Status of the Spin/CP analyses of the MELA/MEGA group

F.Rossi

Università degli Studi di Napoli "Parthenope"

on behalf of the MELA/MEGA group:

N. Bruscino, F. Cirotto, F.Conventi, C.Dionisi, S. Giagu, G. Gustavino, V.Ippolito, M. Rescigno + ANL/UC Chicago

What's new respect to Moriond

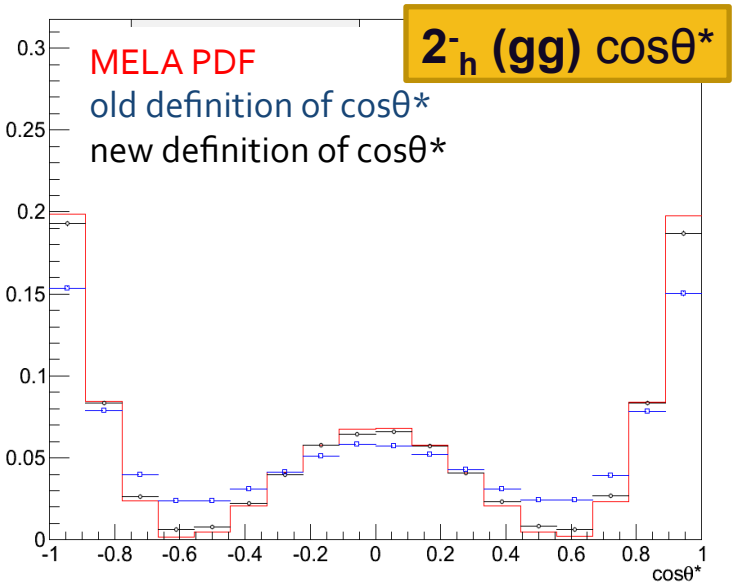
- **1D Hypothesis test almost all as in Moriond analysis but:**
  - cosθ* definition consistent with the new JHU paper adopted
  - new acceptances definition for Good Paired events
  - 2^-_h spin samples (both qq and gg) added and studied
  - **Major improvements on going:** new approach to treat Wrong Paired events

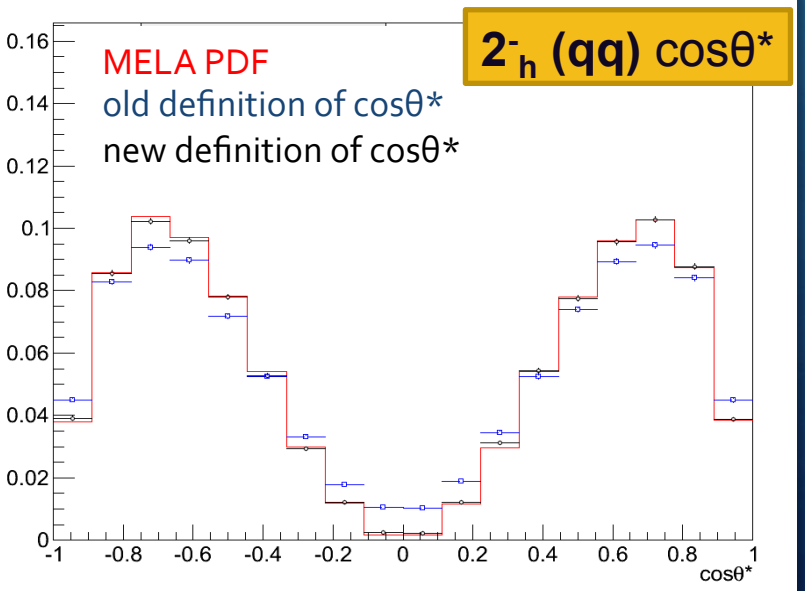
- **8D Likelihood fit:** Full description of the final state: (8D: m_{4l}, m_1, m_2, Ω)
- **2D Likelihood fit:** : reduce the dimensionality of the problem, by building a discriminant function of the g_4 and g_2 parameter, and test a given g_4 (or g_2) hypothesis

Definition of cosθ* consistent with latest JHU Paper

JHU paper: http://arxiv.org/abs/1208.4018

Truth MC distributions





- MELA pdf: 100k toys
- truth MC distributions with old definition
- truth MC distributions with new definition

Better agreement between MC and MELA pdf for spin 2^-_h samples

Other spin cases have NO significant changes.

New Acceptance definition

New Acceptance definition

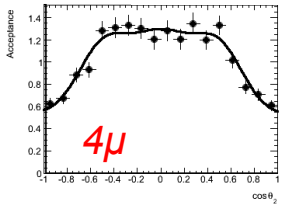
$$\text{Acceptance}\left(x\right) = \frac{\text{JHU reco distribution of x}}{\text{MELA truth pdf for x}}$$

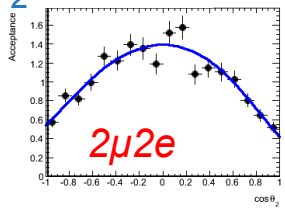
Acceptance distribution of the x variable is defined as ratio between reconstructed JHU MC distribution and MELA truth pdf (100k toys generated).

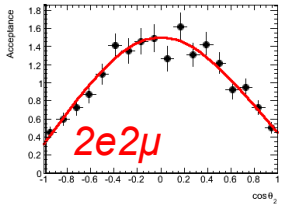
OLD Acceptance definition

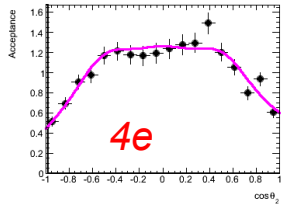
$$\text{Acceptance}\left(x\right) = \frac{\text{JHU reco distribution of x}}{\text{JHU truth distribution of x}}$$

$0^- \cos\theta_2$ - 8TeV

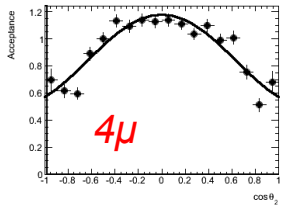


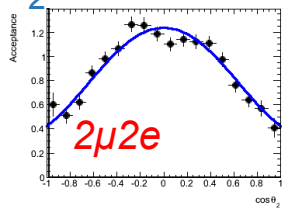


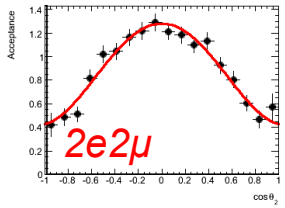


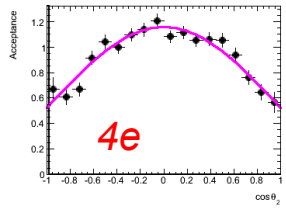


$1^- \cos\theta_2$ – 7TeV

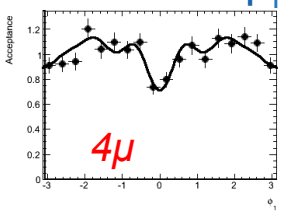


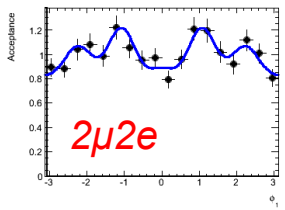


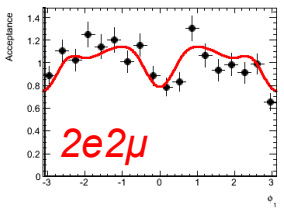


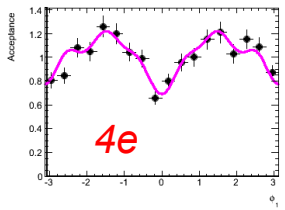


$2^+ \varphi_1$ - 8TEV





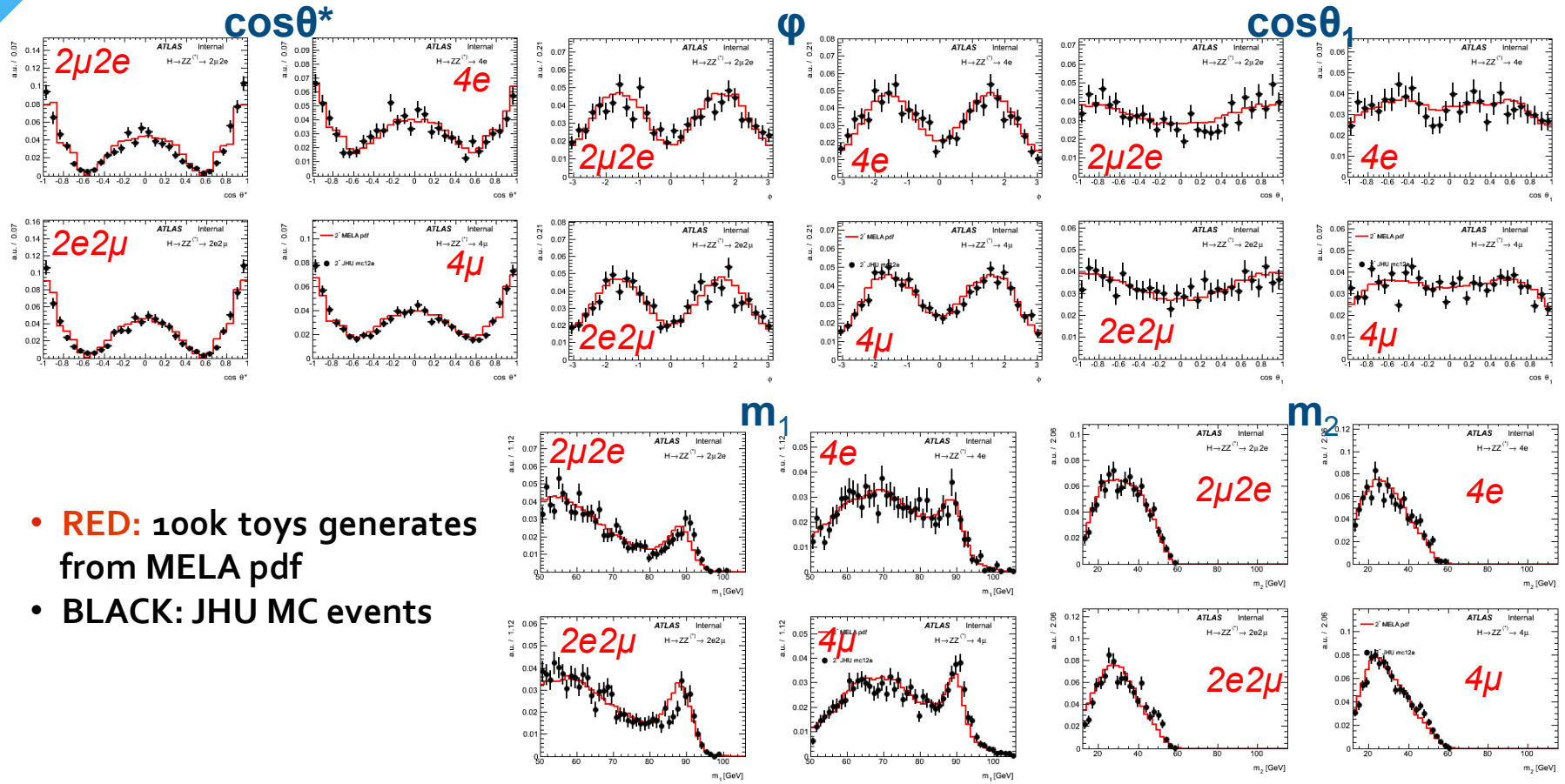




New approach improves the agreement between MELA pdf and JHU distributions

Fits for acceptances distributions of the angular variables are ready and almost optimized both for 2011 and 2012 MC samples

Spin 2^-_h (fqq=0%): Closure tests



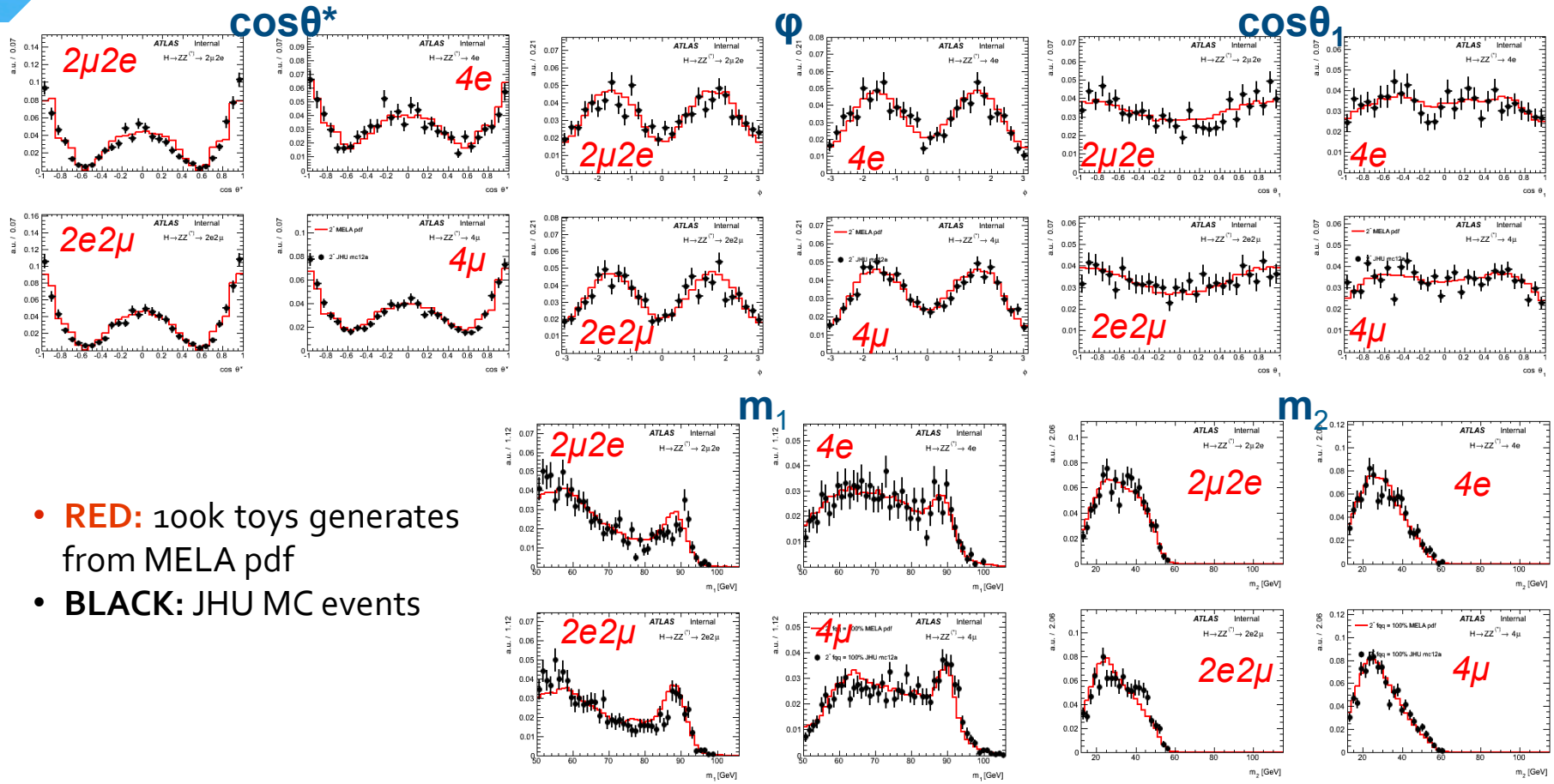
- **RED:** 100k toys generates from MELA pdf
- **BLACK:** JHU MC events

✧ Reminder: p.d.f.'s are used to build a multivariate discriminant

✧ The better these comparisons look like, the more optimal is J^P-MELA as a discriminant

✧ If something is suboptimal this will give lower separation between spin hypotheses, but not a bias!

Spin 2^-_h (fqq=100%): Closure tests



- **RED:** 100k toys generates from MELA pdf
- **BLACK:** JHU MC events

Good agreement observed for all distributions

(See N. Bruscino's talk for details: https://indico.cern.ch/conferenceDisplay.py?confId=266091)

Preliminary Separations: 7 TeV and 8 TeV

using profile likelihoods, asymptotic separations with systematics

Expected μ=1

tested \ assumed	0^+	0^-	1^+	1^-	2^+_m	2^-
0^+	-	0.011	0.021	0.008	0.124	2.95e-07
0^-	0.012	-	0.003	0.004	0.016	6.94e-05
1^+	0.021	0.002	-	0.033	0.021	6.62e-07
1^-	0.010	0.004	0.032	-	0.007	4.12e-06
2^+_m	0.126	0.019	0.024	0.007	-	8.98e-08
2^-	0.0001	0.0008	3.48e-05	0.0002	4.13e-05	-

$2^- = 2^-_h$

Moriond results: 100k toys using profile likelihood ratio

Expected 7+8 TeV (μ=1)

Tested \ Assumed	0+	0-	1+	1-	2+m
0+		0.011	0.027	0.011	0.134
0-	0.010		0.004	0.004	0.022
1+	0.020	0.002		0.033	0.023
1-	0.008	0.004	0.029		0.004
2+m	0.131	0.024	0.031	0.005	

toys running on grid

Preliminary Separations ($2^+_m/2^-_m$): 7 TeV and 8 TeV

using profile likelihoods, asymptotic separations with systematics

Expected μ=1	assumed				
tested	0^+	$2^+(25\%qq)$	$2^+(50\%qq)$	$2^+(75\%qq)$	$2^+(100\%qq)$
0^+	-	0.123963	0.129047	0.127552	0.127435
$2^+(25\%qq)$	0.128326				
$2^+(50\%qq)$	0.136875				
$2^+(75\%qq)$	0.130373				
$2^+(100\%qq)$	0.129048				

$2^- = 2^-_h$

Expected μ=1	assumed				
tested	0^+	$2^-(25\%qq)$	$2^-(50\%qq)$	$2^-(75\%qq)$	$2^-(100\%qq)$
0^+	-	6.49e-07	1.40e-06	1.07e-06	3.29e-07
$2^-(25\%qq)$	6.82e-05				
$2^-(50\%qq)$	9.74e-05				
$2^-(75\%qq)$	8.12e-05				
$2^-(100\%qq)$	8.65e-05				

toys still running on grid

see in backup slides the 1D Hypothesis tests for 7 TeV and 8 TeV

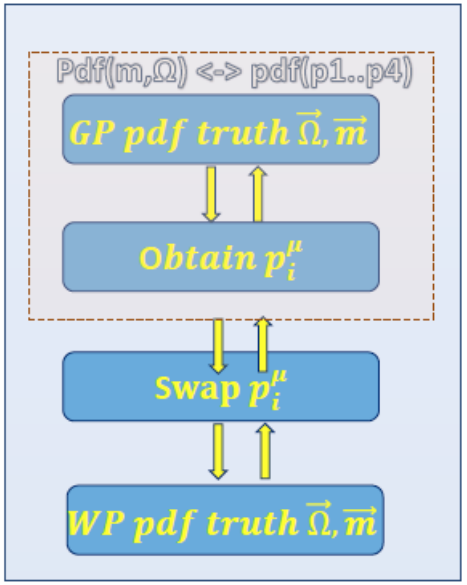
Improvement to the analysis: building WP pdfs

Why a Wrong Paired events pdf?

- Extend the use of ME to build Wrong Pair pdf
- Towards complete symmetrical approach for Good Pair (GP) and Wrong Pair (WP):
  - Improved description of signal
  - Full analytical 7D joint pdf over all the fit observables for the WP component
  - WP acceptances
- Plan to use WP pdf as a function of the g_i couplings in the likelihood fit
  - immediately extendable for any g_i values
- Expect some sensitivity gain in both hypothesis testing and likelihood fit and expect reduced systematic from WP in likelihood fit

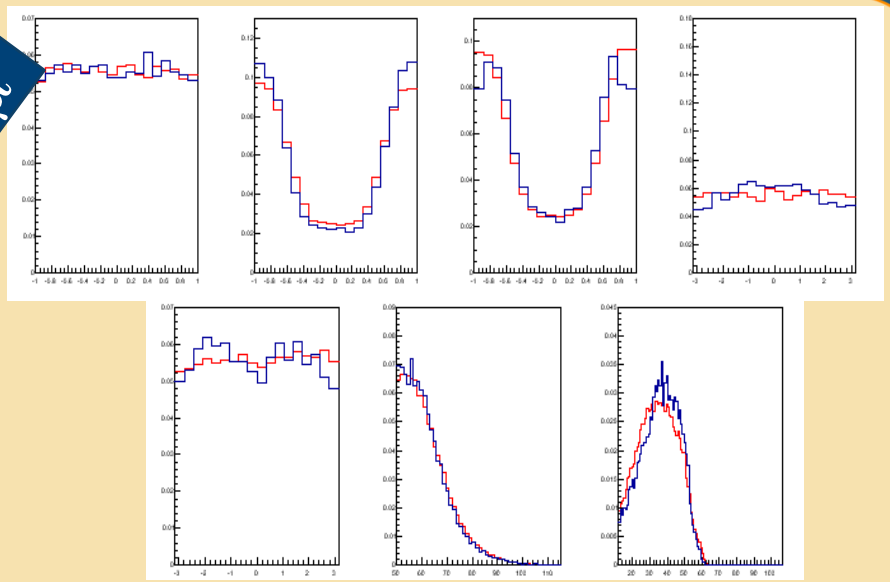
How to build a WP pdf?

- From GP truth pdf we have the five angles and the masses
- Perform a trasformation to obtain the pdf as a function of the 4 leptons quadrimomenta
- Swap leptons to obtain WP couples
- Calculate WP pdf variables
- Procedure applied to all spin hypotheses



WP pdf and Accpetances

$0^+ 4\mu$



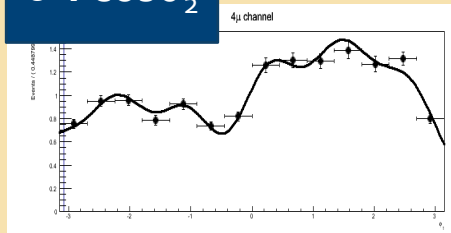
RED: MC Wrong Paired events truth distributions

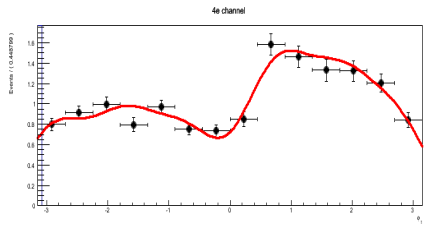
BLU: Wrong Paired events truth pdf

2012 and 2011 fit on WP acceptances ready

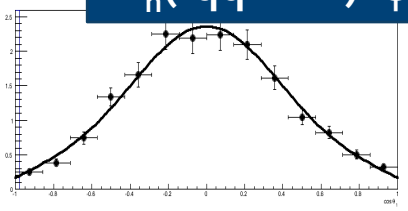
WP fit acceptances

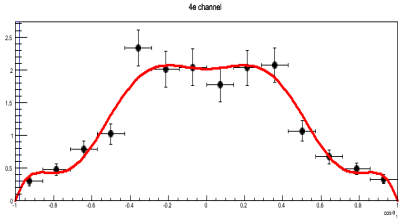
0^+: $\cos\theta_2$



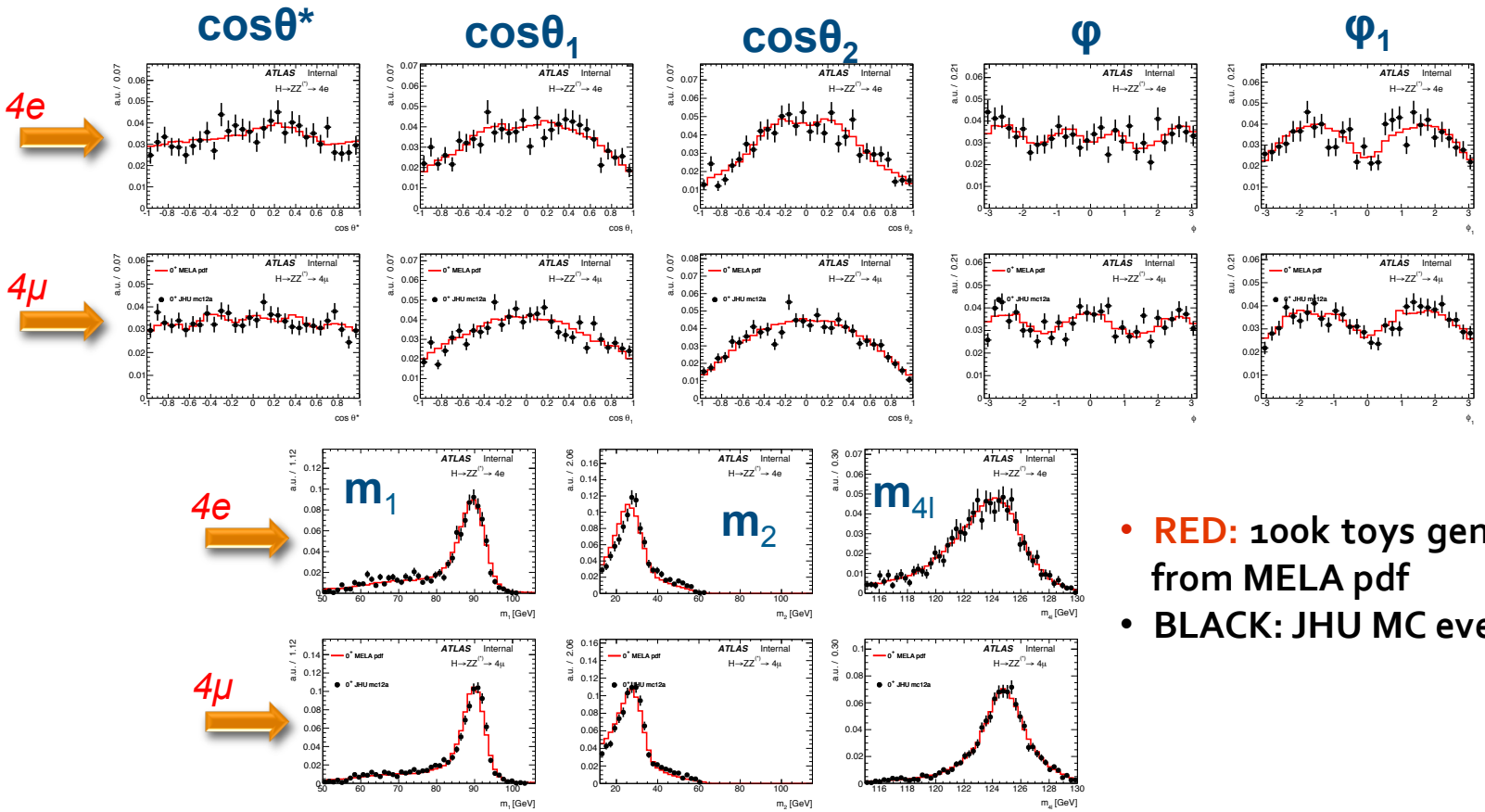


2^-_h(fqq=100): ϕ_1





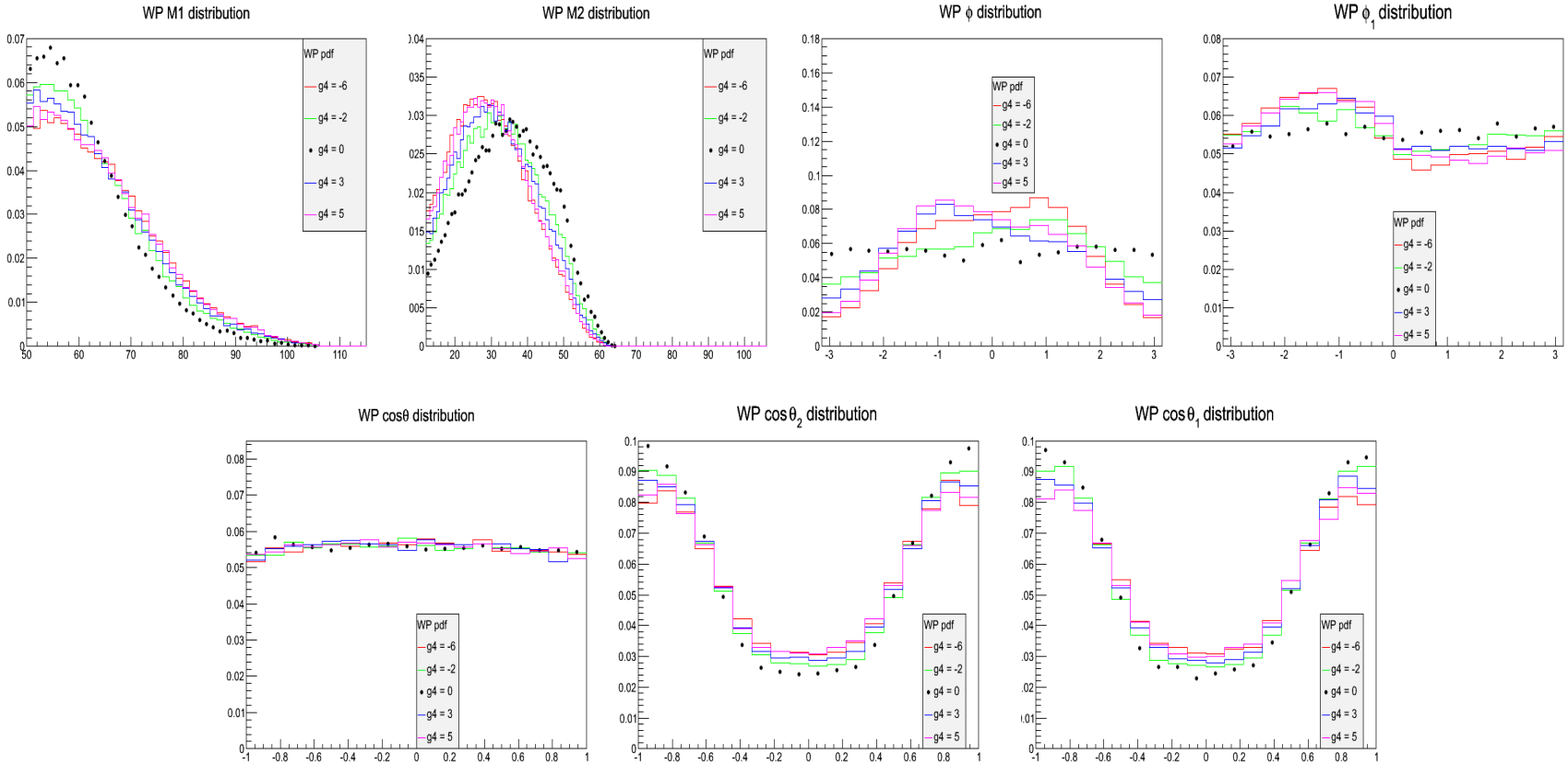
Preliminary Spin 0^+ Closure tests using WP pdfs



- **RED:** 100k toys generates from MELA pdf
- **BLACK:** JHU MC events

We described WP as we've done for GP: preliminary closure tests give a very good agreement between Pdfs and MC

WP pdf for g4≠0:



For more details on the WP pdf studies see F. Cirotto's talk: https://indico.cern.ch/conferenceDisplay.py?confId=266091)

Ongoing work

- 1D Hypothesis test (**Nello et al.**):
  - almost all ready, some minor optimization ongoing, waiting for the toys running on grid

- Wrong Paired events Pdf studies (**Francesco Cirotto et al.**):
  - The method to build Wrong Pair pdf from Good Pair Matrix Element pdf has been implemente and validated
  - Re-run hypothesis test with the new WP pdf approach
  - Insert WP pdf in the likelihood fit (immediately extendable for any g_i values)

- **Documentation (Everyone):**
  - work to document in internal note started and will go on during august
- **Schedule:**
  - Aim at having the analysis ready and documented by the end of august

MEGA Fit Strategy

- Signal reconstruction and selection:
  - same as main HSG2 4l analysis
- Inputs:
  - full simulation samples: JHU & Powheg (SM), Powheg ZZ
  - data driven samples: reducible BG (Moriond samples so far)
- Re-weighting:
  - to produce ($g_4/g_2 \neq 0$ samples)
  - based on JHU truth-level ME^2 (procedure validated wrt 0^- (validation wrt g_2 not yet done))

- Two complementary approaches developed in parallel:
  - 2D discriminant analysis based on matrix element re-weighting
  - full 8D matrix element based likelihood fit

- Produce sensitivity plots in the ($Re[g_4]/g_1$, $Im[g_4]/g_1$) and ($Re[g_2]/g_1$, $Im[g_2]/g_1$) planes and eventually fit data when ready to open the box

MEGA Fit 8D

Full description of the final state: (8D: m_{4l}, m_1, m_2, Ω) Ω = angular variables

- optimal way to extract information from available data → maximize sensitivity
- sensitive to interference effects between CP_{odd} and CP_{even} amplitudes (~lost when using 1D LR discriminant)

from analytical LO JHU ME calculation

from templates based on full-sim MC

$$pdf_{sig}(m_{4l}, m_1, m_2, \Omega) = p_{CB}(m_{4l})\, p_{ME}(m_1, m_2, \Omega)\, Acc(m_{4l}, m_1, m_2, \Omega)$$

$pdf_{bkg}(m_{4l}, m_1, m_2, \Omega)$ ZZ: based on templates from full-sim powheg MC

$pdf_{bkg}(m_{4l}, m_1, m_2, \Omega)$ Reducible: based on data-driven templates + smoothing

- event-by-event unbinned extended maximum likelihood fit
- likelihood: $\mu\, N_S\, pdf_{sig} + \Sigma\, \mu_{BG}\, N_B\, pdf_{bkg}$
- simultaneous fit to the four decay channels
- confidence regions for the parameter of interest from CL_{s+b} frequentist procedure
- POI: $Re\{g_4\}/g_1$, $Im\{g_4\}/g_1$, $Re\{g_2\}/g_1$, $Im(g_2\}/g_1$: at the moment only 1 parameter at a time, 2D parameters estimation in progress
- Nuisance: μ, μ_{bkg}, *luminosity*
- Systematic uncertainties:
  - luminosity, signal/BG (ZZ and reducible) overall normalizations (implemented)
  - Other sources (acceptance, energy scale, etc..) in progress

MEGA Fit 2D

Idea: reduce the dimensionality of the problem, by building a discriminant function of the g_4 and g_2 parameter, and test a given g_4 (or g_2) hypothesis

Use a 2D space:

- ✓ one dimension against the BKG: in the current version m_{4l}
- ✓ the other dimension is against SM signal: build a multivariate 1D discriminant (likelihood ratio)

$$D_{g_4} = \frac{p(data|SM)}{p(data|SM) + p(data|g_4)}$$

2D likelihood model:

- take SM signal MC ➟ $pdf_{SM}(m_{4l}, D_{g_4})$
- use ME re-weighting to obtain a MC sample for the given g_4 hypothesis ➟ $pdf_{g4}(m_{4l}, D_{g_4})$
- do the same for BG samples and produce $pdf_{BG}(m_{4l}, D_{g_4})$
- build the likelihood model (one for each decay channels):

$$p_{sig} = \epsilon \cdot pdf_{g_4} + (1 - \epsilon) \cdot pdf_{SM}$$

$$p_{tot} = Pois(\mu N_{sig} + \mu_{bkg} N_{bkg})(f_{sig} p_{sig} + f_{bkg} p_{bkg})$$

- simultaneous fit to the four decay channels:

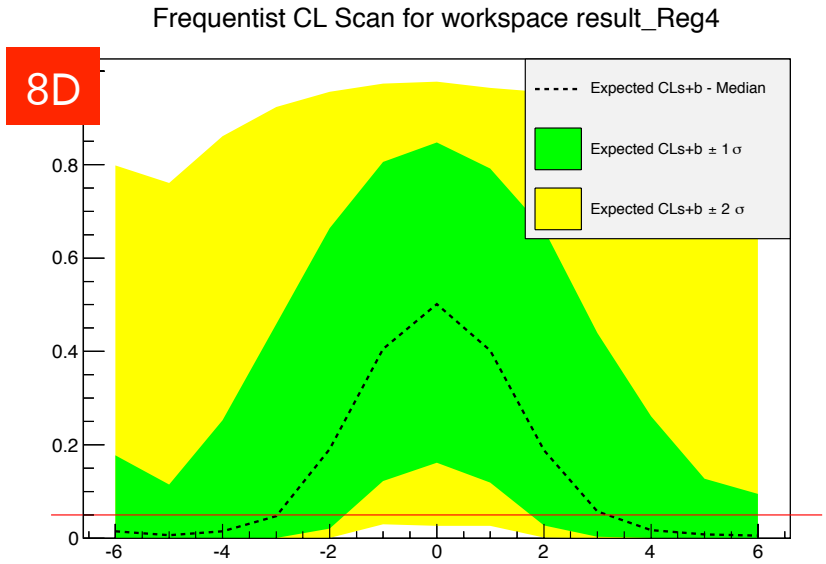
  ϵ ➟ POI (0 means SM, 1 means this g_4 hypothesis)

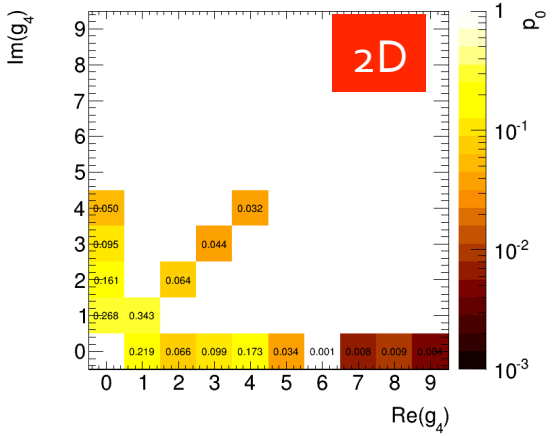
  μ, μ_{bkg}, *Luminosity* ➟ nuisance parameters

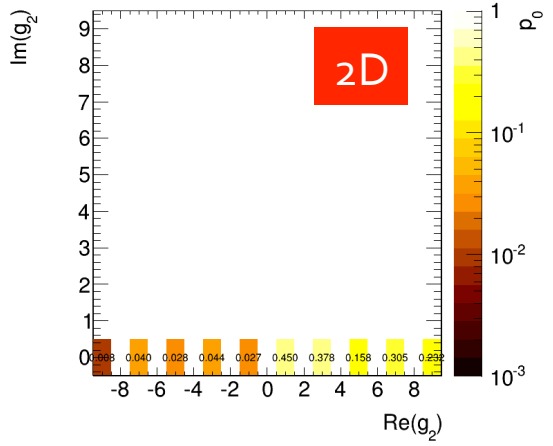
- use profile likelihood test statistic (separation obtained using Asimov datasets) to obtain p-values of the tested hypothesis and the SM hypothesis
- scan the g_4 and g_2 complex plane to build 95% CL contours on the parameters

Current results

- Closure tests for both methods based on toy checks and comparison with full-sim. MC: done
- First test of sensitivities with the 2 methods ongoing (systematic uncertainties partially implemented yet): in progress







with full 2011/12 statistic, normalization systematic considered with gaussian uncertainties as in Moriond analysis:

- **8D: can set a 95% CL limit on Re{g_4}/g_1 at ~3**
- **2D: smaller sensitivity wrt 8D (as expected) but consistent results**

For details see: G. Gustavino: https://indico.cern.ch/conferenceDisplay.py?confId=266091
V. Ippolito: https://indico.cern.ch/conferenceDisplay.py?confId=261823

Ongoing work

- 8D (Giuliano et Al.):
  - extend to 2D parameters fitting {Re vs Im g_i}
  - include full systematic uncertainties
  - refine wrong-pair model (based on ME)
  - produce high granularity 2D sensitivity plots
- 2D (Valerio et Al.):
  - include full systematic uncertainties
  - produce high granularity 2D sensitivity plots
- Documentation (Everyone):
  - work to document in internal note both analysis is starting now and will go on during august
- Schedule:
  - Aim at having both analyses ready and documented by the end of august

Summary and Perspective

- 1D Hypothesis test:
  - almost all ready waiting for the toys running on grid
- Wrong Paired events Pdf studies:
  - the method to build Wrong Pair pdf has been implemented and validated
  - Re-run hypothesis test with the new WP pdf approach
  - Insert WP pdf in the likelihood fit
- 8D analysis:
  - include full systematic uncertainties
  - adding wrong-pair model (based on ME)
  - produce high granularity 2D sensitivity plots
- 2D analysis:
  - include full systematic uncertainties
  - produce high granularity 2D sensitivity plots
- **Documentation (Everyone):** work to document in internal note both analysis started and will go on during august
- **Schedule:** aim at having the analysis ready and documented by the end of august

the end

Systematic uncertainties

Same approuch as in Moriond:

- **normalization systematics:**
  - signal x-section + MC statistic: 20%
  - ZZ BG x-section + MC statistic: 7%
  - ZJ BG: uncertainty from data-driven estimates: 32%
  - all: high/low m4l bins migration due to assumed m_H and due to ES systematic: 14% (anti-correlated high-low)
- **shape systematics:**
  - wrong-pairing: very small with new selection
  - ES: very small
  - ZJ shape parametrisation: from variations in the multi-gaussian and adaptive-KDE models + variations related to the available data-driven statistic
- **All systematics taken not correlated between 2011 and 2012 with the exception of the ZJ shape systematics (same data-driven sample used in both cases)**

Preliminary Separations: 7TeV and 8 TeV

using profile likelihoods, asymptotic separations with systematics

Expected μ=1

assumed

tested

$2^- = 2^-_h$

	0^+	0^-	1^+	1^-	2^+_m	2^-
0^+	-	0.016	0.027	0.013	0.136	1.16e-06
0^-	0.0165	-	0.005	0.006	0.022	0.0001
1^+	0.027	0.004	-	0.041	0.028	3.00e-06
1^-	0.015	0.006	0.040	-	0.011	1.11e-05
2^+_m	0.139	0.025	0.031	0.011	-	3.77e-07
2^-	0.0003	0.001	8.85e-05	0.0003	9.73e-05	-

Table 3: Expected separations between different spin hypotheses using 8 TeV simulation.

tested assumed	0^+	0^-	1^+	1^-	2^+_m	2^-
0^+	-	0.213	0.254	0.205	0.357	0.051
0^-	0.215	-	0.177	0.172	0.243	0.118
1^+	0.247	0.156	-	0.267	0.238	0.042
1^-	0.202	0.160	0.265	-	0.163	0.086
2^+_m	0.358	0.249	0.254	0.178	-	0.046
2^-	0.097	0.149	0.080	0.111	0.089	-

Table 1: Expected separations between different spin hypotheses using 7 TeV simulation.