Status and plans of the MSSM subgroup

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The 20th workshop of the LHC Higgs working group

lhc-higgs-mssm-group@cern.ch

Outline

Subgroup mission

- To be a common ground for discussion between experimentalists and theorists
- To clarify theoretical aspects important for experimental studies
- To provide benchmark scenarios to be used by experimental collaboration
- To discuss possible future developments on probing the MSSM Higgs sector at the LHC

Task list

- Scenarios/ROOT files
- Experimental/phenomenological aspects
- A/H Higgs transverse momentum distribution
- Working group notes

Lines of activity

Task	Status	Timescale ↑
Keep an eye on potentially missing signatures	In progress	Continuous
WG support to the release of experimental likelihoods	In progress	Continuous
Prioritize channels according to importance for end of LHC run2/3 or HL-LHC	In progress	Continuous
Support the experimental effort, mainteinance of the ROOT files	In progress	Continuous
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Public note on the ROOT files

LHCHWG-2021-001

Benchmark Scenarios for MSSM
Higgs-Boson Searches at the LHC

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ROOT file note

- The public note on the ROOT files was accepted in its final version in January 2022 -- `https://cds.cern.ch/record/2791954/`
- Release of the ROOT files on Zenodo has started (title of the record ``LHCHWG MSSM ROOT files'')
- Versioning of the Zenodo record is used -- please cite the exact version that you use in your study
- Last update in September 2023 $\rightarrow$ fixed 14 TeV cross sections for the hMSSM

Structure of the ROOT files

File Content

- Six scenarios from [EB et al. EPJC 79 (2019) 7, 617] which covers different phenomenologies
- Three $\mu < 0$ scenarios from [Bahl et al. EPJC 80 (2020) 10, 916]
- Two low **tan** β scenarios from [Bahl et al. EPJC 79 (2019) 3, 279]
- hMSSM scenario from [Djouadi & Quevillon JHEP 10 (2013) 028, Maiani et al. PLB 724 (2013) 274-277, Djouadi et al. EPJC 73 (2013) 2650, Djouadi et al. JHEP 06 (2015) 168]
- Cross sections evaluated at three different energies: 8, 13, 14 TeV $\rightarrow$ 13.6 TeV work-in-progress

Branching ratios

Neutral Higgs
<ϕ> = h,H,A

br_<ϕ>_bb
br_<ϕ>_cc
br_<ϕ>_gamgam
br_<ϕ>_gluglu
br_<ϕ>_mumu
br_<ϕ>_SUSY
br_<ϕ>_tautau
br_<ϕ>_tt
br_<ϕ>_WW
br_<ϕ>_Zgam
br_<ϕ>_ZZ
br_H_AA
br_H_hh
br_H_WHp
br_A_Zh

Charged Higgs
<ϕ> = h,H,A

$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3

br_Hp_cb
br_Hp_cd
br_Hp_cs
br_Hp_munu
br_Hp_taunu
br_Hp_tb
br_Hp_ts
br_Hp_td
br_Hp_ub
br_Hp_<ϕ>W
br_Hp_SUSY
br_t_Hpb

Neutral Higgs
$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3

br_<ϕ>_bb
br_<ϕ>_cc
br_<ϕ>_gamgam
br_<ϕ>_gluglu
br_<ϕ>_mumu
br_<ϕ>_SUSY
br_<ϕ>_tautau
br_<ϕ>_tt
br_<ϕ>_WW
br_<ϕ>_Zgam
br_<ϕ>_ZZ
br_H2_H1H1
br_H3_H1H1
br_H2_WHp
br_H3_WHp
br_H2_ZH1
br_H3_ZH1

SM Higgs

br_HSM_bb
br_HSM_cc
br_HSM_gamgam
br_HSM_gluglu
br_HSM_mumu
br_HSM_tautau
br_HSM_tt
br_HSM_WW
br_HSM_Zgam
br_HSM_ZZ

Cross sections

Neutral Higgs
<ϕ> = h,H,A

$\mathcal{CP}$ violating scenario
<ϕ>= H1,H2,H3

xs_bb_<ϕ>
xs_bb_<ϕ>_down
xs_bb_<ϕ>_up
xs_gg_<ϕ>
xs_gg_<ϕ>_pdfasdown
xs_gg_<ϕ>_pdfasup
xs_gg_<ϕ>_scaledown
xs_gg_<ϕ>_scalesup
xs_vbf_<ϕ>
xs_hs_Z<ϕ>
xs_hs_W<ϕ>
xs_tth_<ϕ>

SM Higgs

xs_bb_HSM
xs_gg_HSM
xs_vbf_HSM
xs_hs_ZHSM
xs_hs_WHSM
xs_tth_HSM

Charged Higgs

xs_pp_Hp
xs_pp_down
xs_pp_up

Other quantities

Masses
<ϕ> = h,H,A,Hp

$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3,Hp

m_<ϕ>

Couplings
<ϕ> = h,H,A
lam3_HHH only for M_H^{125}

rescale_gt_<ϕ>
rescale_gb_<ϕ>
rescale_deltab
rescale_im_deltab
lam3_hhh (lam3_HHH)
lam3_HSM
lam3_HSM_tree
alpha

Couplings
$\mathcal{CP}$-violating scenario
<i>,<j>=1,2,3

rescale_deltab
rescale_im_deltab
lam3_H1H1H1
lam3_HSM
lam3_HSM_tree
Hmix_<i><j>
alpha_tree

Total widths
<ϕ> = h,H,A,Hp

$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3,Hp

width_<ϕ>
width_HSM
width_t

Interference factors
$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3

int_bb_tautau_<ϕ>
int_gg_tautau_<ϕ>

Theory setup

Overview

- Branching ratios are obtained by combining state-of-the-art predictions from **FeynHiggs** and **HDECAY**, aside from the EFT and CPV scenarios, for which only **FeynHiggs** is used, and the **hMSSM** for which only **HDECAY** is used
- Gluon fusion production cross-sections are computed using the code **SusHi**
- Bottom-associated production cross-sections are computed by rescaling the matched predictions provided by the bbH working group
- Cross sections for the other production processes (VBF, WH, ZH and ttH) are computed by rescaling the grids provided the LHCHWG
- Charged Higgs cross sections are interpolated from LHCHWG grids as well

$$\Gamma_{\phi} = \Gamma^{\mathrm{FH}}_{\phi\to\tau^+\tau^-} + \Gamma^{\mathrm{FH}}_{\phi\to\mu^+\mu^-} + \Gamma^{\mathrm{FH/P4f}}_{\phi\to \mathrm{W}^{(*)}\mathrm{W}^{(*)}} + \Gamma^{\mathrm{FH/P4f}}_{\phi\to \mathrm{Z}^{(*)}\mathrm{Z}^{(*)}} + \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{b\bar{b}}} + \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{t\bar{t}}} + \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{c\bar{c}}}$$
$$+ \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{gg}} + \Gamma^{\mathrm{HD}}_{\phi\to \gamma\gamma} + \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{Z}\gamma} + \Gamma^{\mathrm{FH}}_{\phi\to \mathrm{Higgs}} + \Gamma^{\mathrm{FH}}_{\phi\to \mathrm{SUSY}}$$

$$\Gamma_{\mathrm{H}^\pm} = \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to\tau\nu_\tau} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to\mu\nu_\mu} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to \mathrm{hW}} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to \mathrm{HW}} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to \mathrm{AW}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{tb}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{ts}}$$
$$+ \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{td}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{cb}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{cs}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{cd}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{ub}} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to \mathrm{SUSY}}$$

Cross sections at 13.6 TeV/PDF4LHC21 -- open issues

- For gluon fusion no problem, since we use the code **SusHi** that we run autonomously
- New cross sections are/should be run with **PDF4LHC21** -- consistency would require to rerun also the cross sections at 8 and 13 TeV with the same PDFs

- For $bb\phi$ we rescale the cross sections provided by *bbH* subgroup by the author of [1508.03288, 1605.01733].
- We are currently in contact with F. Tackmann (DESY) and M. Bonvini (INFN Rome 1) to provide grids at 13.6 TeV

bbH

- Joined forces with the *Extended Higgs Sector subgroup* → See my talk on Wednesday

Charged Higgs

- For $tt\phi$ we rescale the cross sections provided by *ttH* subgroup, as they are included in **FeynHiggs**
- In contact with M. Zaro (ttH convener)

ttH

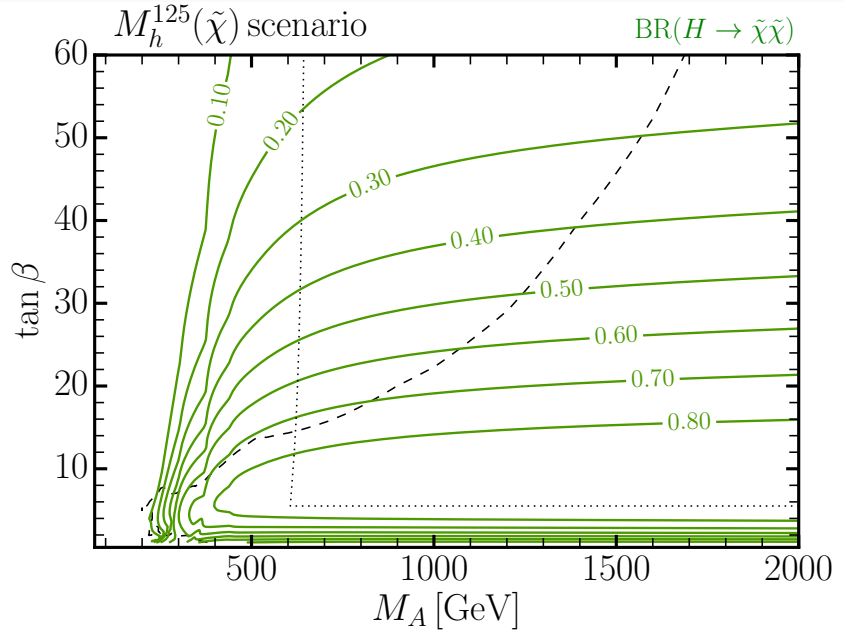
- For $v\phi$ we rescale the cross sections provided by *VH* subgroup, as they are included in **FeynHiggs**
- In contact with G. Ferrera (VH convener)

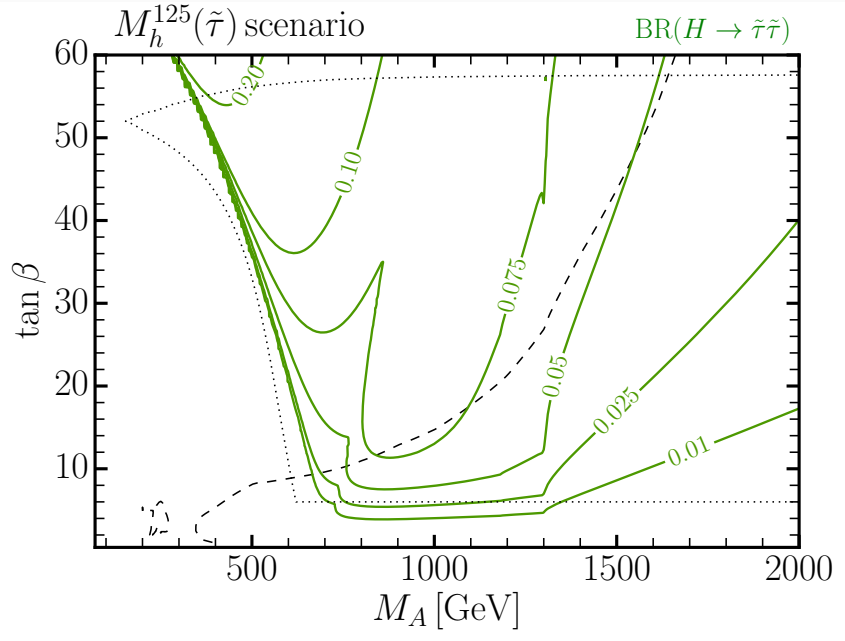
VH

A/H to SUSY states

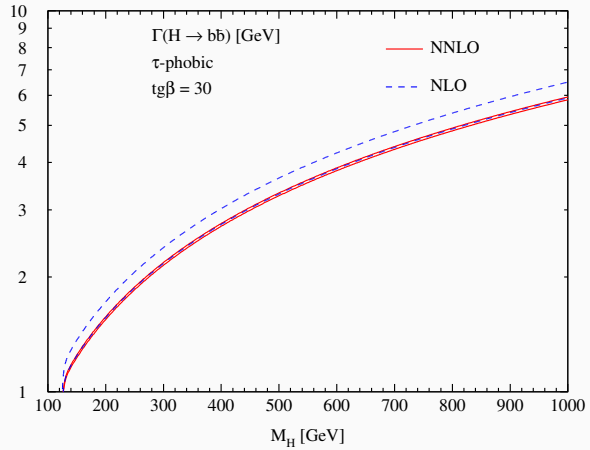
- Some of the scenarios are characterized by large branching ratios to SUSY states.
- A separate set of ROOT files is planned to be released with the different channels saved separately (in the current ROOT files all the BRs to SUSY are summed in a single histogram).
- Discussions in progress to see whether there is interest from the experimental community in probing these decay channels. Feedback welcome.

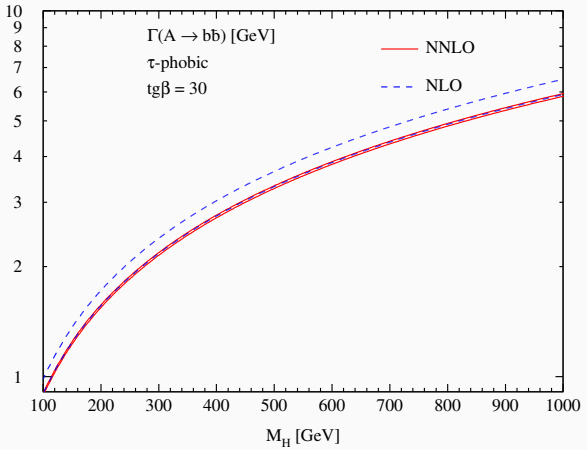
New ROOT files

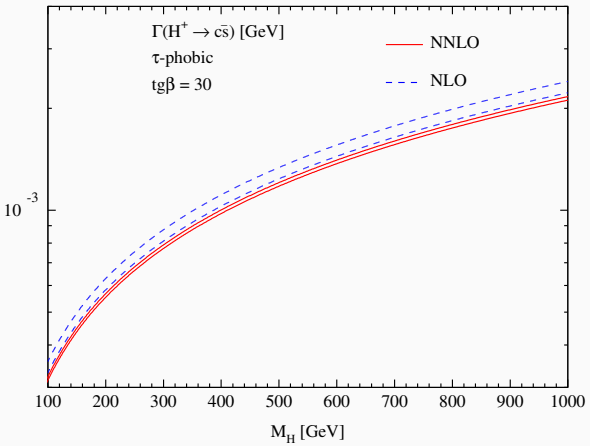




New developments on the theory side: neutral Higgs



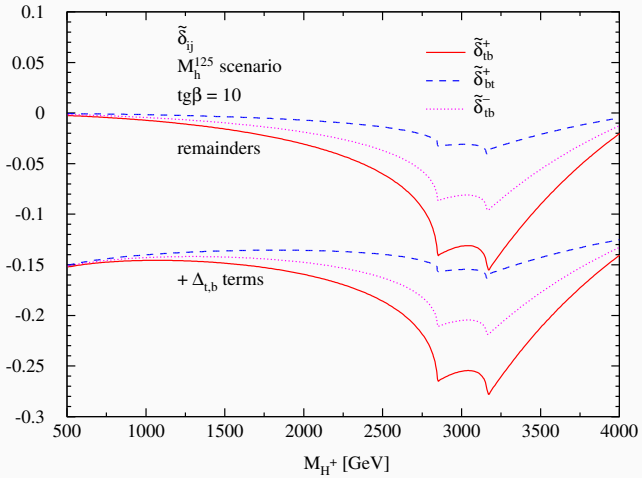


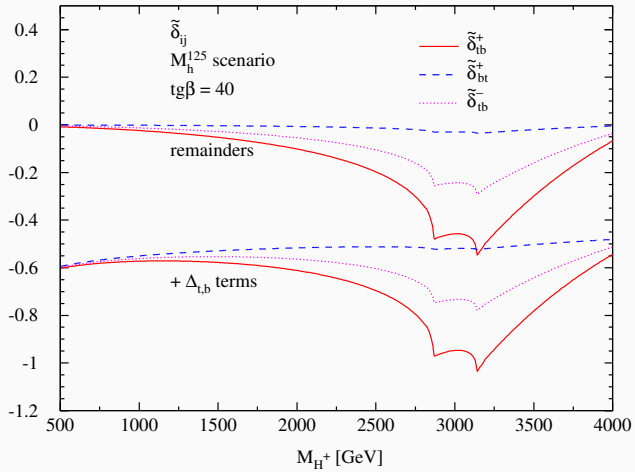


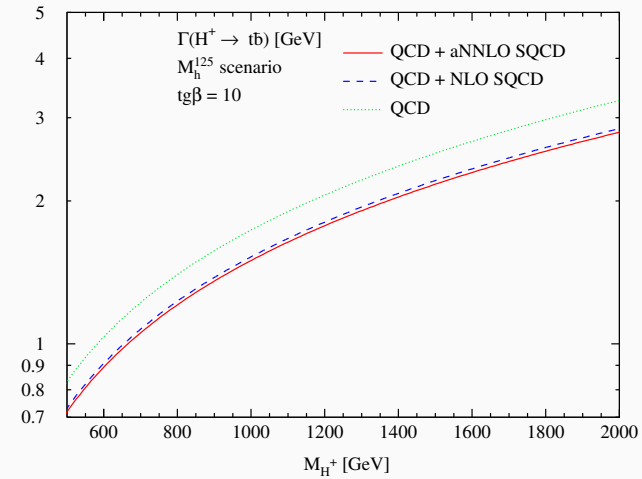
Ghezzi, Glaus, Müller, Schmidt, S.

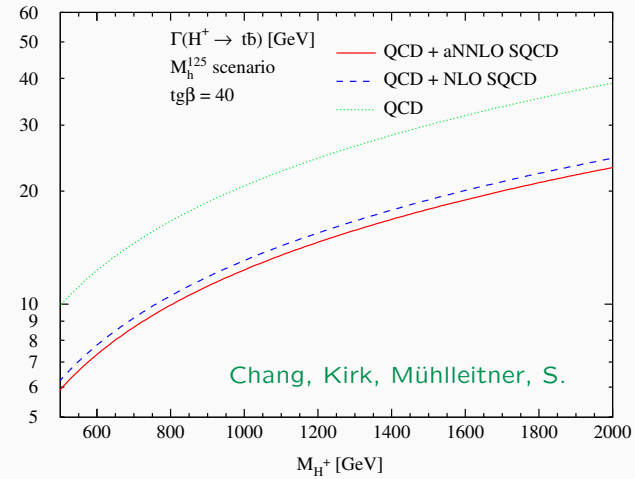
- Extension of Δ_b resummation to A_b terms and electroweak gauge couplings; calculation also extended for strange Yukawa couplings
- See the talk of M. Spira in the WG3 BSM Higgs parallel on Wednesday

New developments on the theory side: charged Higgs





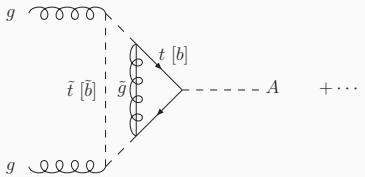


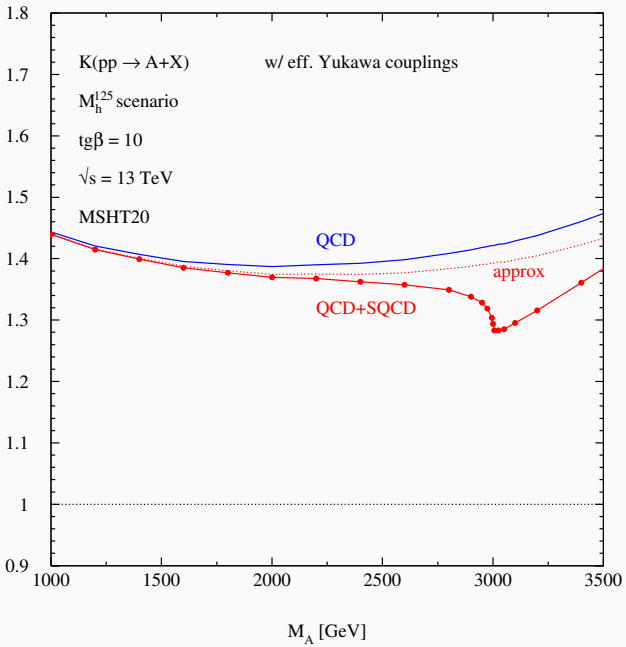


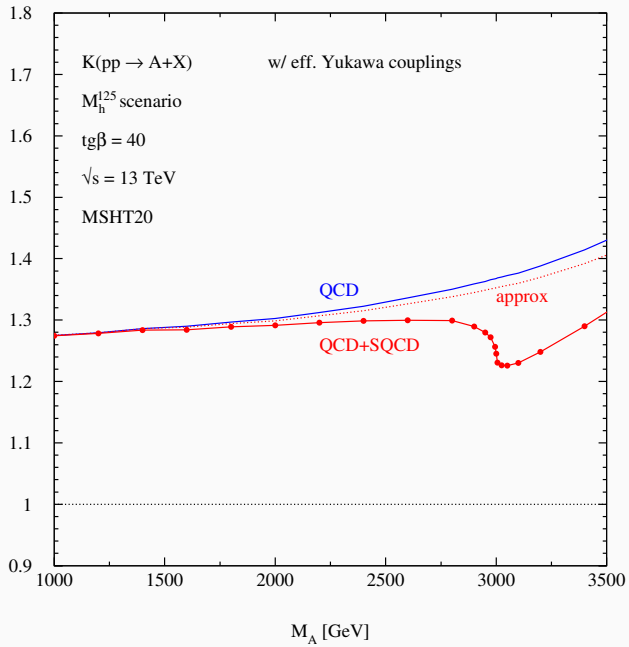
- Extension of Δ_t resummation
- See the talk of M. Spira in the WG3 BSM Higgs parallel on Wednesday

New developments on the theory side: ggA

$$\sigma(gg \to A) = \sigma_{LO}(\tilde{g}_t^A, \tilde{g}_b^A)\left[1 + \delta_{QCD} + \delta_{SQCD}\right]$$







Bagnaschi, Fritz, Liebler, Mühlleitner, Nguyen, S.

- $gg \to A$ complete SUSY-QCD calculation
- See the talk of M. Spira in the WG3 BSM Higgs parallel on Wednesday

Summary and outlook

- Ongoing work on the scenarios
- ROOT files upgrade to support LHC 13.6 TeV analyses
- Possible interactions with other working groups

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