WG3: more ideas and discussion

Workshop on the physics of HL-LHC, and perspectives at HE-LHC
CERN - 30 October 2017

Speakers

H. Baer, R. Ruiz, M.A. Sanchis-Lozano, A. Iyer, S. Chekanov, D. Barducci, S. Westhoff, S. Amoroso

Additional material is available on the Indico page of this session

Radiative natural SUSY at HL- and HE-LHC

Howard Baer, University of Oklahoma

- In light of recent LHC bounds (m(glno)>2 TeV, m(t1)>1 TeV) and m(h) requiring TeV-scale highly mixed top squarks, concern has arisen about an emerging Little Hierarchy problem characterized by m(weak)~100 GeV<< m(SUSY)~multi-TeV rendering perhaps SUSY as ``unnatural"
- We propose an improved naturalness measure based upon scalar potential minimization condition

$$m_Z^2/2 = \frac{m_{H_d}^2+\Sigma_d^d-(m_{H_u}^2+\Sigma_u^u)\tan^2\beta}{\tan^2\beta-1} - \mu^2 \simeq -m_{H_u}^2 - \Sigma_u^u(\tilde{t}_{1,2}) - \mu^2$$

DM=WIMP/axion mix?

This leads to upper bounds from naturalness:

- m(higgsinos)~100-300 GeV (the lighter the better)
- m(t1)<~3 TeV
- m(glno)<~6 TeV

process	current	HL-LHC	HE-LHC
glno-glno	m(glno)>2 TeV	~2.8 TeV	5.5 TeV
t1-t1	m(t1)>1 TeV	1.3 TeV	3.5 TeV
SSdB (winos)	x	m(W2)~1 TeV	?
z1 z2j->l+lb+j+MET	barely	mu~250 GeV	?

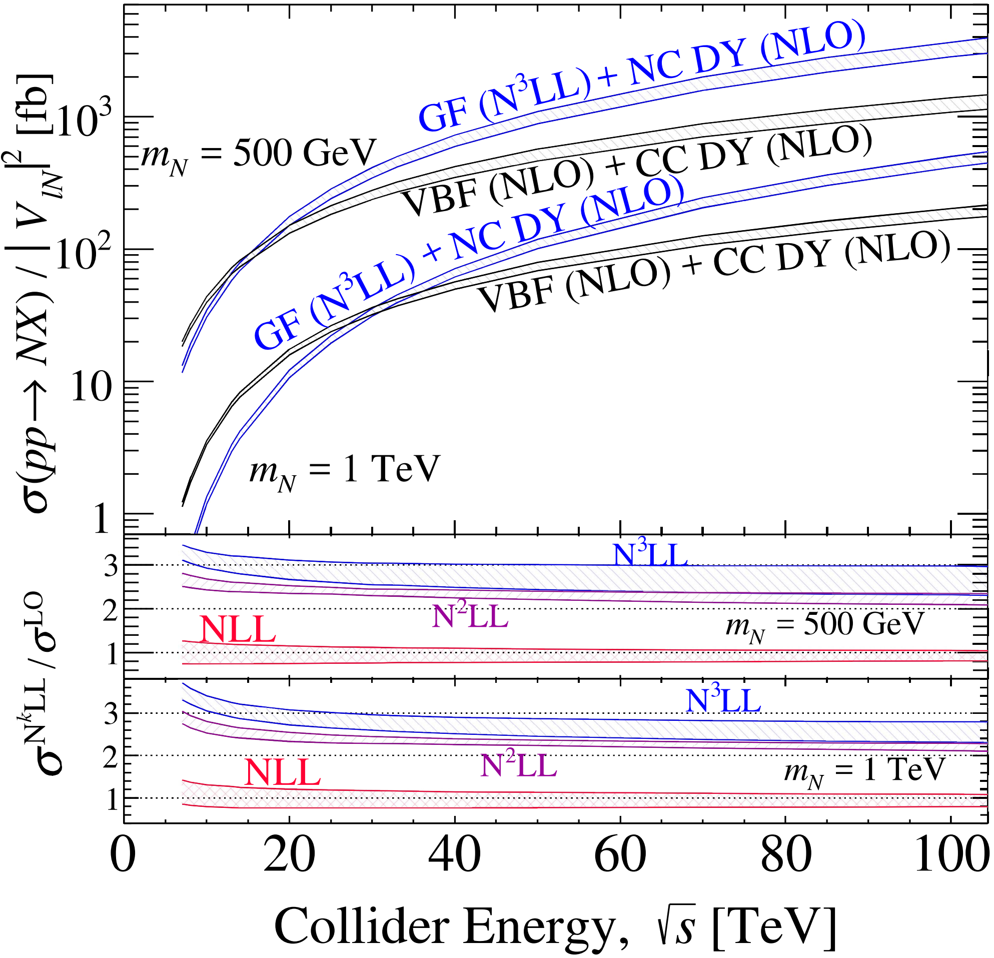
Conclusions:
1. SUSY still natural;
2. hunt for nSUSY has only begun;
3. HL-LHC handle most SUSY with ino-mass unification;
4. other (e.g. mirage) may require HE-LHC to complete search

arXiv:1604.07438
1612.00795
1702.06588
1708.09054
1710.09103

HB, Barger,Gainer, Huang,Tata, Savoy, Mustafayev, Sengupta,Serce

Low-Scale Type I Seesaws:

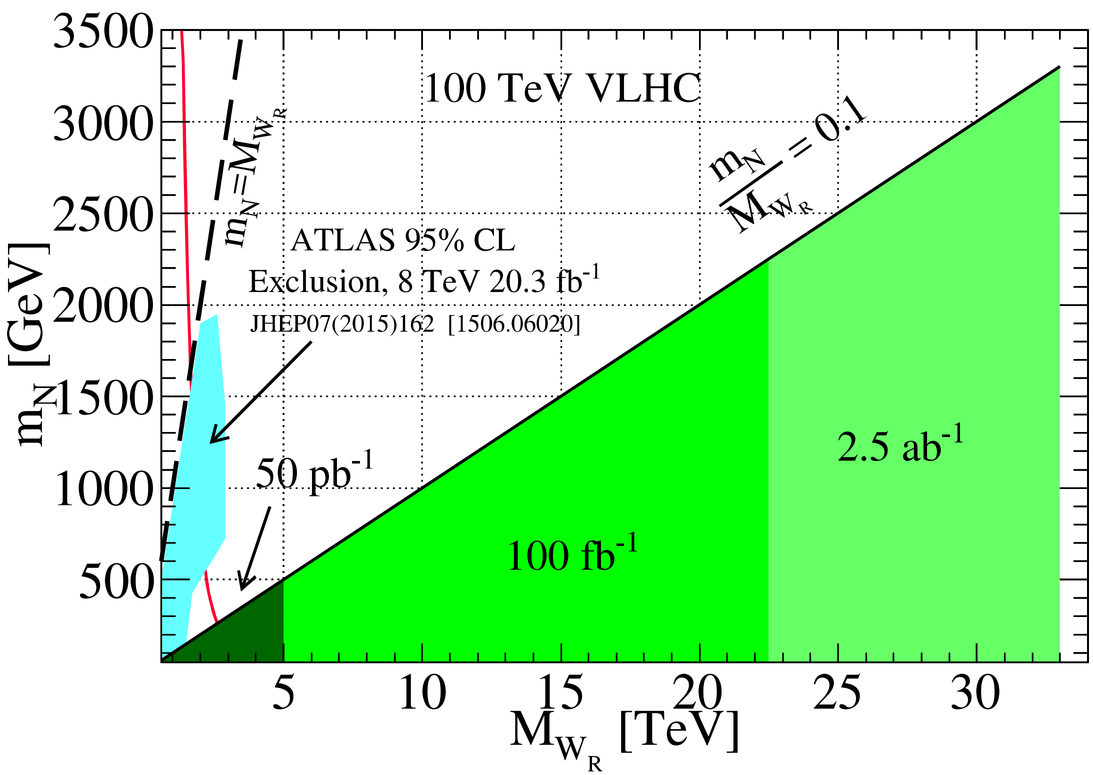
(Pseudo-Dirac N + sizable mixing)



- $gg \to N\nu_\ell$ dominant channel for $\sqrt{s} \gtrsim 20 - 25$ TeV [1706.02298]
- FeynRules file [1602.06957]

Left-Right Symmetric Models:

($W_R^\pm$, Z_R, $H^{\pm\pm}$, Majorana N)



- High-mass W_R decays to light N
  $\Longrightarrow$ N decays are collimated
  $\Longrightarrow$ neutrino jets! [1607.03504]
- Sensitivity to $M_{W_R} \lesssim 20$ (35) with 100 (2500) fb^{-1} at 100 TeV

New ***Seesaws@Colliders*** review by Y. Cai, T. Li, T. Han, **RR** (this week!)

Searching for new physics in multiparticle production @ HL-LHC

M.A. Sanchis-Lozano, IFIC - University of Valencia

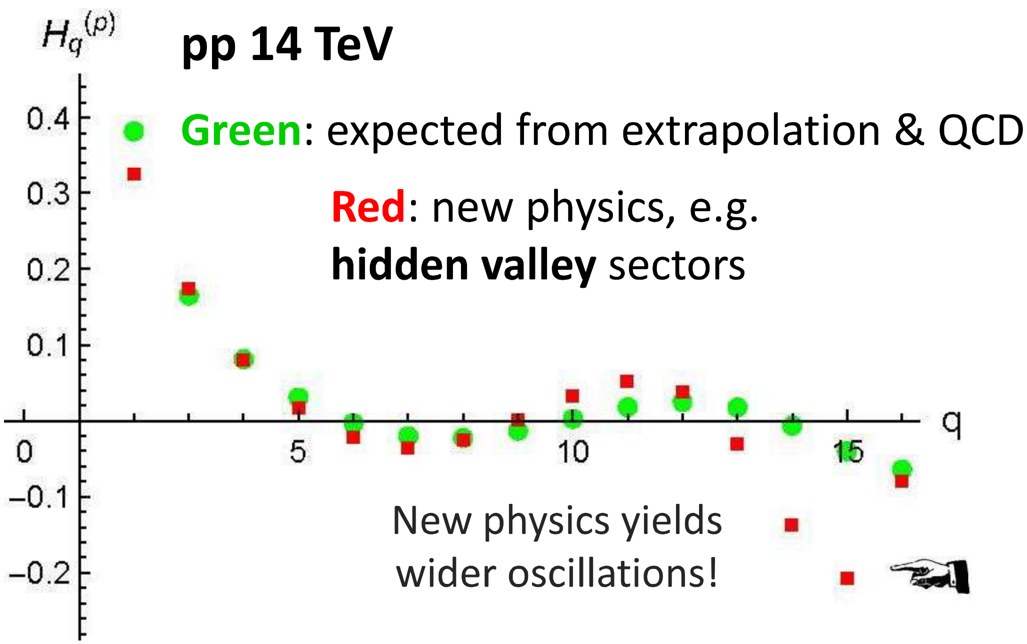
based on **Phys.Lett. B754 (2016) 353-359** [arXiv:1510.08738]

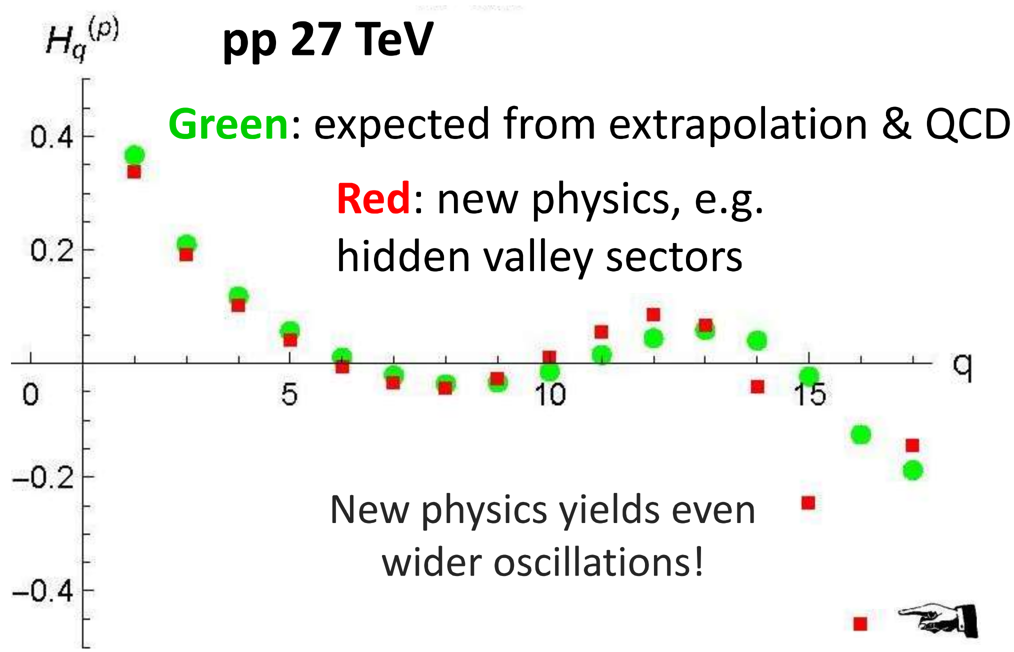
Complementary to more "conventional" searches

Particle correlations and multiplicity moments

(similar to searches for QGP)

H_q normalized cumulants (oscillations seen at lower energies)

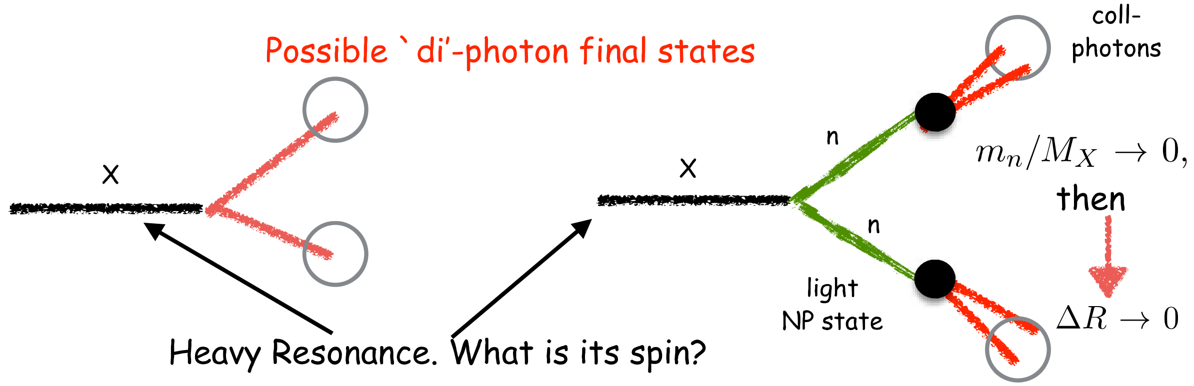




Dissecting `multi' photon resonances at the LHC

B.Allanach, D. Bhatia, A. Iyer '17

Eur.Phys.J. C77 (2017) no.9, 595



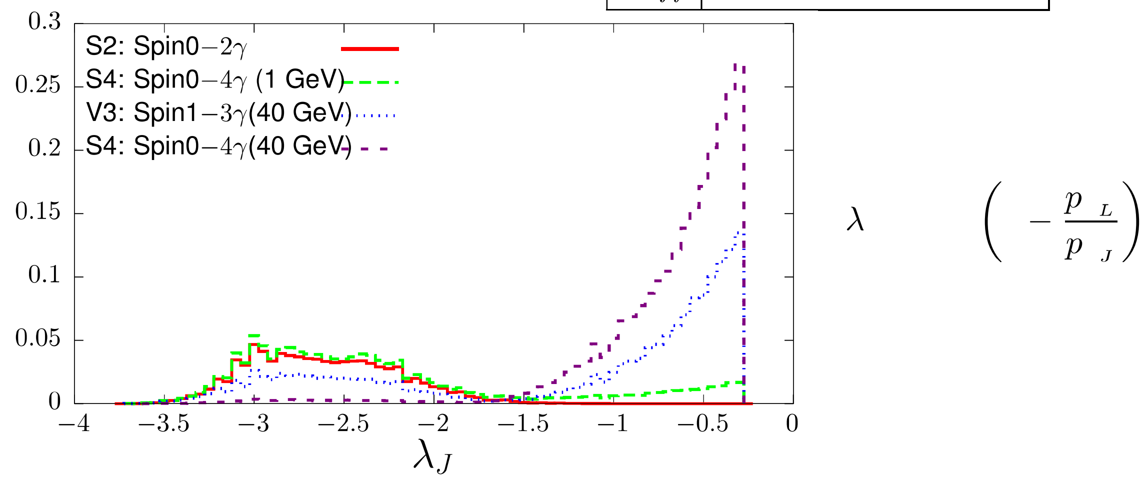
Model	Process
$S2$	$pp \to S \to \gamma\gamma$
$S4$	$pp \to S \to nn \to \gamma\gamma + \gamma\gamma$
$V3$	$pp \to Z' \to n\gamma \to \gamma + \gamma\gamma$
$G2_{ff}$	$q\bar{q} \to G \to \gamma\gamma$
$G2_{gg}$	$gg \to G \to \gamma\gamma$
$G4_{gg}$	$gg \to G \to nn \to \gamma\gamma + \gamma\gamma$
$G4_{ff}$	$\bar{q}q \to G \to nn \to \gamma\gamma + \gamma\gamma$

Give up isolation and switch to photon jets!

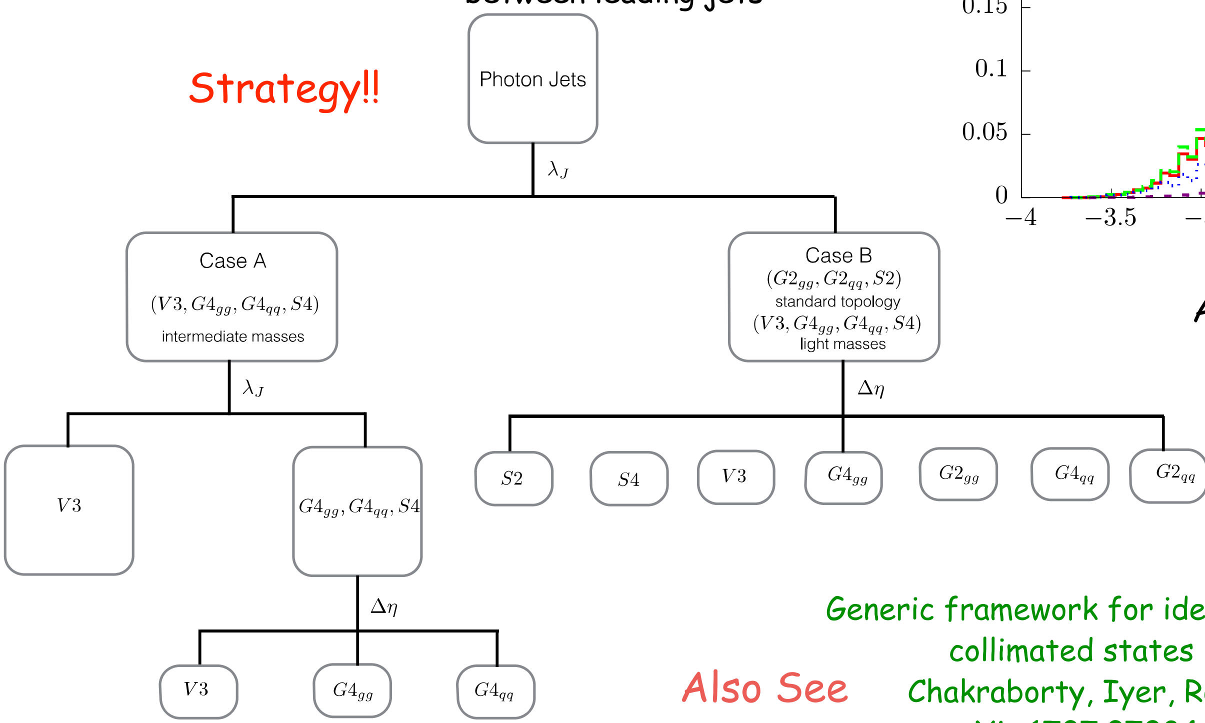
Method

Look at jet substructure

$\Delta\eta$ between leading jets



Strategy!!



Analysis quantified by solving

$$\frac{1}{R} = \frac{p(H_S|N \text{ events from } H_T)}{p(H_T|N \text{ events from } H_T)}$$

N_R	$S2$	$S4$	$V3$	$G2_{gg}$	$G4_{gg}$	$G2_{ff}$	$G4_{ff}$
$S2$	∞	> 2000	272	27	15	91	14
$S4$	> 2000	∞	255	26	15	96	13
$V3$	260	248	∞	54	9	37	21
$G2_{gg}$	32	31	65	∞	5	13	38
$G4_{gg}$	23	24	14	6	∞	54	4
$G2_{ff}$	102	110	44	12	40	∞	8
$G4_{ff}$	19	18	28	37	5	12	∞

Also See

Generic framework for identifying collimated states
Chakraborty, Iyer, Roy
arXiv:1707.07084

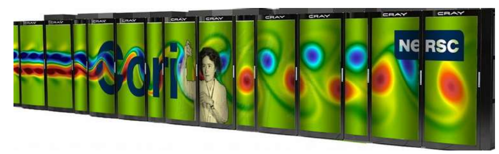
Precision searches in dijets at the HL-LHC and HE-LHC

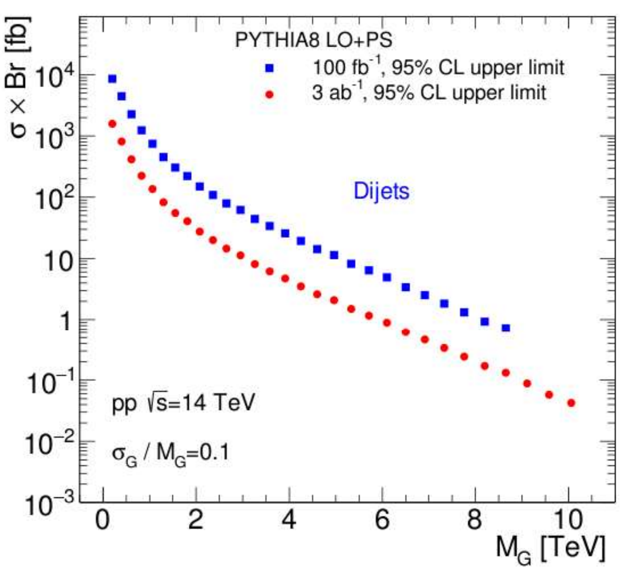
S.Chekanov, T.Childers, D.Frizzell, J.Proudfoot, R.Wang
(ANL, USA)

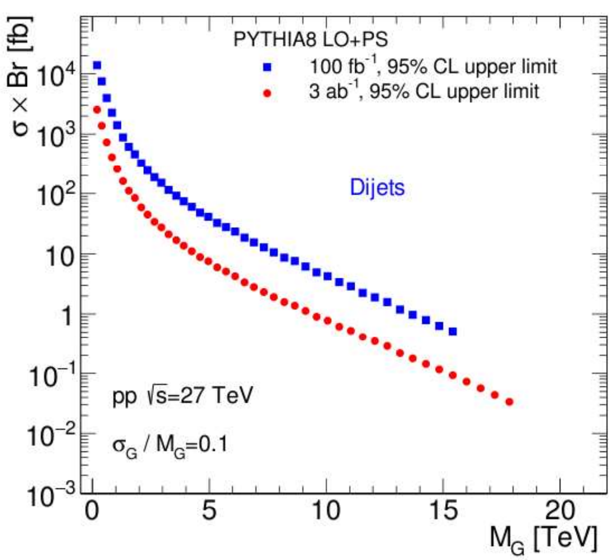
arXiv:1710.09484 (ANL-HEP-139751)

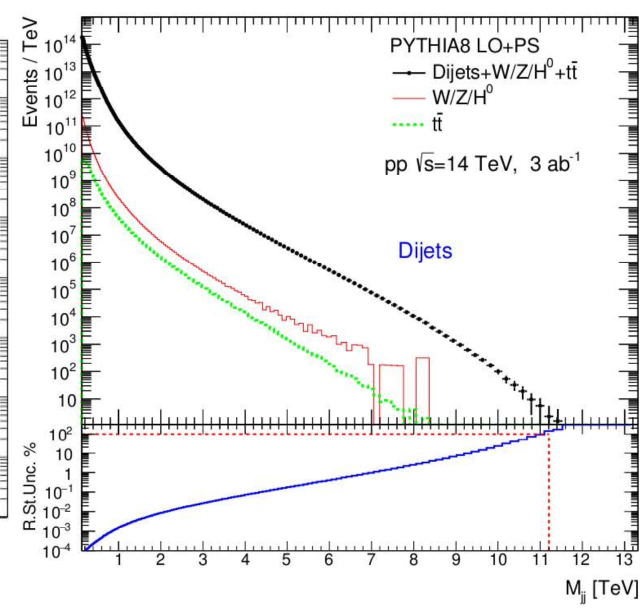
Answered questions:

- How will searches in *dijet* masses evolve for the HL-LHC and HE-LHC?
- What are the model independent mass reach for 14 TeV and 27 TeV + lumi dependence
- What are 95% C.L. upper limits for generic signals and Z' → 2 jets?
- What are the exclusion limits for *di b-jets* and *jets+leptons*
  - EWK region < 1 TeV (not limited by jet trigger), sensitivity to V-bosons and top
- How to extract signals in dijets spanning 14 orders of magnitude in rate?
- Used simulations: Pythia8 multijets, W/Z/H and top. 100 B events
  - 10 M CPU*h on supercomputers at NERSC







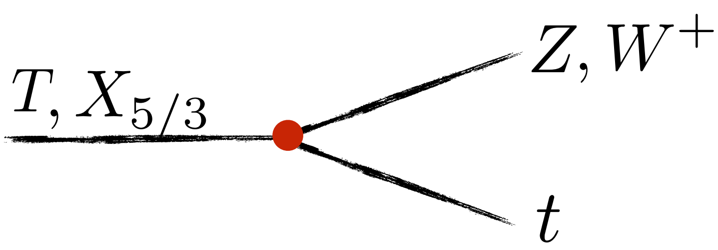


VLQs coupling discrimination at hadron colliders

D. Barducci & L. Panizzi
arXiv:1710.02325

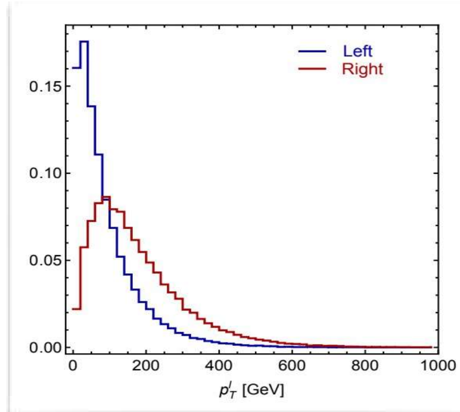
- VLQs are predicted by many NP scenarios and under great experimental investigation
- Their couplings to SM quarks and bosons have a dominant chiral structure: **Left** or **Right**

Q: Could the HL/HE-LHC discriminate against the two hypotheses if a signal were observed?

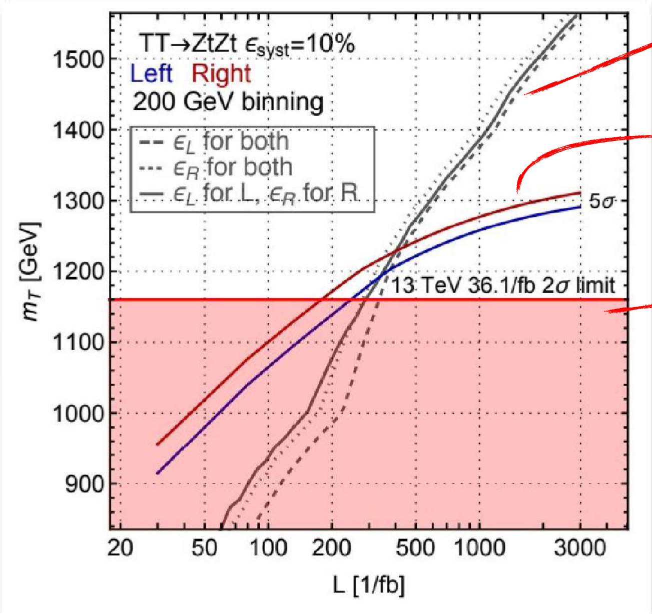


<u>Longitudinal:</u> no information on the vertex structure

<u>Polarised:</u> Harder objects for a right-handed coupling
Kinematic distributions can be used as discriminators



HL-LHC

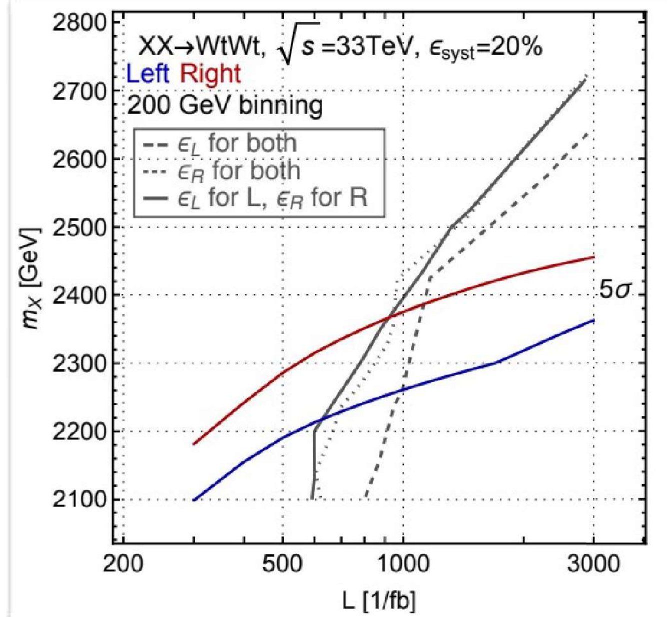


95% CL discrimination

5σ VLQ discovery

Current 95% CL exclusion

HE-LHC



Discrimination possible in all the discovery range of the HL/HE-LHC

Universität Heidelberg

Carl Zeiss Stiftung

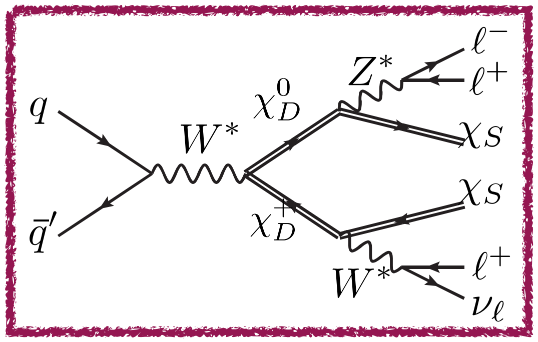
Fermion Dark Matter at the future LHC

Ayres Freitas - Alexander Voigt - Susanne Westhoff - Jure Zupan

Can we test the Higgs portal $\frac{y^2}{m}(H^\dagger H)(\chi\ \ \chi\ \ )$ at the LHC? - Not easy.

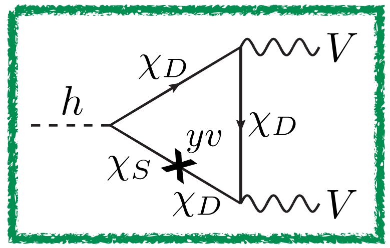
y

Resonant: like SUSY

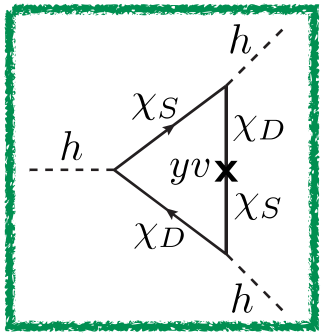


thermal WIMPs

Virtual: Higgs couplings



beyond



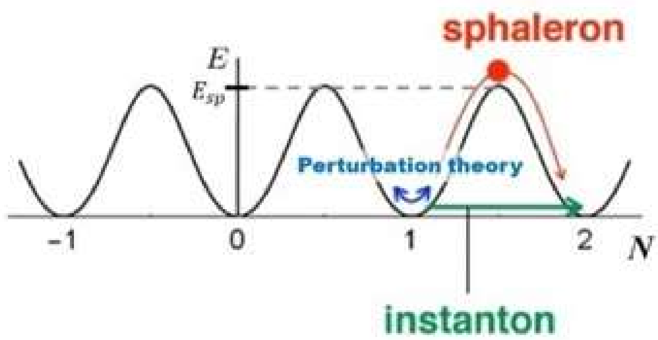
Δm_χ

HL/HE-LHC is sensitive to dark fermions up to the TeV scale.

Details are available from arXiv:1708.01614 and arXiv:1506.04149.

Sphalerons and Instantons at colliders

- The Standard Model has a non trivial vacuum structures with an infinite number of ground states differing by topological charges
  - These solutions *cannot be described* in ordinary perturbation theory



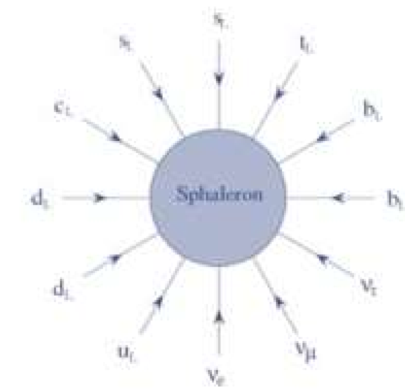
  - In the EWK sector transitions between different vacua "*Sphalerons*" violate Baryon and Lepton number (B+L)

$$q_1 + q_2 \to 7\bar{q} + 3\bar{l} + n_B W(Z) + n_H H$$

  - SU(3) *Instantons* violate chirality

$$g + g \to V + (2n_f - 1)\bar{q}_R + n_f q_R + n_g g$$

- While no reliable estimate of their cross-sections exists sphalerons might be accessible at future high energy colliders and in some optimistic models even at 14 TeV
  - Due to the large number of gauge bosons produced one can define an effective search strategy looking at large lepton multiplicities



- Small size Instantons have been searched for in DIS at HERA, with limits reaching the predicted range of cross-sections
  - Their cross-section is expected to be large at the LHC, where however no search has been performed so far