Highlights from the BSM session

PhysTev 2019

Les Houches - 28 June 2019

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CERN & INFN Genova

on behalf of the

BSM Conveners: Gustaaf Brooijmans, Marco Nardecchia, Riccardo Torre, Giovanni Zevi della Porta

BSM activities

- Flavor anomalies seem to be still intriguing for the BSM community
- Flavor was the leading topic in the BMS working group
- There is interest both in flavor model building and in high-pT implications of flavor anomalies
- The high-pT flavor precision program joins the electroweak precision program (and both are part of the very active EFT studies at the LHC, also relevant for the Higgs BSM working group)
- Other ideas, extend the implications of flavor anomalies towards Dark Matter
- Some working groups also interested in VLQ, LLP and DM signatures at the LHC

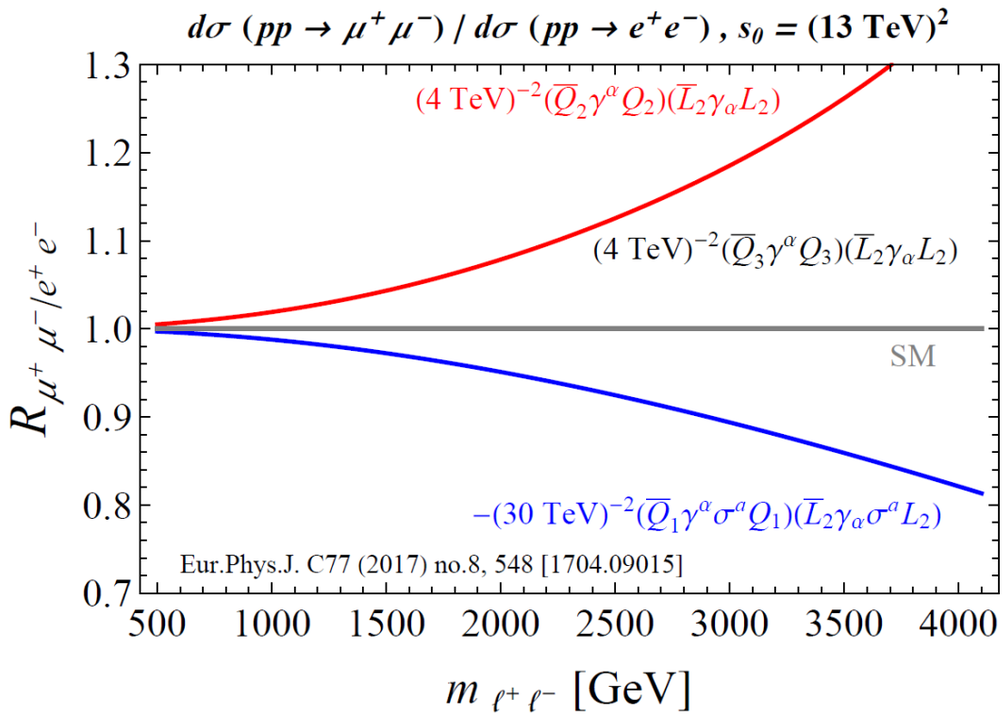
All activity well documented on the Wiki

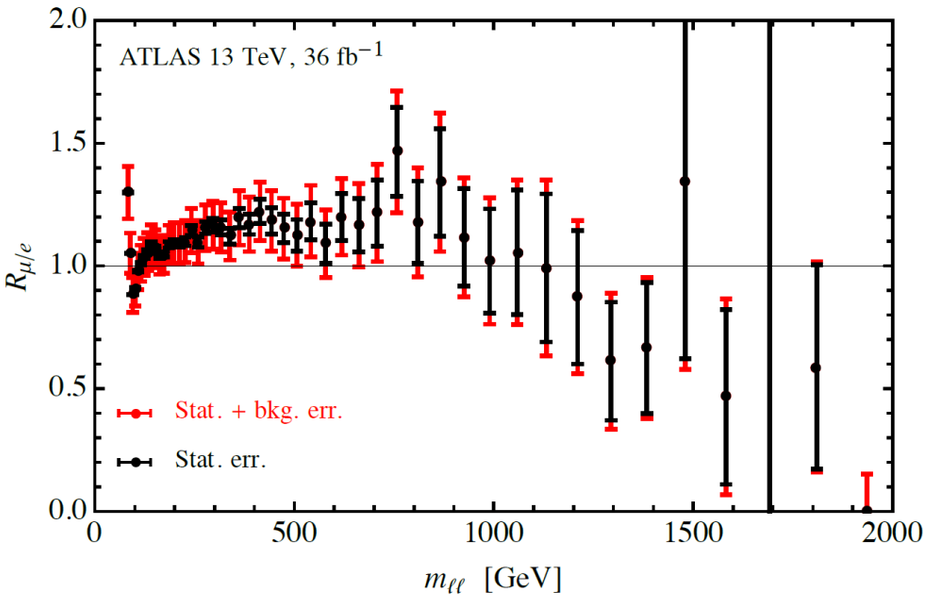
Project pages

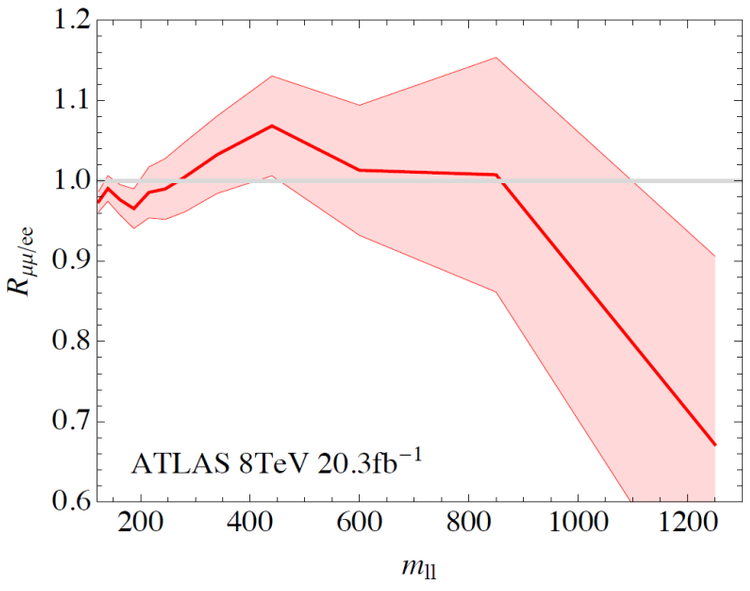
- LQ single production in top,tau,neutrino (Priscilla)
- New Signatures of VLQs (Thomas)
- UV Model for flavour anomalies FCNC (Werner)
- RDM (Jose Zurita)
- Tagging SM hadrons in LLP searches (Jan)
- Freeze-in from scattering at the LHC (Andreas)
- High-pT dilepton tails: LFU ratio with actual data (Tanya)
- High-pT dilepton tails: SMEFT and LFU (David)
- High-pT tails: pp--> tau nu + b (Giacomo)

High-pT dilepton tails: LFU ratio with actual data

- Team: Tanya Berger-Hryn'ova, Dario Buttazzo, Juhi Dutta, David Marzocca, Marco Nardecchia, Minho Son
- Aim: investigate R=dσ(pp→μμ)/dσ(pp→ee) for deviations from unity as expected in some BSM scenarios
- Theoretical uncertainties at high mass will cancel in such ratio
- No experimental results of this kind is directly available, public results from ATLAS resonant search at 13TeV (36fb^{-1})* and ATLAS SM DY measurement at 8TeV 20fb^{-1} are used







Results are statistically limited and currently consistent with unity within ~1σ

Improvement is expected with an increase of the dataset as well as combined ATLAS+CMS high mass DY differential cross-section measurement

*For the search DY includes Photon Induced processes (same for ee and μμ)

High-pT dilepton tail - SMEFT limits

Participants: Aoife Bharucha, Dario Buttazzo, Juhi Dutta, Berni Gaud, Tetiana Hrynova, David Marzocca, Marco Nardecchia, Giacomo Polesello, Priscilla Pani, Minho Son, Elena Venturi, Natascia Vignaroli, Tevon You

Goals:

1) Provide a **global likelihood** for deriving limits on ALL **four-fermion SMEFT operators** contributing to $pp \to \ell^+\ell^-$ (where ℓ=μ,e - separately)
2) Study the impact of **angular observables** in the fit ($\Delta\eta_{\ell\ell}$)

Done:

We discussed the physics goals and prepared a UFO model for all relevant operators

To Do:

We will start by using Drell-Yan data from ATLAS 8 TeV, which shows Born-level double-differential cross-section and all uncertainties. Eventually, extend to 13 TeV analyses when available.

$$\mathcal{L}_{\rm EFT} = \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + O(\Lambda^{-4}).$$

$(\mathcal{O}_{lq}^{(1)})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu l_\alpha)(\bar{q}_i \gamma^\mu q_i)$	$(\mathcal{O}_{lq}^{(3)})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu \sigma^a l_\alpha)(\bar{q}_i \gamma^\mu \sigma^a q_i)$
$(\mathcal{O}_{qe}) = (\bar{q}_i \gamma^\mu q_i)(\bar{e}_\alpha \gamma^\mu e_\alpha)$	
$(\mathcal{O}_{lu})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu l_\alpha)(\bar{u}_i \gamma^\mu u_i)$	$(\mathcal{O}_{ld})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu l_\alpha)(\bar{d}_i \gamma^\mu d_i)$
$(\mathcal{O}_{eu})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu l_\alpha)(\bar{u}_i \gamma^\mu u_i)$	$(\mathcal{O}_{ed})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu l_\alpha)(\bar{d}_i \gamma^\mu d_i)$

18 (μ) + 18 (e) operators to consider (no top)

$$\frac{d^2\sigma(pp \to \ell\ell)}{dm_{\ell\ell} d\Delta\eta_{\ell\ell}} \longrightarrow \textbf{Compare limits} \longleftarrow \frac{d\sigma(pp \to \ell\ell)}{dm_{\ell\ell}}$$

Single-production of third-generation LQ with tops and missing energy in the final state.

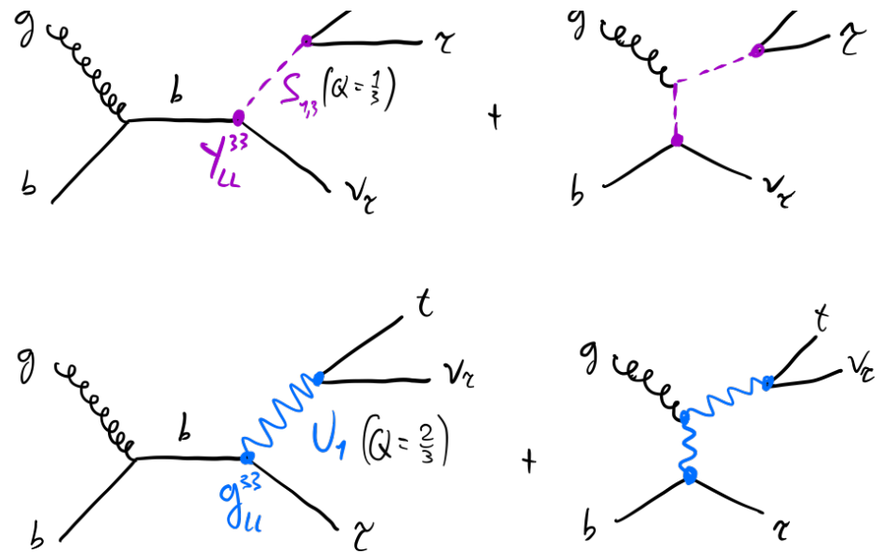
- Participants: Dario Buttazzo, David Marzocca, Priscilla Pani, Giacomo Polesello

$S_1 = \left(\bar{3}, 1, \frac{1}{3}\right)_{Q=\frac{1}{3}}$ $\quad S_3 = \left(\bar{3}, 3, \frac{1}{3}\right) \supset \left\{S_3^{1/3}, S_3^{4/3}, S_3^{-2/3}\right\}$

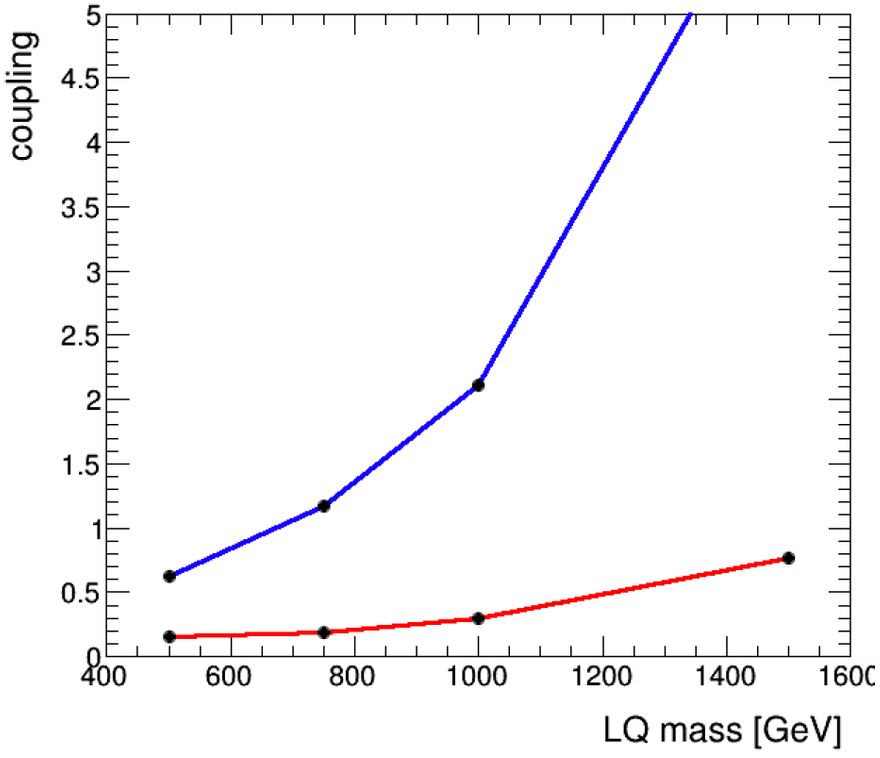
$$\mathcal{L}^{int}_{S_1} = y^{i\alpha}_{LL}\, S_1\, \bar{q}^{ic}_L\, \ell^{\alpha}_L + y^{i\alpha}_{RR}\, S_1\, \bar{u}^{ic}_R\, e^{\alpha}_R + h.c.$$

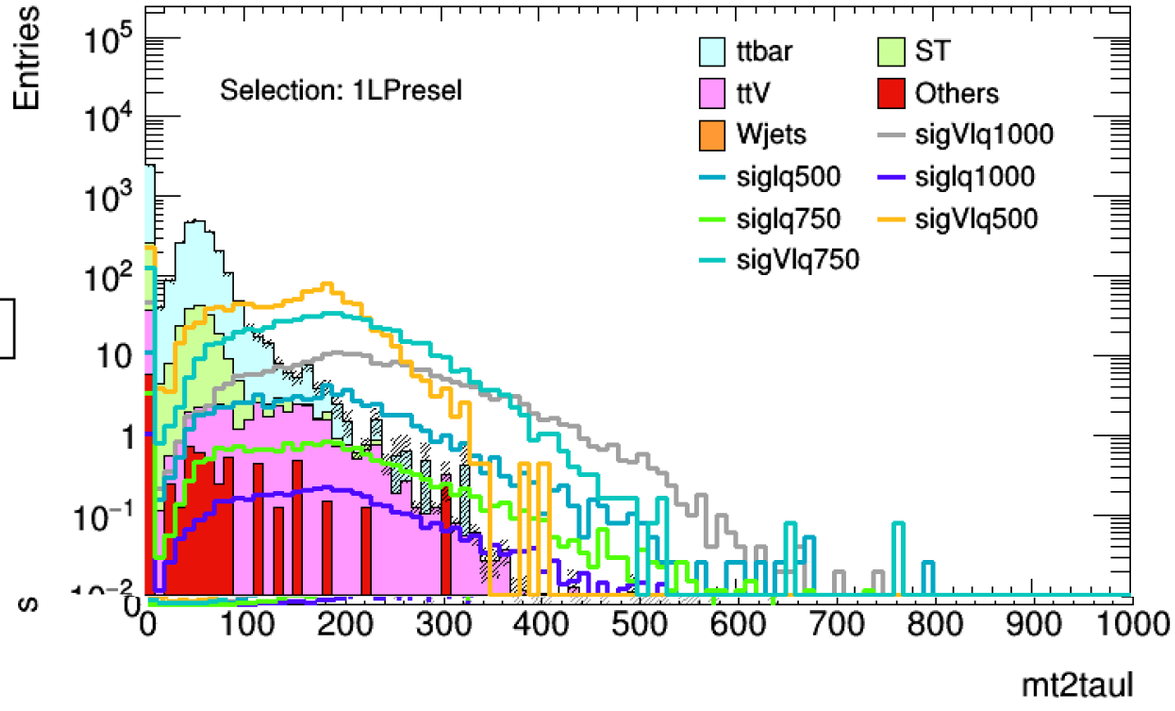
$U_1 = \left(3, 1, \frac{2}{3}\right)_{Q=\frac{2}{3}}$

$$\mathcal{L}^{int}_{U_1} = g^{i\alpha}_{LL}\, U_1^{\mu}\, \bar{q}^{i}_L\, \gamma_\mu\, \ell^{\alpha}_L + h.c.$$



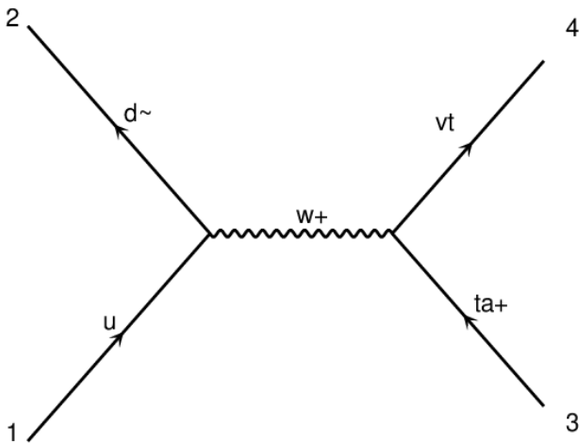
See also CMS analysis in 1806.03472 (LQ->btau)

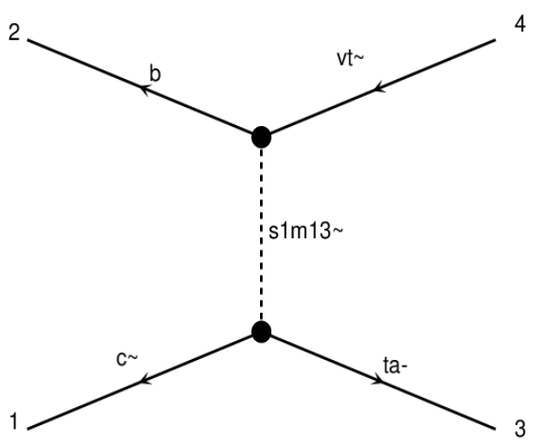




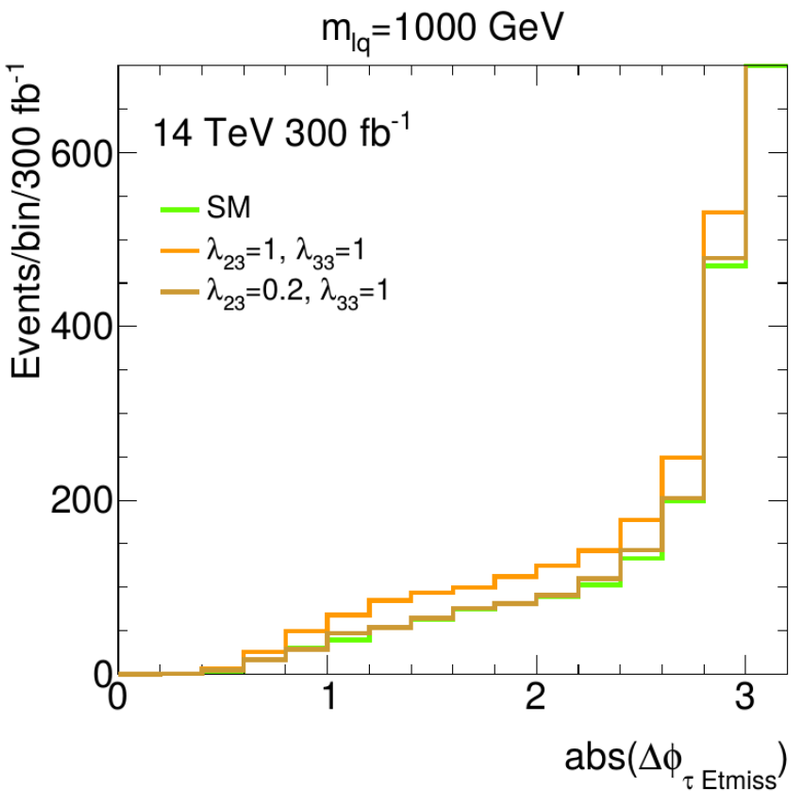
τν final state from t-channel LQ exchange

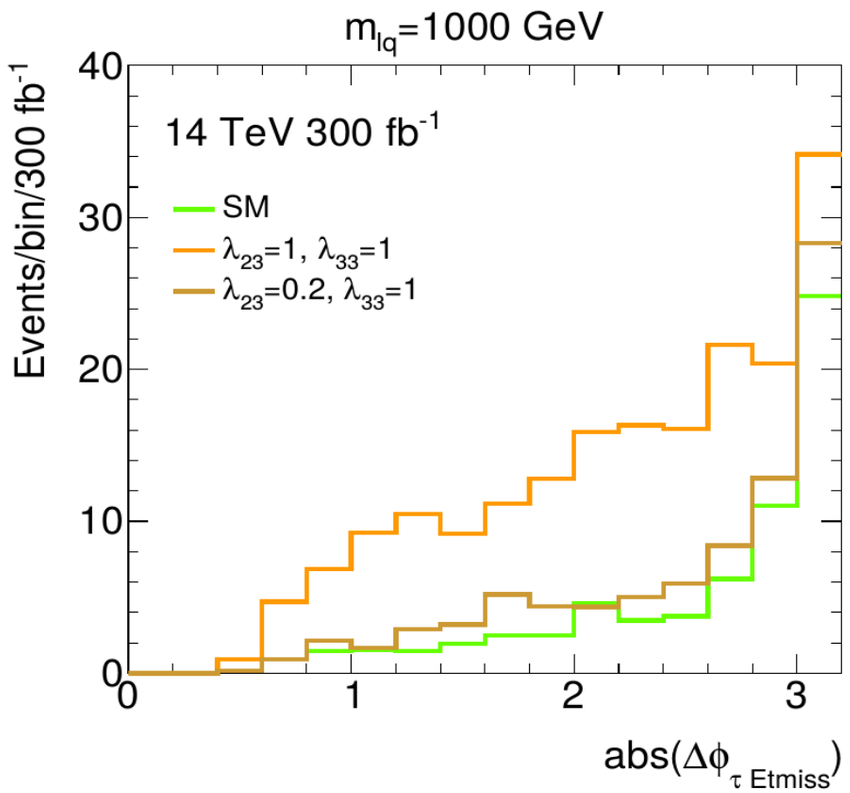
Participants: D. Marzocca, M. Nardecchia P. Pani, G. Polesello





- Require MT(tau,Etmiss)>200 GeV to remove W pole
- Require Etmiss>400 GeV
- Enhance LQ contribution by requiring an additional b-jet
- With pt>150 GeV





Simulate exchange of S1 LQ with UFO from Greljo

Left: without requiring a b-jet,
Right: requiring a b-jet with pt>150 GeV

Preliminary: need to validate jet matching in generation and apply parametrised efficiency for tau jet tagging

Assuming 15% systematic on background, approximately exclude at 95% λ23=0.2 λ33=1 with a 300 fb-1 LHC

Plan: map for LHC and HL-LHC coverage on coupling space

UV Model for flavour anomalies FCNC

Aoife Bharucha, Jon Butterworth, Thomas Faber, Thomas Flacke, Benjamin Fuks, Adil Jueid, Yang Liu, Priscilla Pani, Giacomo Polesello, Werner Porod, David Yallup

- Model (extension of arXiv:1808.05511)
  - gauge group: $SU(4) \times SU(2)_L \times U(1)_R$
  - vector particles: SM + U_1 + Z_{B-L}
  - fermions: SM + 3 gen. ν^c + 2 gen. vector-like leptons L_i (+ vector quarks)
  - scalars: 2HDM + scalar gluons G^0, G^+ + LQ R_2, $\tilde{R}_2$
- Aims:
  - 2 sets of benchmark scenarios: (i) one explaining B-physics anomalies, (ii) one assuming that these anomalies are gone
    check consistency with LHC data using `contur` + `MadAnalysis`
  - some interesting decays:
    $G^+ \to t\bar{b}, \mathrm{LQ}^{1/3} \to \bar{b}\nu^c, \mathrm{LQ}^{2/3} \to t\nu^c, \nu^c \to b\bar{c}l^+, \mathrm{LQ} \to L_i q$
  - study of specific channels which can also serve as simplified models for BSM searches, e.g.

$$p\,p \to \mathrm{LQ}^{-1/3} l^+ \to b\bar{\nu}^c l^+ \to \bar{b}bcl'^- l^+$$

$$p\,p \to \mathrm{LQ}^{2/3} l^- \to t\nu^c l^- \to tb\bar{c}l'^+ l^-$$

$$p\,p \to \mathrm{LQ}\overline{\mathrm{LQ}} \to L_i^- L_j^+ q\bar{q}'$$

- status:
  - `SPheno` + interface to `flavio` ready,
  - creating UFO-file and setting up `contur` to explore LHC constraints; on the way to explore LHC phenomenology

RDM project

Merry crew (in INVERSE alphabetical order): J. Zurita, D. Sengupta, G. Polesello, P. Pani, J.M. No, A. Lessa, A. Jueid, J. Heisig, B. Fuks, C. Delaunay, B. Bhattacherjee, A. Bharucha, J. Bernigaud, G. Bélanger

Goal: relate the S1 LQ model that solves RD and RD* "anomalies" to dark matter.

Project roadmap:

1) UFO model including 3 new fields (S_1, χ_1,χ_0) and 3 new couplings (y_D,y^L_{33},y^R_{23})
2) Find a viable point that solve flavor anomalies, RD ~ $y^L_{33} * y^R_{23}$ / $(m_{S1})^2$
3) Check model viability w.r.t:
   1) Flavor constraints (y^L_{33} . y^R_{23} m_{S1})
   2) Direct LQ production: $m_{S1,}$ BRs (S_1 -> SM, dark)
   3) Monojet bounds (mostly on $m_{\chi 1}$)
   4) S1 associated production with hard lepton (recast existing searches? new searches? for 2l + j)
   5) Dark matter: Ωh^2 from either co-annihilation or conversion driven freeze-out
   6) Existing LQ (resonant) + MET search from CMS (no ATLAS search yet?)
4) Write down proceeding (internal deadline Dec 1st)
5) Publish paper (after LH2019 proceedings appear on arXiv).

RDM
Réseau Des Mécaniciens

exotic VLQ decays, bounds, signatures

[Thomas Flacke, Benjamin Fuks, Werner Porod, Minho Son, Tetiana Berger-Hryn'ova, Louie Corpe, ++]

Many SM extensions with VLQs (Q) also contain BSM bosons which might be lighter than Q.

New VLQ decays can be classified according to the VLQ and boson quantum numbers:

$\psi_{\rm VLQ} = (\mathbf{3},\mathbf{1},Y)$			
$\psi_{\rm SM}$	scalar	$\psi_{\rm VLQ}$	$Q_{\rm VLQ}$
q_L	(**1**⊕ **8**,**2**,1/2)	(**3**,**1**,2/3)	2/3
		(**3**,**1**,-1/3)	-1/3

$\psi_{\rm VLQ} = (\mathbf{3},\mathbf{2},Y)$			
$\psi_{\rm SM}$	scalar	$\psi_{\rm VLQ}$	$Q_{\rm VLQ}$
t_R	(**1**⊕ **8**,2,1/2)	(**3**,**2**,1/6)	(2/3,-1/3)
		(**3**,**2**,7/6)	(5/3,4/3)
b_R	(**1**⊕ **8**,**2**,1/2)	(**3**,**2**,1/6)	(2/3,-1/3)
		(**3**,**2**,-5/6)	(-2/3,-4/3)

$\psi_{\rm VLQ} = (\mathbf{3},\mathbf{3},Y)$			
$\psi_{\rm SM}$	scalar	$\psi_{\rm VLQ}$	$Q_{\rm VLQ}$
q_L	(**1**⊕ **8**,**2**,1/2)	(**3**,**3**,2/3)	(5/3, 2/3, -1/3)
		(**3**,**3**,-1/3)	(2/3,-1/3,-4/3)

etc.

(Last Les Houches 1803.10379)

With these decays, VLQ pair production gives a multitude of new final states, and current search bounds and sensitivities are altered.

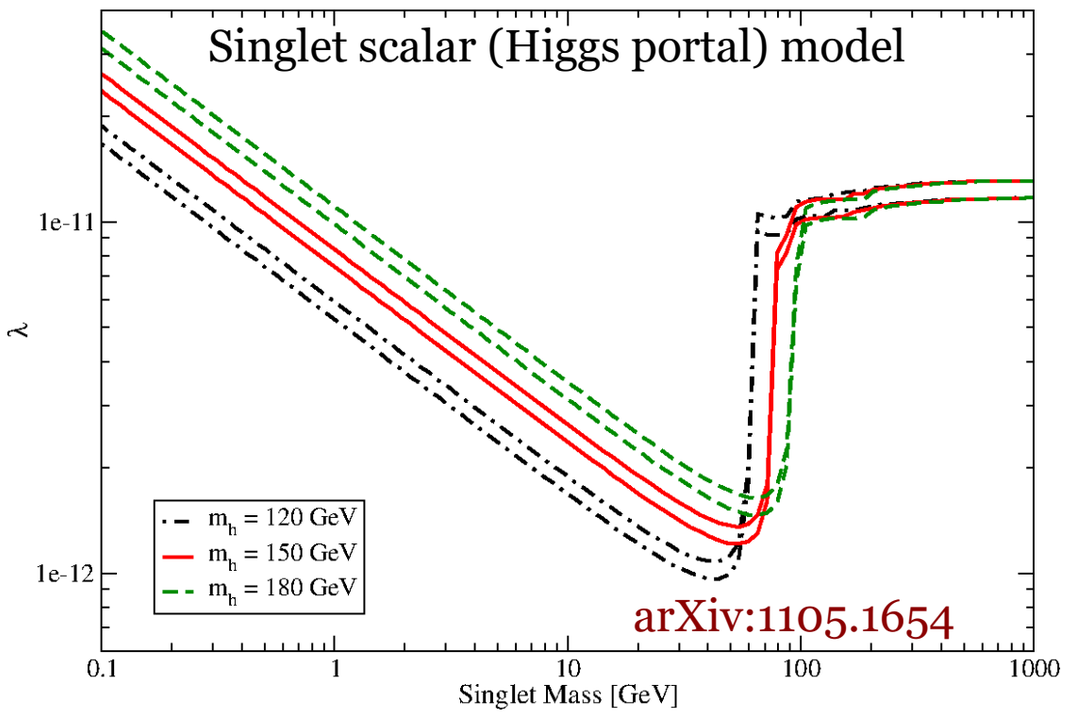
Aim of the LH working group:

- Build (public) VLQ + scalar effective model implementation for event generators
- Determine bounds from existing searches and measurements (Contur,MA,CheckMATE)
- Survey new final states: where are the gaps? where are lighthouses?

Freeze-in with large couplings @ the LHC

People interested: G. Belanger, A. Bharucha, F. Boudjema, C. Delaunay, N. Desai, J. Dutta, A. Goudelis, J. Heisig, S. Kraml, A. Lessa, J. M. No, S. Sekmen, D. Sengupta, H.-S. Shao, J. Zurita

Freeze-in typically involves tiny couplings of DM with the Standard Model.



Typical LHC signatures:
- LLPs
- Resonances
- None

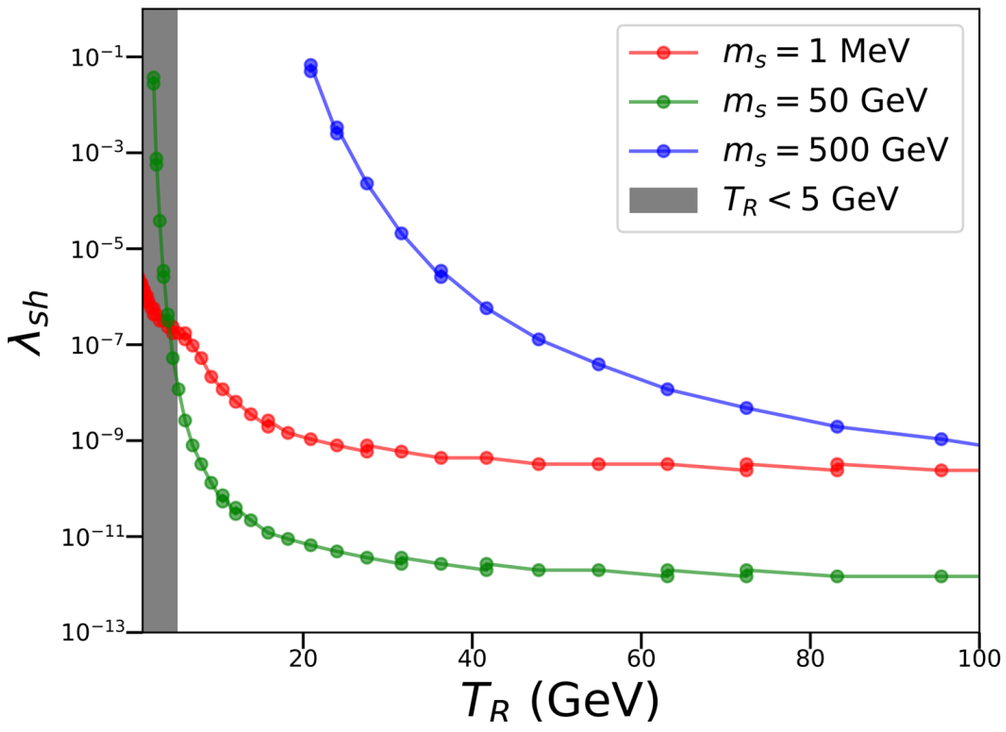
Is there a way to boost the DM-SM interactions?

Consequences for LHC pheno?

Idea: decrease the reheating temperature.
→ Successful FI requires much larger couplings.

Constraints from conventional LHC searches?

New signatures?

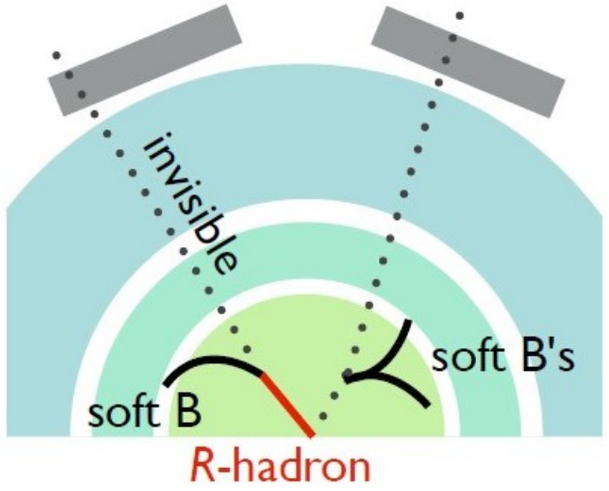


LLPs from DM with 'softish' decays

14 people interested: Genevieve Belanger, Aoife Bharucha, Biplob Bhattacherjee, Nishita Desai, Benjamin Fuks, Andreas Goudelis, Jan Heisig, Andre Lessa, Jose Miguel No, Priscilla Pani, Sezen Sekmen, Dipan Sengupta, Hua-Sheng Shao, José Zurita

Motivation and scope

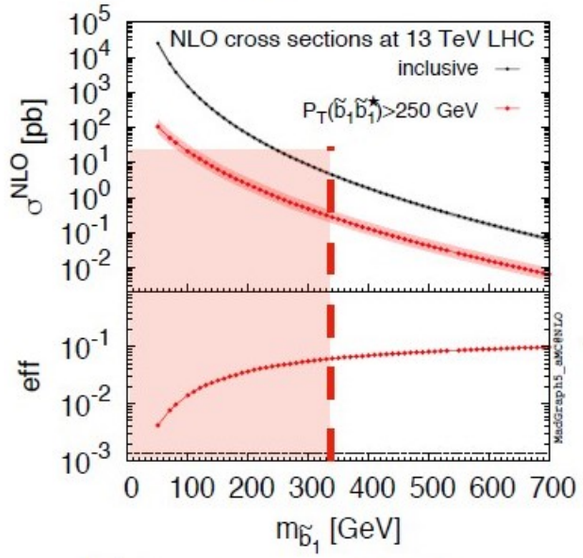
- Search region not targeted so far:
  DM t-channel mediator model with $\mathcal{O}(10)\,\mathrm{GeV}$ mass splitting and small couplings → LLPs
  [Realized e.g. in conversion-driven FO 1705.09292]
- Explore trigger and search strategies!



Ideas and discussions

Trigger:

- MET trigger eff.

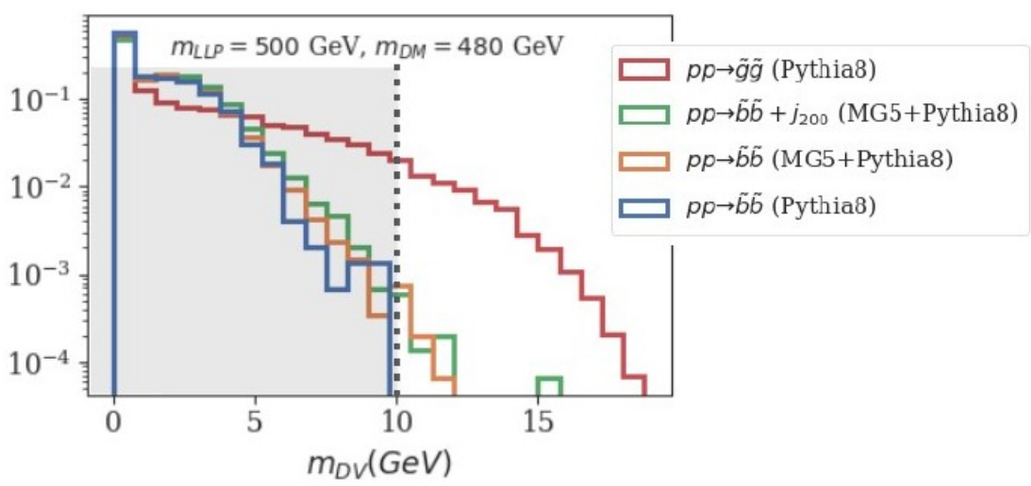


~10^{-1}

- J/ψ trigger: BR($B \to J/\psi \to \mu\mu$)=10^{-3}
- Timing trigger? [see e.g. 1805.05957]

Search strategy:

- Displaced jets+MET; suffers from m_{inv}-cut:



- Disappearing tracks; suffers from veto next layer
- Kinked tracks; kink to large?
- B's decaying in ECAL/HCAL? Prompt searches?
  [see e.g. 1902.03094]

Summary slide, J. Heisig, Les Houches, June 28, 2019

Conclusion

The BSM session was very successfull

Lots of promising studies towards good contributions to the proceedings

Thanks to all BSM participants and hope to see you again in LH!