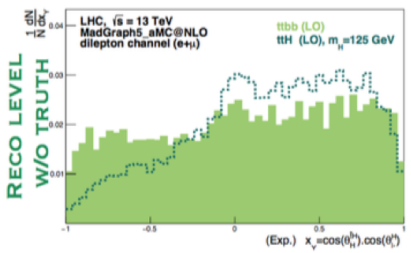




- Product of cosines can be used for S/B discrimination





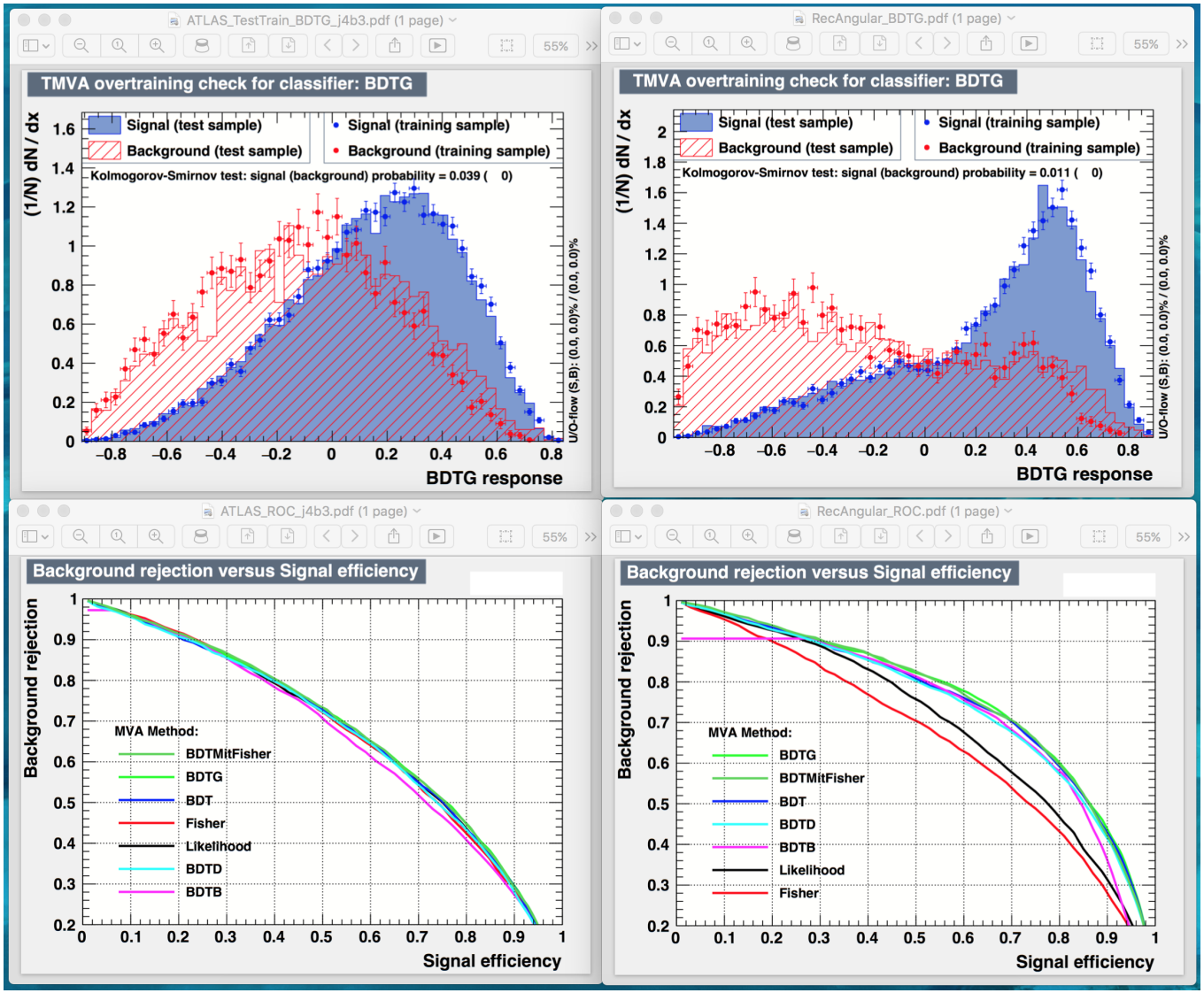


Marco Zaro, 17-09-2015

11

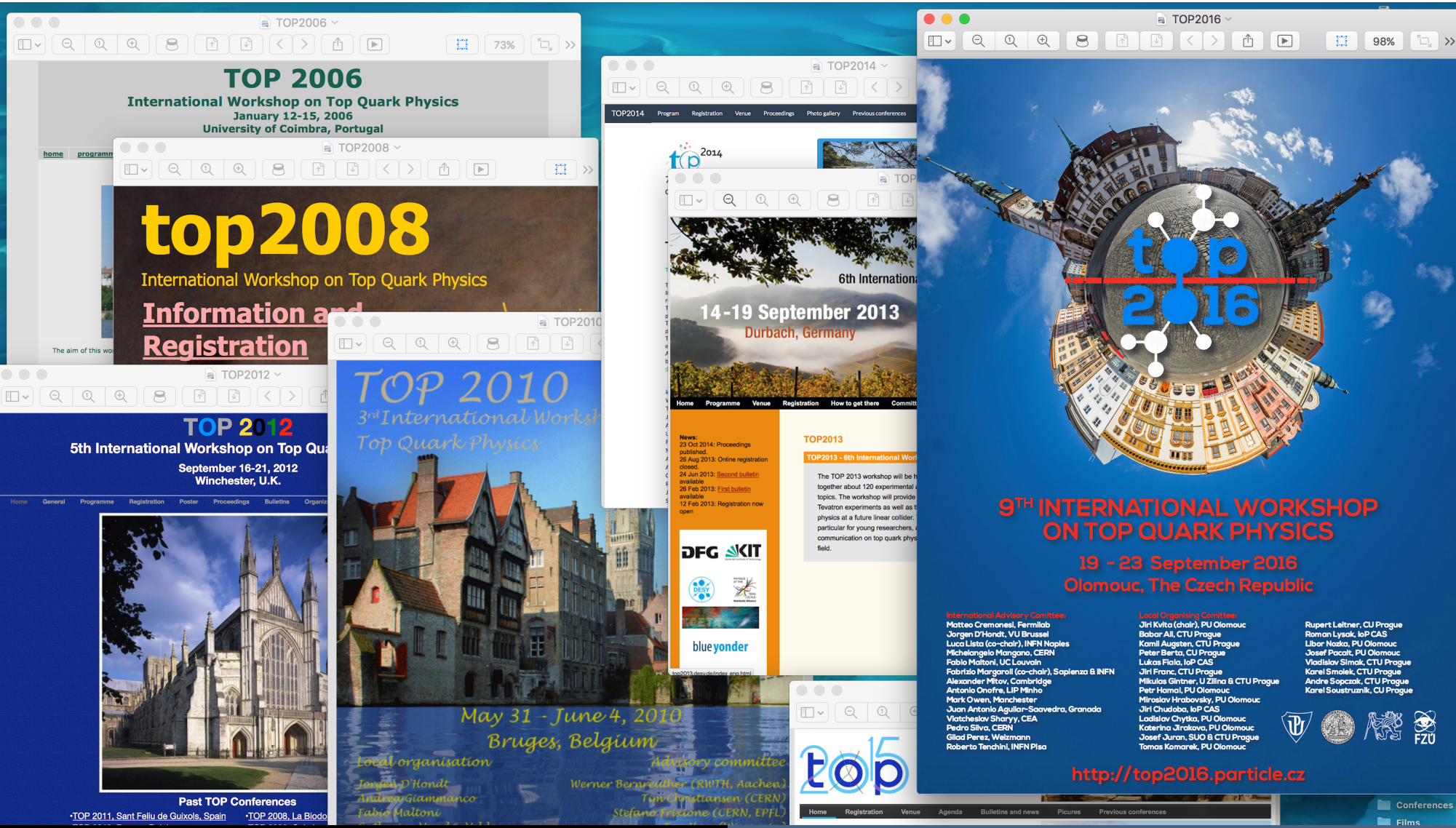
Loss of sensitivity @ 13TeV + Angular Dist.

☞ tough game



Top Quark workshops

Next workshop TOP2016 @ https:indico.cern.chevent486433overview



Next Steps and conclusions

- **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