HH multilepton channel combination

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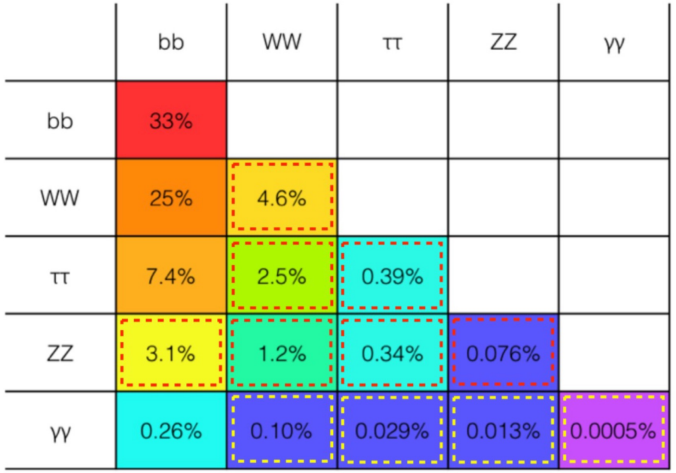
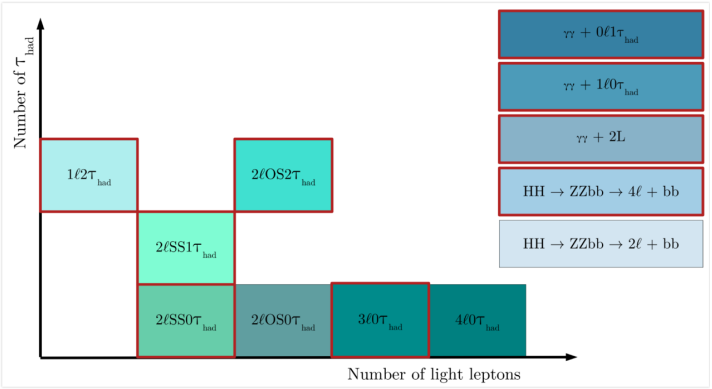
Introduction

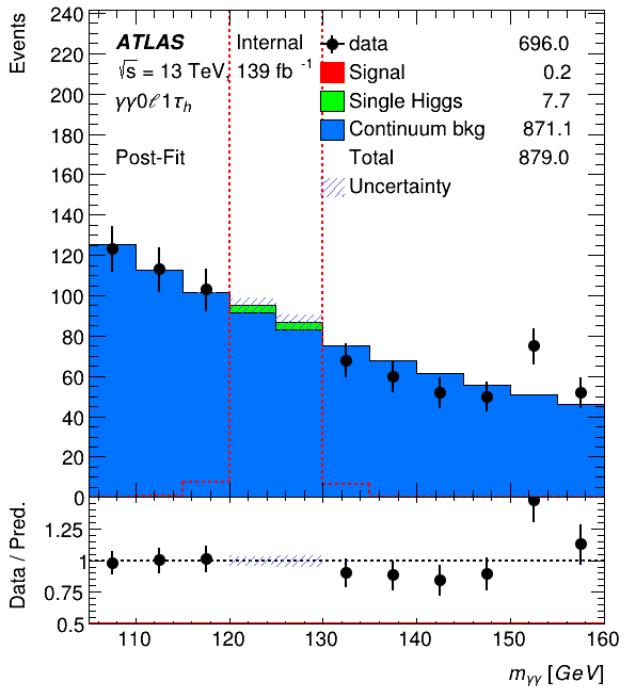
- **Di Higgs non-resonant search in multi-lepton channels**
  - Focus on small Br HH decay channels: $VVVV$, $VV\gamma\gamma, VV\tau\tau, \tau\tau\tau\tau, bbZZ$ ~ 12%.
  - Separated to 9 orthogonal channels:
    - 2 same-sign light leptons w/wo τ_{had}: $2lSS0\tau_h$, $2lSS + 1\tau_h$
    - Three light leptons: $3l$
    - One/Two light leptons + 2 τ_h: $1/2l + 2\tau$
    - 4 light leptons and 2 b-jets: $b\bar{b}4l$.
    - 2 photons with light leptons and τ_h ($\gamma\gamma + ML$): $\gamma\gamma + 1l0\tau, \gamma\gamma + 0l1\tau, \gamma\gamma + 2l$.
  - Analysis details in Yulei's unblinding approval talk.
  - Today's talk: combination between 9 channels.

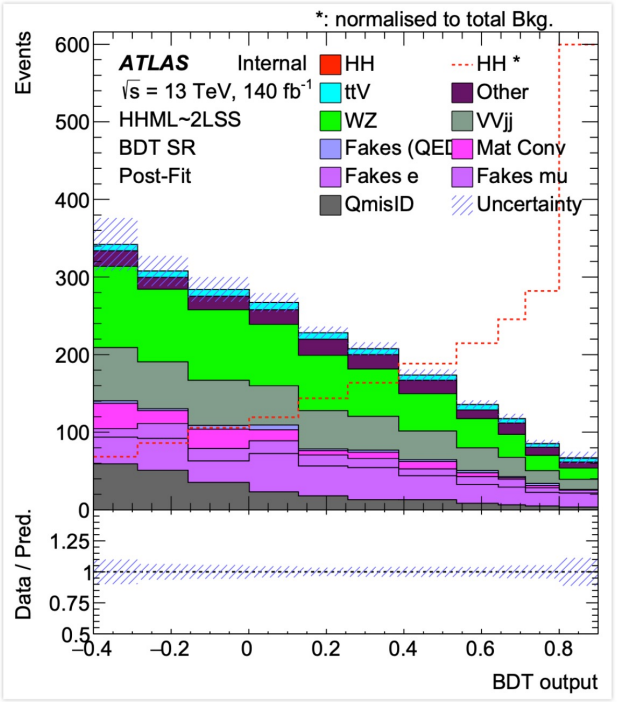




Overview of workspace

- **Binned fit in the signal region:**
  - Observables chosen by channels: mostly BDT(BDTG) score; $m_{\gamma\gamma}$ in $\gamma\gamma + ML$ channels.
  - Background: MC, data-driven (for fake), normalization factors.
  - Workspace building: TRexFitter.





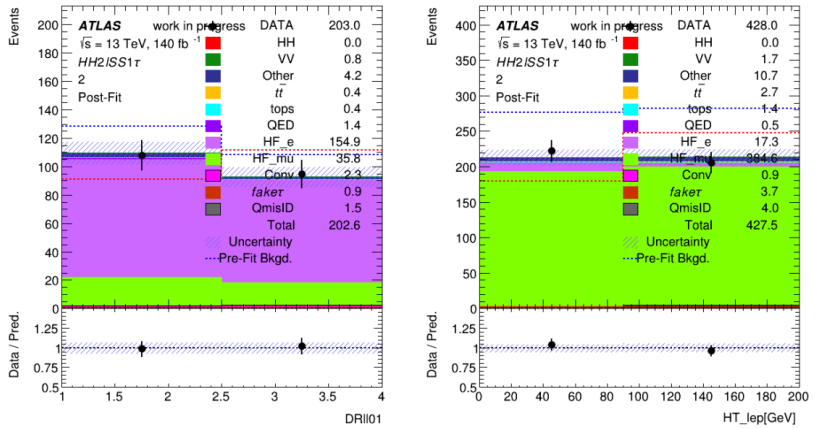
Normalization factors

- **13 normalization factors used in the analysis**
  - 7 in 2lss, 3 in 3l, 3 in $2lss + 1\tau$ and 5 in $b\bar{b}4l$.
  - 3 are common between channels: fake factor for external converted & heavy flavor decayed e/μ.
  - Treatment of NFs can influence the final fit results.

NormFactor	2ℓSS	3ℓ	2ℓSS+$1\tau_{\text{had}}$	$b\bar{b}4\ell$	combined
NF_IntConv_e	2.01 ± 0.28	-	-	-	-
NF_ExtConv_e	0.80 ± 0.36	0.66 ± 0.13	-	-	0.79 ± 0.16
μ_{HF-e}	1.18 ± 0.27	1.50 ± 0.50	$1.27 \pm 1.14(0.87)$	-	1.34 ± 0.17
$\mu_{HF-\mu}$	1.57 ± 0.17	1.51 ± 0.23	$0.59 \pm 1.03(0.75)$	-	1.56 ± 0.12
μ_{WZ}	0.82 ± 0.06	-	-	-	-
μ_{VVjj}	1.62 ± 0.13	-	-	-	-
μ_{ttW} (fake)	1.24 ± 0.36	-	-	-	-
NF_VV	-	-	$0.98 \pm 0.42(0.94)$	-	-
$\mu_{t\bar{t}}$	-	-	-	1.50 ± 0.28	-
$mu_{t\bar{t}Z}$	-	-	-	1.27 ± 0.22	-
μ_{VV}	-	-	-	1.12 ± 0.46	-
μ_{Higgs}	-	-	-	1.09 ± 0.42	-
$\mu_{Z+\text{jets}}$	-	-	-	1.01 ± 0.36	-

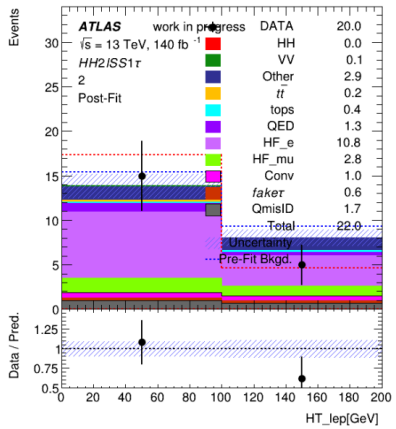
Normalization factors

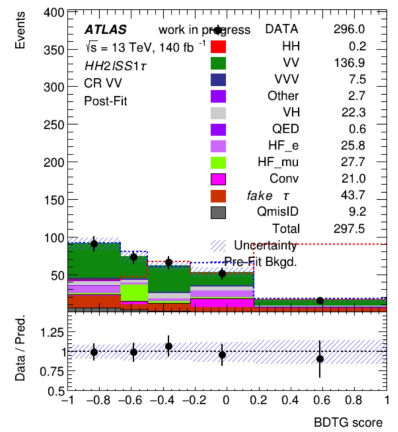
- **Check the performance in $2lss + 1\tau$ channel:**
  - NFs are fitted from $2lss + 1\tau$ CR with stat. only, and fixed in the fit in SR.

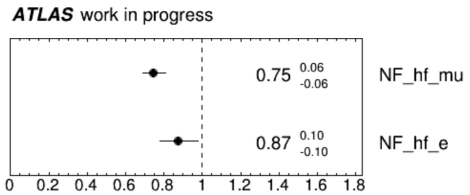


(a)

(b)







	-2σ	-1σ	Expected	$+1\sigma$	$+2\sigma$	Observed
$\sigma_{HH}/\sigma_{HH}^{SM}$ Stats.	27.2	36.5	50.6	70.5	108.6	blinded
$\sigma_{HH}/\sigma_{HH}^{SM}$ Sys.	28.9	38.7	53.8	78.8	115.4	blinded

Normalization factors

- **Considering μ_{HF-e} and $\mu_{HF-\mu}$ are also used in $2lss$ and $3l$:**
  - Float them in SR fitting:

NormFactor	2ℓSS	3ℓ	2ℓSS+1τ_{had}	$b\bar{b}4\ell$	combined
NF_IntConv_e	2.01 ± 0.28	-	-	-	-
NF_ExtConv_e	0.80 ± 0.36	0.66 ± 0.13	-	-	0.79 ± 0.16
μ_{HF-e}	1.18 ± 0.27	1.50 ± 0.50	$1.27 \pm 1.14(0.87)$	-	1.34 ± 0.17
$\mu_{HF-\mu}$	1.57 ± 0.17	1.51 ± 0.23	$0.59 \pm 1.03(0.75)$	-	1.56 ± 0.12
μ_{WZ}	0.82 ± 0.06	-	-	-	-
μ_{VVjj}	1.62 ± 0.13	-	-	-	-
μ_{ttW} (fake)	1.24 ± 0.36	-	-	-	-
NF_VV	-	-	$0.98 \pm 0.42(0.94)$	-	-
$\mu_{t\bar{t}}$	-	-	-	1.50 ± 0.28	-
$mu_{t\bar{t}Z}$	-	-	-	1.27 ± 0.22	-
μ_{VV}	-	-	-	1.12 ± 0.46	-
μ_{Higgs}	-	-	-	1.09 ± 0.42	-
$\mu_{Z+\text{jets}}$	-	-	-	1.01 ± 0.36	-

  - Impact on the fitted upper limit:

Channel	fix NFs (individual value)	fix NFs (combined value)	float NFs
2ℓSS	$30.91^{44.00}_{22.27}$		$34.81^{49.61}_{25.08}$
2ℓSS+1τ_{had}	$53.8^{78.8}_{38.7}$	$53.36^{78.64}_{38.45}$	$63.52^{93.27}_{45.77}$

Treatment of NFs influence the upper limit.
For conservative all NFs are floated in the combination.
Any suggestions?

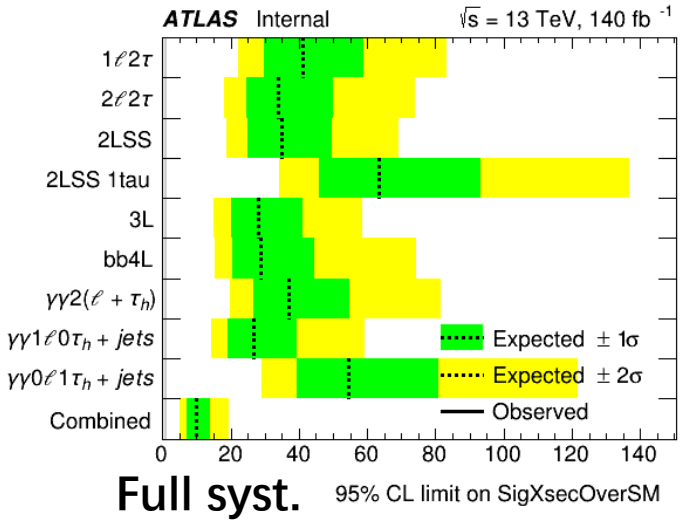
Systematics correlation scheme

- **Use TRexFitter, so 100% correlation (same NP) or 0%.**

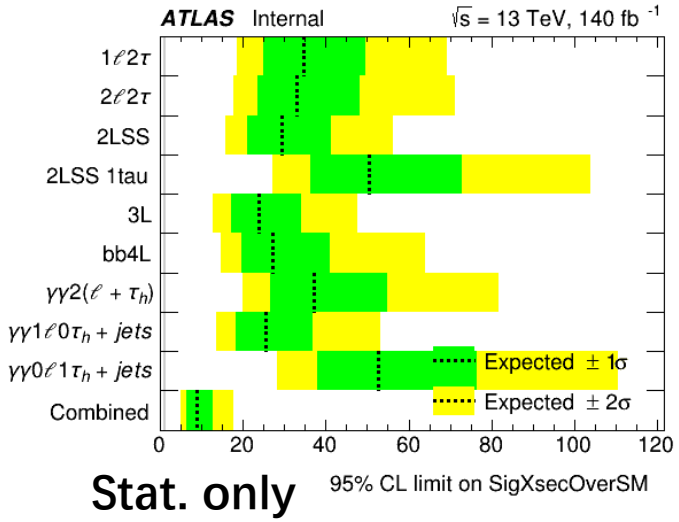
NPs	2lss	2lss1tau	3l	1l2tau	2l2tau	bb4l	yyml	Treatment
Lumi.+PRW	LUMI_Run2 PU_PRW_DATASF							**correlated**
EGamma	RES_ALL, SCALE_ALL, SCALE_AF2					RES_ALL SCALE_AF2	RES_ALL SCALE_ALL SCALE_AF2	**correlated**
Photon	-	-	-	-	-	-	EFF_ID EFF_ISO EFF_TRIGGER	**-**
Lepton	Common ATLAS NPs							**correlated**
Tau								
Jet+MET								
Flavor								
Theory	HH signal backgrounds					ggHH signal VBF HH signal backgrounds	HH signal Single Higgs	**Mostly correlated**
Others	QMisID			Fake tau			Background modeling	**uncorrelated**

Results

- **Upper limit fit**
  - 95% CL expected upper limit on μ_{HH}: 9.74.
  - MC statistics limitation shows impact in all channels except $\gamma\gamma + ML$.



Full syst.

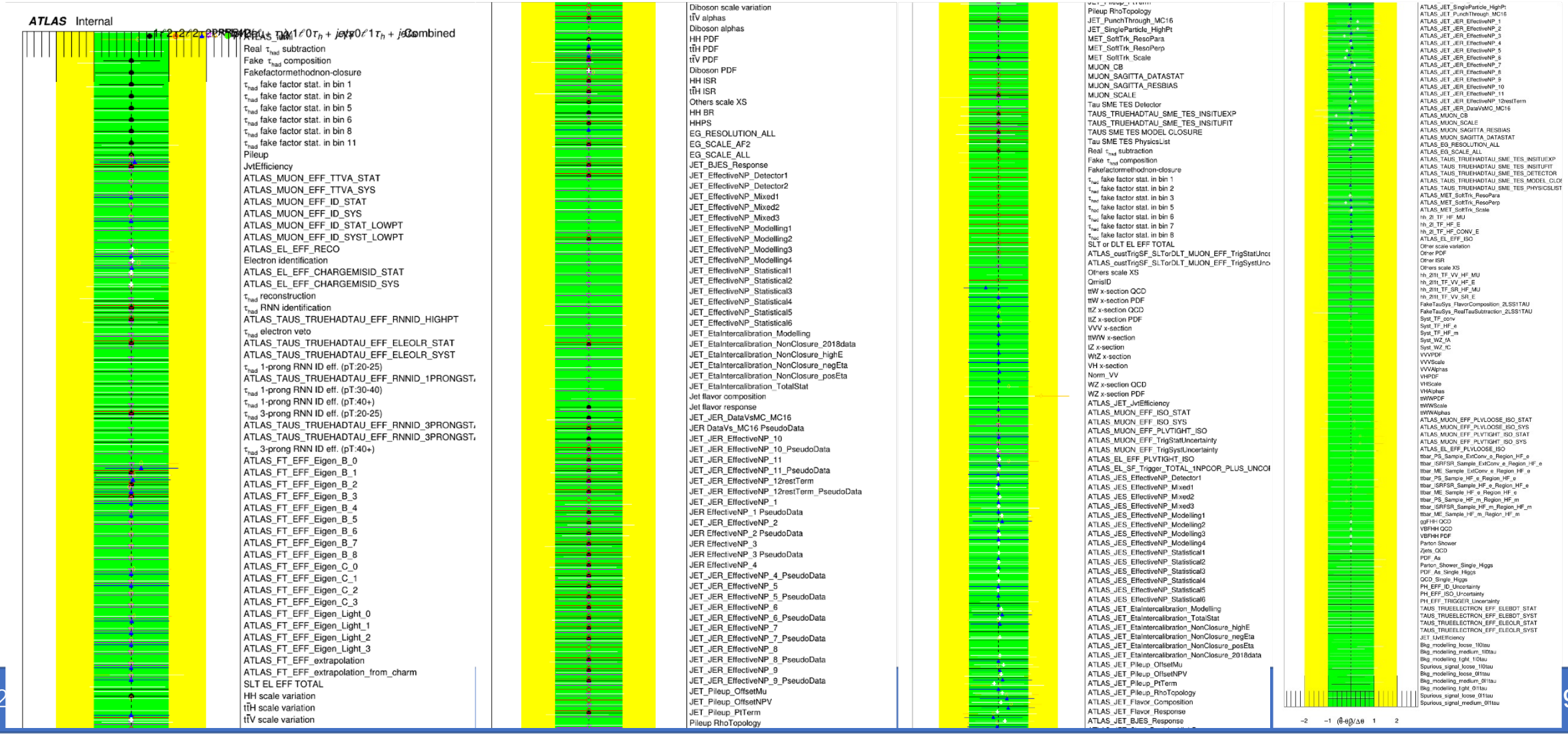


Stat. only

Channels	Stats. Only	Stats. + MC syst.	Stats.+ full syst.
2ℓSS	$30.70^{43.47}_{22.12}$	$31.62^{44.76}_{22.79}$	$34.81^{49.61}_{25.08}$
3ℓ	$23.82^{34.03}_{17.16}$	$25.58^{37.00}_{18.43}$	$28.13^{40.94}_{20.27}$
$b\bar{b}4\ell$	$27.24^{40.90}_{19.63}$	$27.62^{41.76}_{19.90}$	$28.71^{44.41}_{20.68}$
1ℓ+$2\tau_{\text{had}}$	$34.64^{49.51}_{24.96}$	$38.31^{54.33}_{27.60}$	$41.21^{58.92}_{29.70}$
2ℓ+$2\tau_{\text{had}}$	$32.82^{48.34}_{23.65}$	$33.46^{49.12}_{24.11}$	$33.99^{50.09}_{24.49}$
2ℓSS+$1\tau_{\text{had}}$	$50.50^{72.83}_{36.39}$	$62.37^{91.18}_{44.94}$	$63.52^{93.27}_{45.77}$
$\gamma\gamma$+$1\ell0\tau_{\text{had}}$	$25.43^{36.95}_{18.32}$	$25.43^{36.95}_{18.32}$	$26.68^{39.53}_{19.23}$
$\gamma\gamma$+$0\ell1\tau_{\text{had}}$	$52.58^{76.54}_{37.89}$	$52.50^{76.57}_{37.90}$	$54.50^{80.98}_{39.27}$
$\gamma\gamma$+2L	$37.05^{54.86}_{26.70}$	$37.05^{54.86}_{26.70}$	$38.21^{57.76}_{27.53}$
Combined	$8.93^{12.69}_{6.44}$	$9.29^{13.22}_{6.70}$	$9.74^{13.91}_{7.02}$

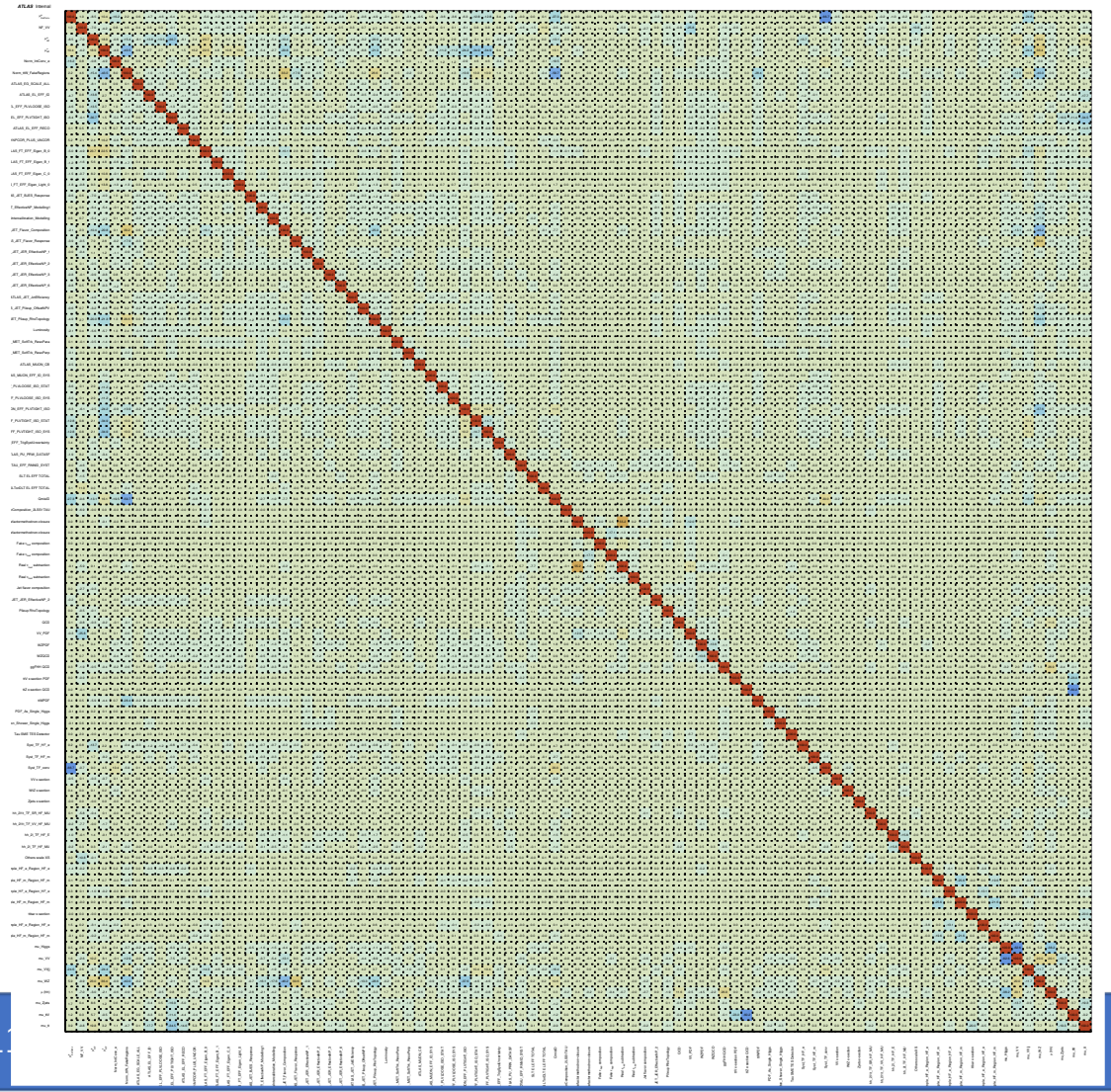
Results

- **NP Pulls: no obvious strange NPs.**



Results

- **NP correlation matrix**



Summary

- **We derived the combined results in HH multi-lepton channels.**
  - Combined workspace is built, and preliminary results are done.
  - Still need to decide: treatment of NFs.
  - Comments or suggestions on NP correlation scheme?
  - Workspace: /afs/cern.ch/work/f/faguo/public/HHComb_ML_ws/ws_combined.root
  - κ_Λ is working on in individual channels, will have the combination when mature.

Summary

- **Feedback from meeting:**
  - For the NFs: both fixing and floating are reasonable, this should be decided as analysis strategy and can be discussed with EB. But when fixing them we should add a gaussian constrain to include the uncertainty of the fitted NFs.
  - For the results in slide 8: normally people call the 2nd row (stat. + MC) as stat., and don't show 1st row. This can be discussed with EB and stat. group.
  - For the HH theoretical uncertainty in page 7: normally people have ggF HH and VBF HH separately as bb4L channel did, so it's better to separate them, and correlate them between channels. It would be easier for the further HH combination.
  - HHComb convener care about the κ_Λ results. Maybe it’s good to give them a timeline.