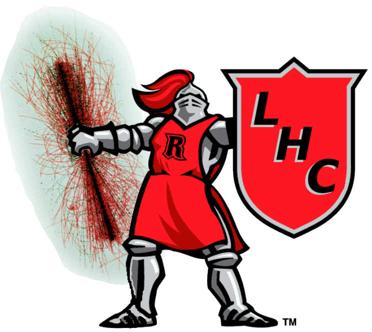
(Non)-Standard Higgs Physics at the LHC

Scott Thomas
Rutgers University



Emmanuel Contreras-Compana, John Paul Chou,
Nathaniel Craig, Jared Evans, Yuri Gershtein,
Richard Gray, Yevgeny Kats, Can Kilic,
Amit Lath, Michael Park,
Sunil Somalwar, Matt Walker

+ CMS Collaboration

December 17, 2012

Higgs Physics at the LHC

Searching for the 2nd Higgs Doublet

SM Channels: H -> $\gamma\gamma$, ZZ

H,h -> WW   Reconstruct Masses

New Channels: H -> hh

A -> Zh

SM Higgs (Precision) Measurements

σ.Br(h -> $\gamma\gamma$, ZZ*, Zγ)   The New Precision EW Physics

h -> ZZ* -> l l l l   Time Reversal Violation + …

Using Higgs to Search for New Physics

h -> $\gamma\gamma$ + X

t -> c h

Searching for Higgsino

$\tilde{H}$ -> Z, h + Neutralino, Goldstino

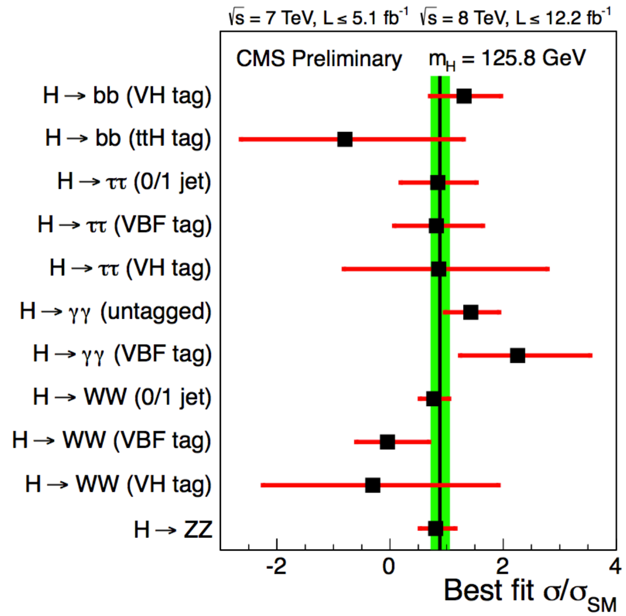
Higgs Boson Rate Measurements

Signals of New Physics in
SM Higgs Rate Measurements

Deviations in SM Higgs Couplings

- Specific Underlying Theoretical Framework

- Effective Operator Analysis



Any Deviations at Discovery Level
are by Definition Large …

Searching for 2nd Higgs Doublet in SM Higgs Boson Rate Measurements

(Craig, ST)

Two Higgs Doublets h, A, H, H^{+-}

h-H mix

Large modifications of h couplings Possible

Four Discrete Two Doublet Models that Satisfy Glashow-Weinberg Condition

Four types of Couplings –
Two Parameters, α , β
Correlations
(see paper)

	2HDM I	2HDM II	2HDM III	2HDM IV
u	Φ_2	Φ_2	Φ_2	Φ_2
d	Φ_2	Φ_1	Φ_2	Φ_1
e	Φ_2	Φ_1	Φ_1	Φ_2

	2HDM I	2HDM II	2HDM III	2HDM IV
hVV	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
hQu	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
hQd	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
hLe	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$
HVV	$\cos(\beta-\alpha)$	$\cos(\beta-\alpha)$	$\cos(\beta-\alpha)$	$\cos(\beta-\alpha)$
HQu	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
HQd	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
HLe	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$
AVV	0	0	0	0
AQu	$\cot\beta$	$\cot\beta$	$\cot\beta$	$\cot\beta$
AQd	$-\cot\beta$	$\tan\beta$	$-\cot\beta$	$\tan\beta$
ALe	$-\cot\beta$	$\tan\beta$	$\tan\beta$	$-\cot\beta$

Searching for 2nd Higgs Doublet in SM Higgs Boson Rate Measurements

(Craig, ST)

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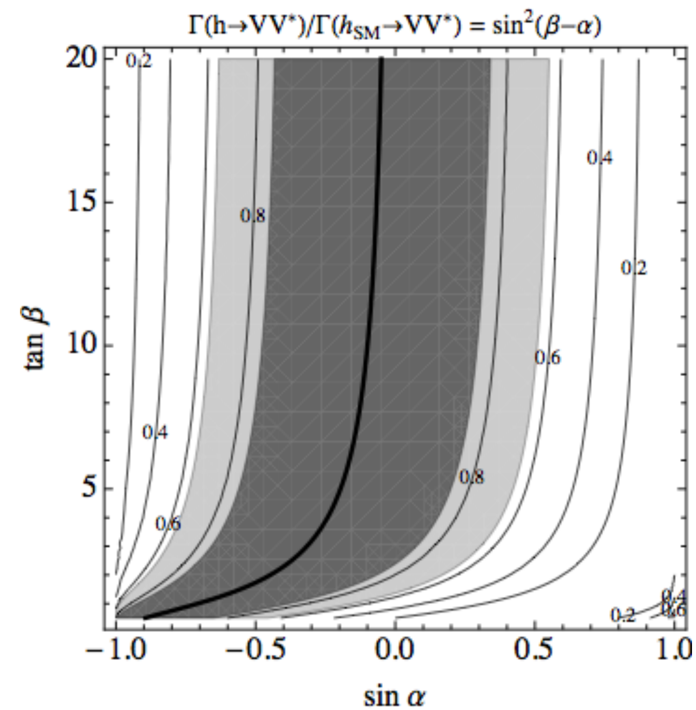
Four types of Couplings – Two Parameters, α , β Correlations (see paper)

Using CMS 5 + 12 fb^{-1} 7 + 8 TeV



Searching for 2nd Higgs Doublet
Extra Higgs Bosons in SM Channels

(Craig, ST)

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Four Discrete Two Doublet
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Four types of Couplings –
Two Parameters, α , β
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h, H -> VV
h,H,A -> $\gamma\gamma$

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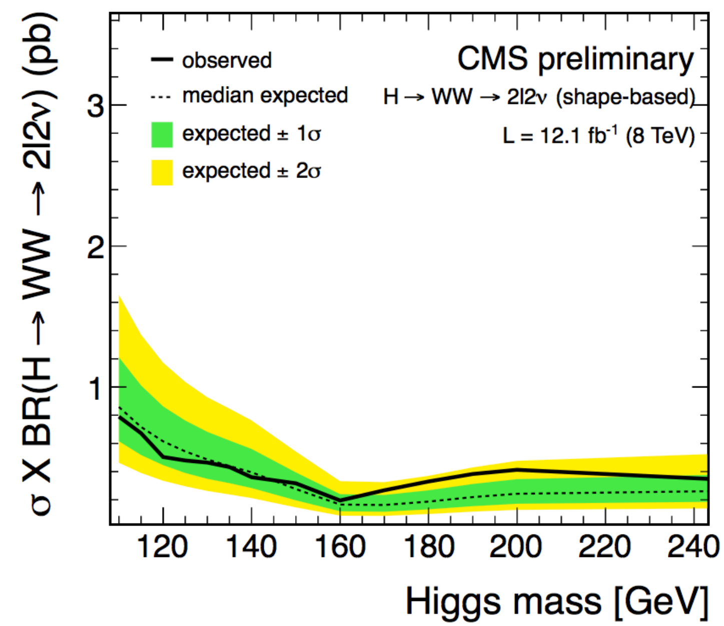

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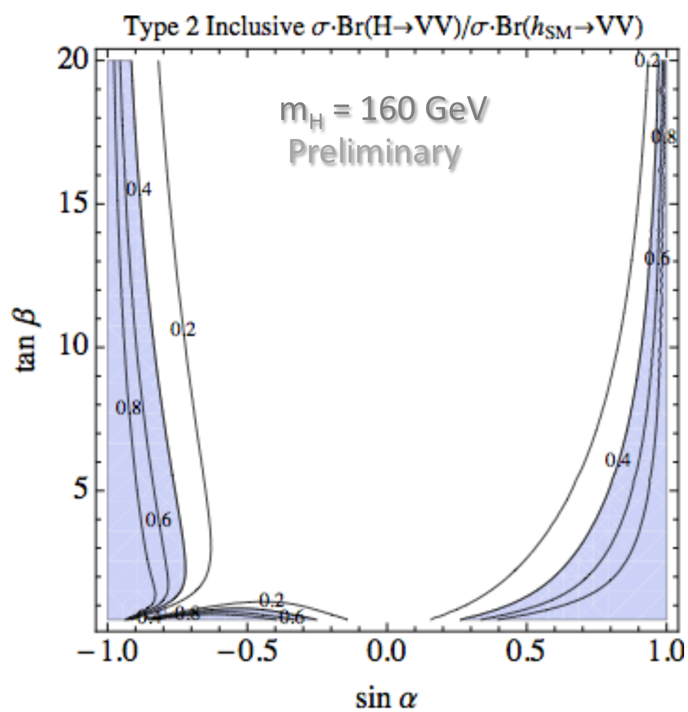

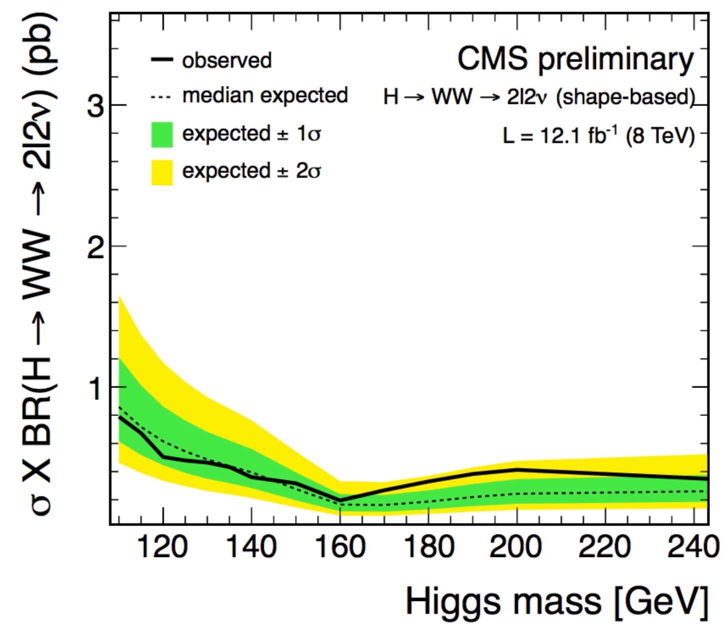

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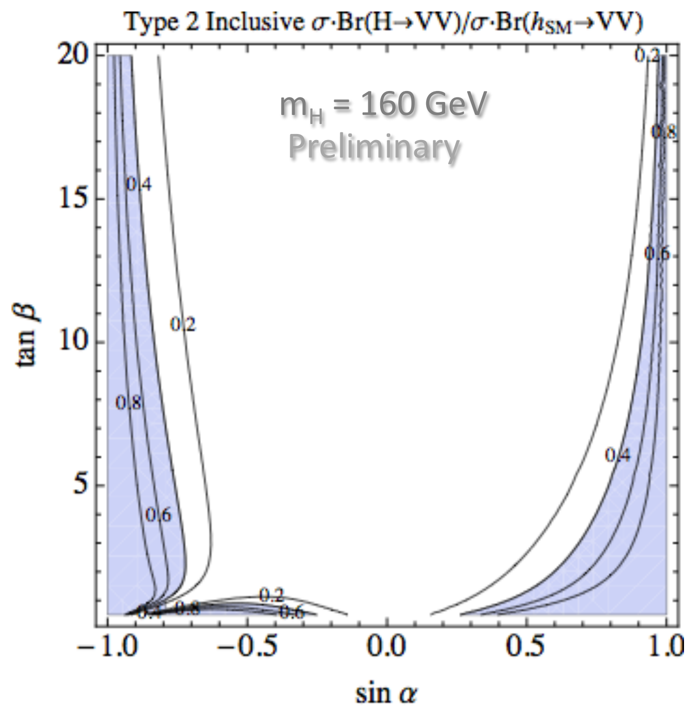

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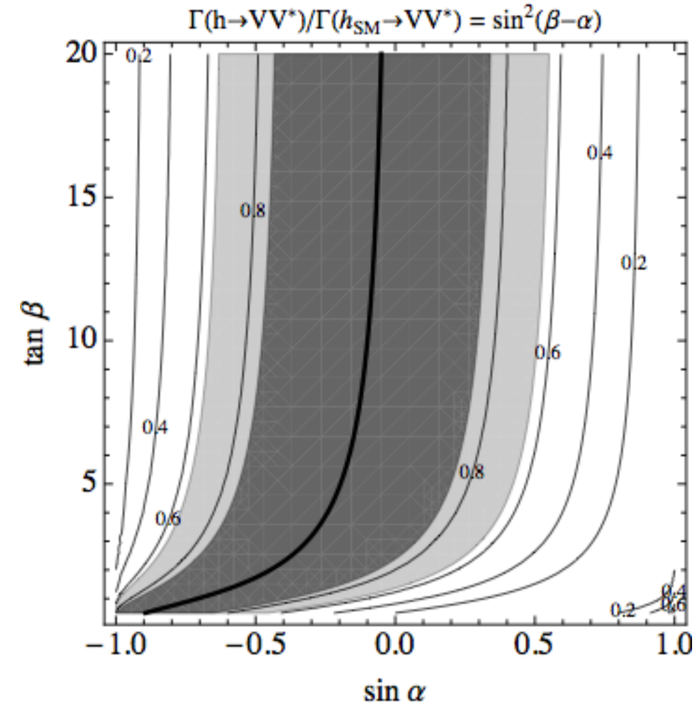

h ->VV Deviations more Sensitive than
H -> VV Search (for now) ...
(More Later in Talk)

Searching for 2nd Higgs Doublet
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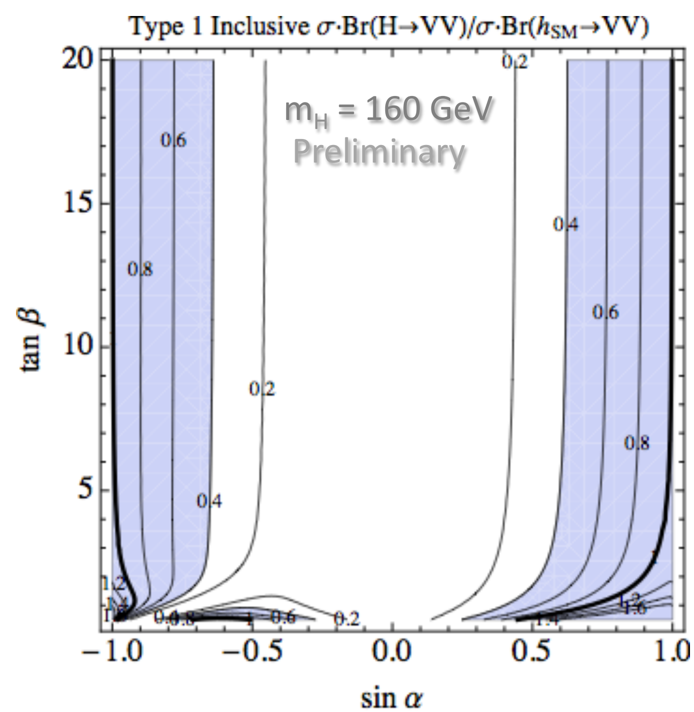

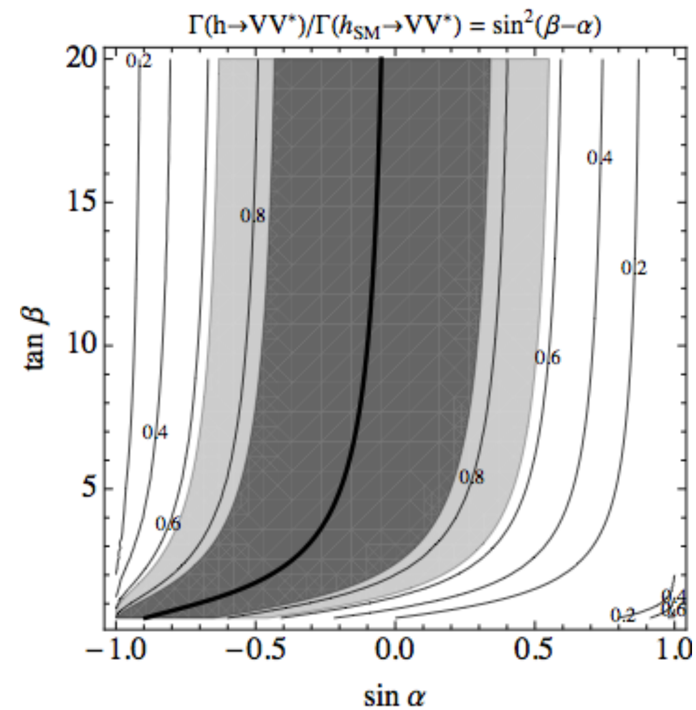

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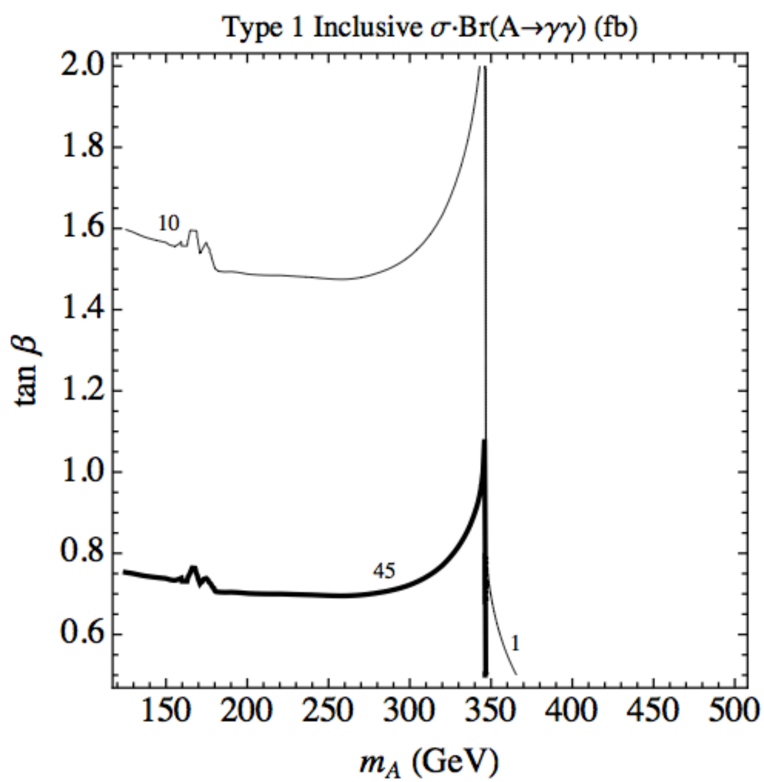
h, A, H -> $\gamma\gamma$



σ . Br(h -> $\gamma\gamma$) = 45 fb
for m_h = 125 GeV

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Extra Higgs Bosons in SM Channels

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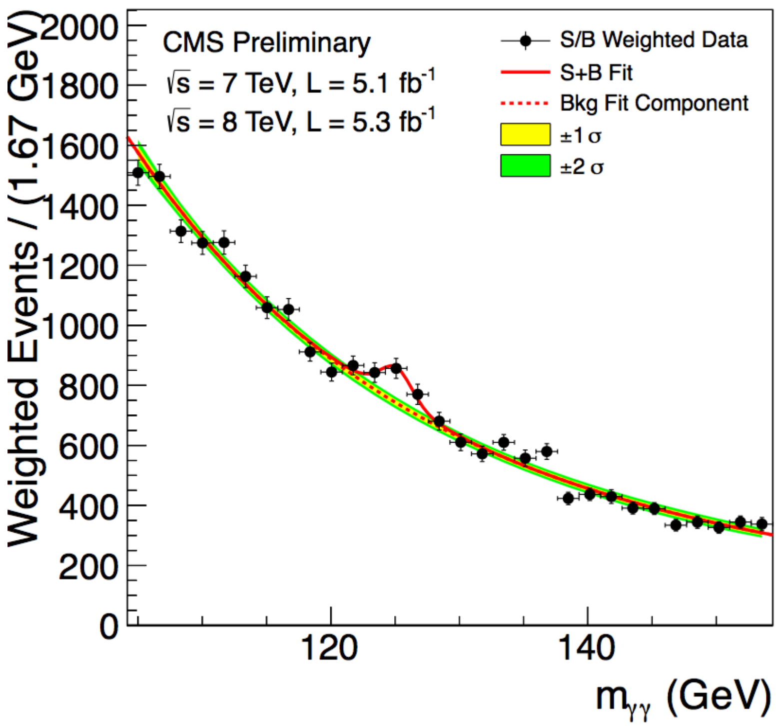
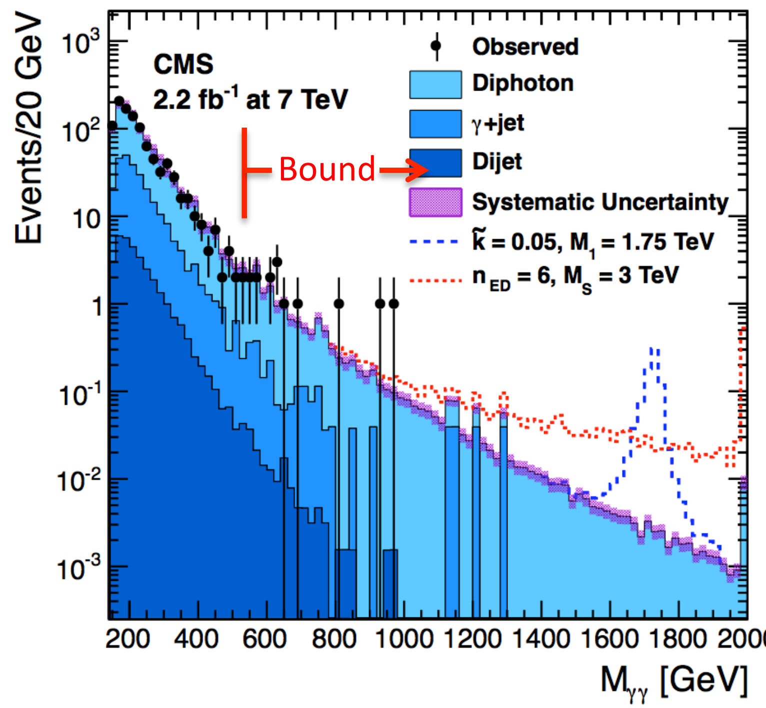
$h, A, H \to \gamma\gamma$





Multi-Lepton Searches

(CMS)

Extremely Sensitive Probes
for New Physics

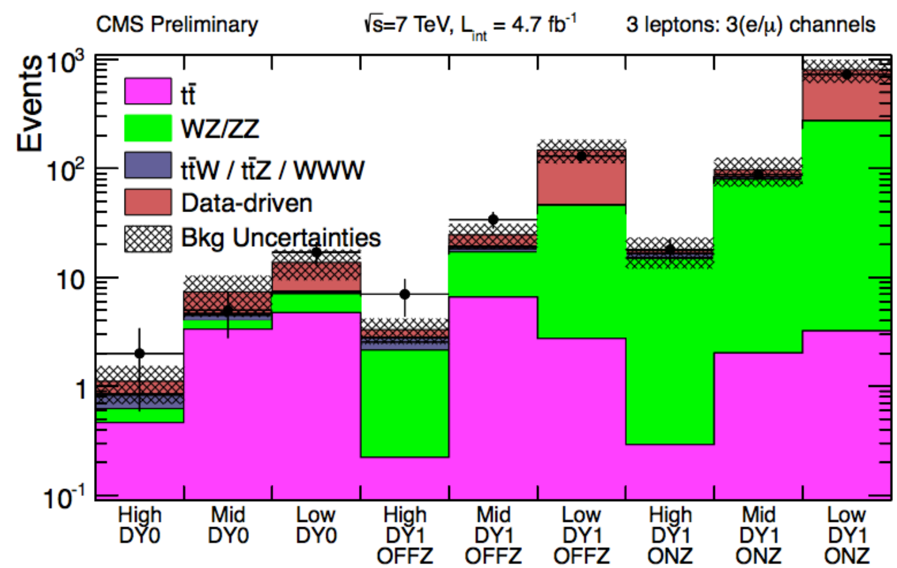
Exclusive Channels Based on

<u>All</u> Flavor + Charge Combinations
Two or More Leptons (and taus)
HT, MET, ST, …
b-tags, … , jets
Kinematics Discriminants + …

Events -> Channels Lowest to
Highest Background <u>Exclusively</u>

<u>Maximizes</u> Sensitivity
(Given Signal may Overlap with
Low Background Channels)

Exclusive Combination of <u>All</u>
(100's) of Channels



Multi-Lepton Signals of Higgs

(Contreras-Compana, Craig, Gray, Kilic, Park, Somalwar, ST)

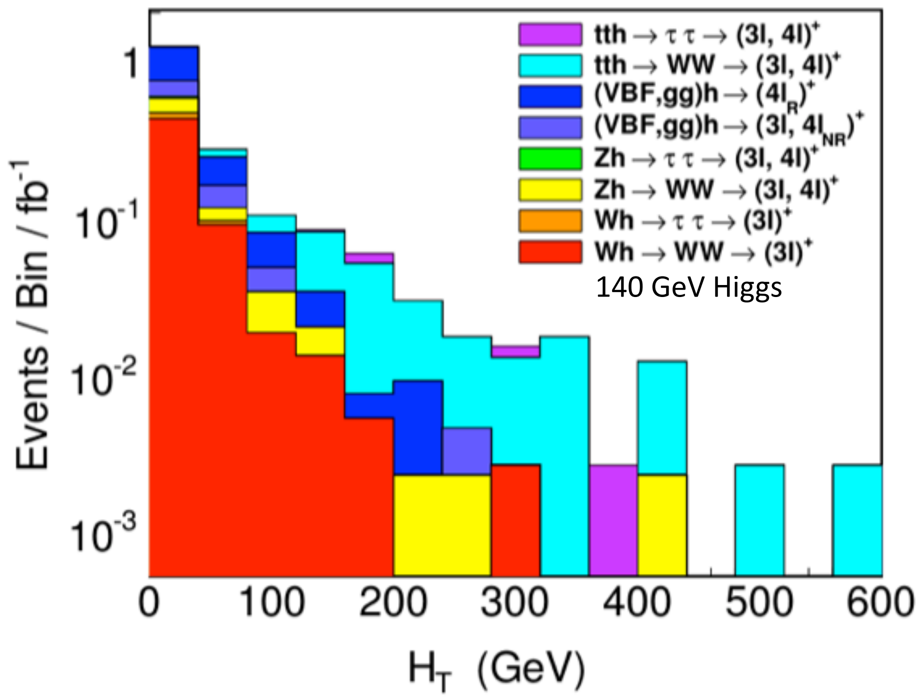
Higgs Final States Will Eventually Contaminate
Multi-lepton Search …

Turn Around – Multi-Leptons as Search for Higgs

h : (120-150) GeV
(11 Signal Topologies)

Production	Decay
$gg \to h$	$h \to 4\ell$
$VBF \to h$	$h \to 4\ell$
$q\bar{q} \to Wh$	$Wh \to WWW, W\tau\tau, WZZ$
$q\bar{q} \to Zh$	$Zh \to ZWW, Z\tau\tau, ZZZ$
$t\bar{t}h$	$t\bar{t}h \to t\bar{t}WW, t\bar{t}\tau\tau, t\bar{t}ZZ$

Multi-Lepton Non-Resonant Channels Exceed Resonant 4 Lepton Channel



Signal Spread Out over Many Channels
Minimal Significance in Any Given Channel

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No Kinematic Optimization

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Multi-Lepton Non-Resonant Channels Exceed Resonant 4 Lepton Channel

Estimated σ / σ_{SM} Limit 5 fb^{-1}

	120 GeV	130 GeV	140 GeV	150 GeV
All Contributions				
Standard Model Higgs	4.3	2.7	2.0	1.8
Fermi-phobic Higgs	2.2	2.3	2.9	3.0
b-phobic Higgs	1.6	1.4	1.4	1.5
Non-resonant Contributions				
Standard Model Higgs	5.8	3.8	3.0	2.6
Fermi-phobic Higgs	2.2	2.4	3.1	3.2
b-phobic Higgs	2.0	2.0	2.1	2.2

Calculated $A(m_h)$ for All Topologies
Exclusive Combination - (extrapolation)
(c.f. CDF Simplified Model Topology Study)

Signal Spread Out over Many Channels
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Illustrates Power of Multi-Channel Multi-Lepton Search

Multi-Lepton Signals of 2nd Higgs Doublet

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$$\sigma \cdot \mathrm{Br} \cdot \mathcal{A}(pp \to f) = \sum_t \sigma(pp \to t)\mathcal{A}(pp \to t \to f) \prod_a \mathrm{Br}_a(t \to f)$$

$h/A/H^{\pm}/H$:
125/230/230/500 GeV
(105 Signal Topologies)

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$t\bar{t}A$	$t\bar{t}A \to t\bar{t}\tau\tau$
	$t\bar{t}A \to t\bar{t}Zh \to t\bar{t}ZWW, t\bar{t}Z\tau\tau, t\bar{t}Zb\bar{b}, t\bar{t}ZZZ$

Sensitivity Beyond Standard Searches

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Multi-Lepton Signals of 2nd Higgs Doublet

(Craig, Evans, Gray, Park, Kilic, Somalar, ST)

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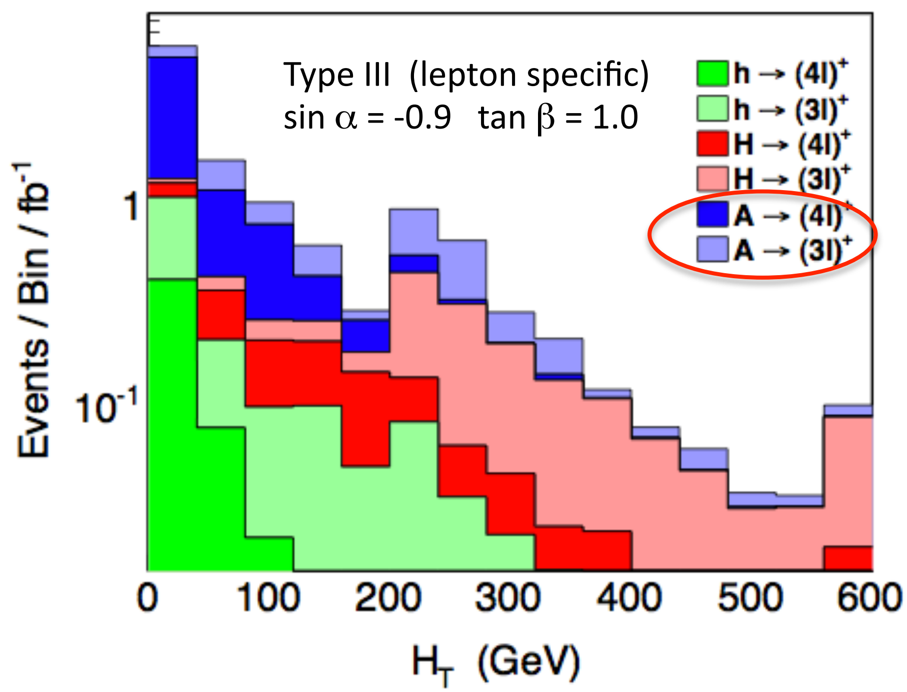

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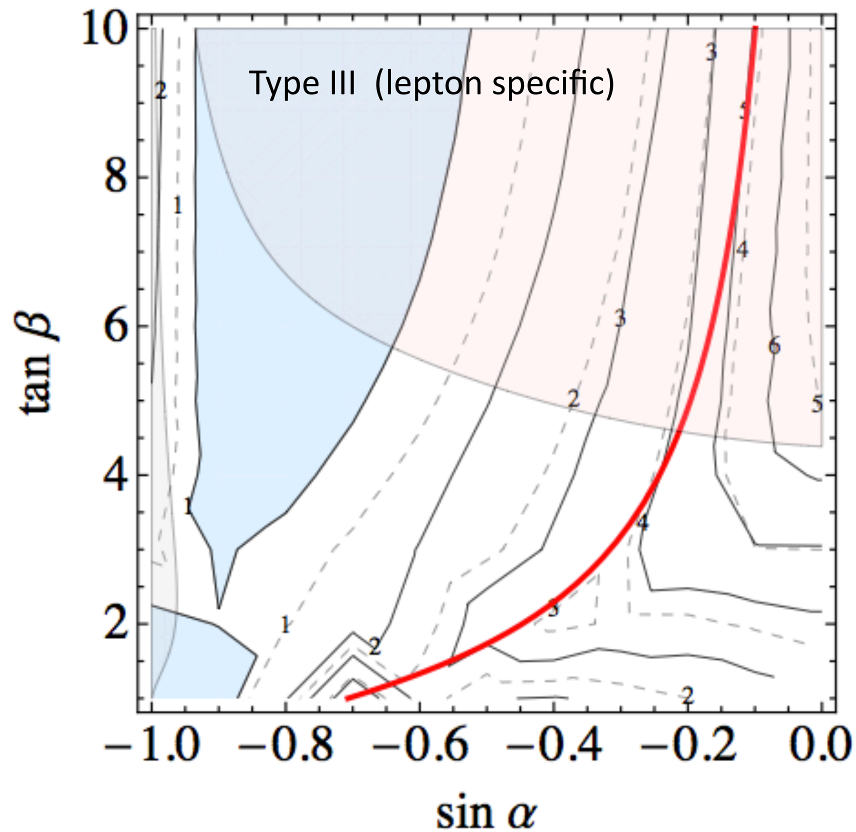

h/A/H^{+-}/H :
125/230/230/500 GeV
(105 Signal Topologies)

Sensitivity Beyond
Standard Searches

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Blue Multi-Lepton Excluded
Gray H ->VV Excluded

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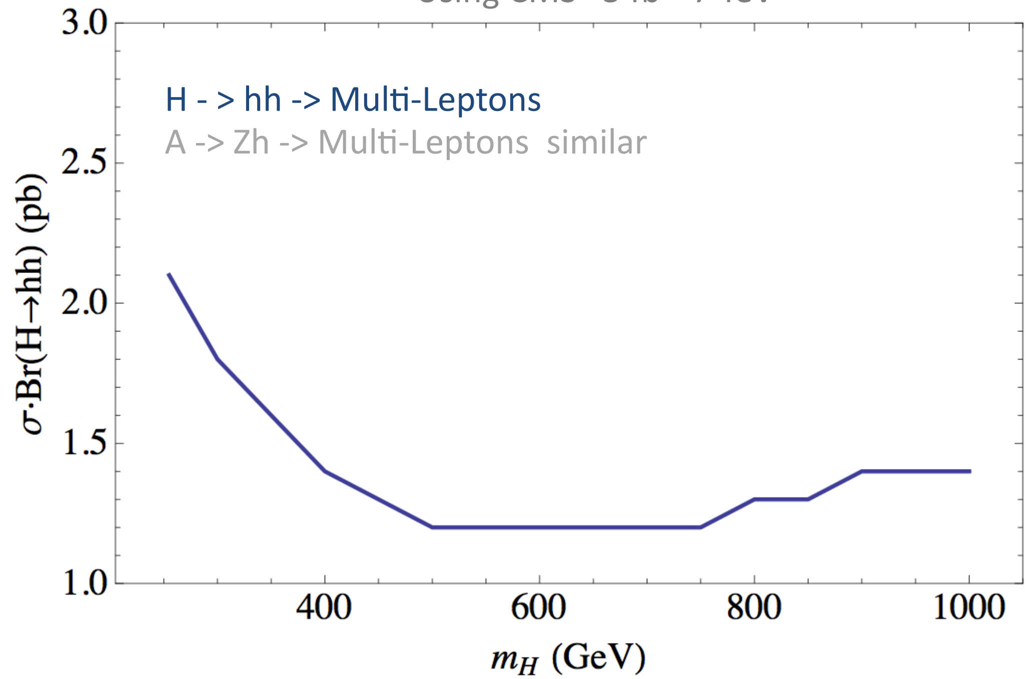


First Bounds on di-Higgs Production
from Existing Data

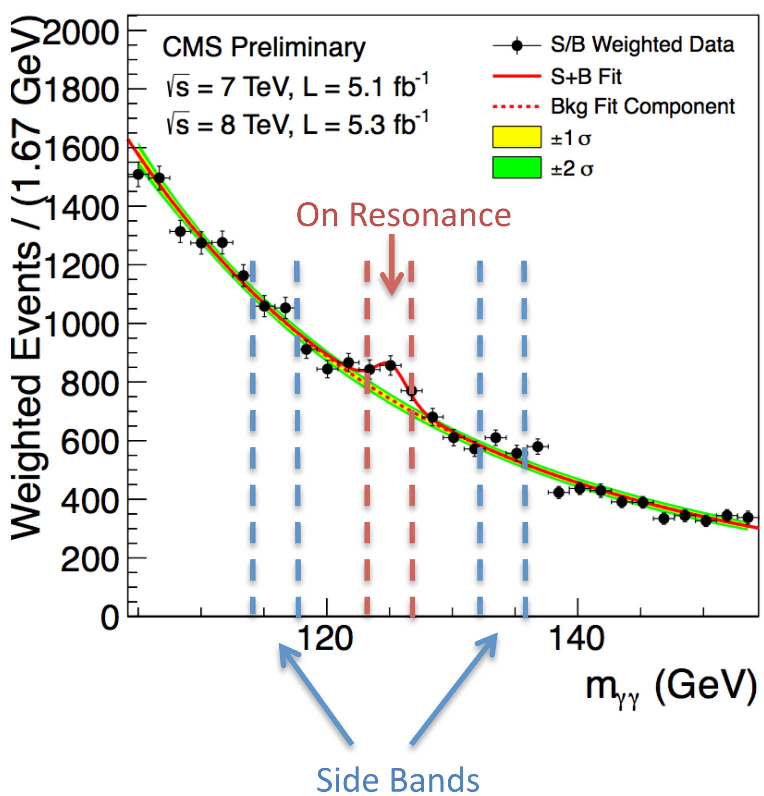
Using Higgs to Discover New Physics

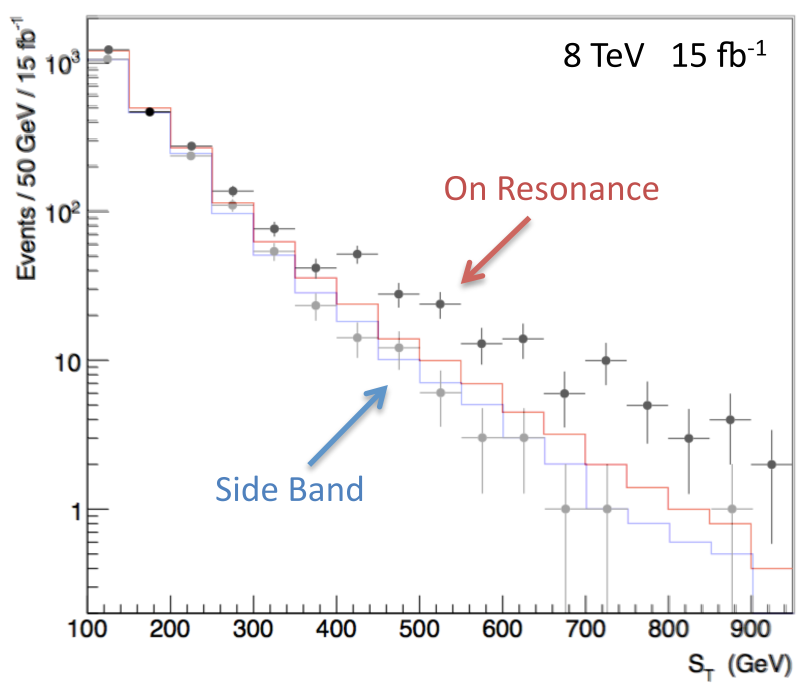
(Gershtein, Chou, Y. Kats, ST)

Use 125 GeV Higgs as Calibration to Search for New Physics

$h \to \gamma\gamma$ + X (On-Resonance + Upper and Lower Side Bands)

Even Blunt Variables Suffice + More focused + …





Blue = Side Band Background
Red = On Resonance SM Higgs + Background + Stop -> h + X

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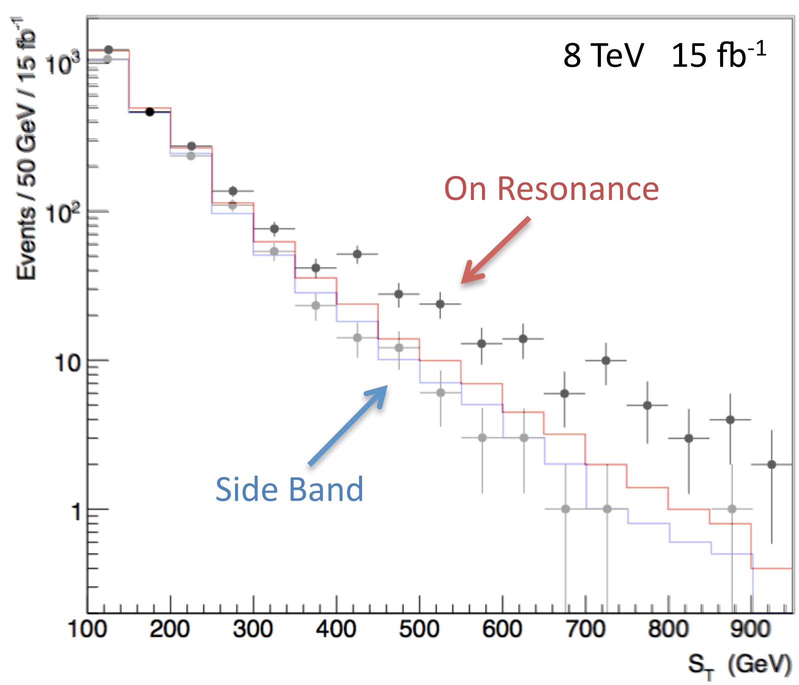
$h \to \gamma\gamma$ + X (On-Resonance + Upper and Lower Side Bands)

Even Blunt Variables Suffice + More focused + …

Stop Pair Production 250 GeV
with stop -> b + Higgsino and
Higgsino -> h + Goldstino

Many other Examples …

Compare SM tth benchmark



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Red = On Resonance SM Higgs + Background + Stop -> h + X

Using Higgs to Discover New Physics

(Craig, Evans, Gray, Park, Somalwar, ST, Walker)

Use 125 GeV Higgs as Calibration to Search for New Physics

h -> WW*, ZZ*, $\tau\tau$ -> Multi-Leptons + X

tt Pair Production with

t -> c h and t -> leptonic

5 fb^{-1} Multi-Lepton 7 TeV Data:

Br(t -> c h) < 2.7%

(with b-tags + kinematics in progress)

First Use of Higgs Boson to Search for New Physics in Existing Data

First Direct Probe of Flavor Violation in Higgs sector (for fermion that is most strongly coupled to Higgs Sector)

Precision Probes of New Physics

Electroweak Observables

G_F, m_W, m_Z, Γ_Z, A_{FB}, …

Renormalizable SM +
D=6 Operators

H = <H>

$$\frac{\xi_T}{M^2}\,(H^\dagger D_\mu H)(H^\dagger D^\mu H)$$

$$\frac{g_1 g_2 \xi_{S_{12}}}{M^2}\; H^\dagger W_{\mu\nu} H\; B^{\mu\nu}$$

PDG

S = 0.01 +- 0.10

T = 0.03 +- 0.11

Systematics: m_t, $\ln(m_h)$, α_S , ….

Precision Physics Through the Higgs

(Craig, ST)

Higgs Observables

σ . Br (Initial -> h -> Final)

Precision Physics Through the Higgs

(Craig, ST)

Higgs Observables

σ . Br (Initial -> h -> Final)

<u>Best Channels</u>:

σ . Br (Inclusive -> h -> Resonant Final)

Precision Physics Through the Higgs

(Craig, ST)

Higgs Observables

σ . Br (Initial -> h -> Final)

$$\frac{\mathrm{Br}(h \to \gamma\gamma)}{\mathrm{Br}(h \to ZZ)}$$

<u>Best Channels</u>: (Ratios)

σ . Br (Inclusive -> h -> Resonant Final)

Precision Physics Through the Higgs

(Craig, ST)

Higgs Observables

σ . Br (Initial -> h -> Final)

$$\frac{\mathrm{Br}(h\to\gamma\gamma)}{\mathrm{Br}(h\to ZZ)} \simeq \left.\frac{\mathrm{Br}(h\to\gamma\gamma)}{\mathrm{Br}(h\to ZZ)}\right|_{\mathrm{SM}} \left[1+\mathcal{O}\left(\frac{\alpha}{4\pi v^2}\frac{M^2}{\xi}\right)\right]$$

Best Channels: (Ratios)

σ . Br (Inclusive -> h -> Resonant Final)

Renormalizable SM + D=6 Operators

H = ‹H› + h

$$\frac{\xi_T}{M^2}\,(H^\dagger D_\mu H)(H^\dagger D^\mu H)$$

$$\frac{g_1 g_2 \xi_{S_{12}}}{M^2}\; H^\dagger W_{\mu\nu} H\; B^{\mu\nu}$$

$$\frac{g_1^2 \xi_{S_{11}}}{2M^2}\; H^\dagger H\; B_{\mu\nu} B^{\mu\nu}$$

$$\frac{g_2^2 \xi_{S_{22}}}{2M^2}\; H^\dagger H\; W_{\mu\nu} W^{\mu\nu}$$

Precision Physics Through the Higgs

(Craig, ST)

Higgs Observables

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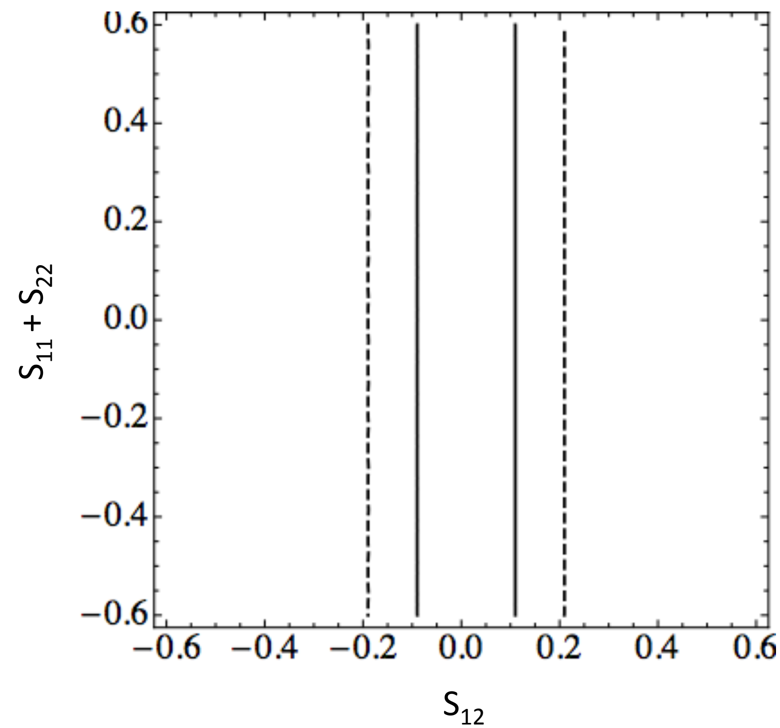
PEW



Precision Physics Through the Higgs

(Craig, ST)

Higgs Observables

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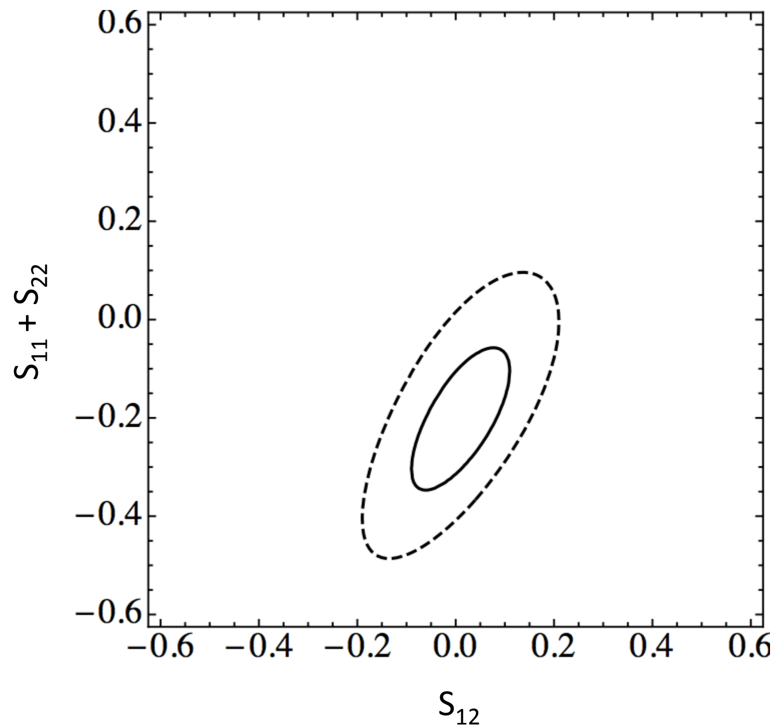
$$\frac{g_2^2 \xi_{S_{22}}}{2M^2}\; H^\dagger H\; W_{\mu\nu} W^{\mu\nu}$$

PEW + CMS 5 + 12(5) fb^{-1} 7 + 8 TeV



Systematics: Statistics, Resonant-Continuum Separation + Interference, …

Precision Physics Through the Higgs

(Craig, ST)

Higgs Observables

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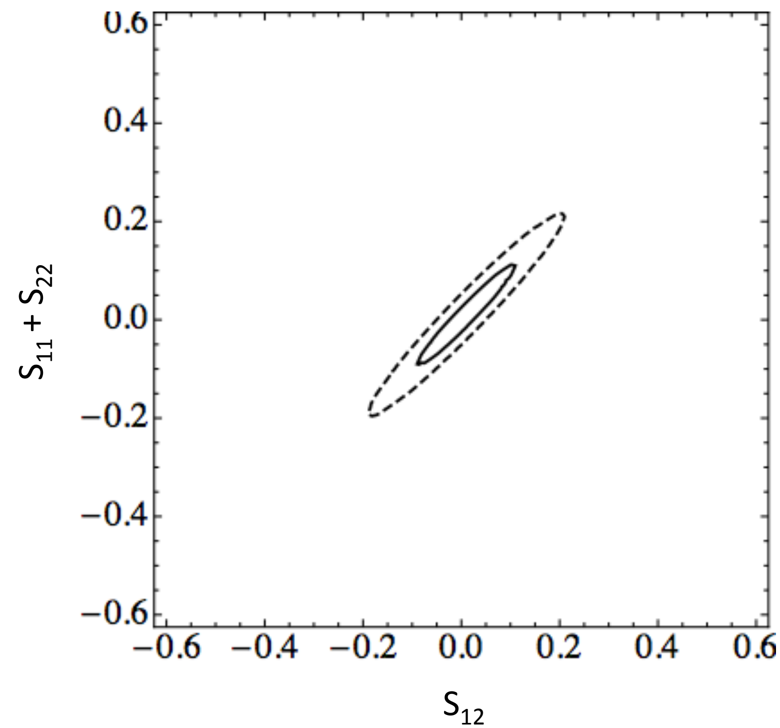
$$\frac{g_2^2 \xi_{S_{22}}}{2M^2} H^\dagger H\ W_{\mu\nu} W^{\mu\nu}$$

PEW + 5% Uncertainty Br(h->γγ)/Br(h->ZZ)



Systematics: Statistics, Resonant-Continuum Separation + Interference, …

Precision Higgs -> ZZ* -> l l l l

(Park, ST)

Four Lepton Kinematics

12 Dimensional Phase Space
= 1 + 1 + 10 (Mass Factorized)

Azimuth Mass Dimensionless

Multi-Variate Description
Factorizes =
Mass X Dimensionless

Mass Variable	$m_{\ell\ell\ell'\ell'}$	$(0,\infty)$	Relevant
Center of Mass Variables	$y_{\ell\ell\ell'\ell'}$	$[0,\infty)$	Relevant
	$\pi_{T\ell\ell\ell'\ell'}$	$[0,\infty)$	Transverse Irrelevant
	Azimuth	$-$	Irrelevant
Production Variables	$\lvert\cos\theta_{\ell\ell-\ell'\ell'}\rvert$	$[0,1]$	Relevant
	$\zeta'_{\ell\ell-\ell'\ell'}$	$[0,\infty)$	Transverse Irrelevant
Decay Variables	$\cos\Theta_{\ell^+\ell'^-}$	$[-1,1]$	Relevant (Universal)
	ρ	$(0,\frac{1}{2})$	Threshold Irrelevant
	ξ	$[0,1)$	Threshold Irrelevant
	$\mathcal{P}_{\ell\ell}$	$[0,1]$	Threshold Irrelevant
	$\mathcal{P}_{\ell\ell'}$	$[0,1]$	Threshold Irrelevant
	$\tau_{\ell\ell-\ell'\ell'}$	$[-1,1]$	Threshold Irrelevant

Absence of Transverse Recoil
2->2 Scattering D=2

D=10 Dimensionless Phase Space ->
D=8 Dimensionless Phase Space

Near h->ZZ* Threshold
1->4 Threshold Decay D=1

D=8 Dimensionless Phase Space ->
D=3 Dimensionless Phase

Dimensional Reduction of
Phase Space in Limits
(Near Physical Distribution)

10 = 3 + 2 + 5

Dimensionless Relevant Transverse Irrelevant Threshold Irrelevant

Precision Higgs -> ZZ* -> l l l l

(Park, ST)

Four Lepton Kinematics

Mass Variable	$m_{\ell\ell\ell'\ell'}$	$(0,\infty)$	Relevant
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Spin

Interesting Information

Parity + Momentum Form Factor

Z Polarization

Z Polarization

Spin

Leading Effects: Irrelevant Variables

Interference of SM Higgs interactions with Modified Interactions (Non-Renormalizable Operators)

Measuring Time Reversal Violation in Higgs -> ZZ* -> l l l l

(Park, ST)

Mass Variable	$m_{\ell\ell\ell'\ell'}$	$(0,\infty)$	Relevant
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Spin ←

Interesting Information ←

Parity + Momentum Form Factor

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Spin +

Time Reversal Violation

Leading Effects: Irrelevant Variables

Interference of SM Higgs interactions with Modified Interactions (Non-Renormalizable Operators)

$$\tau_{\ell^+\ell^-\ell'^+\ell'^-} \equiv \frac{\epsilon_{\mu\nu\rho\sigma}\, p^\mu_{\ell^+} p^\nu_{\ell^-} p^\rho_{\ell'^+} p^\sigma_{\ell'^-}}{m^4_{\ell^+\ell^-\ell'^+\ell'^-}}$$

Odd Under Time Reversal

Measuring Time Reversal Violation in Higgs -> ZZ* -> l l l l

(Park, ST)

hZZ Coupling Through Both T-even + T-odd Couplings

Renormalizable SM +
D=6 Operators

H = <H> + h

$$\frac{g_1 g_2 \tilde{\xi}_{S_{12}}}{M^2} \; H^\dagger W_{\mu\nu} H \; \tilde{B}^{\mu\nu}$$

$$\frac{g_1^2 \tilde{\xi}_{S_{11}}}{2M^2} \; H^\dagger H \; B_{\mu\nu} \tilde{B}^{\mu\nu}$$

$$\frac{g_2^2 \tilde{\xi}_{S_{22}}}{2M^2} \; H^\dagger H \; W_{\mu\nu} \tilde{W}^{\mu\nu}$$

$|A|^2 = |A_{scalar} + A_{pseudo\text{-}scalar}|^2$

Enhance Asymmetry with Specific
Kinematic Structure of
Interference Term

$$\widetilde{\mathcal{T}}_{\ell^+\ell^-\ell'^+\ell'^-} \equiv \tau_{\ell^+\ell^-\ell'^+\ell'^-} \; \widetilde{\mu}_{\ell^+\ell^-\ell'^+\ell'^-}$$

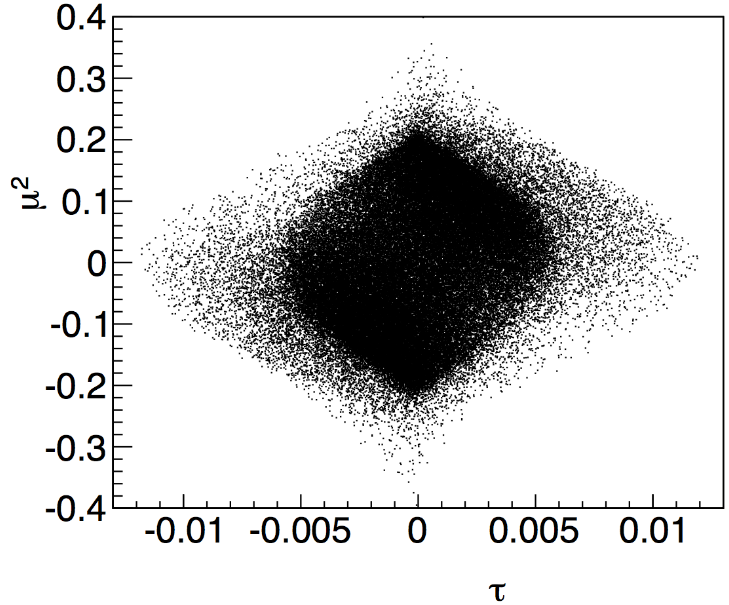
$$\widetilde{\mu}_{\ell^+\ell^-\ell'^+\ell'^-} \equiv \frac{m^2_{\ell^+\ell'^+} - m^2_{\ell^+\ell'^-} - m^2_{\ell^-\ell'^+} + m^2_{\ell^-\ell'^-}}{m^2_{\ell^+\ell^-\ell'^+\ell'^-}}$$

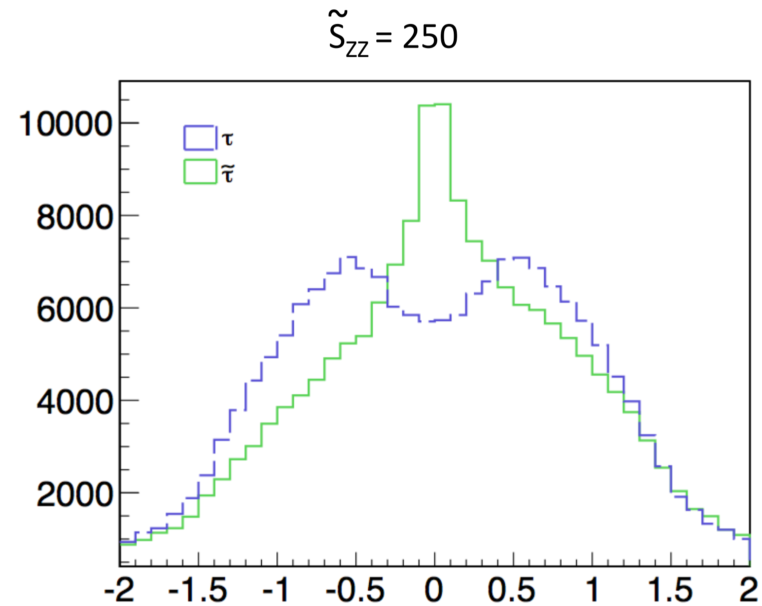
$$\tau_{\ell^+\ell^-\ell'^+\ell'^-} \equiv \frac{\epsilon_{\mu\nu\rho\sigma} \, p^\mu_{\ell^+} p^\nu_{\ell^-} p^\rho_{\ell'^+} p^\sigma_{\ell'^-}}{m^4_{\ell^+\ell^-\ell'^+\ell'^-}}$$

Odd Under Time Reversal

Measuring Time Reversal Violation in Higgs -> ZZ* -> l l l l

(Park, ST)





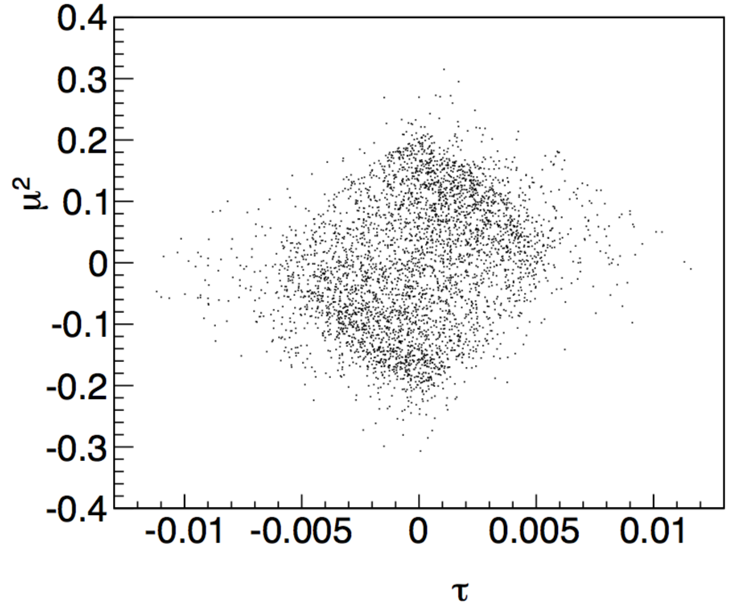
Asymmetry Vanishes for Pure Scalar or Pure Pseudo-Scalar Coupling

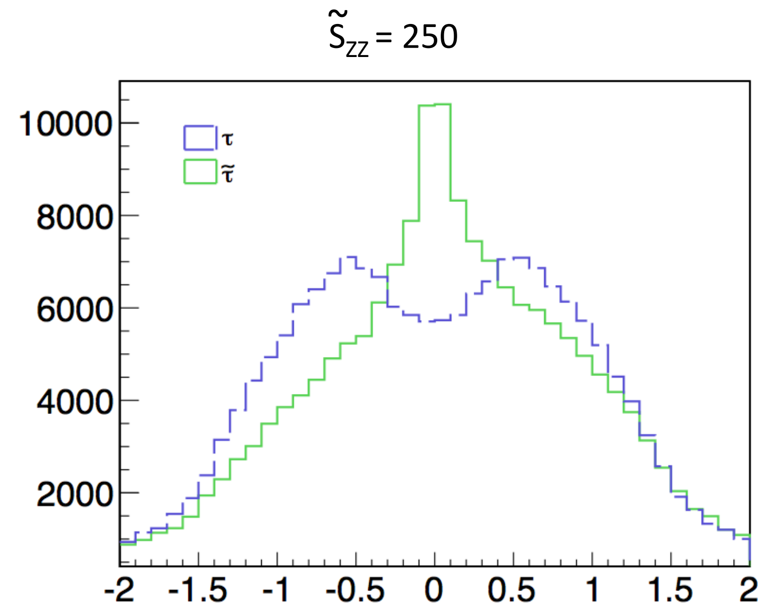
Luminosity >> ab^{-1} to go beyond EDM bounds
But Interesting Complementary
Direct Probe of T-Violation in Higgs Sector

$$\widetilde{\mathcal{T}}_{\ell^+\ell^-\ell'^+\ell'^-} \equiv \tau_{\ell^+\ell^-\ell'^+\ell'^-}\ \widetilde{\mu}_{\ell^+\ell^-\ell'^+\ell'^-}$$

Measuring Time Reversal Violation in Higgs -> ZZ* -> l l l l

(Park, ST)





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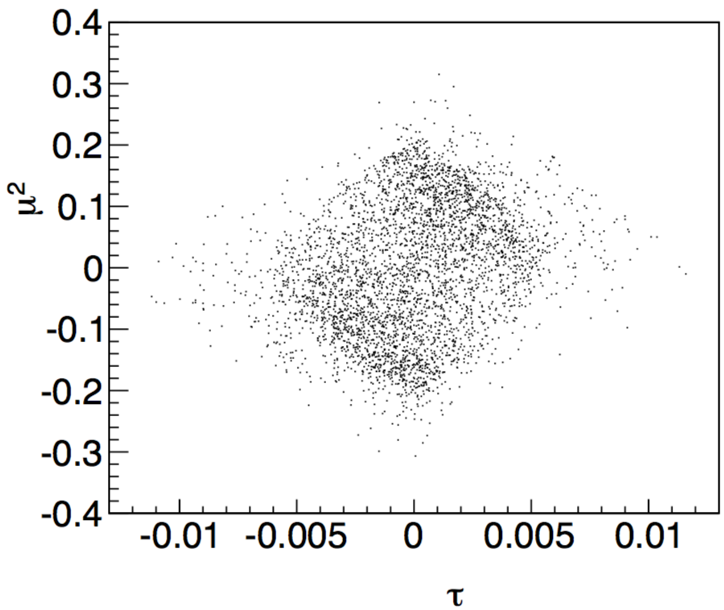
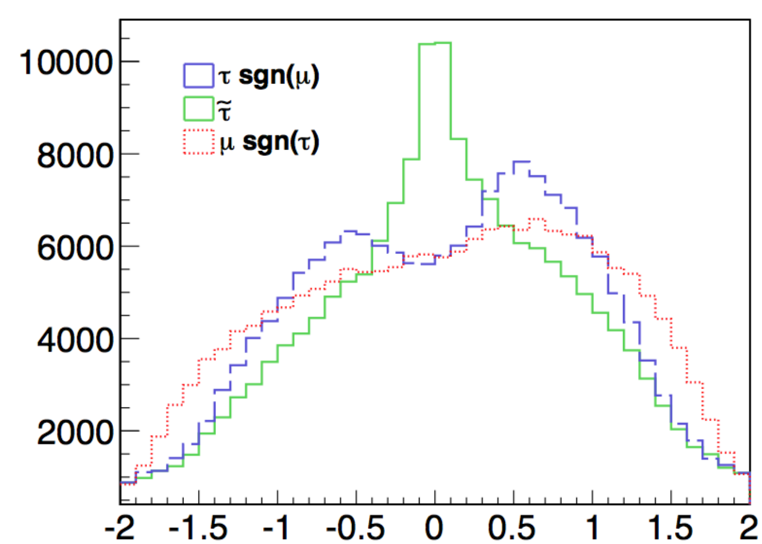
Measuring Time Reversal Violation in Higgs -> ZZ* -> l l l l

(Park, ST)



$\tilde{S}_{ZZ} = 250$



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Next Step: Testing The Higgs Mechanism

…

Reconstructing the Higgs Mass in the Higgs -> WW* -> l ν l ν Channel

(Park, ST)

Much of the Phase Space Distribution Near Threshold

At Threshold:
$E_{l-} = E_{l+}$ In Higgs Rest Frame

Boost to this Frame – form $m_{E=E}$ Without Using MET

$$\eta_0 = \frac{1}{2}\ln\left[\frac{E_{T_{\ell+}}e^{\eta_{\ell+}} - E_{T_{\ell-}}e^{\eta_{\ell-}}}{E_{T_{\ell-}}e^{-\eta_{\ell-}} - E_{T_{\ell+}}e^{-\eta_{\ell+}}}\right]$$

$$\Xi_0 = e^{2\eta_0} = \frac{E_{T_{\ell+}}e^{\eta_{\ell+}} - E_{T_{\ell-}}e^{\eta_{\ell-}}}{E_{T_{\ell-}}e^{-\eta_{\ell-}} - E_{T_{\ell+}}e^{-\eta_{\ell+}}}$$

$$m = \begin{cases} 4E_{T_j}\cosh\left(\eta_j - \frac{1}{2}\ln\Xi_0\right) & \Xi_0 > 0 \\ 4iE_{T_j}\left|\sinh\left(\eta_j - \frac{1}{2}\ln(-\Xi_0)\right)\right| & \Xi_0 < 0 \end{cases}$$

Reconstructing the Higgs Mass in the Higgs -> WW* -> l ν l ν Channel

(Park, ST)

Much of the Phase Space Distribution Near Threshold

At Threshold:
$E_{l-} = E_{l+}$ In Higgs Rest Frame

Boost to this Frame - form $m_{E=E}$ Without Using MET

Systematically Improve Threshold Approximation by

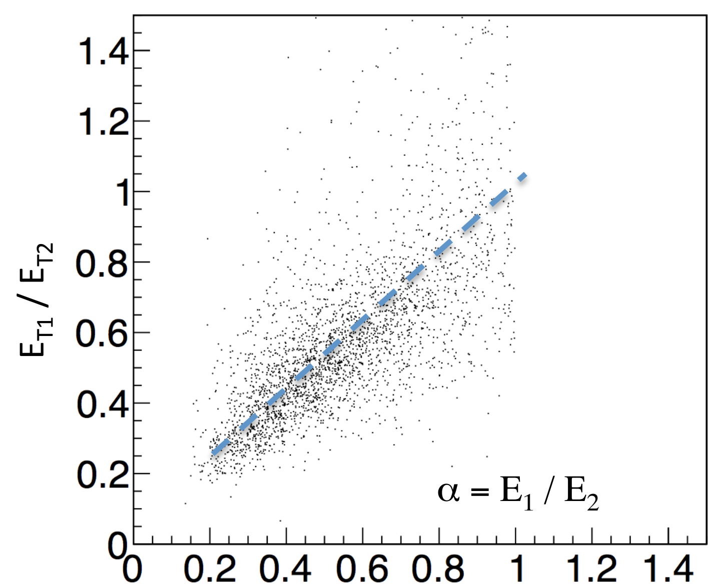
1. Threshold Corrections
   $\alpha = E_1 / E_2$

2. Iterative Transverse Rebooosting - $p_{T\text{-Higgs}} \neq 0$

$$\eta_0 = \frac{1}{2} \ln \left[\frac{E_{T_{\ell_2}} e^{\eta_{\ell_2}} - \alpha E_{T_{\ell_1}} e^{\eta_{\ell_1}}}{\alpha E_{T_{\ell_1}} e^{-\eta_{\ell_1}} - E_{T_{\ell_2}} e^{-\eta_{\ell_2}}} \right]$$

$$\Xi_0 = e^{2\eta_0} = \frac{E_{T_{\ell_2}} e^{\eta_{\ell_2}} - \alpha E_{T_{\ell_1}} e^{\eta_{\ell_1}}}{\alpha E_{T_{\ell_1}} e^{-\eta_{\ell_1}} - E_{T_{\ell_2}} e^{-\eta_{\ell_2}}}$$

$$m = \begin{cases} 2(\alpha+1)E_{T_1} \cosh\left(\eta_1 - \frac{1}{2}\ln \Xi_0\right) & \Xi_0 > 0 \\ 2(\alpha+1) i E_{T_1} \left| \sinh\left(\eta_1 - \frac{1}{2}\ln(-\Xi_0)\right) \right| & \Xi_0 < 0 \end{cases}$$



Reconstructing the Higgs Mass in the Higgs -> WW* -> l ν l ν Channel

(Park, ST)

Much of the Phase Space Distribution Near Threshold

At Threshold:
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Boost to this Frame - form $m_{E=E}$ <u>Without</u> Using MET

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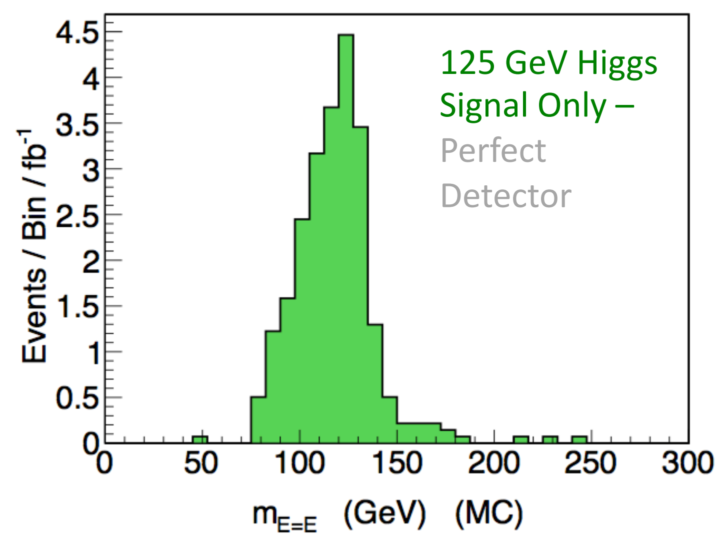

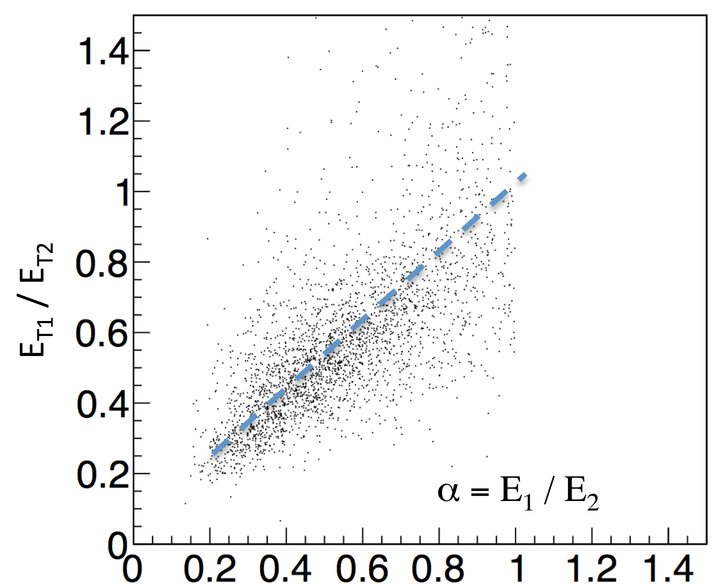

Reconstructing the Higgs Mass in the Higgs -> WW* -> l ν l ν Channel

(Park, ST)

Much of the Phase Space Distribution Near Threshold

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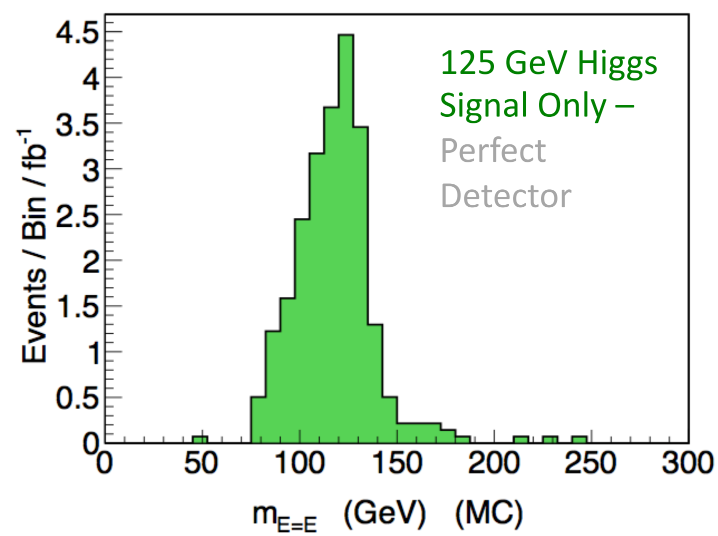

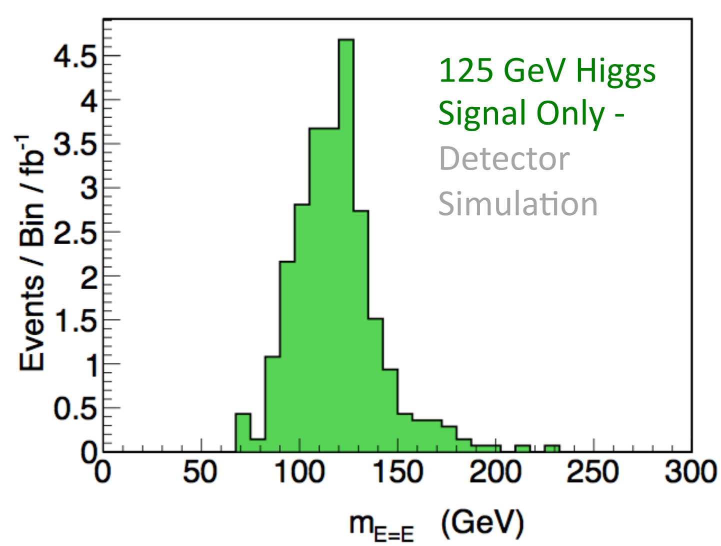

Reconstructing the Higgs Mass in the Higgs -> WW* -> l ν l ν Channel

(Park, ST)

Much of the Phase Space Distribution Near Threshold

At Threshold:
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Boost to this Frame - form $m_{E=E}$ Without Using MET

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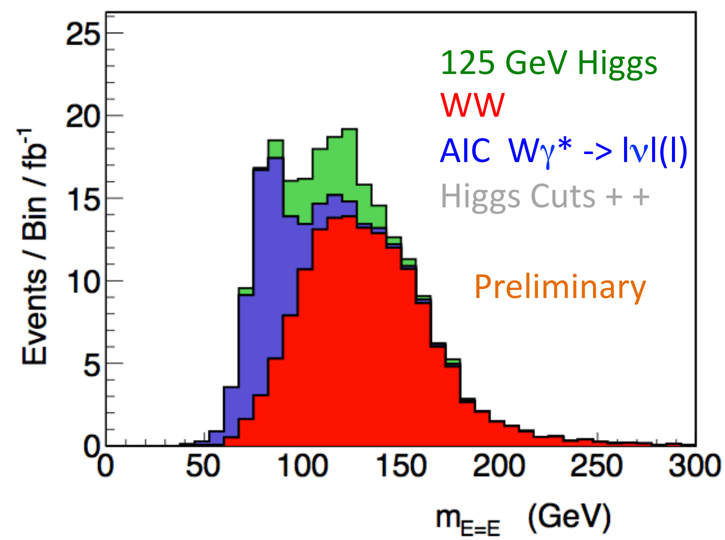
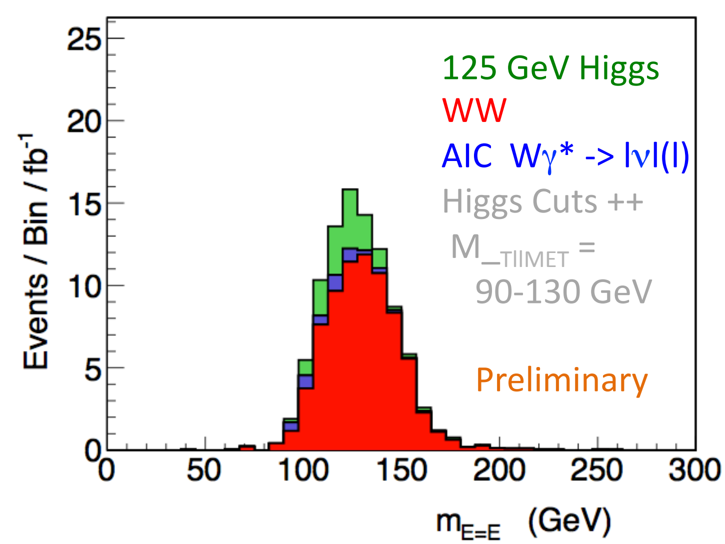
1. Threshold Corrections
   $\alpha = E_1 / E_2$

2. Iterative Transverse Reboosting - $p_{T\text{-Higgs}} \neq 0$





Reconstructing the 2nd Higgs Mass in the Higgs -> WW* -> l ν l ν Channel

(Park, ST)

Much of the Phase Space Distribution Near Threshold

At Threshold:
$E_{l-} = E_{l+}$ In Higgs Rest Frame

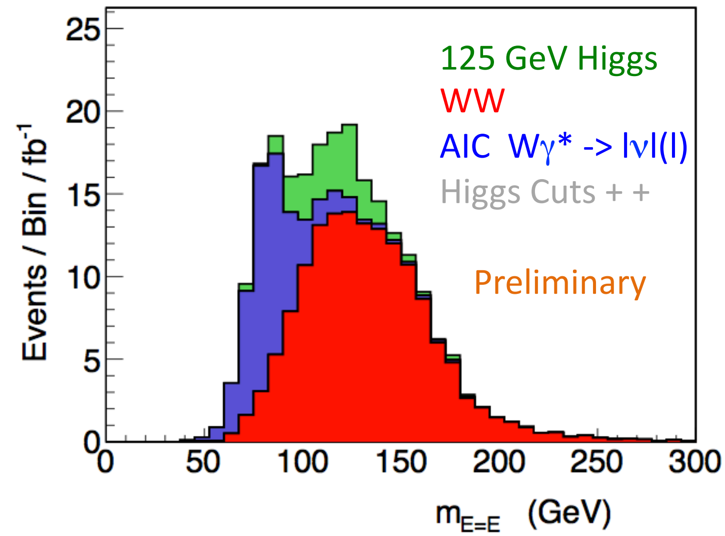
Boost to this Frame - form $m_{E=E}$ Without Using MET

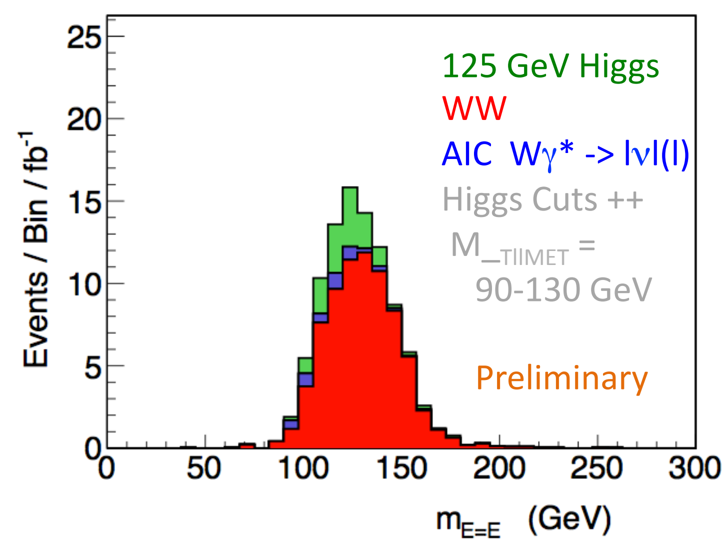
Systematically Improve Threshold Approximation by

1. Threshold Corrections
   $\alpha = E_1 / E_2$

2. Iterative Transverse Reboosting - $p_{T\text{-Higgs}} \neq 0$

Search for H -> WW



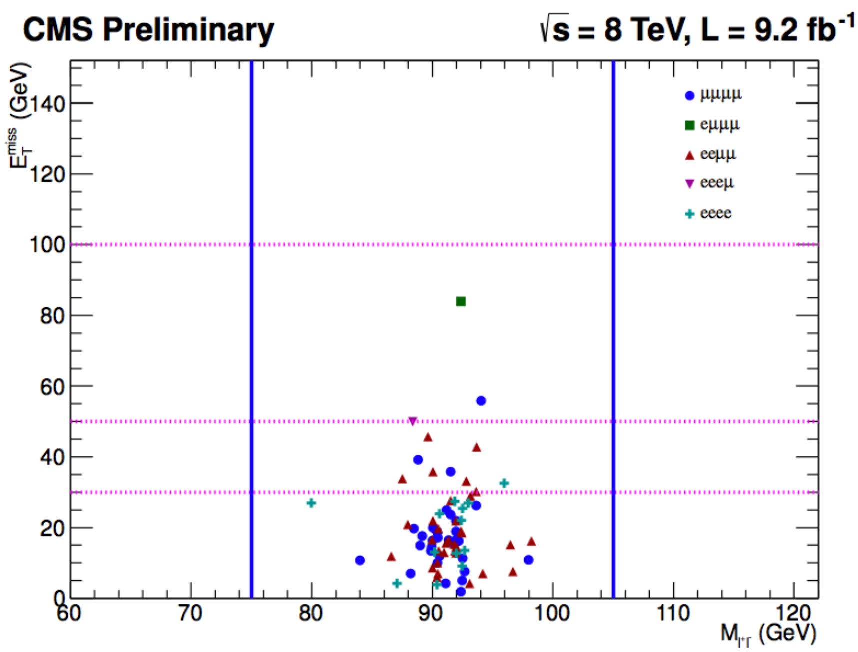


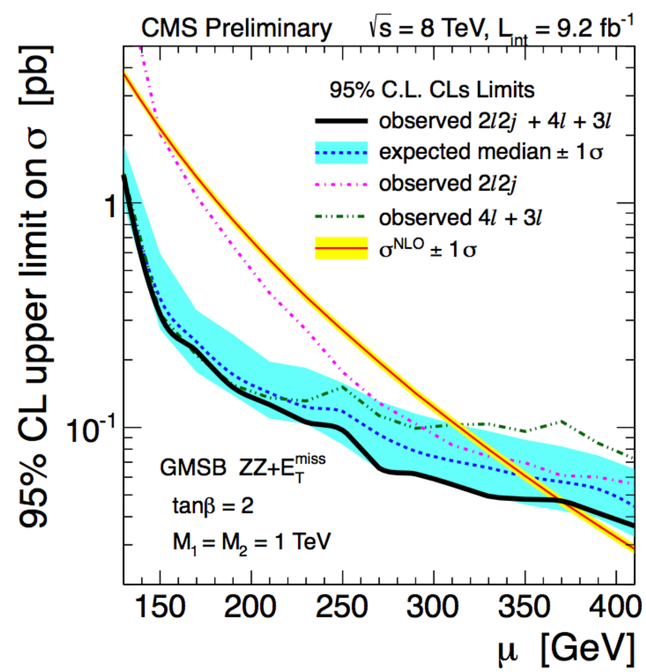
Higgsino Signatures Multi-Leptons

(CMS)

Sensitive to Extremely Rare Processes

Higgsino -> Z , h + Goldstino





SUSY, 2nd Higgs Doublet -> WZ, ZZ ,Wh, Zh, hh, …

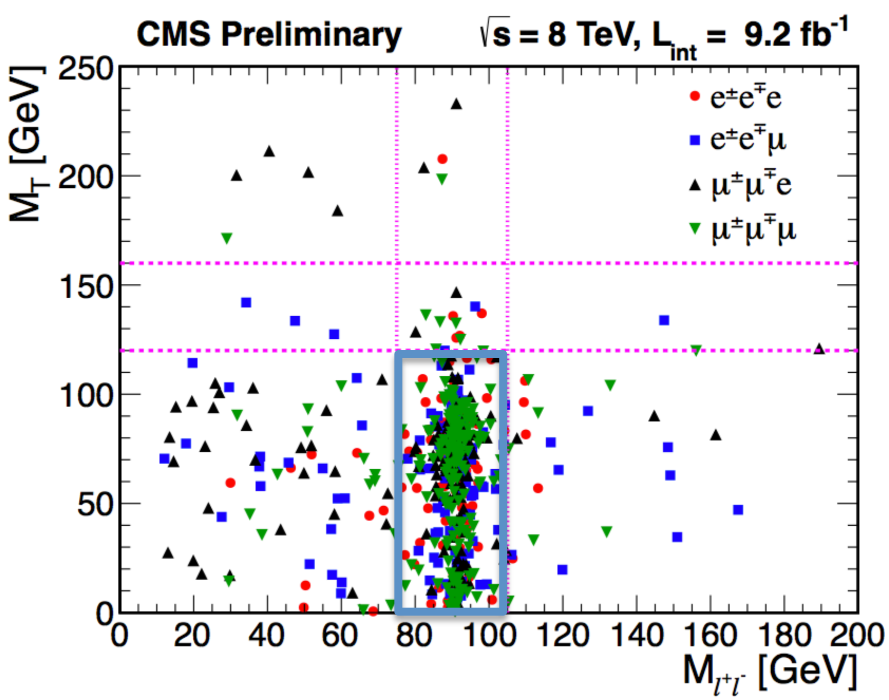
Kinematic Discriminants
(25 fb^{-1} sensitivity)

Multi-Lepton Signals of 2nd Higgs Doublet

(CMS)

Tri-Leptons OSSF + Third Lepton

WZ -> 3 Leptons - Dominant Background



A -> Zh -> (ll)(lνjj)

Lands Right on Top of WZ Background in m_T - m_{ll}

2 Extra Jets

Can Completely Reconstruct Kinematics

Experimental Investigation of the Higgs Sector has Begun !!

Search for Extended Higgs Sectors in
Standard Channels $\gamma\gamma$, ZZ, WW (mass Reconstruction) , …

Use the Higgs to Search for New Physics
Multi-Leptons
$\gamma\gamma$ Resonance + X

Probe Symmetries in the Higgs Sector
Flavor Violation
Time Reversal Violation

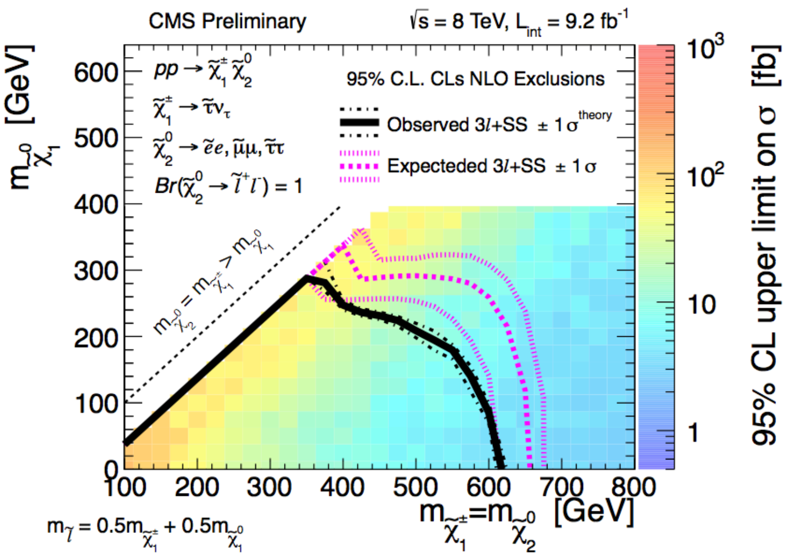
Higgs -> $\gamma\gamma$, ZZ* , Zγ
The New Precision Physics (Will Complement + Surpass Old PEW)

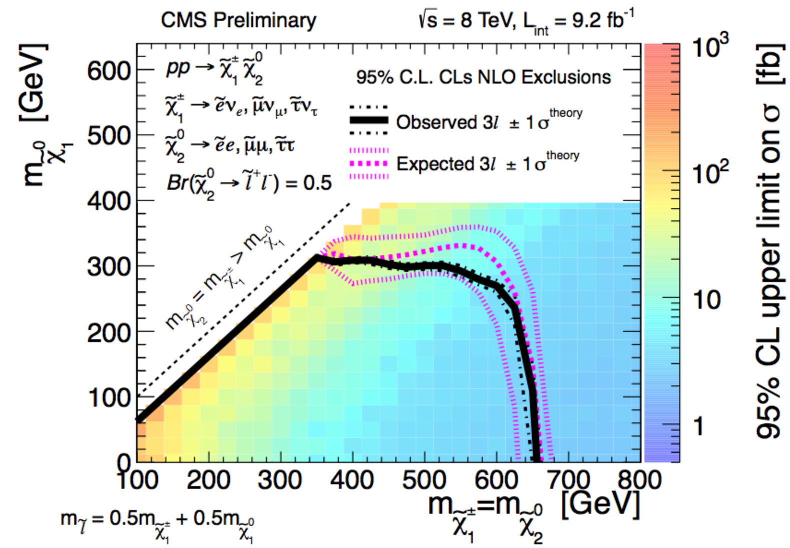
Higgs -> ZZ* -> llll
Test Higgs Mechanism

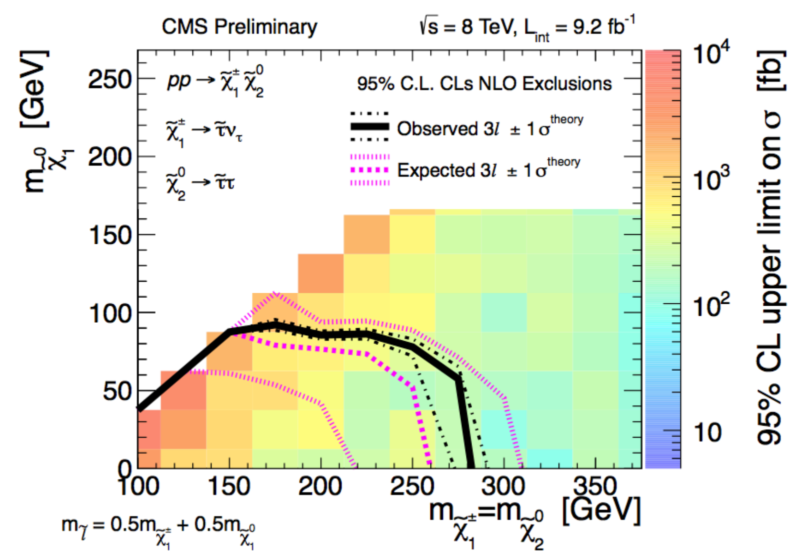
Search for Extended Higgs Sector in
New Channels H->hh , A->Zh, …

Much Much More to Come … Stay Tuned !!

Extra Slides







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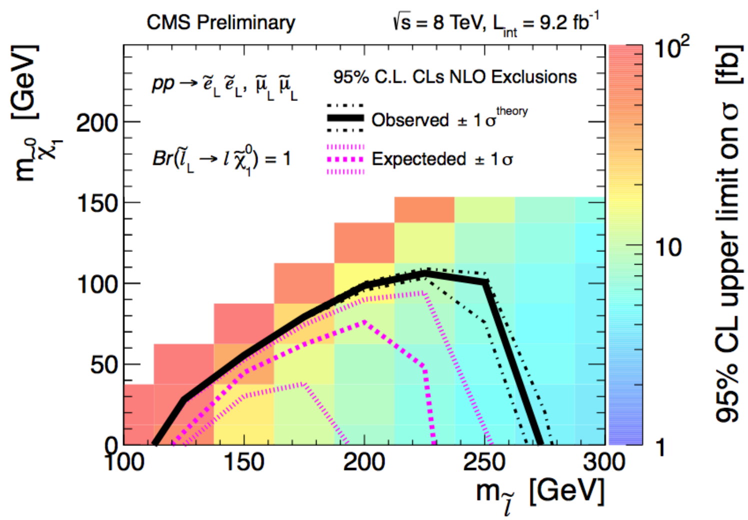

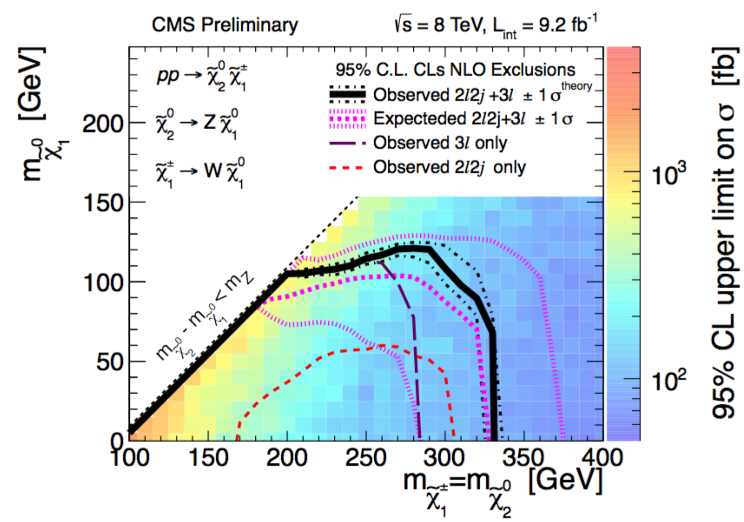

Search for New Physics at the
Electroweak Scale Continues …

Lots of Signature Space
Remains to be Investigated …

Experimental Investigation of the
Higgs Sector has Begun …

Focused on EW Physics at EW Scale
O(100-200) GeV

Stay Tuned !!!