Higgs Mass Reconstruction in $H \to WW^* \to \ell\nu\ell\nu$

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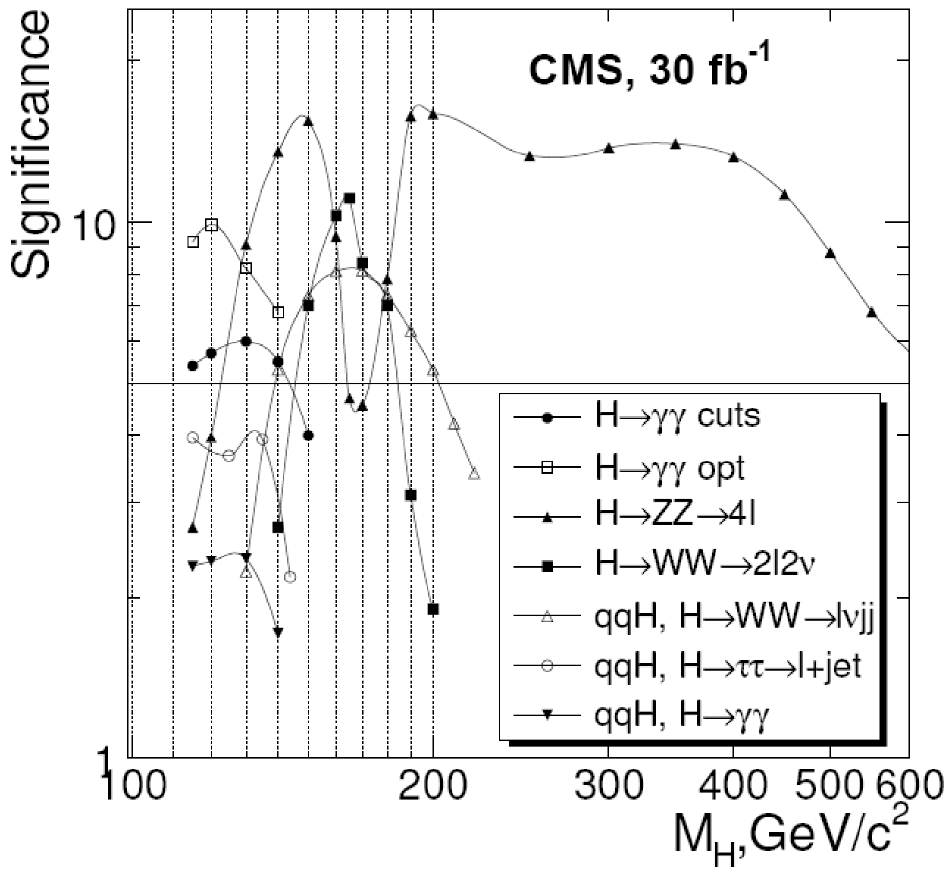
Introduction

- In SM Higgs Search, $H \to WW^* \to \ell\nu\ell\nu$ is important
- Due to 2 neutrinos, we cannot reconstruct Higgs mass directly
  - Dilepton opening angle usually used
- Is Higgs mass reconstruction possible in $H \to WW^* \to \ell\nu\ell\nu$?



$H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$

- Observables
  - Momentum of lepton 1
  - Momentum of lepton 2
  - Transverse momentum of sum of two neutrino momenta – MET
  - To reconstruct Higgs, we need two neutrino momenta
- Unknowns
  - Two neutrino momenta – 2 x 3
- 4 Constraints
  - METx
  - METy
  - M(lepton1 + neutrino1) = M_W
  - M(lepton2 + neutrino2) = M_W
- System is underconstrained

Using MAOS momenta to $H \to WW \to \ell\nu\ell\nu$

- M_{T2} Assisted On-Shell algorithm developed by KAIST group
  - Originally developed to determine neutralino momenta is SUSY events

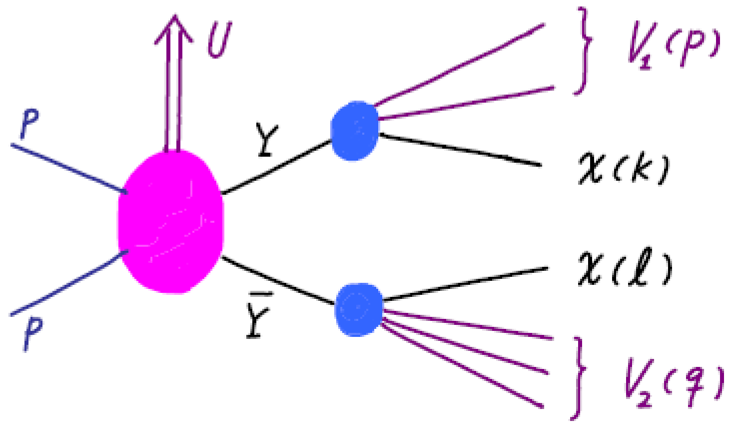
$$pp \to Y(1) + \bar{Y}(2) \to V(p_1)\chi(k_1) + V(p_2)\chi(k_2)$$

  - http://cms.skku.ac.kr/wiki/images/7/77/Mass-spin-LHC.ppt
  - http://cms.skku.ac.kr/wiki/images/5/5c/KChoi.pdf
  - In our case, Y=W, V=ℓ, χ=ν

- Advantage of MAOS method
  - for events with large values of M_{T2}, the approximated momenta approach the true momenta

From M_{T2} to MAOS

- M_{T2} is unique for an event



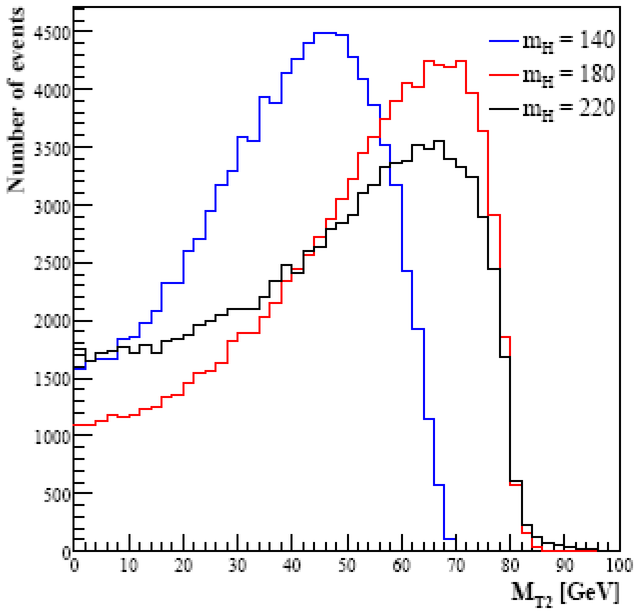
$$M_{T2}(\text{event}; m_\chi) \qquad \left(\{\text{event}\} = \{p^2, \mathbf{p}_T, q^2, \mathbf{q}_T, \not{\mathbf{p}}_T\}\right)$$

$$= \min_{\mathbf{k}_T + \mathbf{l}_T = \not{\mathbf{p}}_T} \left[\max\left(M_T(p^2, \mathbf{p}_T, m_\chi, \mathbf{k}_T), M_T(q^2, \mathbf{q}_T, m_\chi, \mathbf{l}_T) \right) \right]$$

  - Transverse components of neutrino are determined
  - We did not use W-mass constraint

M_{T2} for H→WW events

- Edge is at



$$M_{T2} \leq \min(M_W, \frac{m_H}{2})$$

- How to determine z-components of 2 neutrinos?
  - No unique way of determination

Determining P_z of Neutrinos

- Conditions
  - Massless:

$$(k_{\rm maos})^2 = (l_{\rm maos})^2 = 0$$

  - Mass of lepton+neutrino:

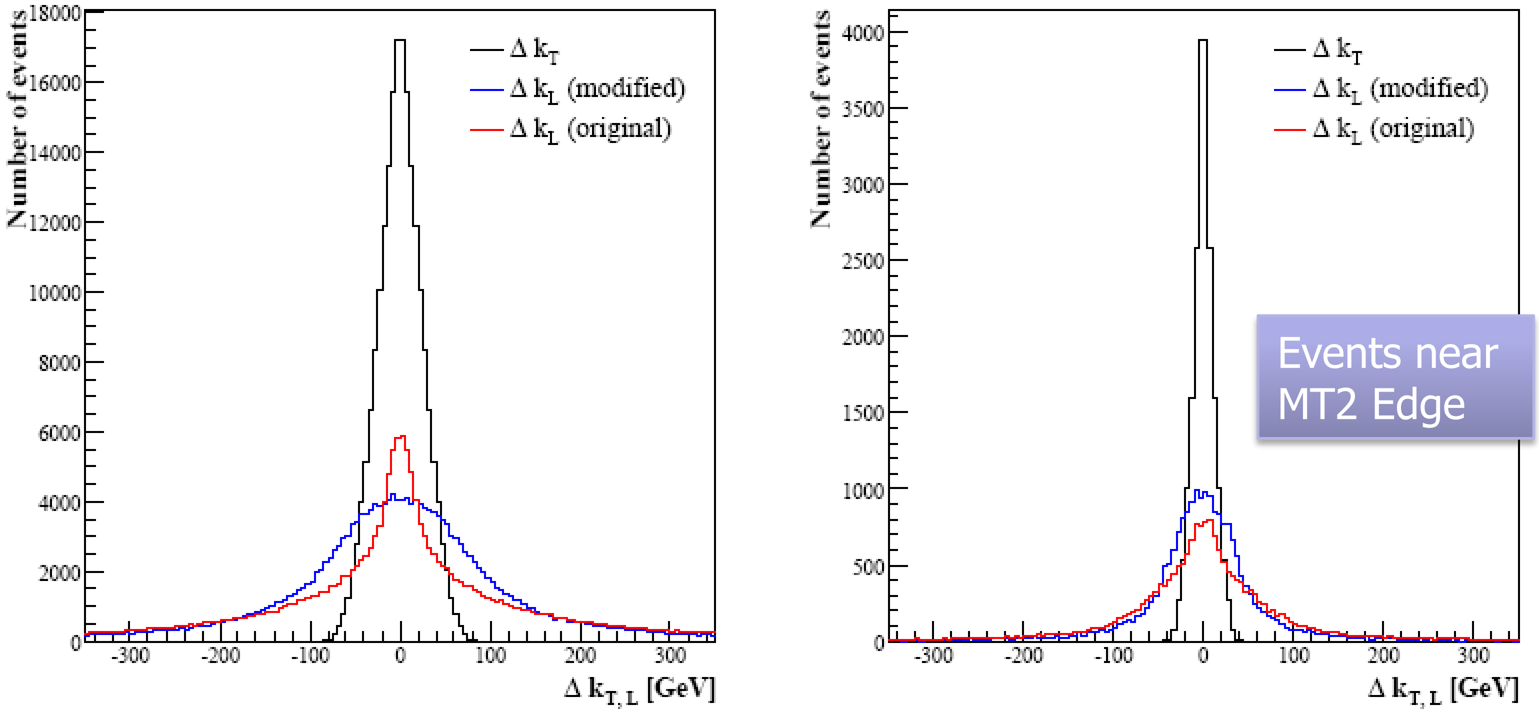
$$(p + k_{\rm maos})^2 = (q + l_{\rm maos})^2 = M_{T2}^2$$

- Unique P_z of Neutrinos in modified MAOS scheme

$$k_L^{\rm maos} = \frac{|\mathbf{k}_T^{\rm maos}|}{|\mathbf{p}_T|} p_L, \quad l_L^{\rm maos} = \frac{|\mathbf{l}_T^{\rm maos}|}{|\mathbf{q}_T|} q_L.$$

Accuracy of MAOS method

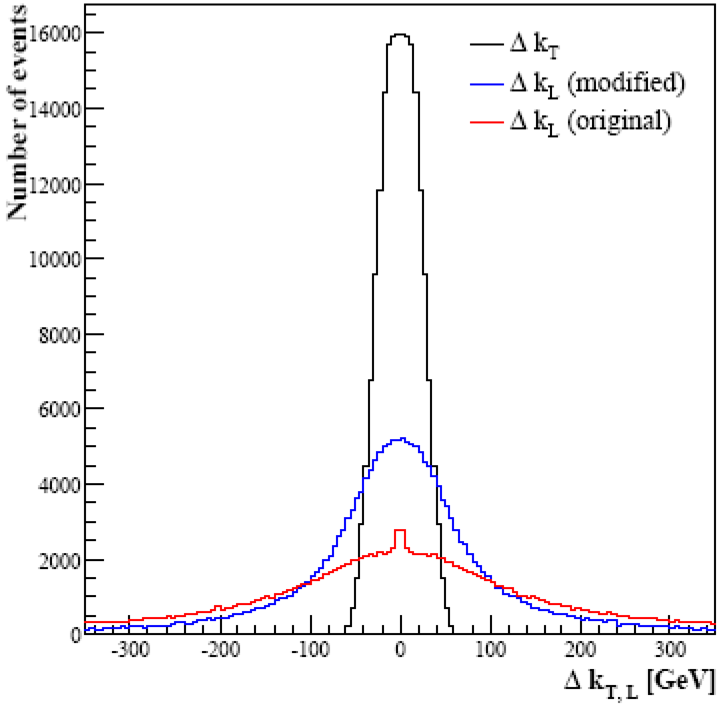
- For M_H=180 GeV

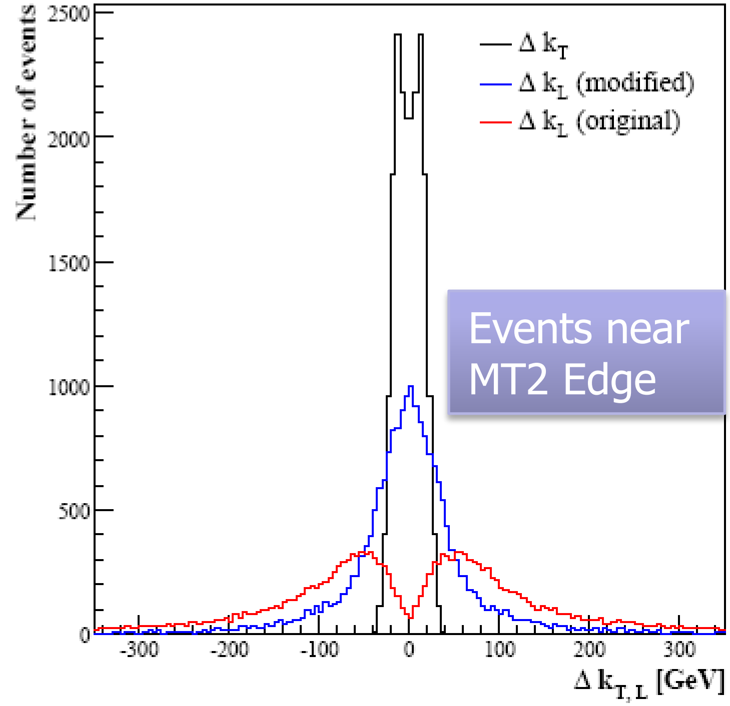


  - In the original MAOS, the lepton+neutrino mass constrained to be M_W
  - Original MAOS scheme slightly more accurate overall
  - For events near edge, both methods are the same

Accuracy of MAOS method

- For M_H=140 GeV





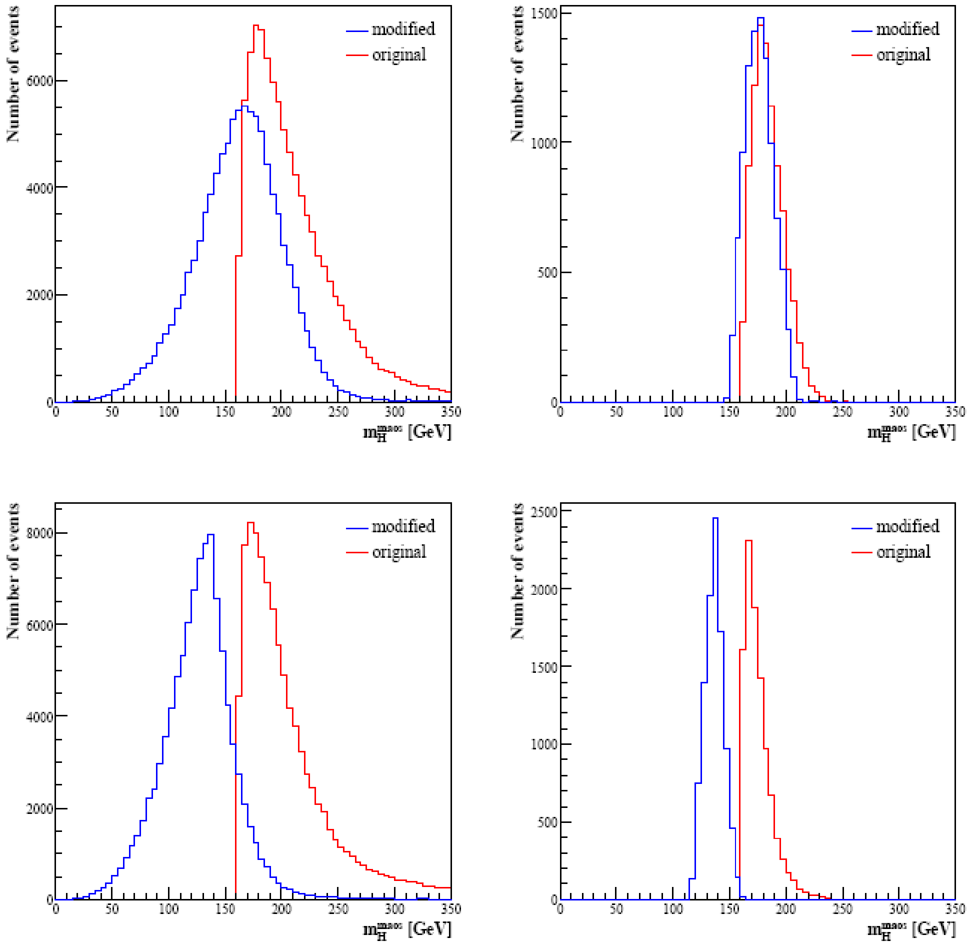
  - One of the W bosons is off-shell
  - Original MAOS scheme more accurate
  - For events near M_{T2} edge, the method is much more accurate

Mass Reconstruction

- Peaks at correct masses with modified MAOS scheme

M_H=180 GeV

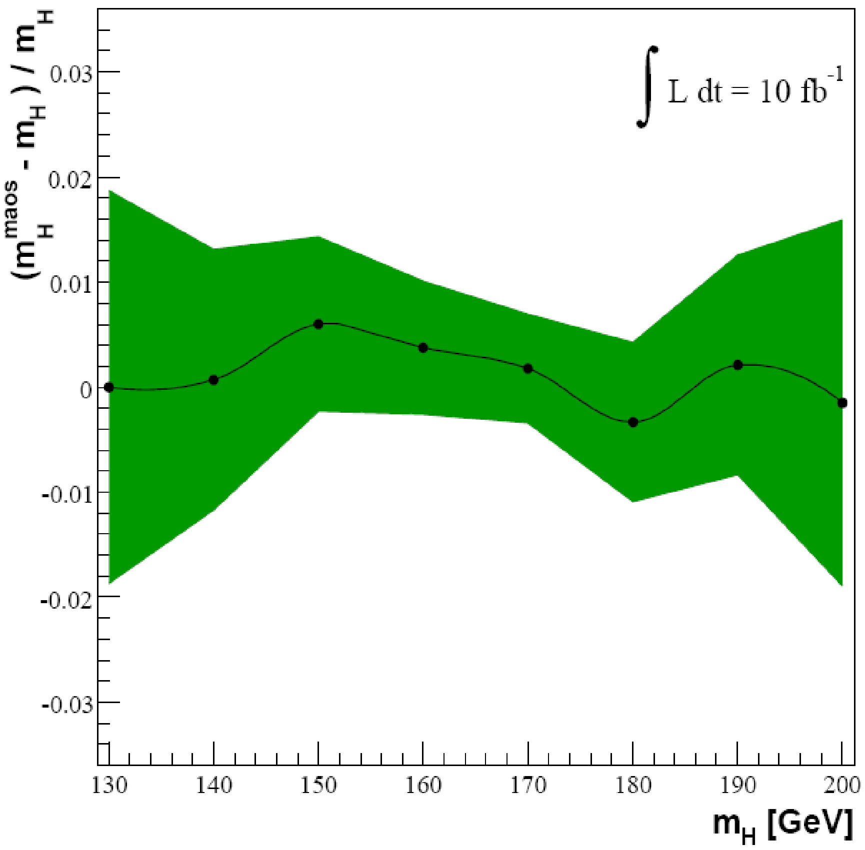
M_H=140 GeV

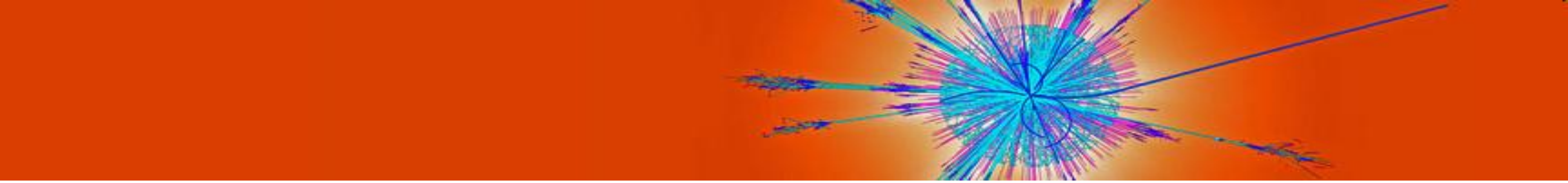


Events near MT2 Edge

Mass Resolution

- <2% mass measurement with 10 fb^{-1} of data
  - PGS simulation
  - Statistical errors only
  - WW and tt-bar background considered





- arXiv:0908.0079 – submitted to PRD

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Reconstructing the Higgs boson in dileptonic W decays at hadron collider

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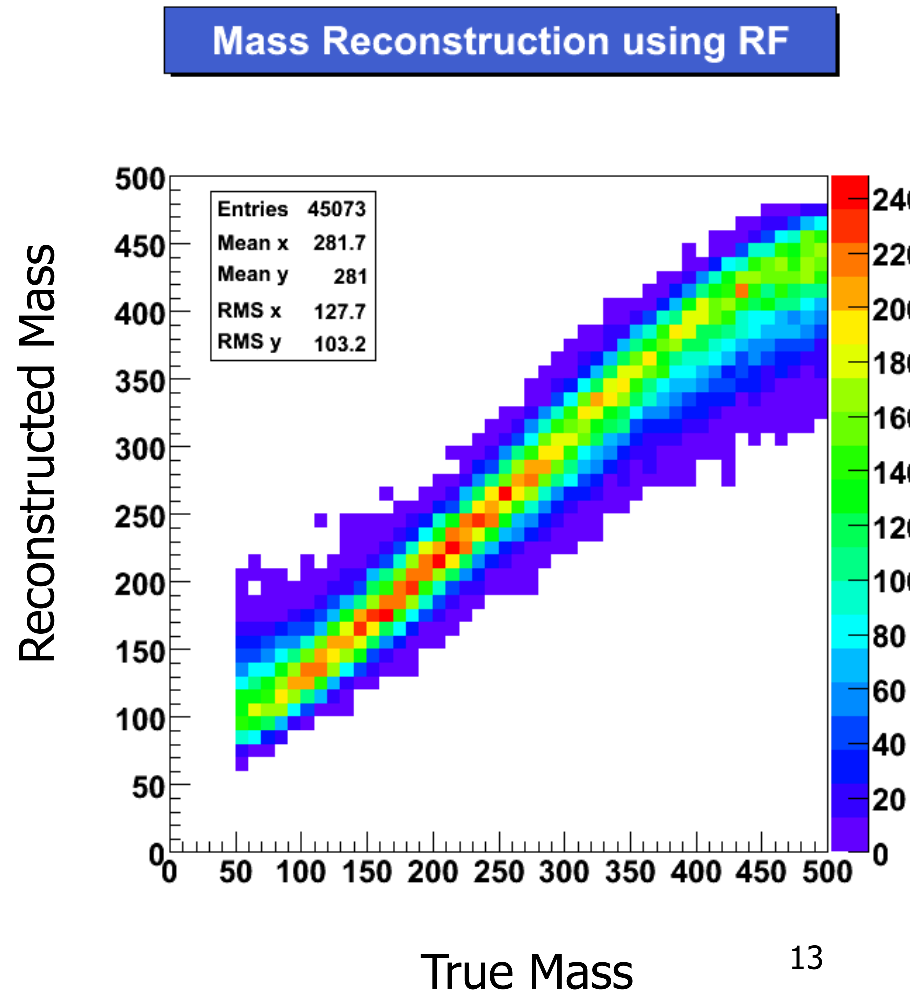
ABSTRACT

We examine the prospect to measure the Higgs boson mass using the recently introduced kinematic variable, the M_{T2}-Assisted On-Shell (MAOS) momentum, that provides a systematic approximation to the invisible neutrino momenta in dileptonic decays of

Multivariate Non-linear Regression

- mass reconstruction as a problem of regression
  - A general function estimator $\{x_i\} \rightarrow m$
- Numerical regression methods have some deficiency
  - Bayesian

- Momentum vectors from a two body decay



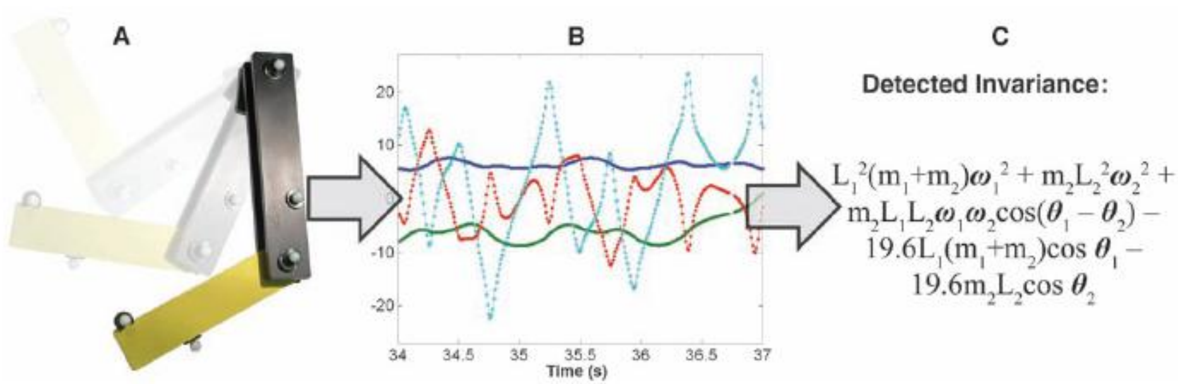
Symbolic Regression

- Science 324, 81 (2009)
  - Find invariants present in the data
  - Analytic equation is constructed
  - Genetic algorithm was used in finding the solution

Distilling Free-Form Natural Laws from Experimental Data

Michael Schmidt[1] and Hod Lipson[2,3]*

For centuries, scientists have attempted to identify and document analytical laws that underlie physical phenomena in nature. Despite the prevalence of computing power, the process of finding natural laws and their corresponding equations has resisted automation. A key challenge to finding analytic relations automatically is defining algorithmically what makes a correlation in observed data important and insightful. We propose a principle for the identification of nontriviality. We demonstrated this approach by automatically searching motion-tracking data captured from various physical systems, ranging from simple harmonic oscillators to chaotic double-pendula. Without any prior knowledge about physics, kinematics, or geometry, the algorithm discovered Hamiltonians, Lagrangians, and other laws of geometric and momentum conservation. The discovery rate accelerated as laws found for simpler systems were used to bootstrap explanations for more complex systems, gradually uncovering the "alphabet" used to describe those systems.

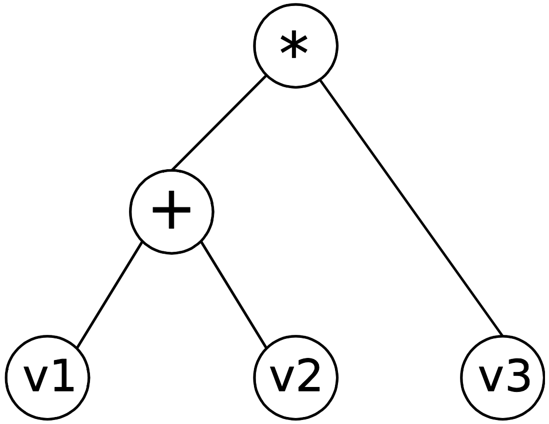


- We can apply similar idea to the problem of finding optimal variables in HEP

Symbolic Regression

- Goal: construct a variable sensitive to mass
  - kinematic variables
  - operators: +, -, *, /
  - functions: sin, cos, exp, log
  - Restricted terms to match the dimension of target
  - Fitness – relative Root Mean Square

- Evolution
  - 150 Generations
  - 1000 individuals (equations)
  - cross-over probability 50%
  - mutation probability 4%



$$(v1+v2)*v3$$

Symbolic Regression with Genetic Algorithms

1. Initialization: random equations are created

2. Creation of new individuals
   1. parents are selected by tournament from random subpool
   2. Cross-over of genes occur at random points
   3. random mutation - probability for this is small

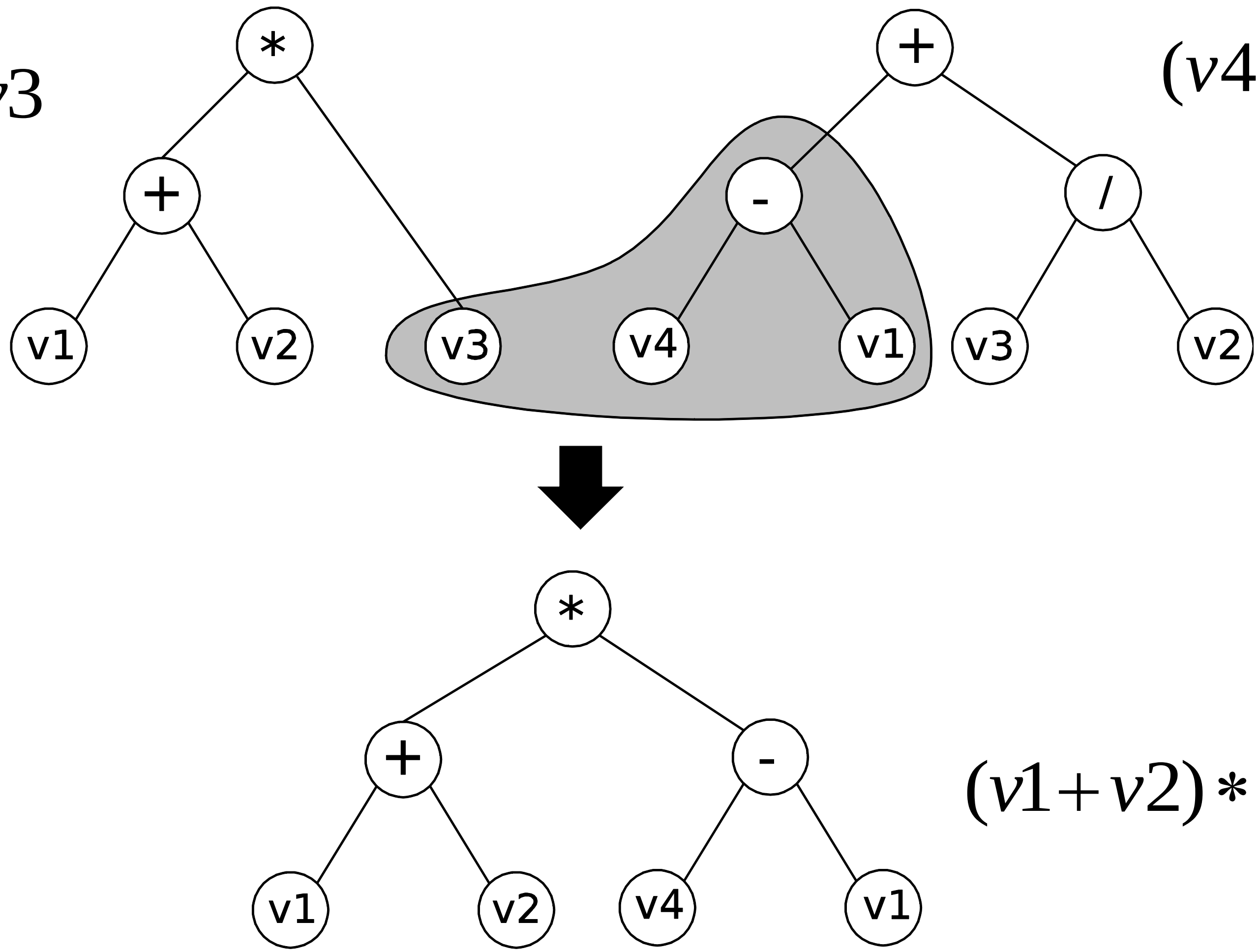
3. Population selection
   1. Population sorted according to fitness
   2. Discard individuals with poor fitness

4. Go to step 2

Example of Cross-over Genetic Operation

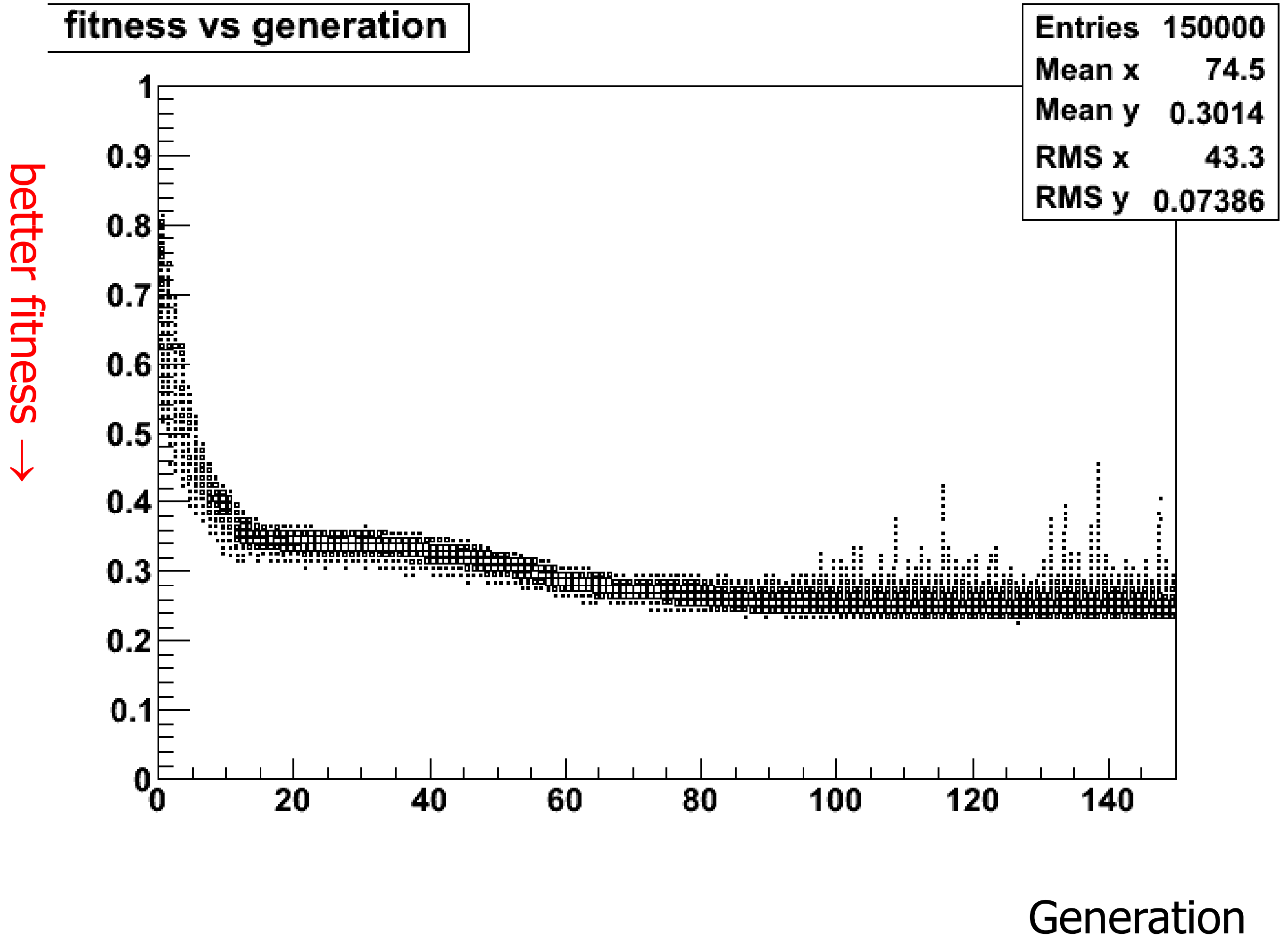
$$(v1+v2)*v3$$

$$(v4-v1)+\frac{v3}{v2}$$

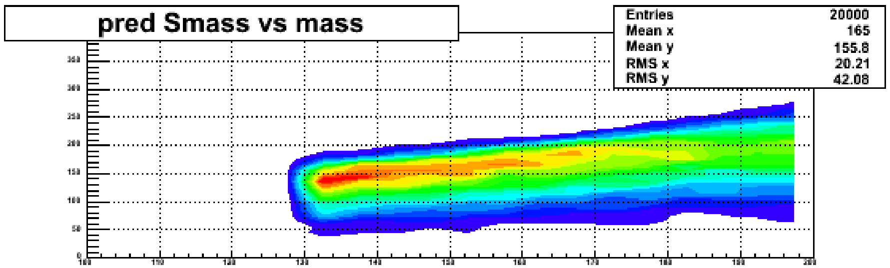


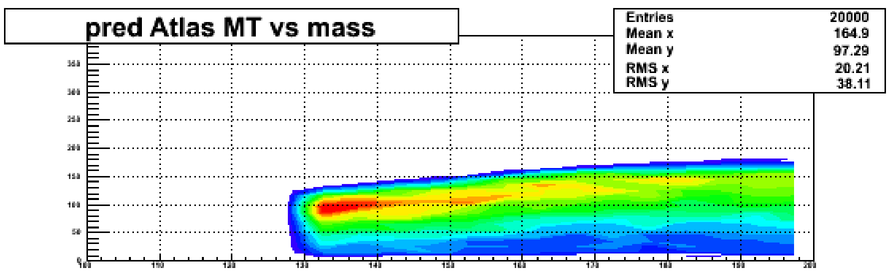
$$(v1+v2)*(v4-v1)$$

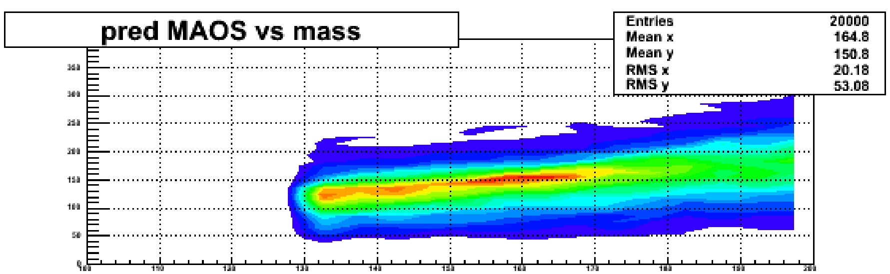
Evolution of Fitness



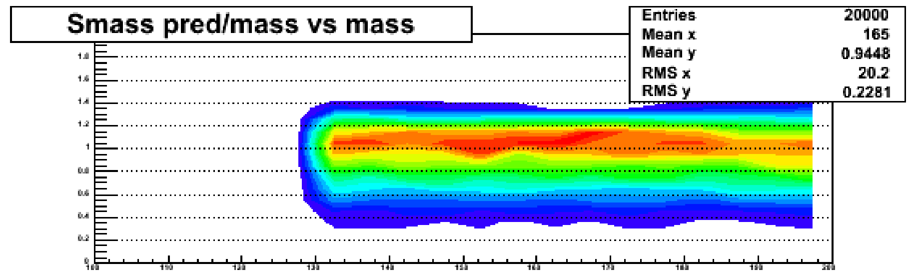
Predicted Mass vs True Mass

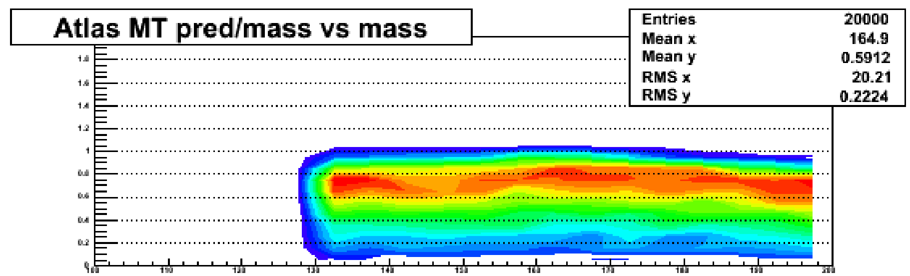


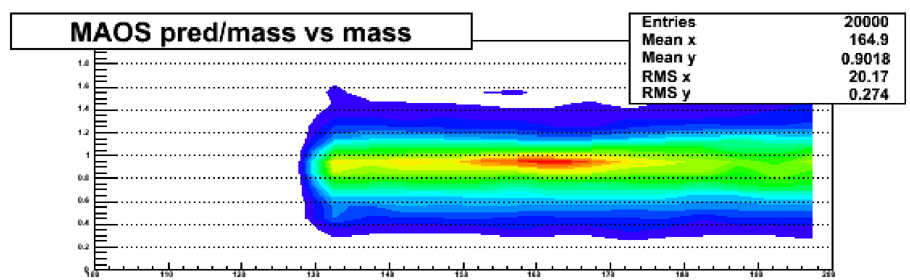




Mass Ratio vs True Mass







Good linearity and resolution is seen

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Summary

- Applied MAOS method for mass reconstruction in $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$
  - competitive with other recently developed techniques

- Symbolic regression allows one to build sensitive variables with correct dimensionality.

- Symbolic regression method is general can be applied to problems with multiple final state particles.