# LHC combination: W helicity fraction in top-pair decays

K.Kroeninger (ATLAS)
Goettingen U.

M.S.Soares (CMS)
CIEMAT Madrid

-TOPLHC group open meeting -
29/Nov/2012

# Outline

- Introduction

- Most recent W helicity measurements

- Summary of BLUE inputs for LHC combination

  - Input measurements

  - Categories of systematics

  - Categories of correlations

- Status and outlook

# Introduction

- W helicity in top pair decays: important test of Wtb structure

- Very sensitive to additional contributions (BSM or "anomalous") couplings

- W helicity fractions measured from **angular distributions**:

  - $\cos(\theta^*)$: in t rest frame - angle between **lepton momentum in W rest frame** and **W momentum in top rest frame**

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

- Unitarity constraint: **$F_L + F_R + F_0 = 1$**

| *in SM:* |
|:---:|
| $F_0 = 0.6902$ |
| $F_L = 0.3089$ |
| $F_R = 0.0009$ |

  - in all measurements (as well as in combination)

  - **measure $F_0$, $F_L$,** retrieve $F_R$ from $F_0$, $F_L$

  - uncertainty in $F_R$: $\quad \sigma_{sys}^{(i)}(F_R) = \sqrt{\sigma_{sys}(F_0^{(i)})^2 + \sigma_{sys}(F_L^{(i)})^2 + 2C_i\sigma_{sys}(F_0^{(i)})\sigma_{sys}(F_L^{(i)})}.$
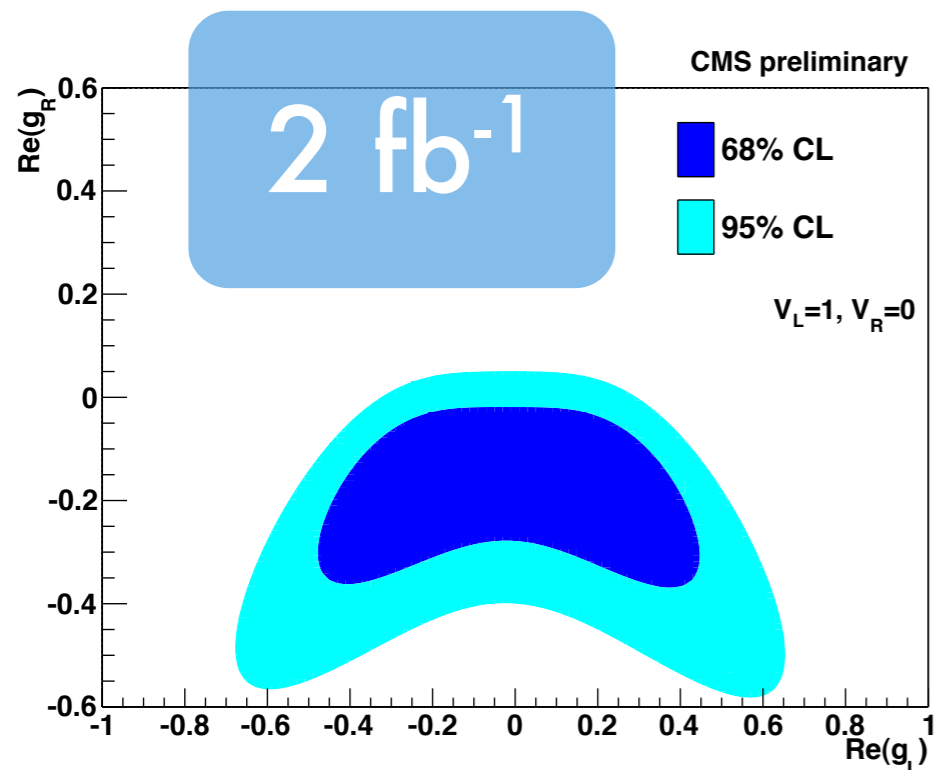
# LHC measurements: CMS

- 2011 data, 2.1 fb-1

- semileptonic decays, muons only

- fractions extracted from fits to cos(θ*) distribution, **reweighting** Madgraph MC

$F_0 = 0.567 \pm 0.074(\text{stat.}) \pm 0.047(\text{syst.})$
$F_L = 0.393 \pm 0.045(\text{stat.}) \pm 0.029(\text{syst.})$
$F_R = 0.040 \pm 0.035(\text{stat.}) \pm 0.044(\text{syst.})$

| Systematic check | Fitting $F_0$, $F_L$ and $\mathcal{F}_{t\bar{t}}$ 3D fit | |
|---|---|---|
| | $\pm$ Uncertainty $F_0$ | $\pm$ Uncertainty $F_L$ |
| b-Tag ($\frac{\epsilon^{DATA}_{b-tag}}{\epsilon^{MC}_{b-tag}}$) | 0.007 | 0.009 |
| QCD Norm | 0.007 | 0.002 |
| Single-t Norm | 0.003 | 0.007 |
| DY Norm | 0.018 | 0.003 |
| W+jet Norm | 0.020 | 0.006 |
| muon (no $\frac{\epsilon^{DATA}_{\mu}}{\epsilon^{MC}_{\mu}}$) | 0.002 | 0.003 |
| PDF | 0.001 | 0.001 |
| JES scale | 0.018 | 0.011 |
| top $Q^2$ scale | 0.014 | 0.007 |
| DY,W $Q^2$ scale | 0.022 | 0.003 |
| top mass ($\pm 3$ GeV/$c^2$) | 0.019 | 0.021 |



CMS preliminary

2 fb⁻¹

68% CL
95% CL

$V_L = 1$, $V_R = 0$

- semileptonic decays to both electrons and muons

- **asymmetry method**: fractions extracted from $A_z = \dfrac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}$

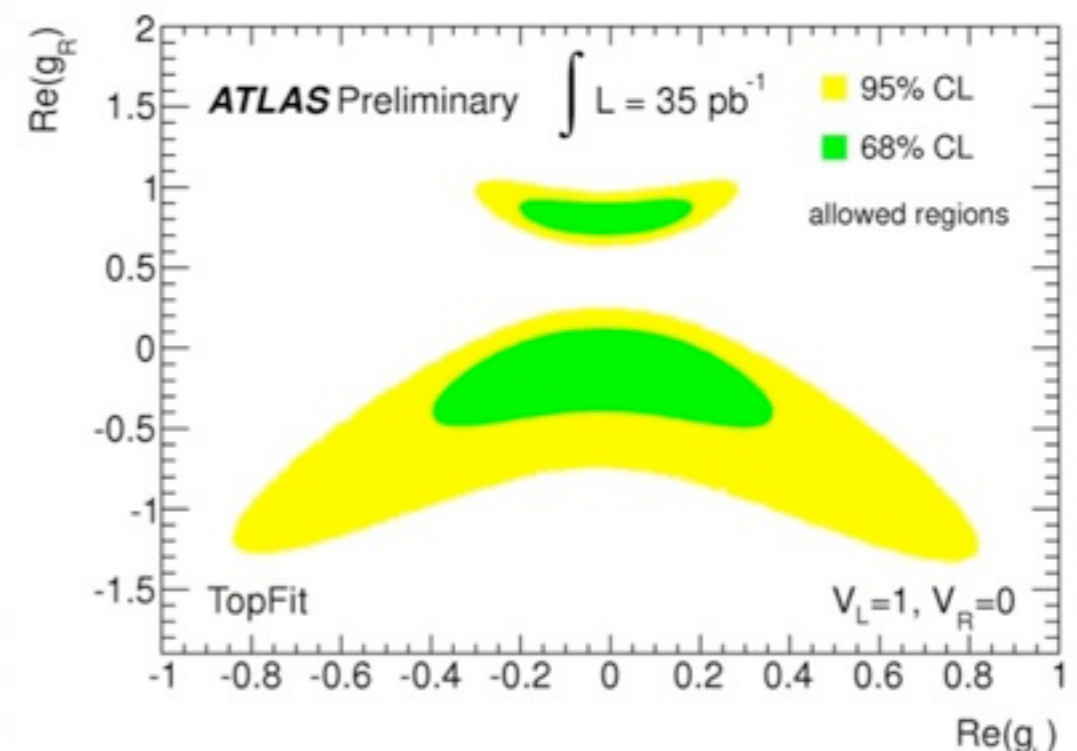$$z = -(2^{2/3} - 1) \quad \rightarrow \quad A_z = A_+ = 3\beta[F_0 + (1+\beta)F_R],$$
$$z = (2^{2/3} - 1) \quad \rightarrow \quad A_z = A_- = -3\beta[F_0 + (1+\beta)F_L],$$
$$z = 0 \quad \rightarrow \quad A_z = A_{FB} = 3/4[F_R - F_L]$$

**35 pb$^{-1}$**

| | $e$+jets | $\mu$+jets | combined |
|---|---|---|---|
| $A_{FB}$ | $-0.30 \pm 0.13$ | $-0.29 \pm 0.10$ | $-0.29 \pm 0.08$ |
| $A_+$ | $0.50 \pm 0.12$ | $0.50 \pm 0.09$ | $0.50 \pm 0.07$ |
| $A_-$ | $-0.85 \pm 0.09$ | $-0.87 \pm 0.05$ | $-0.86 \pm 0.04$ |
| $F_0$ | $0.64 \pm 0.27$ | $0.66 \pm 0.19$ | $0.65 \pm 0.15$ |
| $F_L$ | $0.36 \pm 0.17$ | $0.36 \pm 0.12$ | $0.36 \pm 0.10$ |
| $F_R$ | $0.00 \pm 0.13$ | $-0.02 \pm 0.08$ | $-0.01 \pm 0.07$ |

| Source | $e$+jets | | | $\mu$+jets | | | combined | | |
|---|---|---|---|---|---|---|---|---|---|
| | $A_{FB}$ | $A_+$ | $A_-$ | $A_{FB}$ | $A_+$ | $A_-$ | $A_{FB}$ | $A_+$ | $A_-$ |
| Statistical uncertainty | 0.11 | 0.10 | 0.07 | 0.09 | 0.08 | 0.04 | 0.07 | 0.06 | 0.04 |
| $t\bar{t}$ model | 0.03 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 |
| ISR/FSR | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| top-quark mass | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| Background model | 0.01 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 |
| HF content of $W$+jets | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Lepton energy scale | 0.02 | 0.04 | 0.04 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| Lepton reconstruction | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 |
| Jet energy reconstruction | 0.03 | 0.03 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.01 |
| $b$-tagging | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 |
| Luminosity and pileup | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Method | 0.03 | 0.02 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 |
| Total syst. uncertainty | 0.06 | 0.06 | 0.05 | 0.04 | 0.04 | 0.03 | 0.04 | 0.03 | 0.02 |
| Total uncertainty | 0.13 | 0.12 | 0.09 | 0.10 | 0.09 | 0.05 | 0.08 | 0.07 | 0.04 |



ATLAS Preliminary $\int L = 35$ pb$^{-1}$ — 95% CL, 68% CL, allowed regions. TopFit. $V_L = 1$, $V_R = 0$. Axes: Re($g_R$) vs Re($g_L$).

# LHC measurements: ATLAS 2011

- semileptonic and dileptonic decays, muons and electrons (5 channels)

- fractions extracted from **template fits** to cos(θ*) distribution and **asymmetries**

- combinations: overall and channels combination according to the method

| Channel | $F_0$ | $F_L$ | $F_R$ |
|---|---|---|---|
| *W boson helicity fractions from the template fit* | | | |
| Single leptons | $0.57 \pm 0.06 \pm 0.09$ | $0.37 \pm 0.03 \pm 0.04$ | $0.07 \pm 0.03 \pm 0.06$ |
| Dileptons | $0.92 \pm 0.10 \pm 0.10$ | $0.17 \pm 0.06 \pm 0.07$ | $-0.09 \pm 0.05 \pm 0.06$ |
| Combination | $0.66 \pm 0.06 \pm 0.07$ | $0.33 \pm 0.03 \pm 0.03$ | $0.01 \pm 0.03 \pm 0.06$ |
| $F_R$ fixed | $0.66 \pm 0.03 \pm 0.04$ | $0.34 \pm 0.03 \pm 0.04$ | 0 (fixed) |
| *W boson helicity fractions from the angular asymmetries* | | | |
| Single leptons | $0.66 \pm 0.03 \pm 0.08$ | $0.33 \pm 0.02 \pm 0.05$ | $0.01 \pm 0.01 \pm 0.04$ |
| Dileptons | $0.74 \pm 0.06 \pm 0.10$ | $0.27 \pm 0.03 \pm 0.05$ | $-0.01 \pm 0.03 \pm 0.05$ |
| Combination | $0.67 \pm 0.04 \pm 0.07$ | $0.32 \pm 0.02 \pm 0.04$ | $0.01 \pm 0.02 \pm 0.04$ |
| Overall combination | $0.67 \pm 0.03 \pm 0.06$ | $0.32 \pm 0.02 \pm 0.03$ | $0.01 \pm 0.01 \pm 0.04$ |

| Source | Uncertainties | | |
|---|---|---|---|
| | $F_0$ | $F_L$ | $F_R$ |
| *Signal and background modelling* | | | |
| Generator choice | 0.012 | 0.009 | 0.004 |
| ISR/FSR | 0.015 | 0.008 | 0.007 |
| PDF | 0.011 | 0.006 | 0.006 |
| Top quark mass | 0.016 | 0.009 | 0.008 |
| Misidentified leptons | 0.020 | 0.013 | 0.007 |
| $W$+jets | 0.016 | 0.008 | 0.008 |
| Other backgrounds | 0.006 | 0.003 | 0.003 |
| Method-specific uncertainties | 0.031 | 0.016 | 0.035 |
| *Detector modelling* | | | |
| Lepton reconstruction | 0.013 | 0.006 | 0.007 |
| Jet energy scale | 0.026 | 0.014 | 0.012 |
| Jet reconstruction | 0.012 | 0.005 | 0.007 |
| $b$-tagging | 0.007 | 0.003 | 0.004 |
| Calorimeter readout | 0.009 | 0.005 | 0.004 |
| Luminosity and pileup | 0.009 | 0.004 | 0.005 |
| Total systematic uncertainty | 0.06 | 0.03 | 0.04 |



ATLAS

$\int L \, dt = 1.04 \, \text{fb}^{-1}$

68% CL
95% CL
allowed regions

TopFit

$V_L = 1, V_R = 0$
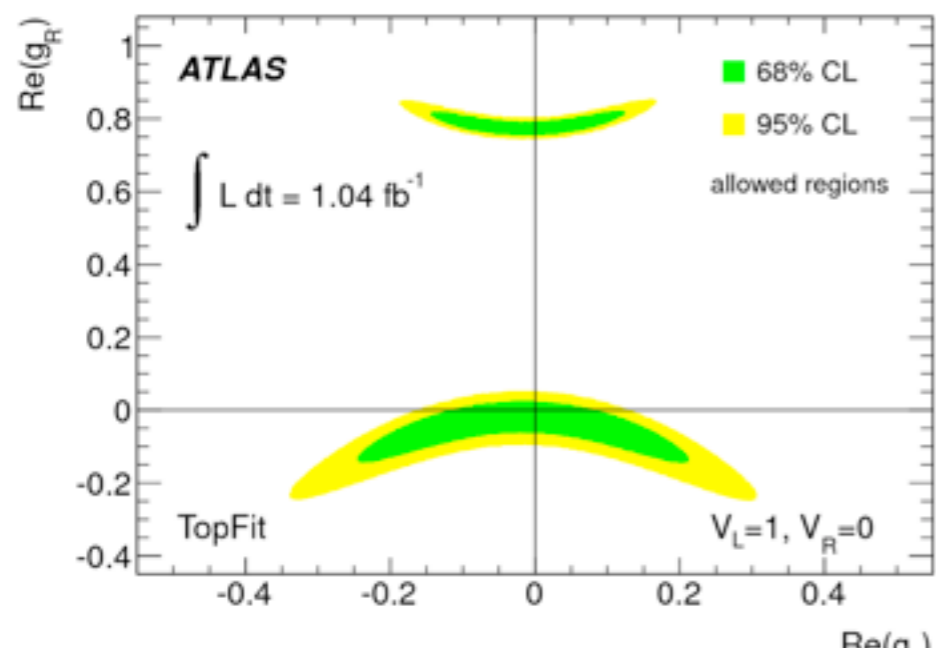
1 fb$^{-1}$

# Tevatron results

Tevatron combination (CDF, D0) with 2.7-5.4 fb[-1] (PRD 85, 071106, 2012)

- **$F_0$= 0.722±0.062(stat)±0.052(syst)**

- **$F_R$=-0.033±0.034(stat)±0.031(syst)**

- uncertainty in $F_0$: 0.081, currently better than individual LHC results

- uncertainty in $F_0$ ATLAS 2011 overall combination: 0.067, better than Tevatron

# Input measurements for LHC combination

- **ATLAS 2010 l+jets** (35 pb$^{-1}$)
  - angular asymmetry method
  - electrons and muons **2**

- **ATLAS 2011 l+jets** (1.04 fb$^{-1}$)
  - template and asymmetry
  - electrons and muons **4**

- **ATLAS 2011 dilepton** (1.04 fb$^{-1}$)
  - template and asymmetry
  - ee, eμ, μμ **6**

- **CMS 2011 l+jets** (2.1 fb$^{-1}$)
  - reweighting method
  - muons only **1**

Total of **13** measurements can not be handled by BLUE

ATLAS "Sub-measurements" pre-combined:

☞ **BLUE inputs** for LHC combination: **BLUE outputs** of ATLAS pre-combination + CMS measurement:

1) **ATLAS 2010 l+jets** *(public)*
2) **ATLAS 2011 l+jets** *(new combin.)*
3) **ATLAS 2011 dilepton+jets** *(new combination)*
4) **CMS 2011 muons+jets** *(public)*

# Categories of systematics

## *Using LHC top mass combination as guideline*

| Uncertainty source | Experiment | | $\neq$ LHC mass | $\rho_{\text{LHC}}$ |
|---|---|---|---|---|
| | CMS | ATLAS | | |
| Statistical | | | strong anticorrel btw $F_0$ and $F_L$ | 0 |
| Detector | btagging<br>lept reconstr<br>(trigger/ID eff)<br>jet resol | btagging<br>lept reconstr<br>jet reconstr<br>jet resol<br>calor. readout | | 0 |
| JES | $\eta, p_T$ | $\eta, p_T$ | only one category (dJES) | 0 |
| Pile-Up, Lumi | NO: PU included in JES bkg from MC | YES (data-driven bkg estim.) | | 0 |
| Monte Carlo: | | | also not estim. for 2011(**) | |
| . Generator | NO (hadr./showr. in JES) | different MC | | 0 |
| . Signal model | Q-scale | colour reconnection | didnt exist | 0 |
| Radiation | Q-scale (signal&bkg) | Monte Carlo ISR/FSR | | 0.5 |
| PDF | | | | 1 |
| Background: | | | | |
| . Backg DD | NO (from MC) | W+jets(2011), QCD | | 0 |
| . W+jets MC | YES (way larger!) | only 2010 | | 1 |
| . QCD MC | QCD | NO (from data-driven) | | 0 |
| . DY,Single-t MC | (way larger!) | +diboson for ll+jets | | 1 |
| Top Mass | shift $\pm 3$ GeV (PAS) | shift $\pm 0.9$ GeV | obviously not | 1 |
| Method | NO (reweighting) | YES (template) | didnt exist | 0 |

**estimated for the combination, similar effect as JE Scale**

**differences between ATLAS/ CMS at the same level than in other LHC combinations**

**rescaled to 1.4 GeV**

(**) Colour reconnection and UE were separated categories in the mass combination, and were estimated in CMS for mass but not for W helicity analysis. Generator also not estimated in CMS mass 2011 measurement.

# Categories of correlations

- Correlations *(as in top mass combination)* valid for $F_0(CMS) \leftrightarrow F_0(ATLAS)$ and $F_L(CMS) \leftrightarrow F_L(ATLAS)$

## Additional complication: $F_0, F_L$ strongly (anti)correlated!

- $\rho(F_0, F_L)$ large and different for each source of systematic uncertainty

- For one single measurement, same channel, correlation is unambiguous:

$$\rho(F_0, F_L) = \frac{\sigma^2[F_R] - \sigma^2[F_0] - \sigma^2[F_L]}{2\sigma[F_0]\sigma[F_L]}$$

## In ATLAS publications: $\rho(F_0, F_L)$ assumed= -1 always, for the combination computed as above

- For all other correlations, hypotheses have to be made:

# Categories of correlations

- **BLUE correlations used in the combination of ATLAS sub-measurements**

- Category I: (ATLAS sub-measurements) same measurement, same channel

  - modified w.r.t. ATLAS publication $\rho(F_0, F_L) = \dfrac{\sigma^2[F_R] - \sigma^2[F_0] - \sigma^2[F_L]}{2\sigma[F_0]\sigma[F_L]}$

- Categories II and IV: same <u>method</u> (template/asymmetry), different <u>channels</u> (electron/muon)

  - statistical, data-driven bkg: $\varrho(F_i, F_i) = 0$, $\varrho(F_i, F_j) = 0$

  - all other uncertainties: $\varrho(F_0, F_0) = \varrho(F_L, F_L) = +1$, $\varrho(F_0, F_L) = -1$

- Category III: different <u>method</u>, same <u>channel</u>

  - statistical correlation: **estimated from pseudo-data**

  - Method: $\varrho(F_i, F_i) = 0$, $\varrho(F_i, F_j) = 0$

  - all other uncertainties: $\varrho(F_0, F_0) = \varrho(F_L, F_L) = +1$, $\varrho(F_0, F_L) = -1$

**Bad side effect: information on $F_0, F_L$ correlations for each systematic check is lost after BLUE**

# Categories of correlations

- **BLUE correlations used in the LHC combination:**
- **Category V:** **CMS** experiment (one measurement, one channel): $\rho(F_0, F_L) = \dfrac{\sigma^2[F_R] - \sigma^2[F_0] - \sigma^2[F_L]}{2\sigma[F_0]\sigma[F_L]}$

- **Category VI:** **ATLAS** experiment, <u>same pre-combined measurement</u>, same channel (<u>l+j or ll+j</u>)
    - $\varrho_{exp}(F_0, F_L)$: **NOT AVAILABLE** (BLUE doesnt give it)
    - **use the simple average of the Category I correlations from the input sub-measurements (both stat and syst)**

- **Category VII:** **ATLAS** experiment, <u>different pre-combined measurements</u>, either l+jets/l+jets or l+jets/ll
    - statistical, data-driven bkg, method: $\varrho_{exp}(F_i, F_i) = \varrho_{exp}(F_i, F_j) = 0$
    - all other uncertainties: $\varrho_{exp}(F_0, F_0) = \varrho_{exp}(F_L, F_L) = +1$, $\varrho_{exp}(F_0, F_L) = -1$

- **Category VIII:** **different experiments**, any measurement/channel (meaning: correlation between CMS and any pre-combined ATLAS measurement)
    - $\varrho_{LHC}(F_i, F_i)$: detector, JES, data-driven = **0**; radiation = **0.5**; all others = **+1**
    - $\varrho_{LHC}(F_0, F_0) = \varrho_{LHC}(F_L, F_L) = $ **- $\varrho_{LHC}(F_0, F_L)$**

# Cross-checks

- We have performed tests of the results' stability against hypothesis assumed for correlations across experiments (Category VIII)

- Radiation systematics: value of 0.5 assumed for

$$\varrho_{LHC}(F_0,F_0) = \varrho_{LHC}(F_L,F_L) = -\varrho_{LHC}(F_0,F_L)$$

varied between -1 and 1, keeping all the others fixed at default values

- Systematics where $\varrho_{LHC}(F_0,F_0) = \varrho_{LHC}(F_L,F_L) = 1$ was assumed: the values of $\varrho_{LHC}(F_0,F_L)$ were varied between -1 and 1, keeping all others fixed at default values

- Results: combined value of $F_0$ and its uncertainty stable at $\%_0$ level; combined value of $F_L$ and its uncertainty unchanged

# Status and outlook

- ***Where we stand:***

- Categories of systematics and correlations well defined for W helicity combination

- Input measurements adjusted : added jet energy resolution effect (CMS),  re-combination (ATLAS)

- ATLAS currently revising internal combination (sub-measurements)

- First editorial board comments implemented


- ***Meanwhile:***

- Two independent set-ups of BLUE code for LHC combination in  place - yielding same results

- Two independent codes deriving limits on anomalous couplings in place - yielding same results

- Combination is ready with current ATLAS *(under revision)* + CMS inputs

- **Note describing combination is ready**, waiting for ATLAS green-light to start publication procedure both in ATLAS and in CMS


- ***Outlook:***

- Current inputs may change slightly as result of ATLAS revision

- CMS may also deliver new results W helicity results in the near future

- Re-running full machinery and updating the Note is a matter of couple of days

- *Very good perspective to have combination approved for Moriond*