JHU Generator for spin/CP measurements

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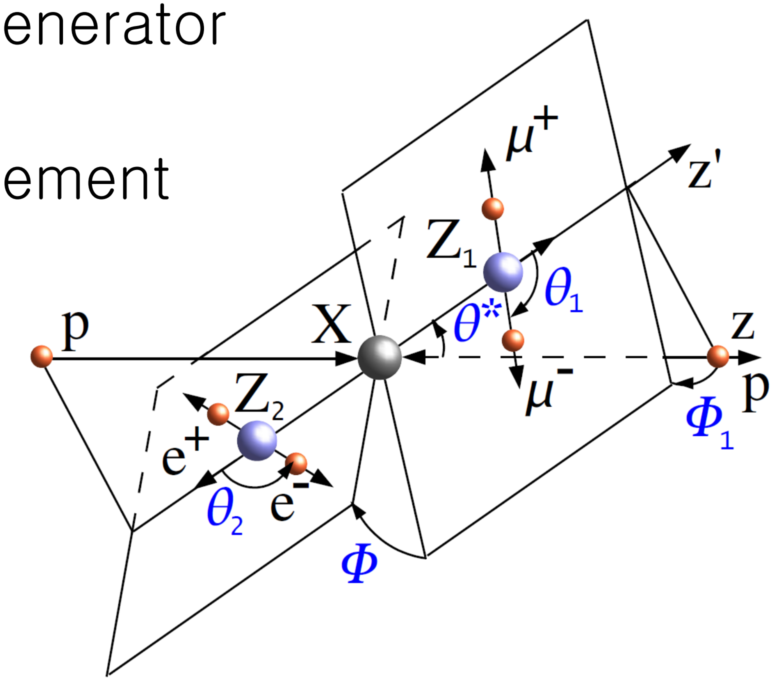
introduction

- Short report on status of JHU generator for spin/CP measurements
- Relationship to MELA [Matrix Element Likelihood Analysis]



References:

Gao et al., PRD81,075022(2010); CMS PAS HIG-2011/027 (2l2q)

Publicly available code:

http://www.pha.jhu.edu/spin

generator basics

- A MC program developed to simulate production and decay of X with spin-zero, -one, or -two in X→VV
  - Includes all spin correlations and all possible couplings
  - Inputs are general dimensionless couplings – calculates matrix elements
  - Both gg and $q\bar{q}$ production
  - Output in LHE format; e.g. can interface to Pythia for hadronization ^^
  - Available with CTEQ and MSTW PDF sets
  - All code publicly available: www.pha.jhu.edu/spin
- List of final states for spin-0,1,2
  - X→ZZ,WW,$\gamma\gamma$
  - Z → ll,νν,ττ,qq
  - W → lν,τν,qq
  - on-shell and off-shell modes included
- Latest updates soon publicly available

^^ Has already been done on CMS for some centrally produced samples

inputs and structures

- Inputs are dimensionless couplings for Lorentz-invariant structures for helicity analysis
  - Couplings can be re-written in another convention

Example: X(J=0) → VV, inputs are a_1, a_2, a_3

$$A(H_{J=0} \to V_1 V_2) = v^{-1} \epsilon_1^{*\mu} \epsilon_2^{*\nu} \left(a_1 g_{\mu\nu} M_X^2 + a_2\, q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta \right)$$

$$a_1 = g_1^{(0)} \frac{m_V^2}{m_X^2} + g_2^{(0)} \frac{2s}{m_X^2} + g_3^{(0)} \kappa \frac{s}{m_X^2}\,, \quad a_2 = -2g_2^{(0)} - g_3^{(0)}\kappa\,, \quad a_3 = -2g_4^{(0)}$$

$$A(X \to VV) = v^{-1} \left(g_1^{(0)} m_V^2 \epsilon_1^* \epsilon_2^* + g_2^{(0)} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + g_3^{(0)} f^{*(1),\mu\nu} f_{\mu\alpha}^{*(2)} \frac{q_\nu q^\alpha}{\Lambda^2} + g_4^{(0)} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu} \right)$$

J=1

$$A(X \to ZZ) = g_1^{(1)} \left[(\epsilon_1^* q)(\epsilon_2^* \epsilon_X) + (\epsilon_2^* q)(\epsilon_1^* \epsilon_X) \right] + g_2^{(1)} \epsilon_{\alpha\mu\nu\beta} \epsilon_X^\alpha \epsilon_1^{*,\mu} \epsilon_2^{*,\nu} \tilde{q}^\beta$$

J=2

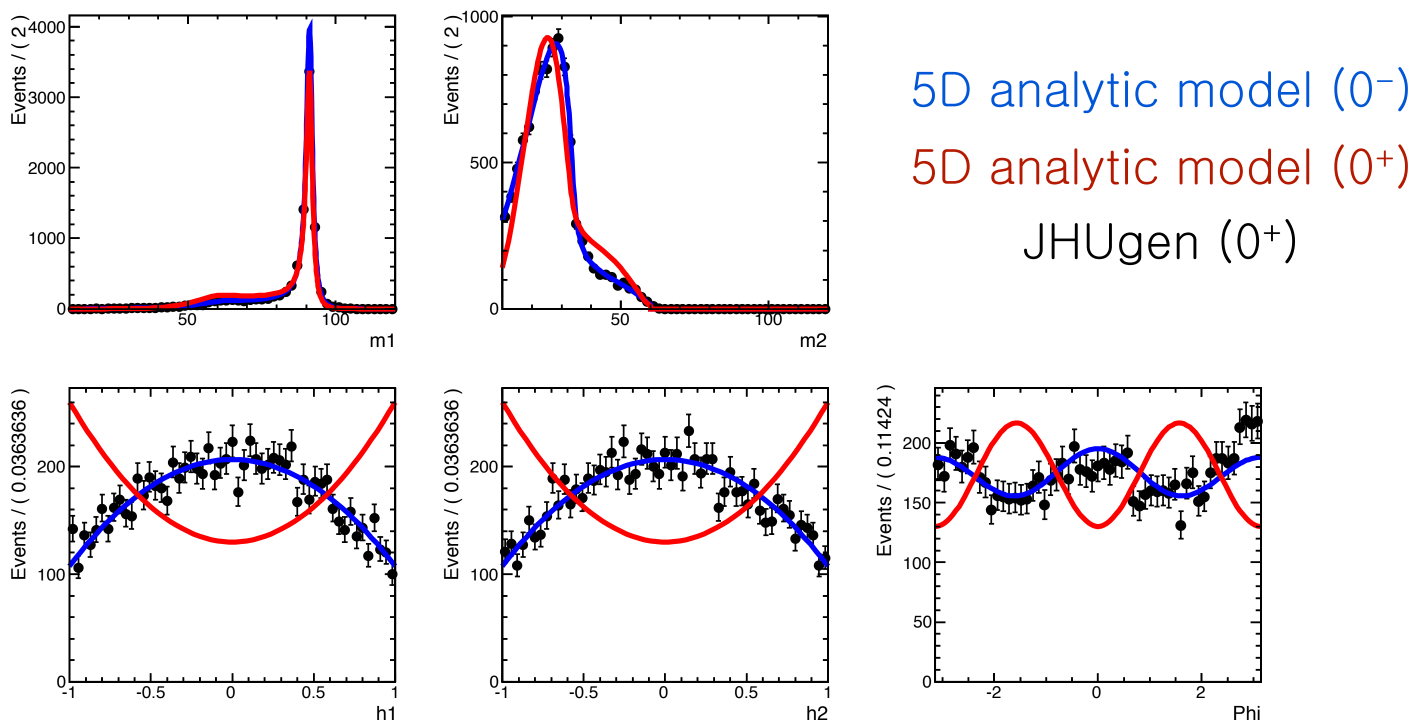
$$A(X \to ZZ) = \Lambda^{-1} e_1^{*\mu} e_2^{*\nu} \Big[c_1\, (q_1 q_2) t_{\mu\nu} + c_2\, g_{\mu\nu} t_{\alpha\beta} \tilde{q}^\alpha \tilde{q}^\beta + c_3\, \frac{q_{2\mu} q_{1\nu}}{m_X^2} t_{\alpha\beta} \tilde{q}^\alpha \tilde{q}^\beta + 2c_4\, (q_{1\nu} q_2^\alpha t_{\mu\alpha} + q_{2\mu} q_1^\alpha t_{\nu\alpha}) + c_5 t_{\alpha\beta} \frac{\tilde{q}^\alpha \tilde{q}^\beta}{m_X^2} \epsilon_{\mu\nu\rho\sigma} q_1^\rho q_2^\sigma + c_6 t^{\alpha\beta} \tilde{q}_\beta \epsilon_{\mu\nu\alpha\rho} q^\rho + \frac{c_7 t^{\alpha\beta} \tilde{q}_\beta}{m_X^2} (\epsilon_{\alpha\mu\rho\sigma} q^\rho \tilde{q}^\sigma q_\nu + \epsilon_{\alpha\nu\rho\sigma} q^\rho \tilde{q}^\sigma q_\mu) \Big]$$

validation: spin-0

- Analytic expression contains both off-shell Z masses

$$\frac{d\Gamma_{J=0}}{\Gamma\, dm_1 dm_2 d\cos\theta_1 d\cos\theta_2 d\Phi} \propto \beta \times \frac{m_1^3}{(m_1^2 - M_Z^2)^2 + M_Z^2\Gamma_Z^2} \frac{m_2^3}{(m_2^2 - M_Z^2)^2 + M_Z^2\Gamma_Z^2} \times \left[\frac{d\Gamma_{J=0}}{\Gamma\, d\cos\theta_1 d\cos\theta_2 d\Phi}(m_1, m_2, \cos\theta_1, \cos\theta_2, \Phi) \right]$$

- Compare signal model to signal simulation



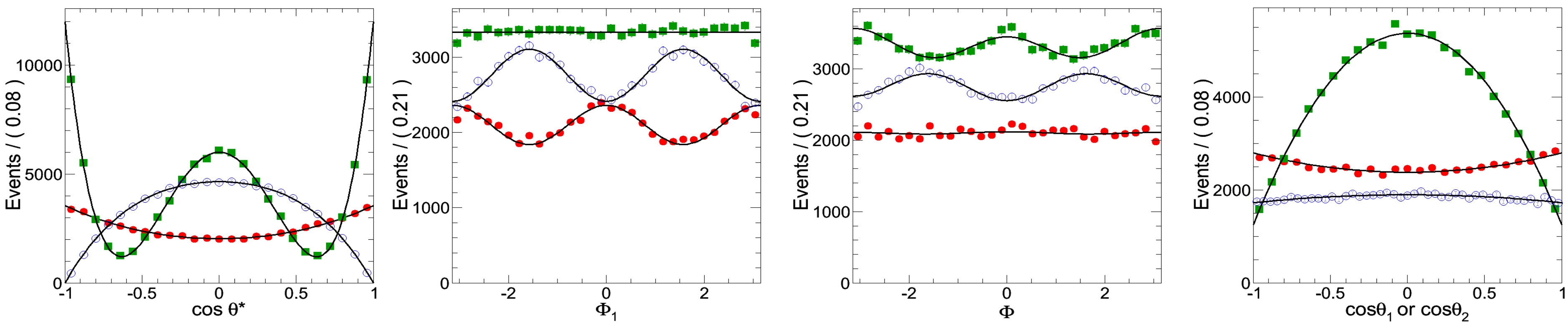
validation: spin-2

More validation, various spin-2 hypotheses

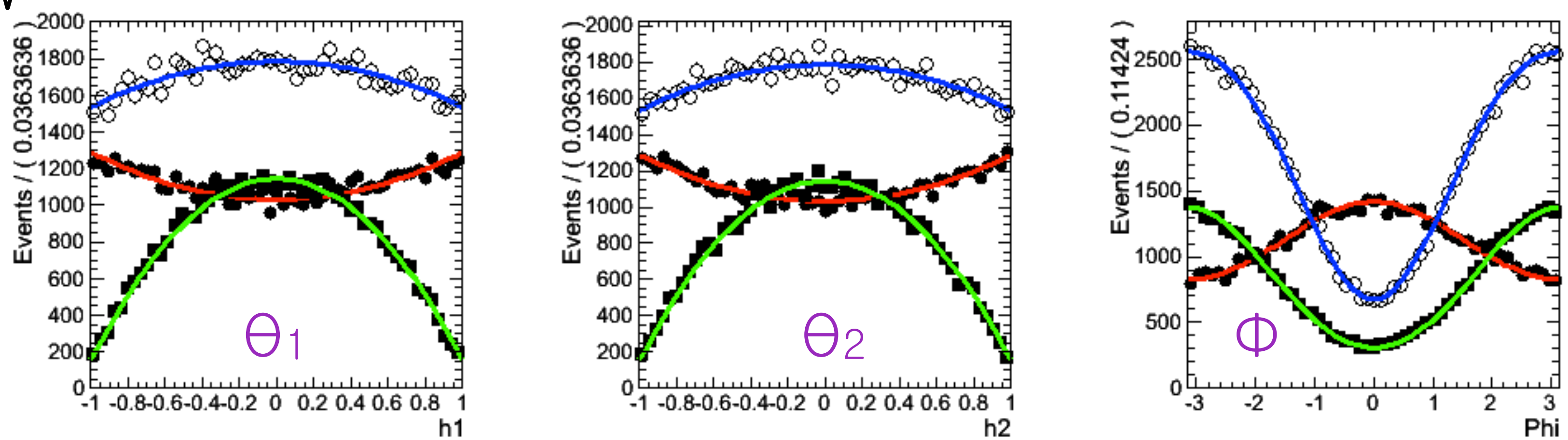
J^P = 2^+ (minimal), 2^+ (longitudinal), 2^-

ZZ

Example: Good agreement for both ZZ and WW modes

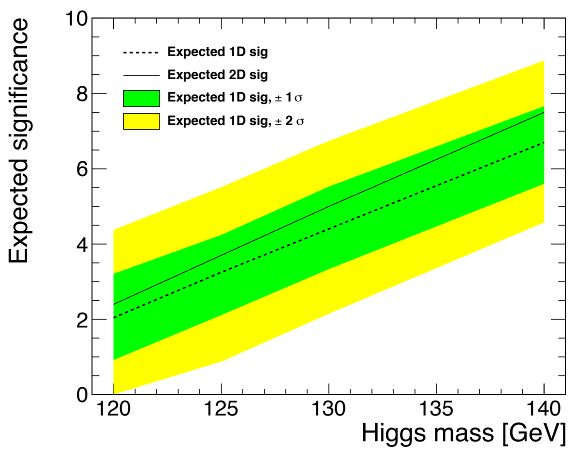


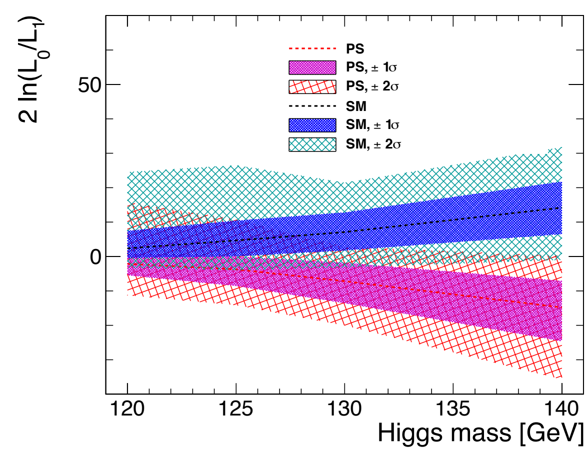
WW

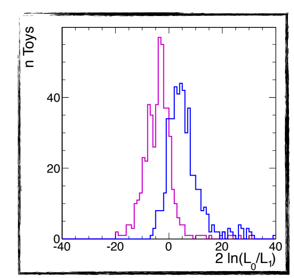


MELA

- Program based on helicity amplitude formalism to characterize resonances
  - Improved separation of signal and background for improved sensitivity
  - Hypothesis separation for a newly discovered resonance
  - Direct measurement of couplings
- Comprehensive introduction can be found <u>here</u>
- The latest: current efforts in implementing MELA analysis into CMS RooStats-based framework







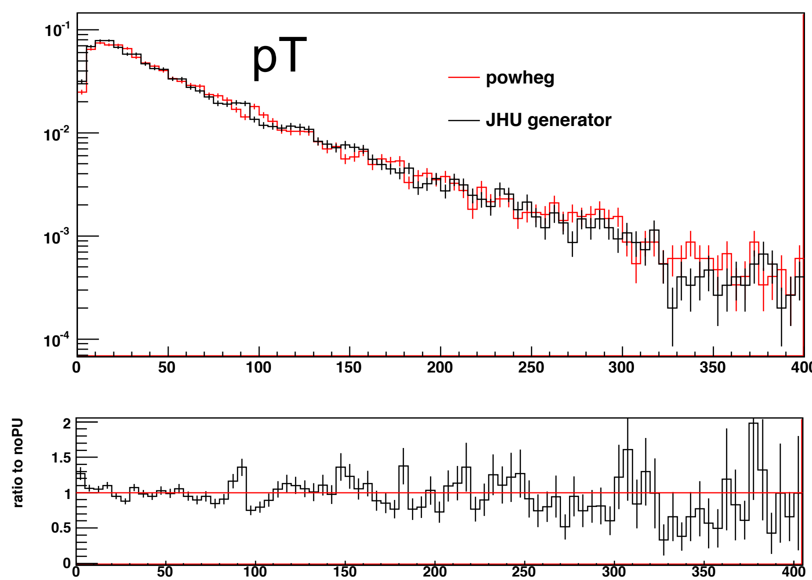
JHU+Pythia interface

- Powheg currently used for ggH production
- A comparison of Powheg+Pythia and JHU+Pythia samples in 2l2q final state with m_H ($J^P = 0^+$) = 300 GeV
  - Tests both lepton and hadronic Z
  - GEN level comparisons, inside detector acceptance with analysis-like cuts

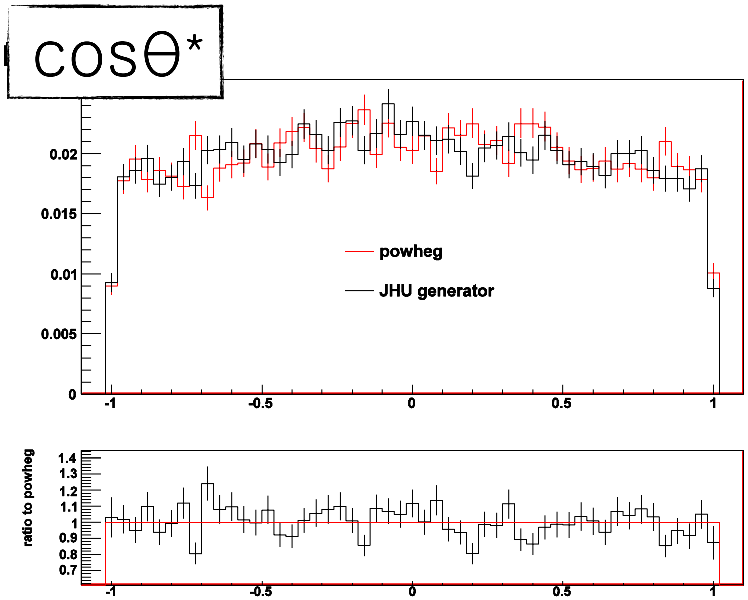
pT distribution comparison:

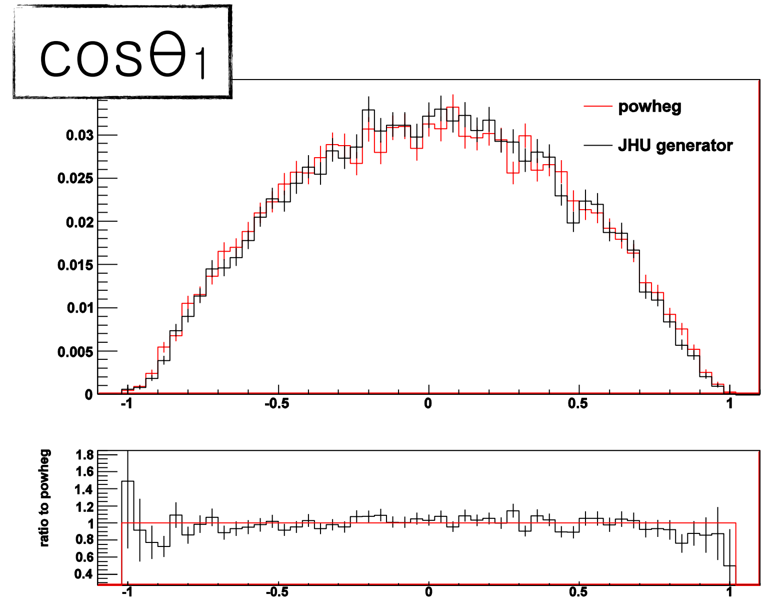
Pythia does a reasonable job of reproducing NLO pT distribution

Current prescription is to reweight Powheg based on HqT anyway. Can do the same for JHUGen



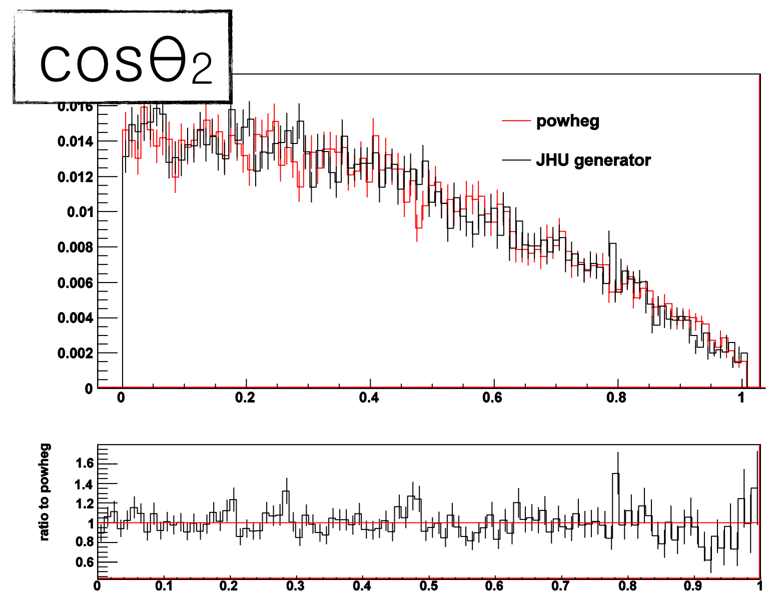
more Powheg vs JHU





Generally good agreement between JHU+Pythia and Powheg+Pythia

Residual differences in kinematic distributions at ~few % level coming for PDFs and NLO treatment



generator options – discussion

- Consider various options for generator for spin/CP studies
  - use JHUGen
  - analytically re-weight Powheg samples
  - numerically re-weight Powheg samples
  - extend JHUGen
- Option: use JHUGen
  - simplest option, just generate LHE files and interface with Pythia and detector simulation
  - generate a sample per hypothesis, require statistically independent samples anyway
    - at the point of discovery, we are working in a narrow mass range, would be a manageable amount of samples
  - good agreement w.r.t. Powheg+Pythia, both Powheg and JHUGen would require reweight with HqT

generator options – discussion

- Option: re-weight Powheg samples
  - practically, assign a weight for each event for each signal hypothesis w.r.t. the SM Higgs
  - analytically: use the ideal angular distributions to find weights for different hypotheses, advantage is very fast
    - requires some work on the phenomenological side
  - numerically: use JHUGen ME calculation to create event-by-event weights
    - weight = ME (hypothesis X) / ME (SM Higgs)
    - technically is a bit awkward and requires some work to create such an interface
    - no statistically independent samples for proper statistical treatment
- Option: extend JHUGen
  - when we enter the systematically dominated regime, could extend JHUGen to NLO using same formalism

backup