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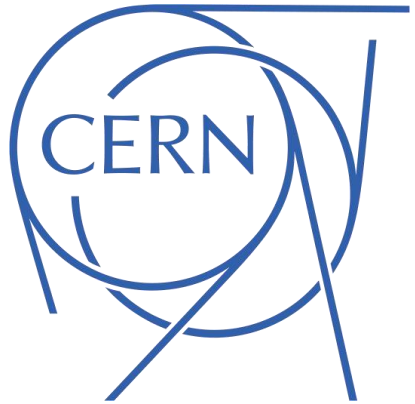

HHFramework - A common framework for HH analyses in the ATLAS experiment

CERN School of Computing 2024

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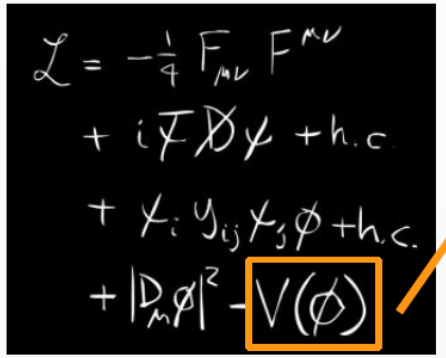
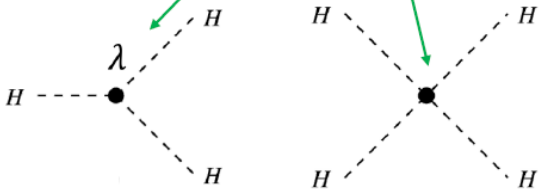
Higgs Boson Pairs (HH)

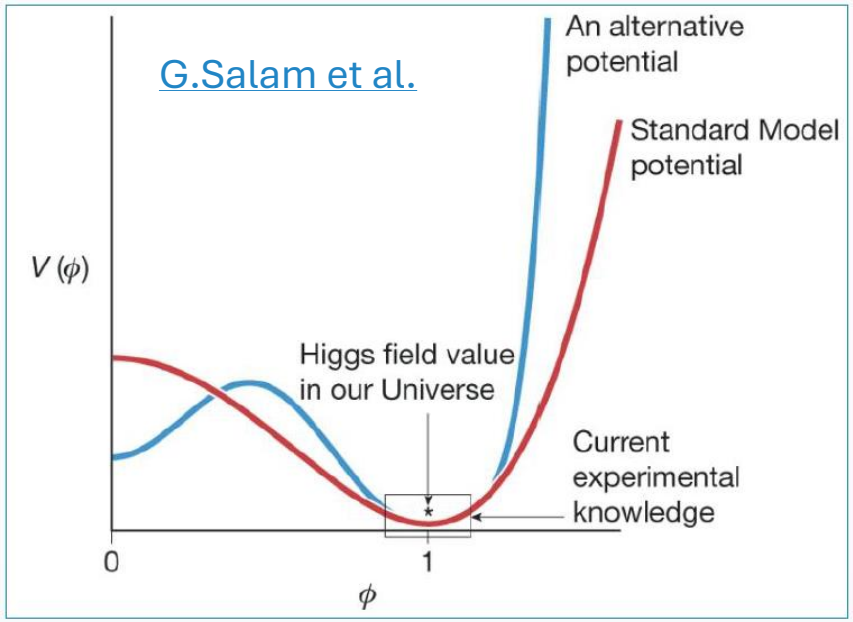
Key priority for the ATLAS and CMS collaborations has been to better understand Higgs properties and couplings.
How does the Higgs boson couple to itself?



$$V\left(\phi^\dagger\phi\right) = \mu^2\,\phi^\dagger\phi + \lambda\left(\phi^\dagger\phi\right)^2$$
$$\supset \lambda\,v^2\,H^2 + \lambda\,v\,H^3 + \frac{\lambda}{4}H^4$$

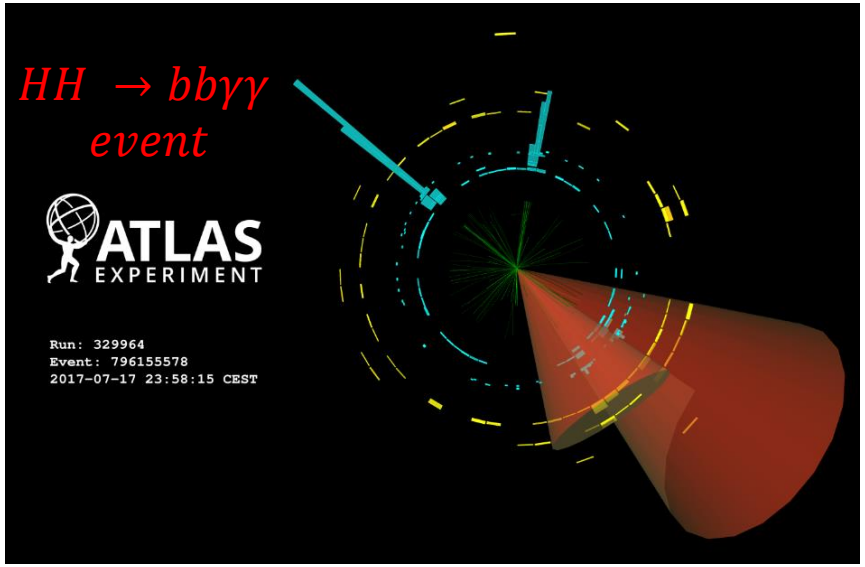
$$m_H = \sqrt{2\,\lambda\,v^2}$$
$$v \simeq 246\,GeV$$
$$\kappa_\lambda = \frac{\lambda_{HHH}}{\lambda_{SM}}$$





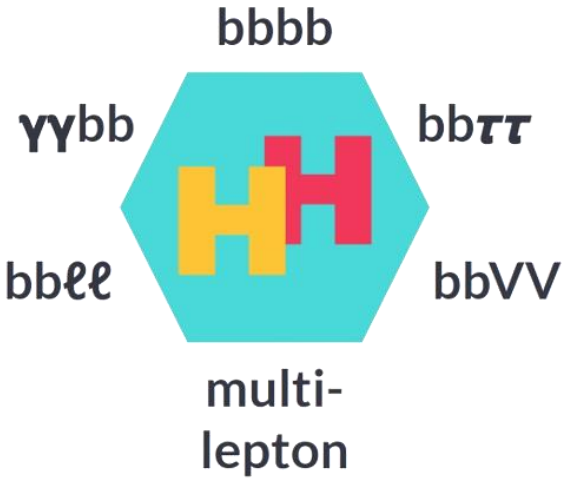
HH production provides a direct probe of the Higgs boson self-coupling which is :

- closely related to the shape of the Higgs scalar field potential.
- crucial for understanding the mechanism of electroweak symmetry breaking.



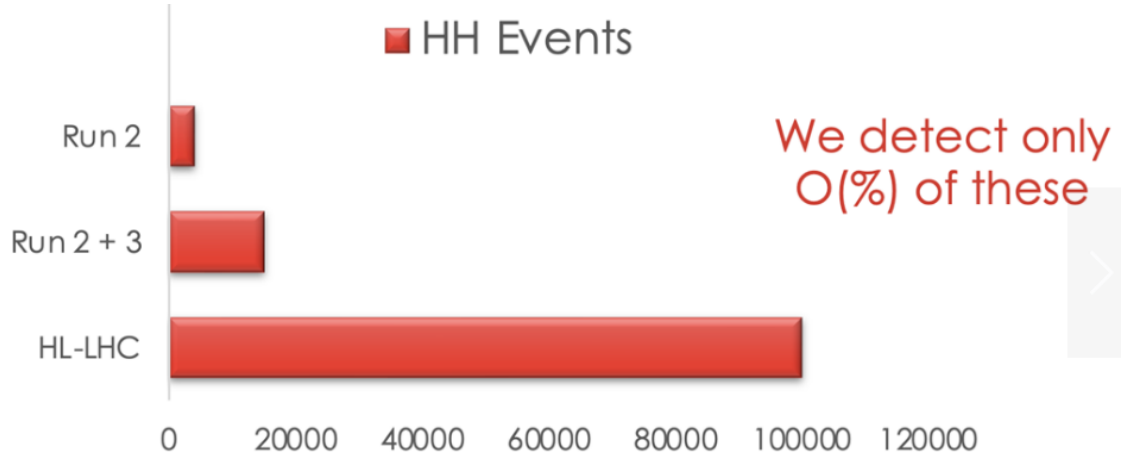
Channels & Combination

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%



But why do we need a common framework?

HH is an extremely rare process, **1000 times rarer than producing a single Higgs boson!**



No "golden" channel in HH. Need to combine multiple signature of Higgs boson decays to increase sensitivity!

The channels

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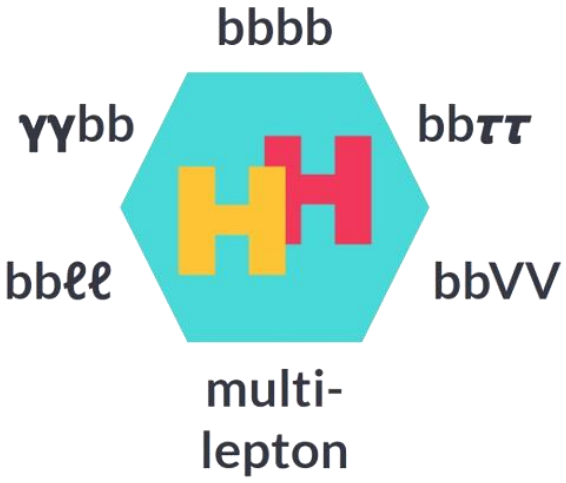
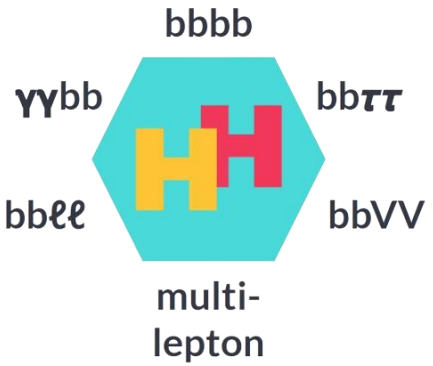


A shared framework will simplify the complexity of combinations!

HHFramework

For LHC Run 3, the **ATLAS DiHiggs group** decided the creation of a **common framework.** It utilizes :



- ✓ Simplifies and streamlines common steps of various analyses.
- ✓ Satisfies specific needs of each individual analysis.

Athena software : which manages almost all ATLAS production workflows:

- generation,
- event simulation, reconstruction
- and derivation production

Million lines of code in C++ , Python etc.

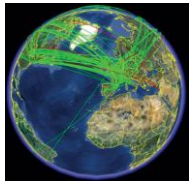
EasyJet framework :

- Object calibration
- Overlap removal
- Event skimming capabilities
- Systematics support
- Multiple working points per object

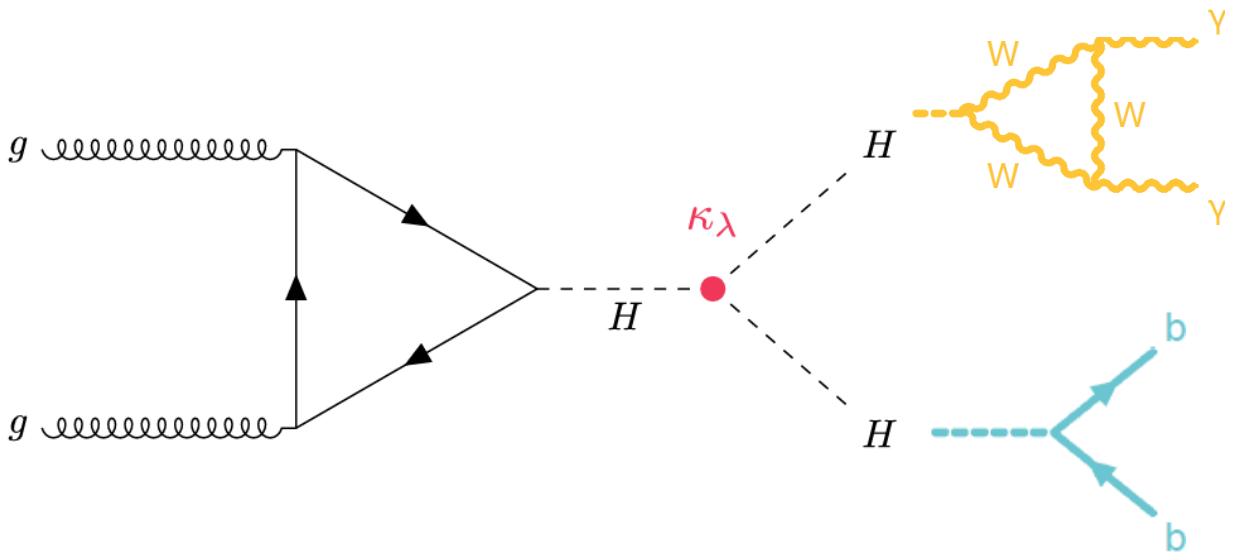
Is and can be used by non HH analyses.

Cern's Grid (WLCG)

- Provides access to data and Monte Carlo (MC) samples stored on the Grid.
- Allows execution of long and resource-intensive jobs on the Grid.



$HH \rightarrow bb\gamma\gamma$ example workflow



$HH \rightarrow bb\gamma\gamma$ on

Yaml files

```yaml
# photon ID and isolation requirements
Photon:
  ID: "Loose" # Loose, Tight
  Iso: "NonIso"
  amount: 2
  variables: ["ptOvermyy"]
  variables_int: ["isEMTight"]
small_R_jet:
  useFJvt: true
  btag_wp: "GN2v01_FixedCutBEff_77"
  btag_extra_wps:
  amount: 4
  variables_int_allJets:
  ["truthLabel", "PassWP", "pcbt"]
```

```yaml
CutList :
      - PASS_TRIGGER
      - TWO_LOOSE_PHOTONS
      - PASS_TRIGGER_MATCHING
      - TWO_TIGHTID_PHOTONS
      - TWO_TIGHTID_ISO_PHOTONS
      - PASS_RELPT
      - DIPHOTON_MASS
      - EXACTLY_ZERO_LEPTONS
      - AT_LEAST_TWO_JETS
      - LESS_THAN_SIX_CENTRAL_JETS
      - EXACTLY_TWO_B_JETS
```

Analysis specific configurations: channels, object working points, triggers, CutList for cutflow

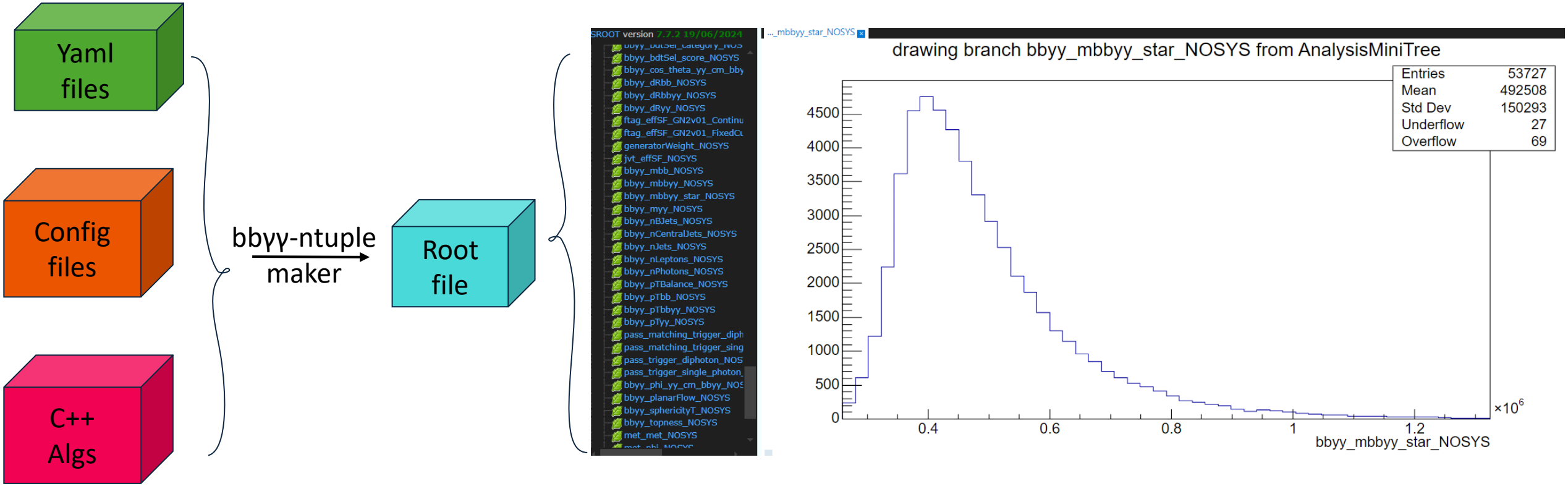
Python Config files

```python
cfg = ComponentAccumulator()
PhotonWPLabel = f'{flags.Analysis.Photon.ID}_{flags.Analysis.Photon.Iso}'
cfg.merge(PhotonSelectorAlgCfg(flags,
                               containerInKey=photonkey,
                               containerOutKey="bbyyAnalysisPhotons_%SYS%",
                               minPt=22. * Units.GeV,
                               loosePhotonWP=PhotonWPLabel,
                               tightPhotonWPs=[f'{wp[0]}_{wp[1]}' for wp in
                                               flags.Analysis.Photon.extra_wps]))
```

Configuration of object selectors + analysis algorithms. Employing of C++ algorithms (athena + easysjet) through python config blocks.

```python
cfg.merge(JetSelectorAlgCfg(
    flags,
    containerInKey=smalljetkey,
    containerOutKey="bbyyAnalysisJets_%SYS%",
    PCBTDecorName="ftag_quantile_" +
    flags.Analysis.Small_R_jet.btag_extra_wps[0],
    minPt=25. * Units.GeV,
    pTsort=False,
    PCBTsort=True,
    bTagWPDecorName="",
    selectBjet=False))
```

$HH \rightarrow bb\gamma\gamma$ example



- ✓ Through easyjet a simply structured **Root** file is produced.
- ✓ It contains all necessary variables & histograms to move on with the more specific calculations.

$HH \rightarrow bb\gamma\gamma$ example

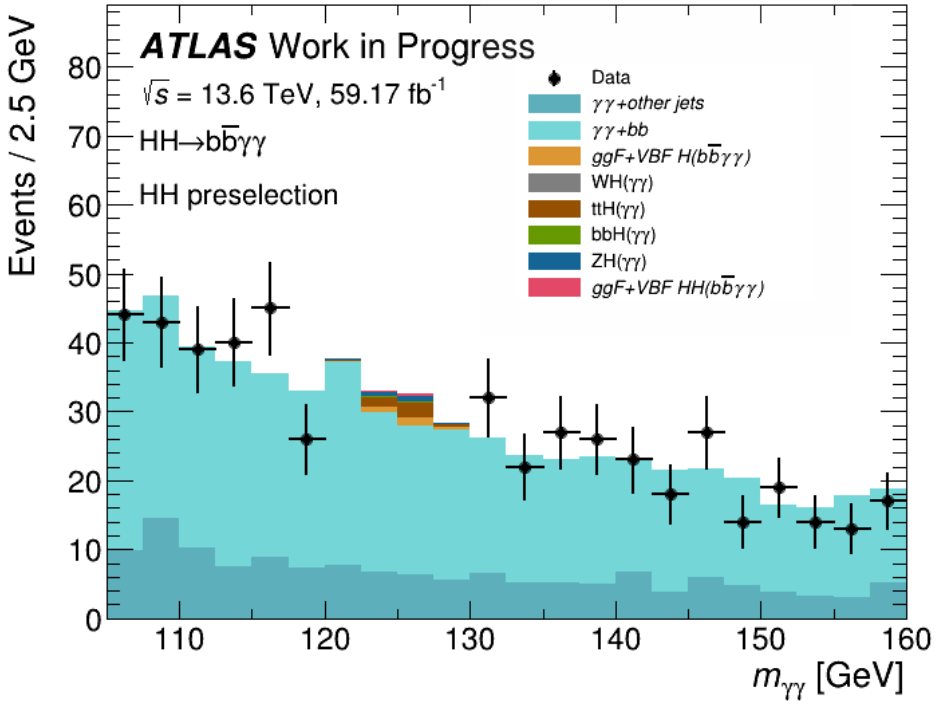
Root file

Post-Processing frameworks

Separate post-processing frameworks accommodating different analysis strategies.

They treat :
- ✓ Plotting
- ✓ MC weight renormalization
- ✓ Statistical analysis etc.

Data / MC agreement for Run 3 (years 2023+2024)



Conclusions

Advantages of a common HHFramework :

- **Uses centrally managed algorithms from Athena**, where the developments have been reviewd and include the latest recommendations.
- **Speeds up the process of developing code** up to ntuple production (much faster compared to each analysis team writing their own code).
- **Easyjet makes it easy to access the grid**, making it straightforward to handle large datasets and run heavy computational tasks.
- **It plays a key role** in bringing together different DiHiggs channels, making it easier to perform a **combined search for this rare process.**

Backup

Analysis package content

Louis D'eramo