Some EFT Aspects at the LHC

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D6 Higgs operators

D6 Lagrangian at face value [HISZ, Warsaw, Trott etal, Goncales-Garcia etal]

– set of Higgs operators

$$\mathcal{O}_{GG} = \phi^\dagger \phi G^a_{\mu\nu} G^{a\mu\nu} \qquad \mathcal{O}_{WW} = \phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{BB} = \cdots$$

$$\mathcal{O}_{\phi,2} = \frac{1}{2} \partial^\mu \left(\phi^\dagger \phi \right) \partial_\mu \left(\phi^\dagger \phi \right) \quad \mathcal{O}_W = (D_\mu \phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \phi) \quad \mathcal{O}_B = \cdots$$

– actual basis after equation of motion, etc

$$\mathcal{L}^{HVV} = -\frac{\alpha_s v}{8\pi} \frac{f_g}{\Lambda^2} \mathcal{O}_{GG} + \frac{f_{BB}}{\Lambda^2} \mathcal{O}_{BB} + \frac{f_{WW}}{\Lambda^2} \mathcal{O}_{WW} + \frac{f_B}{\Lambda^2} \mathcal{O}_B + \frac{f_W}{\Lambda^2} \mathcal{O}_W + \frac{f_{\phi,2}}{\Lambda^2} \mathcal{O}_{\phi,2}$$

– Higgs couplings to SM particles [plus Yukawa structures]

$$\mathcal{L}^{HVV} = g_g \, H G^a_{\mu\nu} G^{a\mu\nu} + g_\gamma \, H A_{\mu\nu} A^{\mu\nu}$$

$$+ g_Z^{(1)} \, Z_{\mu\nu} Z^\mu \partial^\nu H + g_Z^{(2)} \, H Z_{\mu\nu} Z^{\mu\nu} + g_Z^{(3)} \, H Z_\mu Z^\mu$$

$$+ g_W^{(1)} \, \left(W^+_{\mu\nu} W^{-\,\mu} \partial^\nu H + \text{h.c.} \right) + g_W^{(2)} \, H W^+_{\mu\nu} W^{-\,\mu\nu} + g_W^{(3)} \, H W^+_\mu W^{-\,\mu} + \cdots$$

– 7 Δ-like coupling modifications

extended by 4 new Lorentz structures

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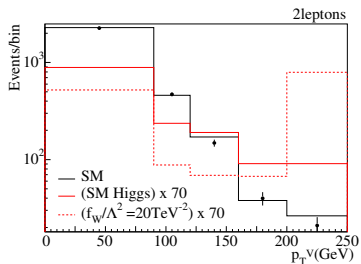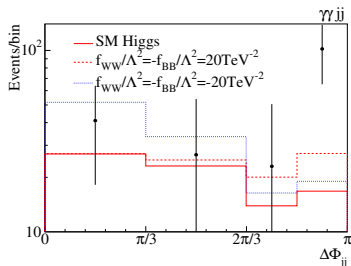
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Run I legacy [not enough analyses for Run II upgrade]

– kinematics: $p_{T,V}, \Delta\phi_{jj}$

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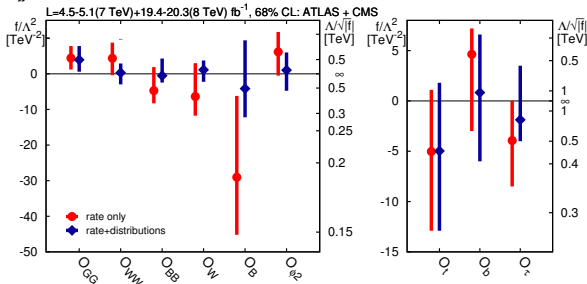
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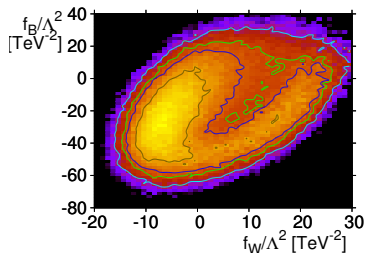
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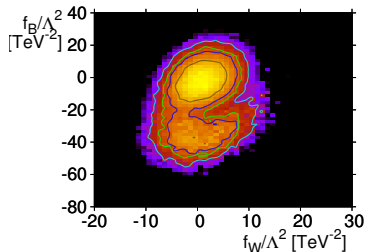
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Triple gauge couplings [Butter, Eboli, Gonzalez-Fraile, Gonzalez-Garcia, TP, Rauch]

– just one more gauge operator

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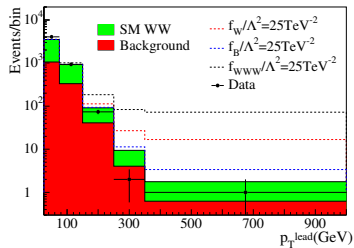
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– pre-gauge invariance known as DeltaKappaLambda

$$\Delta\mathcal{L}_{\text{TGV}} = -ie\,\Delta\kappa_\gamma\,W_\mu^+ W_\nu^- \gamma^{\mu\nu} - \frac{ie\lambda_\gamma}{m_W^2}\,W_{\mu\nu}^+ W^{-\nu\rho}\gamma_\rho^\mu - \frac{ig_Z\lambda_Z}{m_W^2}\,W_{\mu\nu}^+ W^{-\nu\rho}Z_\rho^\mu$$

$$\qquad\qquad - ig_Z\,\Delta\kappa_Z\,W_\mu^+ W_\nu^- Z^{\mu\nu} - ig_Z\,\Delta g_1^Z\left(W_{\mu\nu}^+ W^{-\mu}Z^\nu - W_\mu^+ Z_\nu W^{-\mu\nu}\right)$$

$$\Delta\kappa_Z = \frac{g^2 v^2}{8c_w^2\Lambda^2}\left(c_w^2 f_W - s_w^2 f_B\right) \qquad\qquad \Delta g_1^Z = \frac{g^2 v^2}{8c_w^2\Lambda^2}f_W \qquad\qquad \lambda_Z = \frac{3g^2 M_W^2}{2\Lambda^2}f_{WWW}$$

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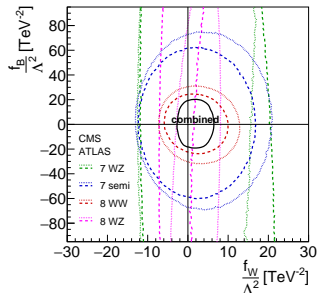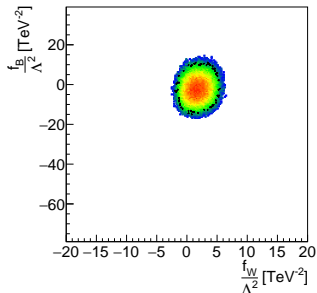
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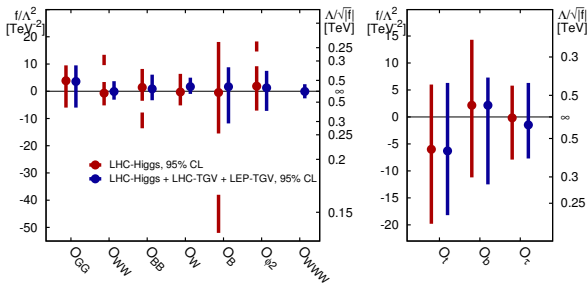– combined LHC channels

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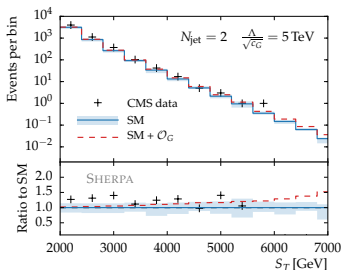
That other gauge theory

The most nasty D6 operator, appearing everywhere [Krauss, Kuttimalai, TP]

– making sense of black hole searches

$$S_T \approx \sum_{\text{jets}} E_T$$

– dimension-6 operators

$$\underbrace{\mathcal{O}_{qq} = \bar{q}\gamma_\mu q \, \bar{q}'\gamma^\mu q'}_{2-3 \text{ jets}} \quad \underbrace{\mathcal{O}_G = f_{abc} G^{a\nu}_\mu G^{b\lambda}_\nu G^{c\mu}_\lambda}_{\gtrsim 5\text{jets}}$$
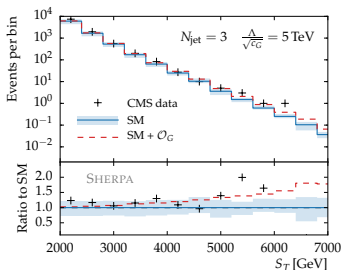
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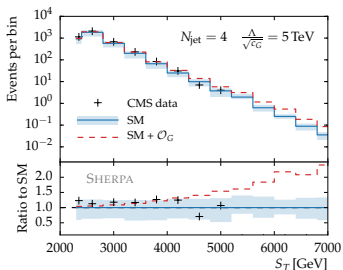
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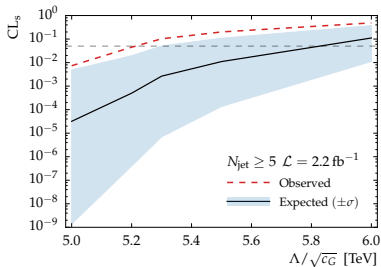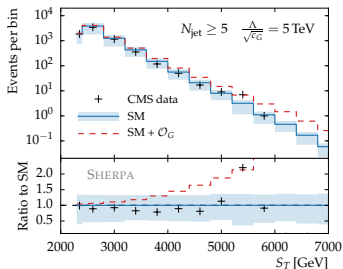**The most nasty D6 operator, appearing everywhere** [Krauss, Kuttimalai, TP]

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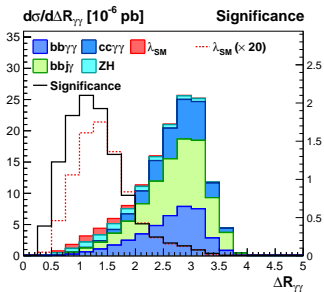$\Rightarrow$ new physics $M \gtrsim 5$ TeV

Kinematic distributions

Kinematical information for example on effective Lagrangian

– simple p_T, m_{ij}, ϕ_{ij} easily included   [Butter etal]

– correlations hard, check impact

⇒ phase space patterns understood?

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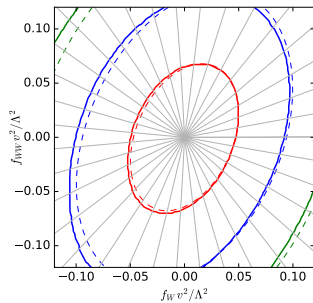
Beyond distributions [That was 90s]

– Log-likelihood estimator for hypothesis testing [MadMax: Cranmer, Kling, TP, Schichtel, Wiegand]

→ Neyman-Pearson lemma

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→ assuming statistics limiting factor

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– Fisher information for parameter estimate
→ Cramer-Rao bound [(co-)variance > Fisher information^{-1}]
→ phase space integration [Fisher information additive]
→ assuming statistics limiting factor
→ information distributions
⇒ LHC theorists: smell the coffee...

$$I_{ij}(\mathbf{g}) \propto \left[\frac{\partial^2 \log f(\mathbf{x}|\mathbf{g})}{\partial g_i \, \partial g_j} \bigg| \mathbf{g} \right]$$

Information geometry

Applied to D6 in WBF $H \to \tau\tau$ [Brehmer, Cranmer, Kling, T

– correlations in Wilson coefficient space

Information geometry

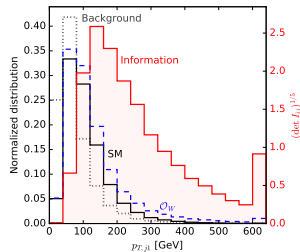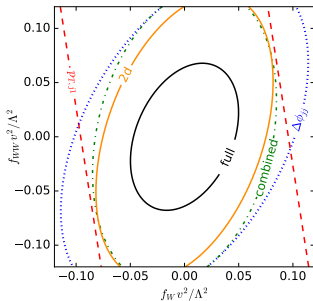### Applied to D6 in WBF $H \to \tau\tau$ [Brehmer, Cranmer, Kling, T

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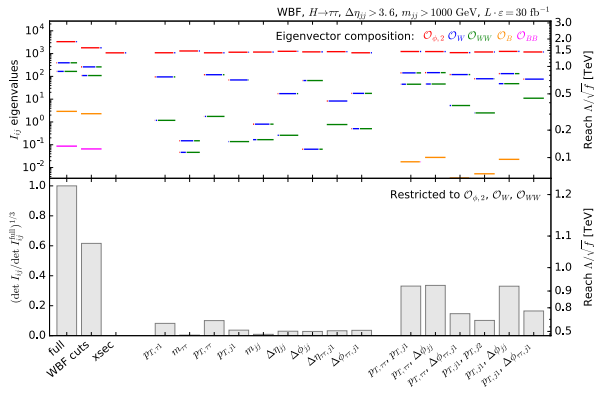**Applied to D6 in WBF** $H \to \tau\tau$ [Brehmer, Cramner, Kling, TP]

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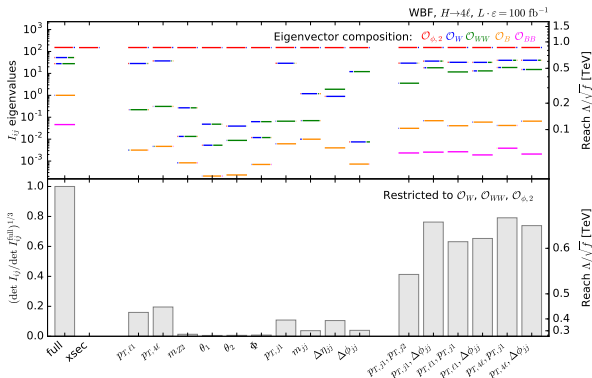## Applied to D6 in WBF $H \to \tau\tau$ [Brehmer, Cramer, Kling, TP]

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Combined with decay $H \to 4\ell$

– precision vs energy
⇒ energy wins

On to discussion

All those EFT fits

dimension-6 Higgs-ew LHC analysis working and done [Butter etal]

dimension-6 QCD analysis working and done [Krauss etal]

effective Lagrangian validated through full models

uncertainties part of matching

time to move on to interesting physics questions

Nov 6 - 10   2017 **HIGGS**
COUPLINGS