BSM Physics since 2020 Workshop

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SMEFT vs models

SMEFT representing UV-Model [Aachen–Heidelberg–Siegen]

– SMEFT questions: combining sectors, flavor assumptions, uncertainties specifically: error from truncating at D6?

– problem: no good scale separation

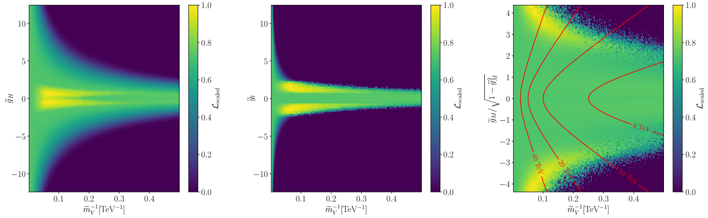
⇒ SMEFT as placeholder for UV-models [vector triplet]

$$\mathcal{L}_{\text{HVT}} = \mathcal{L}_{\text{SM}} - \frac{1}{4} \widetilde{V}^{\mu\nu A} \widetilde{V}^{A}_{\mu\nu} + \frac{\widetilde{m}_V^2}{2} \widetilde{V}^{\mu A} \widetilde{V}^{A}_{\mu} - \frac{\tilde{g}_M}{2} \widetilde{V}^{\mu\nu A} \widetilde{W}^{A}_{\mu\nu}$$
$$+ \tilde{g}_H \widetilde{V}^{\mu A} J^{A}_{H\mu} + \tilde{g}_l \widetilde{V}^{\mu A} J^{A}_{l\mu} + \tilde{g}_q \widetilde{V}^{\mu A} J^{A}_{q\mu} + \frac{\tilde{g}_{VH}}{2} |H|^2 \widetilde{V}^{\mu A} \widetilde{V}^{A}_{\mu}$$

Matching

– 17 Wilson coefficients ↔ 6 model parameters

– SFitter limits in terms of model parameters



SMEFT vs models

SMEFT representing UV-Model [Aachen–Heidelberg–Siegen]

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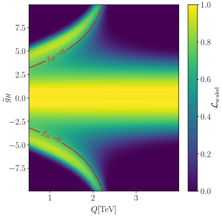
Matching at one loop [Dawson, Giardino, Homiller]

- 17 Wilson coefficients ↔ 6 model parameters plus matching scale
- remember renormalizing α_s with heavy states
- cancellations in Wilson coefficients $f(\tilde{g}, Q_{\text{match}})$



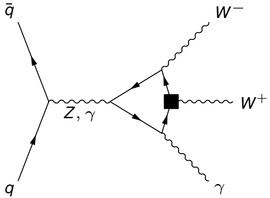
Anomalies in EFTs

Physical S-matrix elements satisfy Ward identities [Cata, Kilian, Kreher]

– In the SM, they do only if (hyper)charge sum rule is satisfied

– SMEFT: extra dim-6 sum rules for mixed $U(1)$ anomalies

– specifically, Wilson coefficients proportional to hypercharge



$$k_\mu(\gamma)\, M^{\mu\cdots}(k,\dots) \neq 0.$$

Puzzle (in progress): some anomaly-free BSM models violate requirements?

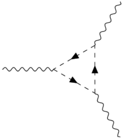
– extend SMEFT to correctly represent low-energy approximation

– map operator space of SMEFT anomalies

SMEFT for VBS

2103.16517: origin and size of EFT operators with field strength tensors

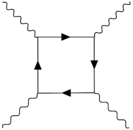
Karlsruher Institut für Technologie



Massive BSM matter fields in isospin J_R multiplets induce EFT operators like

$$O_{WWW} = \text{Tr}\left(\hat{W}^{\mu}{}_{\nu}\hat{W}^{\nu}{}_{\rho}\hat{W}^{\rho}{}_{\mu}\right) ,$$

$$O_{DW} = \text{Tr}\left([\hat{D}_{\alpha}, \hat{W}^{\mu\nu}][\hat{D}^{\alpha}, \hat{W}_{\mu\nu}]\right)$$



and also anomalous quartic gauge couplings (aQGC),
which are searched for in vector boson scattering (VBS), e.g.

$$O_{T_1} = \text{Tr}\left(\hat{W}^{\mu\nu}\hat{W}_{\alpha\beta}\right)\text{Tr}\left(\hat{W}^{\alpha\beta}\hat{W}_{\mu\nu}\right)$$

$$O_{T_2} = \text{Tr}\left(\hat{W}^{\mu\nu}\hat{W}_{\nu\alpha}\right)\text{Tr}\left(\hat{W}^{\alpha\beta}\hat{W}_{\beta\mu}\right)$$

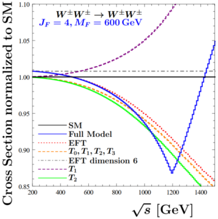
- Loop suppressed, but $(J_R)^3$ enhanced for trilinear couplings, $(J_R)^5$ for aQGC
- Unitarity/perturbativity limit reached at J_F=4 for fermion loops, J_S=6 for scalars
- Any loop-induced EFT operators require massive scalars or fermions ➔generic model
- Find Wilson coefficients, e.g.

$$\frac{f_{WWW}}{\Lambda^2} = \sum_F n_F \frac{13 T_F}{360\pi^2 M_F^2} + \sum_S n_S \frac{T_S}{360\pi^2 M_S^2}$$

$$\frac{f_{T_1}}{\Lambda^4} = \sum_F n_F \frac{(-28 C_{2,F} + 13)\, T_F}{10080\pi^2 M_F^4} + \sum_S n_S \frac{(14 C_{2,S} - 5)\, T_S}{40320\pi^2 M_S^4}$$

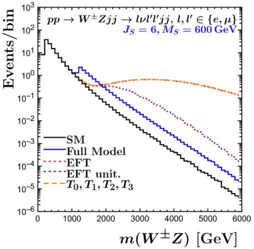
SMEFT for VBS

Problem: Validity range of EFT restricted to <1.5 M_R



←Cross section for on-shell WW scattering below threshold (taken as $2M_F$=1200 GeV)

EFT effects below 10% within EFT validity range, even for SU(2) nonents



←Full VBFNLO simulation:

Large effects of extra multiplets are possible above threshold where

- EFT does not describe new physics
- Unitarization does only slightly better, but reduces huge to merely sizable overestimate of cross section

SMEFT for VBS

Comments:

- Extra SU(2) scalar or fermion multiplets can generate sizable loop effects in VBS, requiring high multiplicity, however
- Model is generic: any loop effects require additional SU(2) multiplets
- Added complexity does not change basic result, e.g.
  - perturbative coupling of two multiplets to Higgs doublet field generates modest multiplet splitting (suppressed by $(v/M_R)^2$)
  - Additional confining gauge interaction of multiplets averages out (analogous to quark-hadron duality in QCD)

- EFT as tool for describing BSM effects is of very limited use in describing processes with vast dynamic range such as VBS at the LHC

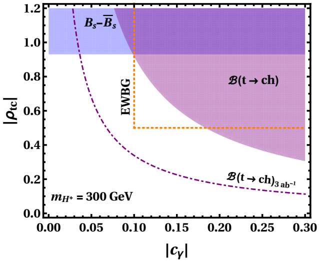
2HDM for baryogenesis

Minimal model for baryogenesis [Hou, Modak, TP]

- first-order ew phase transition plus CP-phase
- complex 2HDM [type-3, Muhlleitner etal]

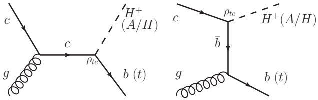
$$V(\Phi,\Phi') = \mu_{11}^2|\Phi|^2 + \mu_{22}^2|\Phi'|^2 - \left(\mu_{12}^2\Phi^\dagger\Phi' + \text{h.c.}\right) + \frac{\eta_1}{2}|\Phi|^4 + \frac{\eta_2}{2}|\Phi'|^4 + \eta_3|\Phi|^2|\Phi'|^2$$
$$+ \eta_4|\Phi^\dagger\Phi'|^2 + \left[\frac{\eta_5}{2}(\Phi^\dagger\Phi')^2 + \left(\eta_6|\Phi|^2 + \eta_7|\Phi'|^2\right)\Phi^\dagger\Phi' + \text{h.c.}\right] .$$

  scalar mixing $c_\gamma^2 = (\eta_1 v^2 - m_h^2)(m_H^2 - m_h^2)$
- complex Yukawa sector $\overline{F}_i(-\lambda_{ij}s_\gamma + \rho_{ij}c_\gamma)hF_i + \cdots$
  rotated to $\lambda_{ij} = \sqrt{2}\,m_i/v\delta_{ij} \in \mathbb{R}$ while $\rho_{ij} \in \mathbb{C}$
- allowed $m_{A,H,H^+} \sim 300 \dots 600$ GeV, $|\rho_{tc}| \sim 0.5$



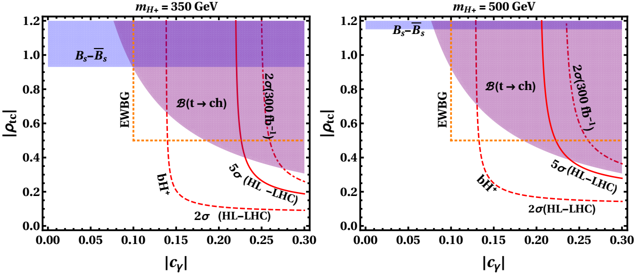
2HDM for baryogenesis

LHC to find the necessary states [Uli's talk]



- ρ_{tc} from anomalous $t \to ch$ decays
- heavy Higgs produced through $|\rho_{tc}|$
- charged Higgs decaying through c_γ

$$cg \to bH^+ \to b\,(W_\ell^+ h) \to b\ W_\ell^+ W_\ell^+ W_\ell^-$$



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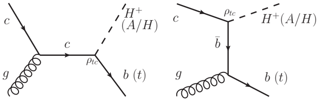


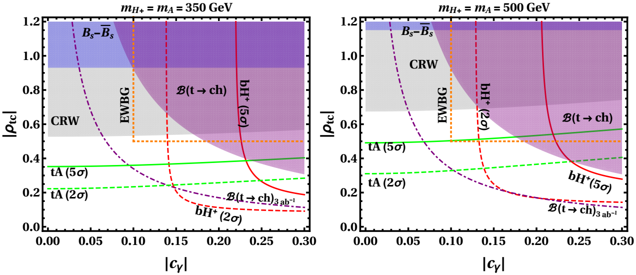
- ρ_{tc} from anomalous $t \to ch$ decays
- heavy Higgs produced through $|\rho_{tc}|$
- charged Higgs decaying through c_γ

$$cg \to bH^+ \to b\,(W_\ell^+ h) \to b\; W_\ell^+ W_\ell^+ W_\ell^-$$

- neutral Higgs decaying through ρ_{tc}

$$cg \to tH/tA \to t\;(t\bar{c})$$

probed by recycled $4t$ search



⇒ So what about finding the CP-violation? [Brehmer, Kling, TP, Tait]

The CP-Violating NMSSM Higgs Sector

- **The NMSSM Higgs Sector:** 2 Higgs doublets and 1 complex singlet

$$H_d = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_d + h_d + ia_d) \\ h_d^- \end{pmatrix} , \quad H_u = e^{i\varphi_u} \begin{pmatrix} h_u^+ \\ \frac{1}{\sqrt{2}}(v_u + h_u + ia_u) \end{pmatrix} ,$$

$$S = \frac{e^{i\varphi_s}}{\sqrt{2}}(v_s + h_s + ia_s) \, .$$

- **The Higgs Potential:** (neglecting D-term contributions)

$$V_H = (|\lambda S|^2 + m_{H_d}^2) H_d^\dagger H_d + (|\lambda S|^2 + m_{H_u}^2) H_u^\dagger H_u + m_S^2 |S|^2 + \left| \kappa S^2 - \lambda H_d \cdot H_u \right|^2 + \left(\frac{1}{3} \kappa A_\kappa S^3 - \lambda A_\lambda S H_d \cdot H_u + \text{h.c.} \right)$$

- **CP Violation in the Higgs Sector:** $\lambda, \kappa, A_\lambda, A_\kappa$ can be complex

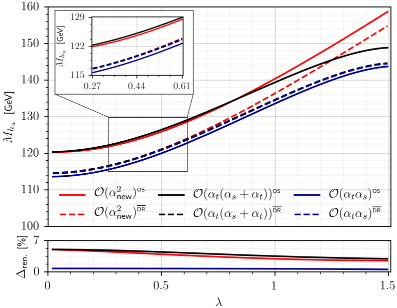
- **Higgs interaction states mix:** Mass term

$$\mathcal{L}_{\text{neutral}}^m = \frac{1}{2} \phi^T M_{\phi\phi} \phi \, , \quad \phi = (h_d, h_u, h_s, a_d, a_u, a_s)$$

mass eigentstates $h_1, ..., h_5$ with $m_{h_1} \leq ... \leq m_{h_5}$

$\mathcal{O}(\alpha_{\text{new}}^2) \equiv \mathcal{O}((\alpha_\lambda + \alpha_\kappa + \alpha_t)^2)$ NMSSM Mass Corrections

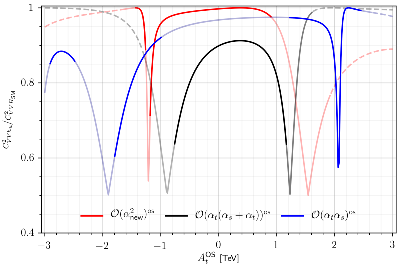
[Dao,Gabelmann,Mühlleitner,Rzehak, preliminary]



Corrections to h_u-like Higgs
($\widehat{=}$ SM-like Higgs)

$$\Delta_{\text{ren}} = \frac{\left| M_h^{m_t(\overline{\text{DR}})} - M_h^{m_t(\text{OS})} \right|}{M_h^{m_t(\overline{\text{DR}})}}$$

remaining theoretical error $\mathcal{O}$(few %)



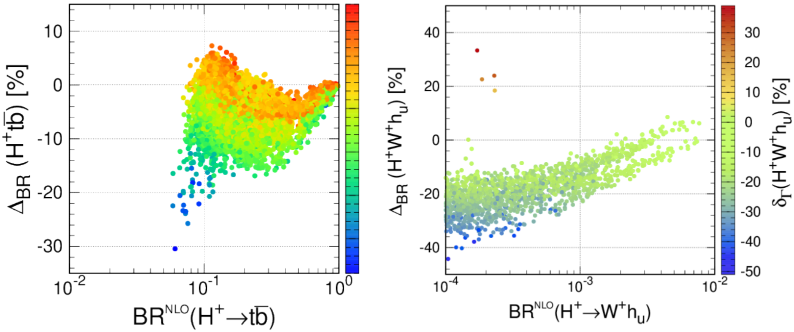
coupling to WW/ZZ normalized to SM

transparent: excluded by Higgs data

full (dashed): $h_u = h_1$ (h_2)

SUSY-EW and SUSY-QCD Corrections to Charged Higgs Decays

[NMSSMCALCEW; Dao,Mühlleitner,Patel,Sakurai,'21]



Points from scan in the NMSSM parameter space, compatible w/ experimental constraints

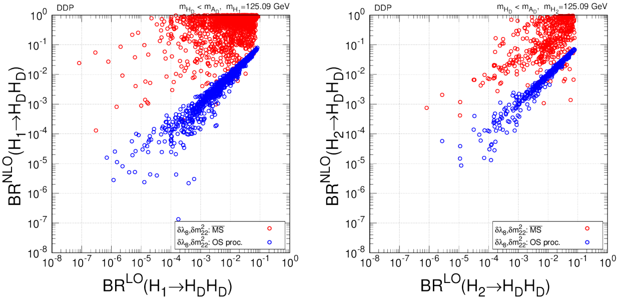
$$\delta_\Gamma(H^+XY) = \frac{\Gamma(H^+ \to XY)^{\mathrm{NLO}}}{\Gamma(H^+ \to XY)^{\mathrm{LO}}} - 1$$

$$\Delta_{\mathrm{BR}}(H^+XY) = \frac{\mathrm{BR}^{\mathrm{NLO}}(H^+ \to XY) - \mathrm{BR}^{\mathrm{LO}}(H^+ \to XY)}{\max(\mathrm{BR}^{\mathrm{NLO}}(H^+ \to XY), \mathrm{BR}^{\mathrm{LO}}(H^+ \to XY))}$$

Invisible Higgs Decays in the N2HDM

- **Updated Limit on Higgs invisible branching ratio:** $\text{BR}_\text{inv} < 0.11$ [ATLAS]
- **Indirect constraints on BR_inv in the N2HDM:** below 0.1 $\rightsquigarrow$ electroweak (EW) corrections to BR_inv become important
- **Dark Doublet Phase (DDP) of the N2HDM:** 2 $SU(2)_L$ doublet fields $\Phi_{1,2}$ and a real singlet field Φ_S with two discrete $\mathbb{Z}_2$ symmetries, DDP: Φ_1, Φ_S get VEV, not Φ_2 $\rightsquigarrow$ dark particles $H_D, A_D, H_D^\pm$ from Φ_2, lightest one is DM candidate

[Azevedo,Gabriel,Mühlleitner,Sakurai,Santos,'21]



$\text{BR}^\text{NLO} < 0.1$: no additional constraints from inclusion of EW corrections

Measuring QCD splittings

Jet properties from low-level observables [Bieringer, Butter, Heimel, Höche, Köthe, TP, Radev]

– using neural networks for simulation-based inference

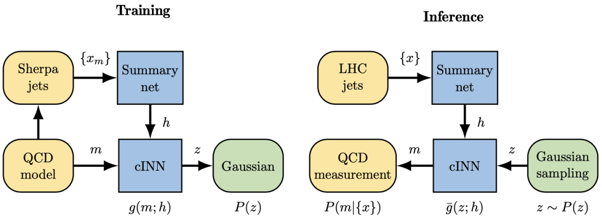
– condition (simulated) jets
train model parameters $\longrightarrow$ Gaussian latent space
test Gaussian sampling $\longrightarrow$ QCD parameter measurement

– going beyond C_A vs C_F [Kluth etal]

$$P_{qq} = C_F \left[D_{qq} \frac{2z(1-y)}{1-z(1-y)} + F_{qq}(1-z) + C_{qq} yz(1-z) \right]$$

$$P_{gg} = 2C_A \left[D_{gg} \left(\frac{z(1-y)}{1-z(1-y)} + \frac{(1-z)(1-y)}{1-(1-z)(1-y)} \right) + F_{gg} z(1-z) + C_{gg} yz(1-z) \right]$$

$$P_{gq} = T_R \left[F_{qq} \left(z^2 + (1-z)^2 \right) + C_{gq} yz(1-z) \right]$$



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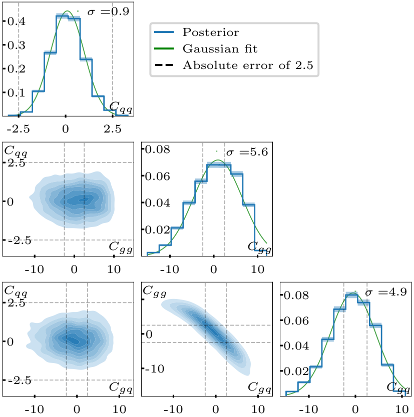
- idealized shower [Sherpa]



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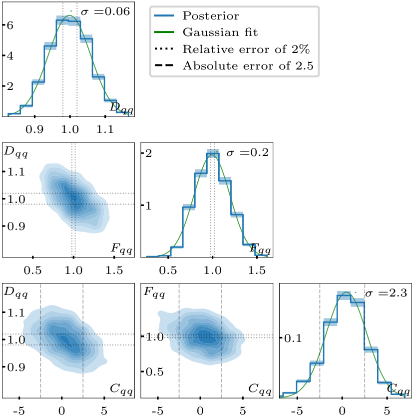
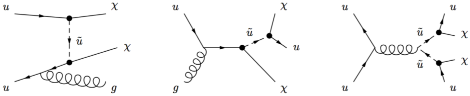
– idealized shower [Sherpa]

– reality hitting...

– Fun measurement?

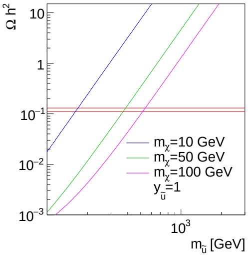


DMEFT troubles all over again



Tree-level scalar mediator [2016]

– relic density for small $m_{\tilde{u}}$



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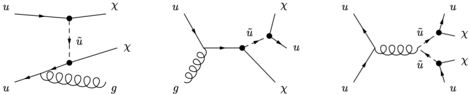

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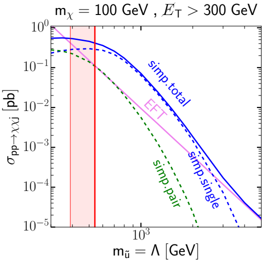
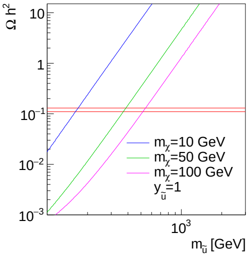
– relic density for small $m_{\tilde{u}}$

– two effective Lagrangians

$$\mathcal{L}_{\text{eff}} \supset \frac{c_{u\chi}}{\Lambda^2} \; (\bar{u}_R \chi) \; (\bar{\chi} u_R) \qquad \mathcal{L}_{\text{eff}} \supset \frac{c}{\Lambda^3} (\bar{\chi}\chi) \, G_{\mu\nu} G^{\mu\nu}$$

– EFT not valid for LHC and relic density...





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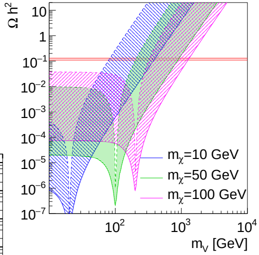
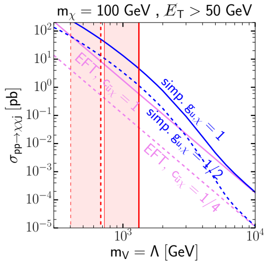
Tree-level vector in *s*-channel

– relic density for small m_V or around pole

– only 4-fermion operator

– EFT not valid...





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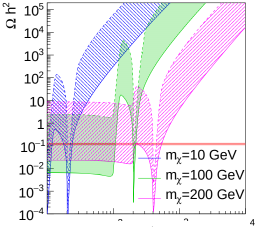
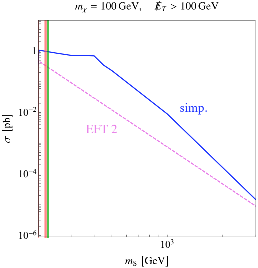


Tree-level vector in s-channel

– relic density for small m_V or around pole

– only 4-fermion operator

– EFT not valid...



Loop-mediated scalar in s-channel

– relic density around pole

– two effective Lagrangians

$$\mathcal{L}_\text{eff} \supset \frac{c_S^t}{\Lambda^2} (\bar{t}t) \; (\bar{\chi}\chi) \qquad \mathcal{L}_\text{eff,3} \supset \frac{c_\chi^g}{\Lambda^3} (\bar{\chi}\chi) \; G_{\mu\nu} G^{\mu\nu}$$

– EFT not valid...

νSMEFT

Replace neutralino with RH neutrino [Bischer, TP, Rodejohann]

– focus on 4-fermion operators to 3rd generation

$(\bar{L}L)(\bar{L}L)$ and $(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$		$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	
$\mathcal{O}_{Ne}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\overline{e}_\gamma \gamma^\mu e_\delta)$	$\mathcal{O}_{Nl}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\bar{l}_\gamma \gamma^\mu l_\delta)$	$\mathcal{O}_{Nlel}$	$(\overline{N}_\alpha l^j_\beta)\epsilon_{jk}(\overline{e}_\gamma l^k_\delta)$
$\mathcal{O}_{Nu}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\overline{u}_\gamma \gamma^\mu u_\delta)$	$\mathcal{O}_{Nq}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\overline{q}_\gamma \gamma^\mu q_\delta)$	$\mathcal{O}_{lNqd}$	$(\bar{l}^j_\alpha N_\beta)\epsilon_{jk}(\overline{q}^k_\gamma d_\delta)$
$\mathcal{O}_{Nd}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\overline{d}_\gamma \gamma^\mu d_\delta)$			$\mathcal{O}'_{lNqd}$	$(\bar{l}^j_\alpha \sigma_{\mu\nu} N_\beta)\epsilon_{jk}(\overline{q}^k_\gamma \sigma^{\mu\nu} d_\delta)$
$\mathcal{O}_{NN}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\overline{N}_\gamma \gamma^\mu N_\delta)$			$\mathcal{O}_{lNuq}$	$(\bar{l}^j_\alpha N_\beta)(\overline{u}_\gamma q^j_\delta)$
$\mathcal{O}_{eNud}$	$(\overline{e}_\alpha \gamma_\mu N_\beta)(\overline{u}_\gamma \gamma^\mu d_\delta)$				

νSMEFT

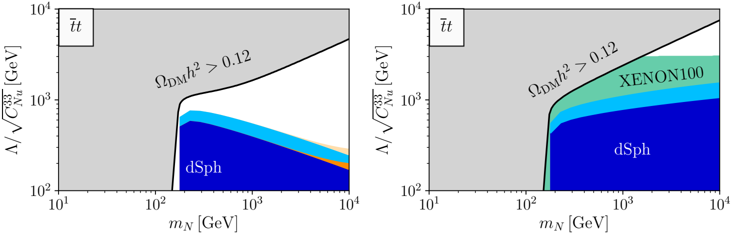
Replace neutralino with RH neutrino [Bischer, TP, Rodejohann]

– focus on 4-fermion operators to 3rd generation

$(\bar{L}L)(\bar{L}L)$ and $(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$		$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	
$\mathcal{O}_{Ne}$	$(\bar{N}_\alpha \gamma_\mu N_\beta)(\bar{e}_\gamma \gamma^\mu e_\delta)$	$\mathcal{O}_{Nl}$	$(\bar{N}_\alpha \gamma_\mu N_\beta)(\bar{l}_\gamma \gamma^\mu l_\delta)$	$\mathcal{O}_{Nlel}$	$(\bar{N}_\alpha l^j_\beta)\epsilon_{jk}(\bar{e}_\gamma l^k_\delta)$
$\mathcal{O}_{Nu}$	$(\bar{N}_\alpha \gamma_\mu N_\beta)(\bar{u}_\gamma \gamma^\mu u_\delta)$	$\mathcal{O}_{Nq}$	$(\bar{N}_\alpha \gamma_\mu N_\beta)(\bar{q}_\gamma \gamma^\mu q_\delta)$	$\mathcal{O}_{lNqd}$	$(\bar{l}^j_\alpha N_\beta)\epsilon_{jk}(\bar{q}^k_\gamma d_\delta)$
$\mathcal{O}_{Nd}$	$(\bar{N}_\alpha \gamma_\mu N_\beta)(\bar{d}_\gamma \gamma^\mu d_\delta)$			$\mathcal{O}'_{lNqd}$	$(\bar{l}^j_\alpha \sigma_{\mu\nu} N_\beta)\epsilon_{jk}(\bar{q}^k_\gamma \sigma^{\mu\nu} d_\delta)$
$\mathcal{O}_{NN}$	$(\bar{N}_\alpha \gamma_\mu N_\beta)(\bar{N}_\gamma \gamma^\mu N_\delta)$			$\mathcal{O}_{lNuq}$	$(\bar{l}^j_\alpha N_\beta)(\bar{u}_\gamma q^j_\delta)$
$\mathcal{O}_{eNud}$	$(\bar{e}_\alpha \gamma_\mu N_\beta)(\bar{u}_\gamma \gamma^\mu d_\delta)$				

– indirect detection from dwarf spheriodals

– direct detection only for Dirac neutrino [induced vector coupling]



νSMEFT

Tree-level models, slightly weirder?

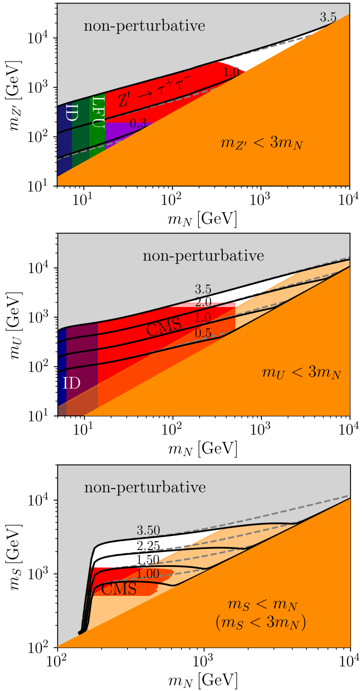
– gauged $(B-L)_3$
vector leptoquarks
scalar leptoquarks

– relic density required

– EFT constraints for DD, ID, etc
model constraints from collider

– EFT consistency improved

$\Rightarrow$ global analysis framework?



DMEFT analysis

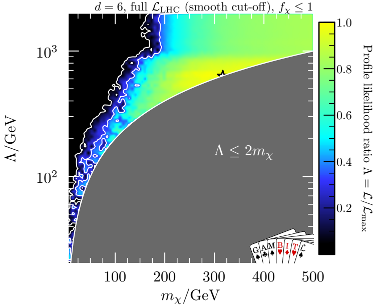
Many technical innovations [Kahlhöfer etal]

- Fully automated calculation of RG evolution and matching onto non-relativistic effective operators for direct detection
- EFT validity at the LHC addressed through flexible form factors suppressing events with large missing energy
- Indirect detection constraints from γ-rays, solar νs and CMB energy injection
- Highly efficient likelihood evaluations allowing scans of up to 14 Wilson coefficients (including interference) simultaneously

Example: Global fits of dim-6 operators (relic density imposed as upper limit)

- No significant excess in any data set (best-fit point "preferred" at 1σ level)
- Plenty of viable parameter space for WIMP models (contribution from parity-violating operators required)
- Preference for $m_\chi \gtrsim 100\,\text{GeV}$

Many other scans with different sets of operators and different constraints



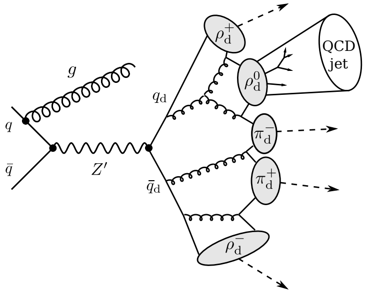
Athron et al. (the GAMBIT collaboration), arXiv:2106.XXXXX

Dark metter in jets

Consider a dark sector with a $SU(3)$ dark gauge group [Aachen–Heidelberg]

- the dark pions $\pi_\mathrm{d}^\pm$ are stable and viable dark matter candidates;
- the interaction between the dark sector and the SM ist mediated by a Z';
- cosmology and direct detection constraints suggest benchmark scenario with $m_\pi \approx 5$ GeV, $m_{Z'} \approx 1$ TeV

Novel LHC signature: Z' production with decay into dark sector:

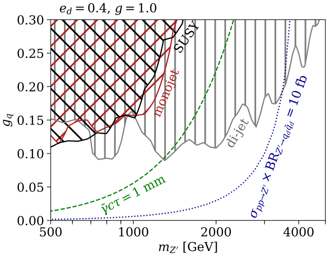


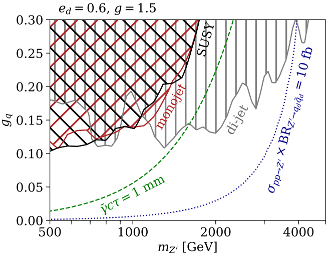
→ semi-visible jets: challenging benchmark scenario for BSM searches at the LHC

[Bernreuther, Kahlhoefer, Krämer, Tunney, JHEP 01 (2020) 162]

Dark matter in jets

Existing LHC searches for missing energy sensitive to such a scenario





To improve the LHC sensitivity to dark sectors one should

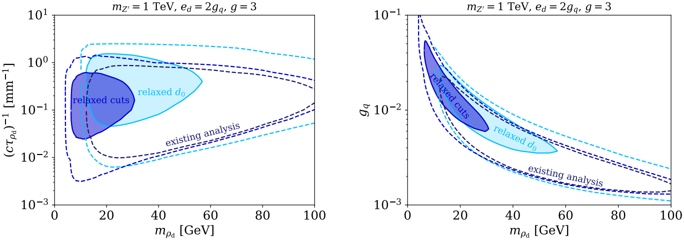
- search for long-lived particles
- suppress QCD backgrounds using neural networks

Dark matter in jets

Long-lived particle searches at the LHC

– are generally tailored towards heavy LLPs and thus not very sensitive to BSM physics at the GeV scale, but

– can be improved by modifications of the vertex reconstruction and the analysis cuts:



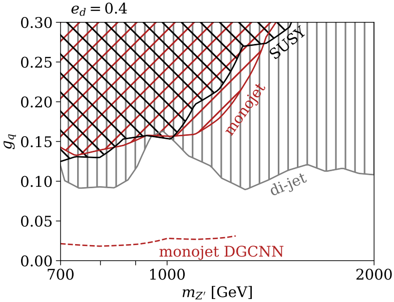
modified vertex corrections: light blue, modified analysis cuts: dark blue.
Dashed lines: projections for 300 fb^{-1}

[Bernreuther, Carrasco Mejia, Kahlhoefer, Krämer, Tunney, JHEP 04 (2021) 210]

Strongly interacting dark sectors at the LHC

Casting a graph net to catch dark showers

- dark showers vs QCD serious generic challenge for jet classification
- supervised deep neural networks now leading jet-taggers
- graph convolutional neural networks most powerful, also for dark showers
- dynamic graph network as a dark shower tagger gives super-powers

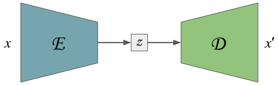


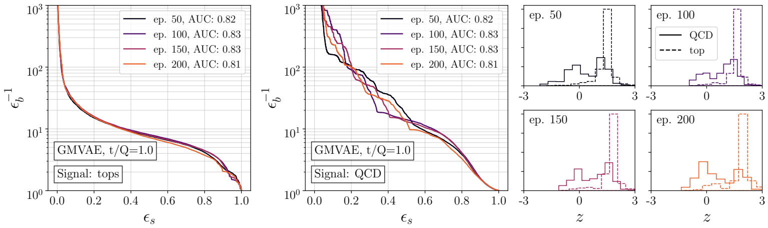
[Bernreuther, Finke, Kahlhoefer, Krämer, Mück, SciPost Phys. 10 (2021) 046]

Jet autoencoders

Unsupervised learning — the typical jets [Heimel, Kasieczka, TP, Thompson; Dillon, TP, Sauer, Sorrenson]

- train network to map jets onto typical jets
- train QCD $\rightarrow$ find anomalous tops $\rightarrow$ works
  train tops $\rightarrow$ find anomalous QCD $\rightarrow$ not good...
- next, give latent space a meaning: VAE
- next, make latent space multi-modal





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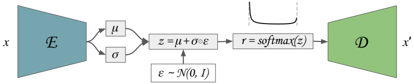
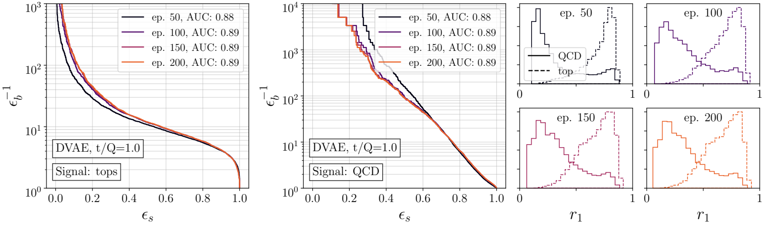
Better latent spaces



– sample from Dirichlet distribution

– separate modes

⇒ Tag symmetrically in latent space [Heidelberg–Aachen]

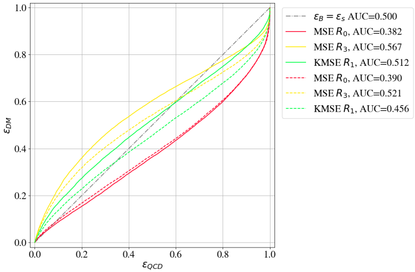


Anomaly detection with autoencoders

Challenging BSM scenarios for unsupervised machine learning?

- Autoencoders shown to work as top-taggers
- however, standard autoencoders have a simplicity bias
  tend to identify complex jet imagines as anomaly, irrespective of training
- improve existing autoencoders:
  modify the data preprocessing, loss function, latent space
- truly model-independent autoencoder for anomaly tagging still to be developed

improved autoencoder for dark shower tagging



[Finke, Krämer, Morandini, Mück, Oleksiyuk, 2104.09051; Heidelberg–Aachen in progress]

Generative networks with uncertainties

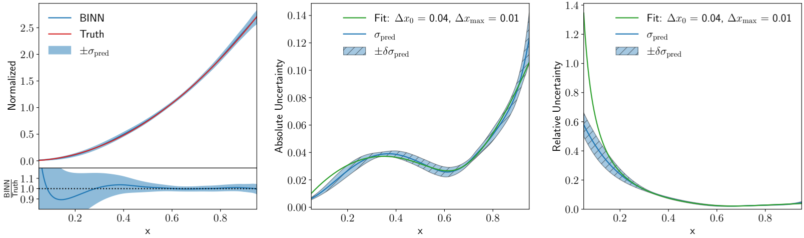
Bayesian generative network [Bellagente, Luchmann, Haußmann, TP]

– generate events with error bars
  i.e. learn density and uncertainty maps over phase space

– normalizing flow/INN [Köthe etal]

– 2D toy models: wedge ramp, kicker ramp, Gaussian ring

⇒ Error estimate works...



...and we see how the network learns!

Generative networks with uncertainties

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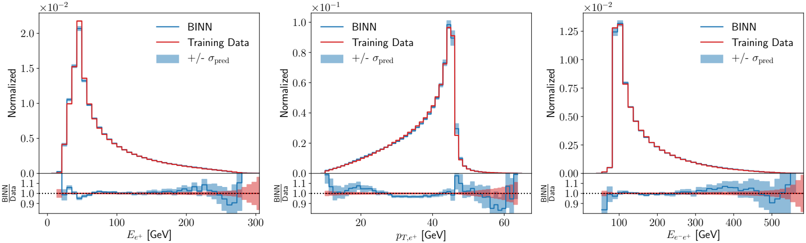
Simple LHC process

– 1D kinematic distributions with errors



Thank you...


ML4Jets hybrid
July 6-8 2021
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