



# WG3: towards the YR

Workshop on the physics of HL-LHC, and perspectives at HE-LHC  
Plenary meeting - CERN - 20 June 2018

## WG3 conveners

**EX:** Monica D'Onofrio (ATLAS), Keith Ulmer (CMS), Xabier Cid Vidal (LHCb)

**TH:** Patrick Fox, Riccardo Torre

**Riccardo Torre**

CERN, INFN Genova



# Timeline

2017

- June/July 2017: creation of the structure
- Oct/Nov 2017: kick-off meeting at CERN
- 21 Dec 2017: meeting of WG conveners and presentation of preliminary table of contents

2018

- March/April 2018: draft table of contents, start writing
- April 2018: joint meeting with WG2/WG4 at FNAL
- April 2018: Vidyo meeting
- May 2018: Vidyo meeting
- 30 May 2018: deadline for theory contributions

now

- June 2018 (now): Plenary meeting at CERN and presentation of first results and contributions
- September 2018: Experimental contributions expected and full draft available

2019

- October/November 2018: Editing work
- End of November 2018: Chapter ready
- 18 December 2018: Start of European Strategy Update
- May 2019: Open Symposium of the ESU

# Status of the YR

Table of contents of the YR is now (almost) final

27 theory contributions already included (about 100 pages + refs)

Contents			
1	Introduction and overview . . . . .	6	1. Introduction
1.1	Bibliography . . . . .	6	
1.2	New Physics models . . . . .	6	
1.3	Analysis methods and approaches . . . . .	6	
1.4	Treatment of systematic uncertainties . . . . .	6	
2	Supersymmetry . . . . .	7	2. SUSY (4 contributions)
2.1	Generic searches for SUSY . . . . .	7	
2.1.1	Prospects for realistic SUSY models at the HL-/HE-LHC . . . . .	7	
2.1.2	Probing SUSY at HL- and HE-LHC - COMPLETED . . . . .	7	
2.1.3	HE-LHC vs HL-LHC potential for SUSY discovery - COMPLETED . . . . .	8	
2.2	SUSY strong production . . . . .	10	
2.2.1	SUSY strong - improved searches for squark/gluinos . . . . .	10	
2.2.2	Prospects for third generation squark production at the HL-LHC and HE-LHC . . . . .	10	
2.2.3	same-sign dilepton SUSY . . . . .	10	
2.2.4	Implications of a Stop Sector Signal at the HL-LHC - COMPLETED . . . . .	11	
2.3	SUSY EWK production . . . . .	13	
2.3.1	Prospects for $C1N2$ via WZ and Wh in multilepton at the HL-LHC and HE-LHC . . . . .	13	
2.3.2	Prospects for chargino pair production at HL- and HE-LHC . . . . .	13	
2.3.3	Search for chargino-neutral in Wh channel using 1Lbb final states . . . . .	13	
2.3.4	Prospects for direct stau production at the HL-LHC . . . . .	13	
2.3.5	Prospects for direct stau production at the HL-LHC . . . . .	13	
2.3.6	Compressed electroweakinos at HL- and HE-LHC . . . . .	14	
2.3.7	Prospects for radiative natural SUSY at HL- and HE-LHC - COMPLETED . . . . .	14	
2.3.8	Constraining slepton and chargino through compressed top squark search . . . . .	18	
2.3.9	light Higgsino - ISR + 2leptons and VBS + 2leptons . . . . .	18	
3	Dark Matter searches . . . . .	19	3. DM (6 contributions)
3.1	DM + jets . . . . .	19	
3.1.1	Prospects for DM interpretations in jet+MET analysis at HL/HE-LHC . . . . .	19	
3.1.2	Monojet searches for DM . . . . .	19	
3.1.3	Monojet Signatures from Heavy Colored Particles: Future Collider Sensitivities and Theoretical Uncertainties - COMPLETED . . . . .	19	
3.2	DM + $t\bar{t}$ / $b\bar{b}$ . . . . .	22	
3.2.1	Prospects for associated production of dark matter and top quark pairs at the HL-LHC . . . . .	22	
3.2.2	Prospects for associated production of dark matter and bottom quark pairs at the HL-LHC - COMPLETED . . . . .	22	
3.2.3	HL/HE-LHC prospect for determining the CP nature of spin-0 mediators in associated production of dark matter and top pairs - COMPLETED . . . . .	24	
3.3	DM + single top . . . . .	26	
3.3.1	HL/HE-LHC prospect for DM and a single top-quark production in a 2HDM model with a pseudoscalar mediator - COMPLETED . . . . .	26	
3.3.2	Studies of DM production in single-top events . . . . .	27	

# Status of the YR

Table of contents of the YR is now (almost) final

27 theory contributions already included (about 100 pages + refs)

	3.3.3	Studies of DM production in single-top events	28
	3.4	More models expected to be targeted	28
	3.4.1	Prospects for pure WIMP (pure triplet) Dark Matter at HL-LHC	28
	3.4.2	Search of Higgs portal dark matter models at HL/HE-LHC - COMPLETED	28
	3.4.3	Prospects for 4 top signatures at the HL/HE-LHC	30
	3.4.4	Electroweak dark matter at future hadron colliders - COMPLETED	30
4. Long Lived Particles (1 contribution)	4	Long Lived particles	33
	4.1	Prospects for disappearing track analysis at HL-LHC	33
	4.2	Prospects for disappearing track analysis at HE-LHC	33
	4.3	Displaced vertex	33
	4.3.1	Prospects for LLP->DV+MET	33
	4.3.2	Displaced muons	33
	4.3.3	Prospects for LLP->mu+jets at the HL-LHC	33
	4.3.4	Prospects for LLP->dijets at the HL-LHC	33
	4.4	Heavy stable charged particles (dE/dx and TOF)	33
	4.5	Fast timing signatures for long-lived particles	33
	4.6	Various interpretations	33
	4.6.1	Searching for Confining Hidden Valleys at the LHCb and ATLAS/CMS	33
	4.7	FASER	33
	4.7.1	Searching for LLP's with the ForwArd Search ExpeRiment (FASER) - COMPLETED	33
5. Dark sectors (2 contributions)	5	Dark sector: dark photons	36
	5.1	Searching for dark photons via Higgs-boson production at the HL-LHC and HE-LHC - COMPLETED	36
	5.1.1	Introduction	36
	5.1.2	Gluon fusion analysis	37
	5.2	Axion-like particles at the LHC	39
	5.3	Prospects for long-lived dark-photon decays (lepton-jets) at HL-LHC and HE-LHC	39
	5.4	Prospects for dark-photon at the HL-LHCb	39
6. Heavy resonances (9 contributions)	6	Heavy resonances	40
	6.1	Precision searches in dijets at the HL-LHC and HE-LHC - COMPLETED	40
	6.2	Prospects for diboson resonance at HL-LHC and HE-LHC	43
	6.3	Improving sensitivity to heavy resonance decaying 4 leptons at the HL-/HE-LHC	44
	6.4	Production of exotic composite quarks at HL-LHC and HE-LHC	44
	6.5	Wprime studies at HL-LHC	44
	6.6	Dissecting heavy di-photon resonances - COMPLETED	45
	6.6.1	Acknowledgements	47
	6.7	Heavy singlet scalars at HL and HE LHC - COMPLETED	47
	6.7.1	Motivation	48
	6.7.2	Current exclusions and future reaches	48
	6.7.3	Interpretation in the NMSSM and in Twin and Composite Higgs	50
	6.8	Z' bosons in supersymmetric and leptophobic scenarios	51

# Status of the YR

Table of contents of the YR is now (almost) final

27 theory contributions already included (about 100 pages + refs)

6.8.1	Introduction . . . . .	52
6.8.2	$Z'$ bosons in the UMSSM . . . . .	52
6.8.3	Results at HL-LHC . . . . .	53
6.8.4	Conclusions . . . . .	55
6.9	Colour octet scalar into gluons and photons - COMPLETED . . . . .	55
6.9.1	Model and effective Lagrangian description . . . . .	55
6.9.2	Pair Production . . . . .	56
6.9.3	Single production . . . . .	57
6.9.4	Conclusion . . . . .	57
6.10	Precision predictions for new di-lepton and $t\bar{t}$ resonances - COMPLETED . . . . .	58
6.10.1	Introduction . . . . .	58
6.10.2	Results for $t\bar{t}$ resonances with PBZp . . . . .	59
6.10.3	Results for di-lepton resonances with Resummino . . . . .	59
6.11	HL- and HE-LHC Sencitivity to 2HDMs with $U(1)_X$ Gauge Symmetries - COMPLETED . . . . .	59
6.11.1	Introduction . . . . .	61
6.11.2	LHC Bounds . . . . .	62
6.11.3	HL-LHC and HE-LHC Sensitivity . . . . .	62
6.11.4	Conclusions . . . . .	62
6.12	The HL-LHC and HE-LHC Scope in Testing compositeness of 2HDMs . . . . .	63
6.12.1	Introduction . . . . .	64
6.12.2	Numerical results . . . . .	64
6.13	Axion-like particles at the HL-LHC and the HE-LHC . . . . .	67
6.13.1	Setup and Motivation . . . . .	67
6.13.2	Present bounds . . . . .	67
6.13.3	Prospects for the HL-LHC and the HE-LHC . . . . .	69
6.13.4	Conclusions . . . . .	70
6.14	Search for light pseudo-scalar with taus . . . . .	70
7	VLQ . . . . .	73
7.1	Radiative Decays of Top-partners at the LHC . . . . .	73
7.2	Sensitivity to heavy Higgs bosons in models with vectorlike quarks and leptons at the HL and HE LHC - COMPLETED . . . . .	73
7.2.1	Introduction . . . . .	73
7.2.2	Model Framework . . . . .	73
7.2.3	Heavy Higgs cascade decays through vectorlike leptons . . . . .	75
7.2.4	Heavy Higgs cascade decays through vectorlike quarks . . . . .	77
7.2.5	Conclusions . . . . .	79
7.3	VLQs at HL- and HE-LHC: discovery and characterization - COMPLETED . . . . .	79
7.3.1	Motivations . . . . .	79
7.3.2	Top quark polarization . . . . .	80
7.3.3	Discovery and discrimination at HL-LHC . . . . .	80
7.3.4	Discovery and discrimination at HE-LHC . . . . .	81

7. Vector-like quarks (maybe fermions?)  
(2 contributions)

# Status of the YR

Table of contents of the YR is now (almost) final

27 theory contributions already included (about 100 pages + refs)

## 8. Flavor related studies (3 contributions)

## 9. Conclusion and outlook

7.3.5	Conclusion	82
7.4	Vector-like quark discovery reach	82
8	Flavor-related studies [to be discussed]	83
8.1	Neutrino mass models at the High Luminosity and High Energy LHC - COMPLETED	83
8.1.1	Introduction	83
8.1.2	The Type I Seesaw and Variants Discovery Potential at the HL- and HE-LHC	83
8.1.3	Type II Scalars Discovery Potential at the HL- and HE-LHC	88
8.1.4	Type III Leptons Discovery Potential at HL- and HE-LHC	89
8.2	Z'/lepto-quark from B decays - COMPLETED	91
8.2.1	Acknowledgements	93
8.3	Like-sign dileptons with mirror type composite neutrinos at the HL-LHC	93
8.3.1	Introduction	94
8.3.2	Model	94
8.3.3	Conclusions	96
8.3.4	Acknowledgments	97
9	Conclusions and outlook	98

A big thanks to all theory contributors for having matched the deadlines and to all experimental contributors for all the ongoing work behind the scenes

# Next steps

- Experimental contributions expected by September 2018
- We need all contributions to be in the document by the end of September to allow for the time necessary for the editing work
- Editing will require some time: final format will be a collection of contributions with a specific introduction and an executive summary for each of the sections and for the whole chapter
- Once all contributions are in the draft we need to agree on and implement a strategy to deal with overlaps with WG2 and WG4 (more in next slides)
- A final form of the document should be ready by the end of November, on time for the deadline set by the starting of the European Strategy Update

# Overlaps with WG2

- Plan is to include in Higgs chapter all Higgs related studies relevant for EWSB
- If needed in both chapters some studies may be duplicated
- Present situation not yet consistent: extended Higgs sector studies are now included in BSM chapter for Composite models and in Higgs chapter for SUSY models
- All these inconsistencies will be solved once all contributions will be in place, also taking into account length constraints
- Whenever contributions will be repeated consistency checks will be done
- Proper cross-referencing will be implemented

**Message for WG2 Conveners: please check our overleaf and let us know if you find any contribution relevant for your chapter or have contributions similar to ours.**



# Overlaps with WG4

- Plan is to include in BSM chapter all high- $p_T$  searches related to flavor
- If needed studies may be duplicated
- There are neutrino related contributions that by now are included in BSM section but need to be discussed with WG4
- Again all duplication will be checked for consistency
- And proper cross-referencing will be implemented in the final editing stage

Message for WG4 Conveners: please check our overleaf and let us know if you find any contribution relevant for your chapter or have contributions similar to ours.

# Overleaf experience

The screenshot displays the Overleaf web interface for a LaTeX document. The top navigation bar includes 'Overleaf', 'PROJECT', 'HISTORY & REVISIONS', 'SHARE', 'PDF', 'JOURNALS & SERVICES', and user options like 'SIGN UP' and 'SIGN IN'. Below the navigation bar, there are tabs for 'Files...', 'Word Count', and 'Source' (selected). The 'Source' tab shows the LaTeX source code for a document, with line numbers 84 to 138. The code includes commands for document structure, title, authors, and sections. The preview window on the right shows the rendered output, including the title 'HL/HE-LHC Physics WG3 Report', authors 'XX<sup>1</sup>, YY<sup>2</sup>', and an abstract 'This is the abstract'.

```
84 \begin{document}
85 \newcommand{\main}{.}
86 \def\biblio{}
87 \def\tg{\tilde g}
88 \def\tw{\widetilde{\chi}^\pm}
89 \def\tz{\widetilde{\chi}^0}
90 \def\tst{\tilde t}
91 \def\tst{\tilde t}
92 \title{HL/HE-LHC Physics WG3 Report\[\[5mm]
93 BSM}
94 \input{authors}
95
96 \maketitle
97
98
99 \begin{abstract}
100 This is the abstract
101 \end{abstract}
102
103 % -- Set the level of the TOC: 2 means including subsection, 1 means
104 % including section
105 \setcounter{tocdepth}{3}
106 \tableofcontents
107 \newpage
108
109 % -- List of sections
110 \subfile{\main/section1IntroductionAndOverview/section}
111 \newpage
112 \subfile{\main/section2SUSY/section}
113 \newpage
114 \subfile{\main/section3DarkMatterSearches/section}
115 \newpage
116 \subfile{\main/section4LongLivedParticles/section}
117 \newpage
118 \subfile{\main/section5DarkSectorDarkPhotons/section}
119 \newpage
120 \subfile{\main/section6HeavyResonances/section}
121 \newpage
122 \subfile{\main/section7VLQ/section}
123 \newpage
124 \subfile{\main/section8FlavorRelatedStudies/section}
125 \newpage
126 \subfile{\main/conclusions/section}
127 \newpage
128
129 % -- Add bibliography to table of contents
130 %\addcontentsline{toc}{chapter}{References}
131
132 % dummy reference to avoid that bibtex fails
133 % -- Add volume bibliography and part specific bibliographies
134 \bibliographystyle{report}
135 \bibliography{\bibfiles}
136
137 \end{document}
138
```

# Overleaf experience

- The report is being written using the Overleaf platform
- WG3 document can be found at:  
<https://www.overleaf.com/14722141bbfgfvqrrvbp#/56185127/>
- We used it in a very “interactive mode” with contributors directly filling in their contributions (we prepared all sections)
- Basic instructions are published on our Twiki page
- We needed some interventions to fix small problems but everything is working pretty smoothly (references will be fixed at the end)
- Final editing will most likely need to be done cloning the document with git and editing locally

**Message for contributors: if you have any problems/doubts on the overleaf please write us an email**

# Status of the experimental analyses

- Experimental contributions are being followed by the conveners for the three relevant experiments
- Experimental Status Reports at this meeting confirmed that the September deadline will be matched for the expected experimental contributions:
  - SUSY, DM, Resonances, LLP, BSM/Higgs, BSM/Flavor
- Order 20 results per experiment expected from ATLAS and CMS and about 4/5 from LHCb
- Once results will be public in September, we will immediately proceed to their inclusion in the report (with all implied consistency checks, etc.)

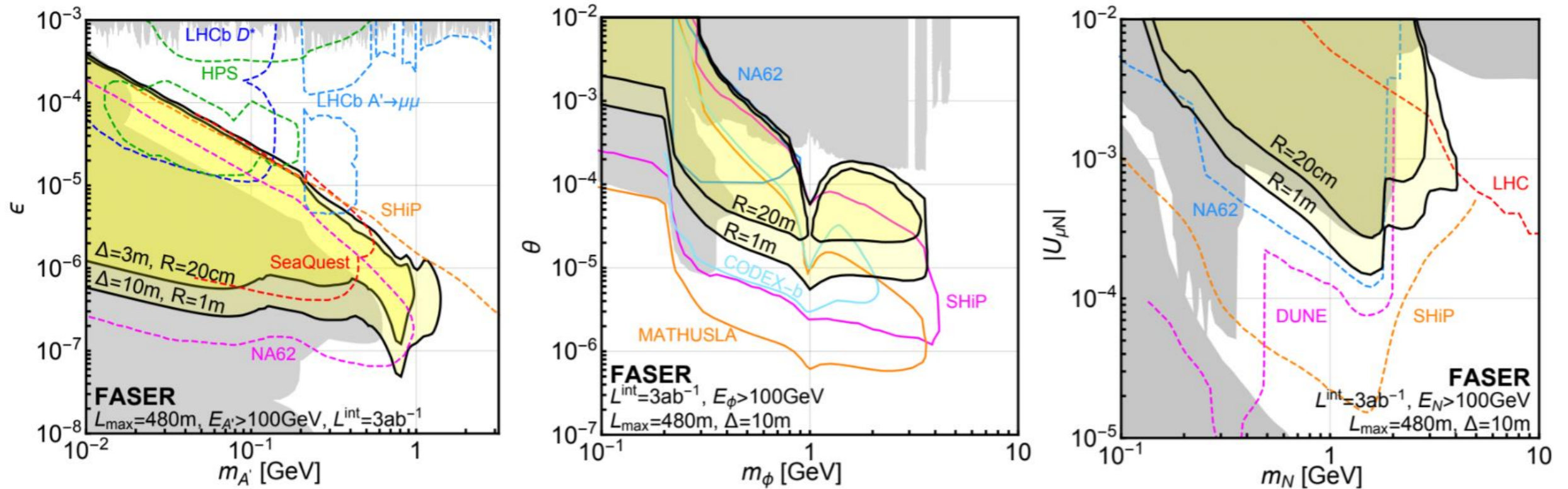
# Mini groups

- Mini-groups formed including ATLAS and CMS experimentalists to discuss common topics, e.g.
  - SUSY: EWKinos, higgsinos, stau pair productions
  - DM+heavy flavor
  - $T\bar{t}$  and other resonances (also @ 27TeV)
- Ensure the usage of same signal cross sections, common treatment of uncertainties, etc.
- During this meeting we also established the need for mini-groups for
  - Dark photons (ensure we understand implications of different scenarios considered) involving also LHCb
  - Higgs decays in LLP relevant for LHCb (with interactions also with WG2)
  - BSM Higgs, in particular  $H \rightarrow \tau\tau$  (with interactions also with WG2)
  - Leptoquarks (with interactions also with theorists)

# Discussion of ‘special’ section 1

- Introduction and overview should include a brief outline of the NP models considered but also a discussion of
  - Analysis methods and approaches
    - Brief but useful to put things in context: projections vs full analyses, usage and details of Delphes cards, assumptions made for PU
  - Treatment of systematic uncertainties
    - Discussion among experiments (especially CMS and ATLAS) to ensure same assumptions are taken (there was a clear plenary overview on the issue)
    - Relevant also for theory studies
- Final outline will be defined once all material is included
- Also, include possible improvements and new techniques
  - E.g. Proposed contribution: “Fitting techniques using Gaussian Process for resonance searches”

# New detectors and physics beyond colliders



- We have in the report results like this one
- The YR will not contain extensive discussion of new detectors
- Only results relevant for HL/HE, also in the context of possible detector upgrades (LHCb + CODEX-b) will be included
- Similar results in other chapters, we need to coordinate

# Messages to contributors

- If you want/can improve your contribution that is already included in the report there is still time (detector simulation, systematics, 27TeV predictions, etc.)
- If you see studies that may be related to yours, please get in contact with the other group and make sure to cross-check
- When replying to emails of conveners or contacting them, please always include the conveners mailing list in cc. If possible, do not just contact a single convener, since this makes communication among us more complicated.



THANK YOU!