Higgs quantum numbers in $e^+e^-\mu^+\mu^-$ final state using MadWeight Matrix-Element Method

Christophe Delaere, Alexandre Mertens, Michele Selvaggi

CP3 - Center for Cosmology, Particle Physics and Phenomenology
UCL, Louvain-la-Neuve
Belgium

May 2013

Our approach

- Goal : Validate the MadWeight matrix element method.
- Our playground is the parity measurement of the newly discovered boson.

Overview :

- Events generation : MadGraph + Pythia.
- Detector simulation with Delphes.
- MadWeight Matrix Element Method (arXiv :1007.3300)
  - Signals : $\mathcal{P}_{sig}^{o^+}$, $\mathcal{P}_{sig}^{o^-}$
  - Bkg : $\mathcal{P}_{ZZ}$
- Discriminant quantity : Kd
- Comparisons with MEKD approach.

Generation and Detector simulation

Generation :

- Implementation of an effective model in MadGraph using FeynRules [1] :

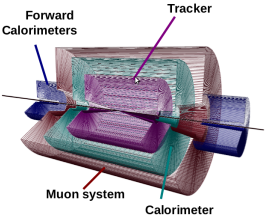
$$\mathcal{L}_{eff} = \frac{g}{\Lambda} 0^{-} \; Z^{\mu\nu} \; \widetilde{Z}_{\mu\nu}$$

- $M_{0^+} = M_{0^-} = 125 GeV$

- Events generation with MadGraph :
  - $pp \rightarrow 0^+ \rightarrow e^+ e^- \mu^+ \mu^-$
  - $pp \rightarrow 0^- \rightarrow e^+ e^- \mu^+ \mu^-$
  - $pp \rightarrow e^+ e^- \mu^+ \mu^-$

- Pythia is used for the showering

- CMS-like Fast Detector simulation (*Delphes* arXiv :0903.2225v3).



1. http ://feynrules.irmp.ucl.ac.be/wiki/HiggsCharacterization

The selection

The selection is as close as possible to CMS selection :

Charged leptons selection :

- $PT > 7$ GeV & $|\eta| < 2.4$

Event selection :

- $p_{T1} \geq 20$ GeV
- $p_{T2} \geq 10$ GeV
- 50 GeV $\leq M(Z1) \leq$ 120 GeV
- 12 GeV $\leq M(Z2) \leq$ 120 GeV
- 110 GeV $\leq M(X) \leq$ 160 GeV

The MadWeight Matrix Element Method

α :	theoretical informations (signal hypothesis).
x :	experimental informations.
$P_\alpha(y)$:	The probability to have a partonic configuration y in the theoretical context α.
$W(x,y)$:	The transfer function represent the evolution from partonic configuration y to a reconstructed event x.

The probability is then defined by :

$$P(x|\alpha) = \int dy P_\alpha(y) W(x,y)$$

In collider physics, $P_\alpha(y)$ can be re-written in terms of $|\mathcal{M}_\alpha|^2(y)$ and the *pdf's* ($f_1(q_1)$ et $f_2(q_2)$) :

$$P(x|\alpha) = \frac{1}{\sigma_\alpha \varepsilon_\alpha} \int d\phi(y) dq_1 dq_2 f_1(q_1) f_2(q_2) |\mathcal{M}_\alpha|^2(y) W(x,y) \,.$$

Transfer Functions : $W(x, y)$

Takes into account finite resolution for MEM (Jet, MET).

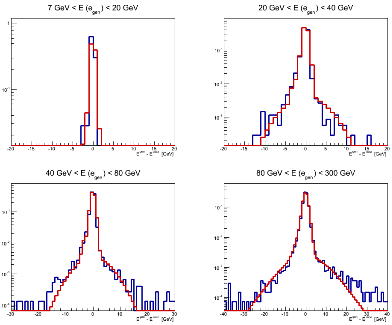
- Top-mass measurements.
- $t\bar{t}h$ analysis (P. Artoisenet's talk of yesterday)
- ...

Question : What is the effect when only high resolution objects ?

Example : Transfer function for electrons.

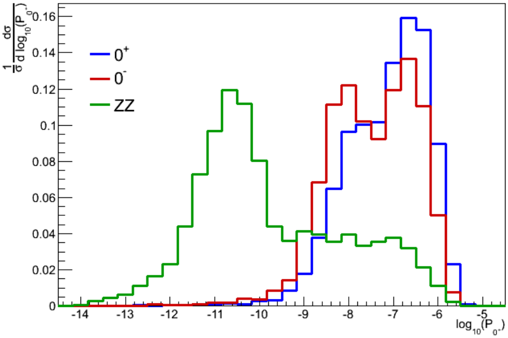
- Transfer function is applied on the measured energy.
- We decided to use triple gaussian (8 parameters).
- Each parameter is a function of the Energy ($p_i = a_i + b_i\sqrt{E_i} + c_i E_i$)
- δ-function applied for angular variables (η, ϕ)

Transfer Function estimation : $W(x, y)$



- In blue : data from simulation.
- In Red : cross-check of the Fit.
- tails well reproduced.
- good enough agreement.

Example : P_h from MadWeight ($110 \leq m_{ee\mu\mu} \leq 160$)



Comparisons with the CMS approach (MEKD) [2]

Moriond recipe :

- $P_{0^+} = \text{JHUGen } 0^+$
- $P_{0^-} = \text{JHUGen } 0^-$
- $P_{Bkg} = \text{MCFM } ZZ$
- $D_{0^-} = \frac{P_{0^+}}{P_{0^+} + P_{0^-}}$

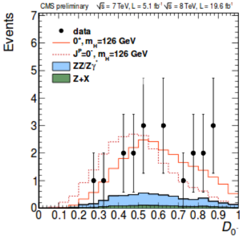


FIGURE: CMS PAS HIG-13-002

Remarks :

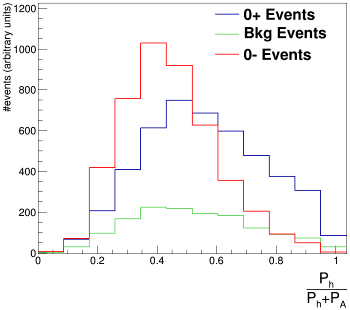
- No transfer function.
- No "Higgs"-mass in the probability computation.

2. *ArXiv : 1210.0896*

Kinematic Discriminants : MadWeight approach

- 0^+ vs. ZZ :
$$Kd = \frac{P_0^+}{P_{0^+} + P_{ZZ}}$$

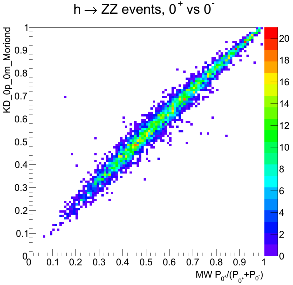
- 0^+ vs. 0^- :
$$Kd = \frac{P_0^+}{P_{0^+} + P_{0^-}}$$

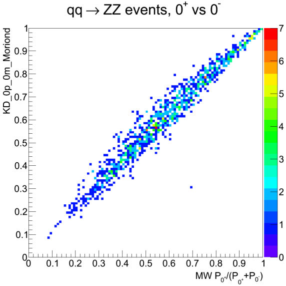


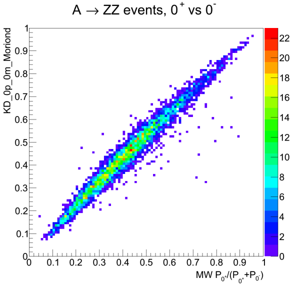
Remarks :

- The MadWeight probabilities contain the full amplitude (with $M_h = 125 GeV$).
- The two methods have been applied on the same events (generated with *Delphes*).

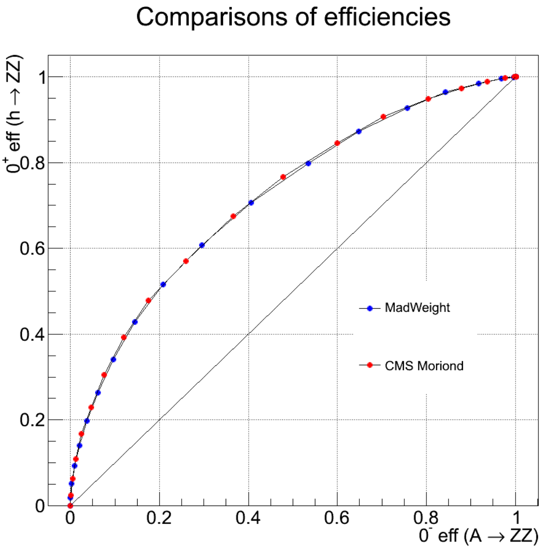
0^+ vs 0^- Kinematic Discriminant Comparisons







0^+ vs. 0^- efficiencies

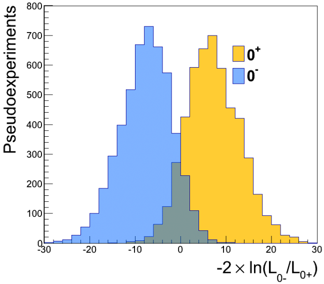


Higgs parity measurement

extended Likelihood :

$$\mathcal{L}_k = e^{-n_s-n_b} \prod_i \left(n_s \times P_s^k(x_i) + n_b \times P_b(x_i)\right) \quad (1)$$

where k is represents the different spin-parity signal hypothesis for the new resonance (0^+, 0^-, 2^+, etc...).



- assuming $\approx 25\ \text{fb}^{-1}$
- only ZZ background considered
- statistical errors only
- expected separation : $\approx 3\sigma$

While similar to CMS and ATLAS approaches for the 4 leptons topology, this method can be **easily extended** to channels with neutrinos or jets.

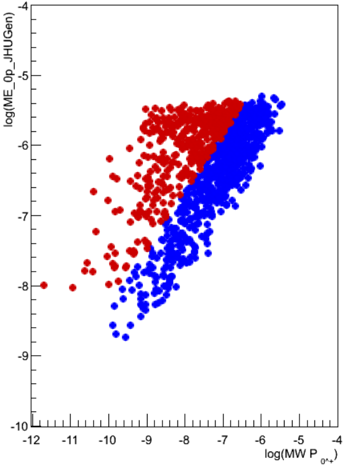
Conclusion

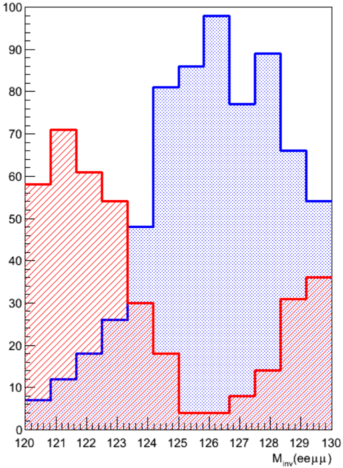
- We wanted to validate our method using Fast simulation.
- The method provides a parity measurement with comparable sensitivity.
- Generalisation to WW, bb, etc... provided by MadWeight.
- Realistic results obtained with *Delphes* within 2 months (learning tool and application).

Thanks

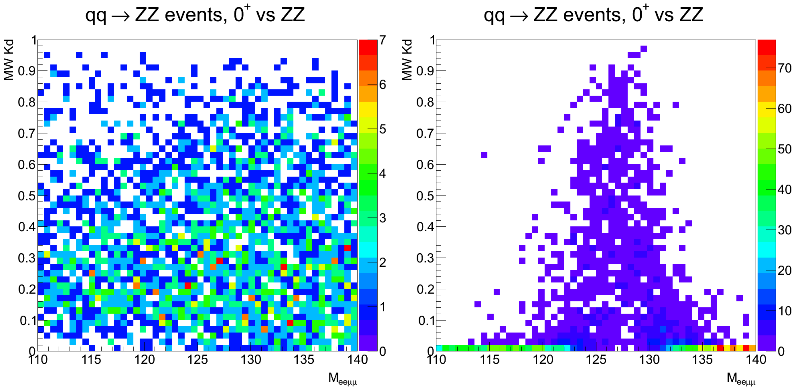
Back-up Slides

P_{0^+} vs. 4-leptons invariant mass : ZZ events

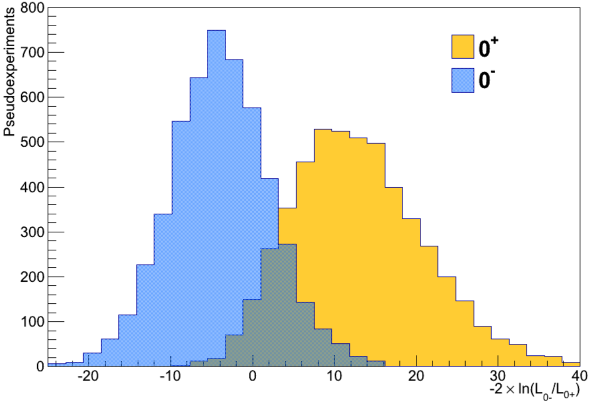




Kinematic Discriminant vs. 4-leptons invariant mass



Preliminary results with the CMS method



- background rejection : Kd(0^+ vs. ZZ) > 0.5
- 10.6 signal events, 1.4 ZZ events expected (generalisation to 4μ, $4e$ and $2\mu 2e$)
- expected separation : $\approx 3.0\sigma$