The electroweak sector of the Standard Model
WG-2

Kick-off meeting

FAPESP Thematic 2020/04867-2

August 10th 2022

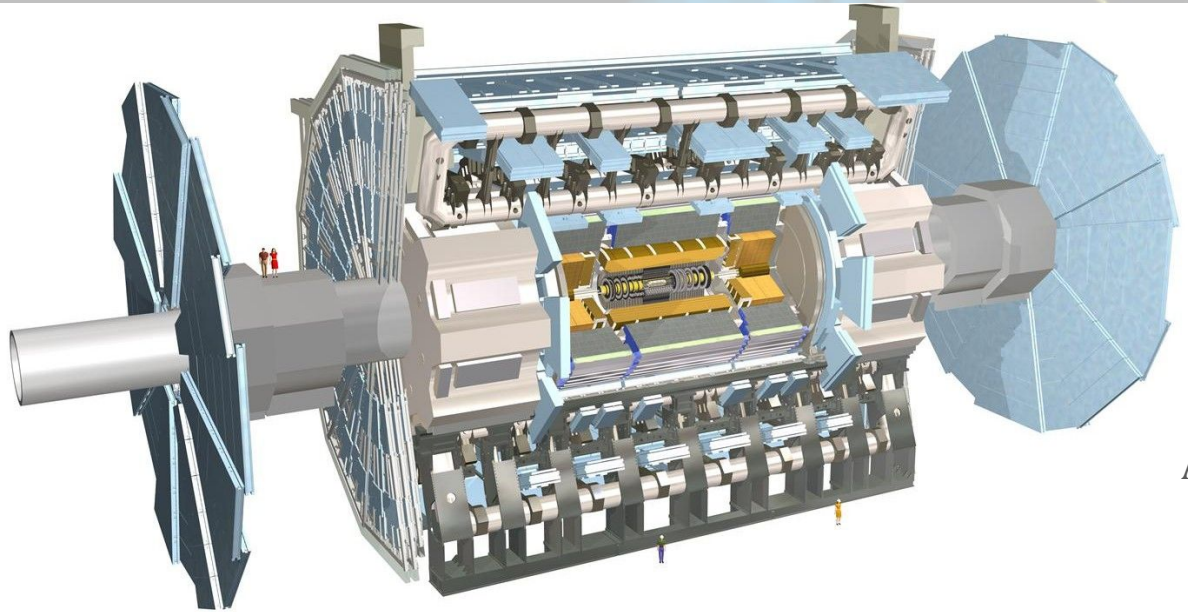
Marco Leite - IFUSP

ATLAS EXPERIMENT

FAPESP
FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO

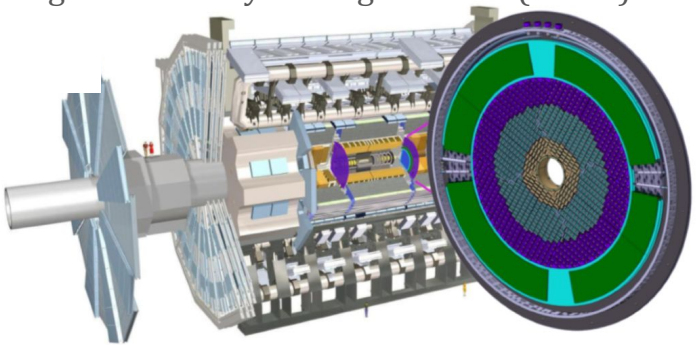
HEPIC IFUSP

WG-2: The ATLAS Experiment



- **Multi-purpose experiment @ LHC**
- **Large acceptance and full azimuthal coverage**
- More than 3000 collaborators
- More than 1000 students developing their thesis topics in ATLAS
- 139f b^{-1} at $\sqrt{s}$=13 TeV available (pp)
- Expecting more ~300 fb^{-1} at $\sqrt{s}$=13.6 TeV (pp) during Run-3

ATLAS Phase-II upgrade for HL-LHC : The new High Granularity Timing Detector (HGTD)



… coming this afternoon

WG-2: Studies in the electroweak sector of the Standard Model

One of the main goals of this project is to explore measurements of the W, Z and H bosons production in several kinematic regimes and final state channels using current and future LHC data acquired by the ATLAS experiment in proton-proton collisions at sqrt(s)=13 and 14 [13.6] TeV.

Precision measurements in SM

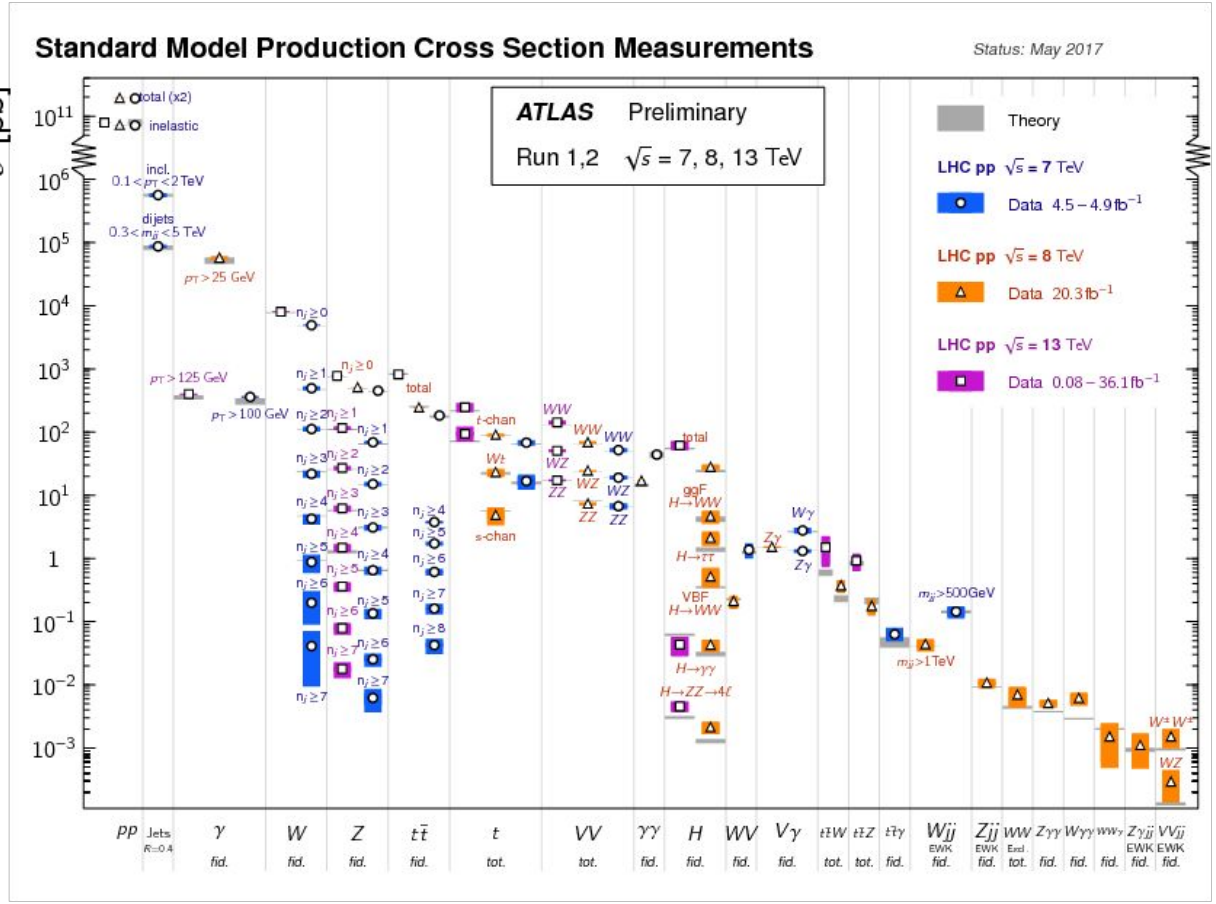
- So far, no signs of new physics (SM works pretty well…)
- New physics may be out of the LHC reach by **direct searches** (too heavy, too broad...)
- We need higher precision (model and experiment) ⇒ then hope it breaks somewhere …
- If it breaks, someone needs to come with a fix to the model used in the global fit (new physics)
- V decays involving 3rd lepton generation is a powerful tool for probing *b*-anomalies

Study of Higgs self-coupling

- Probe the scalar sector of SM trough studies of di-Higgs production
- Direct probe of EWK symmetry breaking potential
- The resonant production of HH is a fertile ground for BSM models validation
- Focus on HH→bb$\tau\tau$ channel

Strategy: build-up on the groundwork of on-going analysis; prepare for Run-3 new data and conditions

WG-2: Studies in the electroweak sector of the Standard Model



WG-2: DD CCDY cross section in high mT_W

ATLAS Note

ANA-STDM-2018-41-INT1

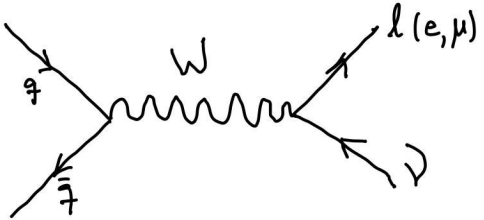
21st May 2022

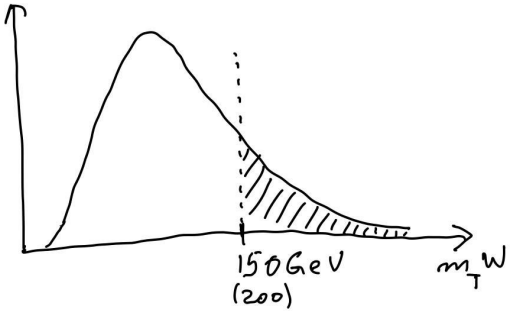
Draft version 0.1

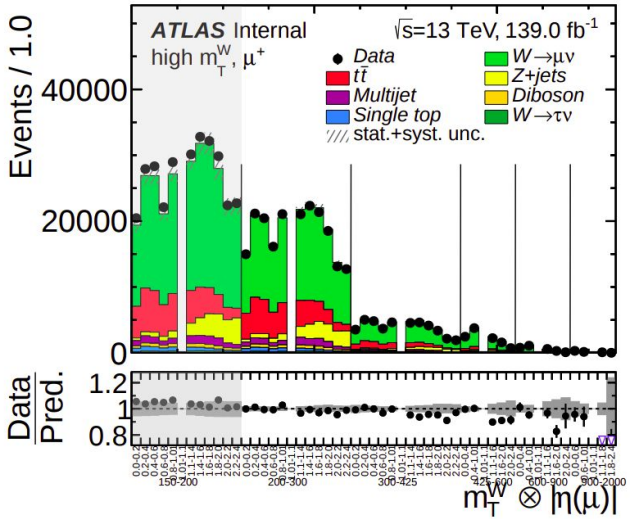
ONGOING - With EB

Double-differential charged-current Drell-Yan cross sections at high transverse masses in pp collisions at $\sqrt{s}$ = 13 TeV

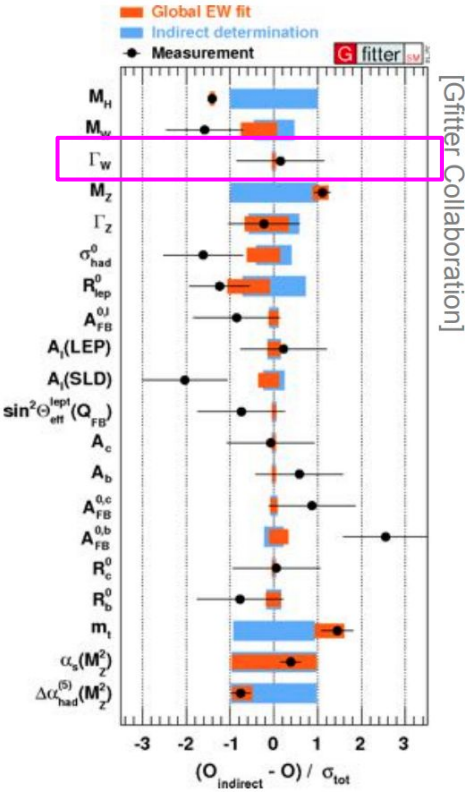
- Full Run-II analysis (139 fb^{-1})
- Precision **double differential born level cross section** measurement in $m_T W$ and $|\eta|$ (e,μ,charge separated)
- **Can provide constraints to proton PDF**
- **Checks of lepton universality**
- **Phase space interesting for SM EFT interpretations**
- **Lays the groundwork for ΓW measurement**







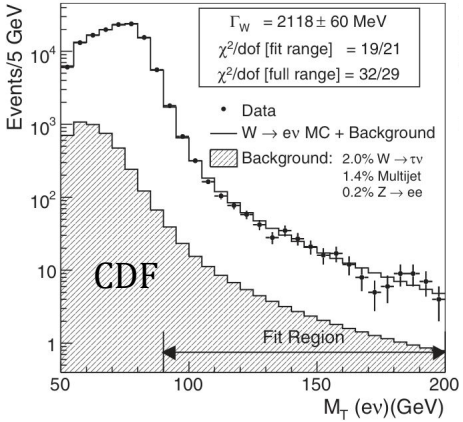
WG-2: Measurement of W width (Γ_W) in proton-proton collisions @13 and 13.6 TeV

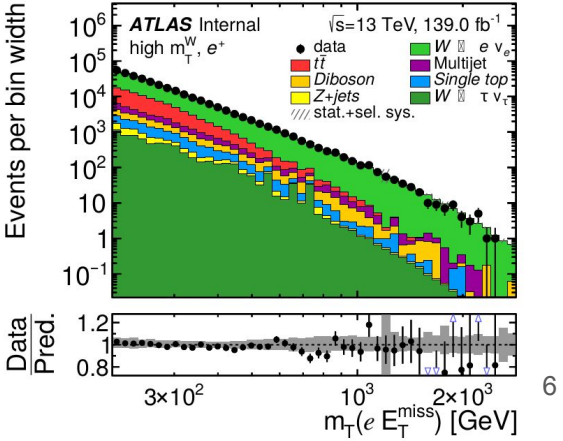


Motivation

- Fundamental observable of SM, enters global EWK fit
- New particle candidates that couple to the W boson and are lighter than m_W, would open a new decay channel and alter Γ_W
- Only direct measurement can enter the EWK fit
- This measurement CM energy and precision is stagnated since the Tevatron
- Remember recent (still unveiling) surprise with D0 m_W measurement
- We should gain even more sensitivity in Run-3 (TBC…)

$$\Gamma_{W\to f\bar{f}'} = \frac{|M_{f\bar{f}'}|^2 N_C G_F {M_W}^3}{6\pi\sqrt{2}} \left[1 + \delta_f^{\mathrm{rad}}(m_t, M_H, \ldots)\right],$$





WG-2: DD NCDY (τ channel) high $m_{\tau\tau}$

ATLAS Note

ANA-STDM-2021-10-INT1

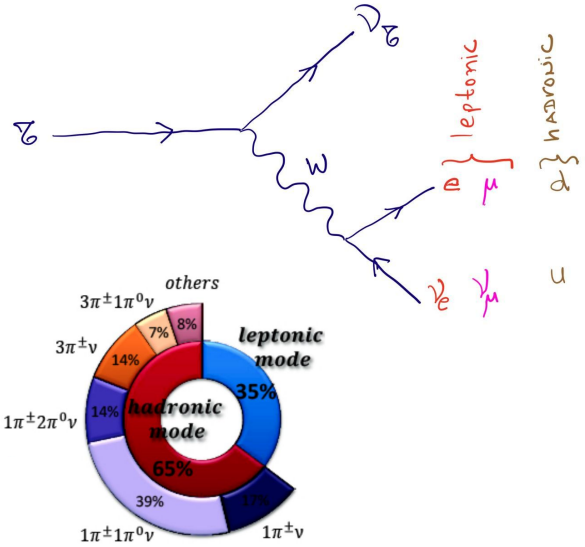
8th August 2022

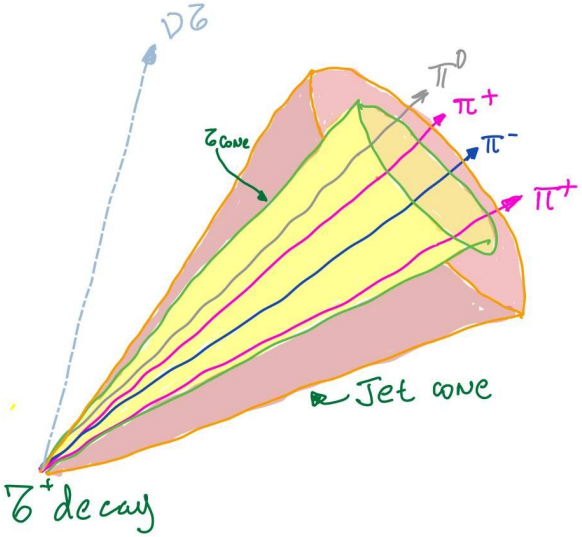
Draft version 0.1

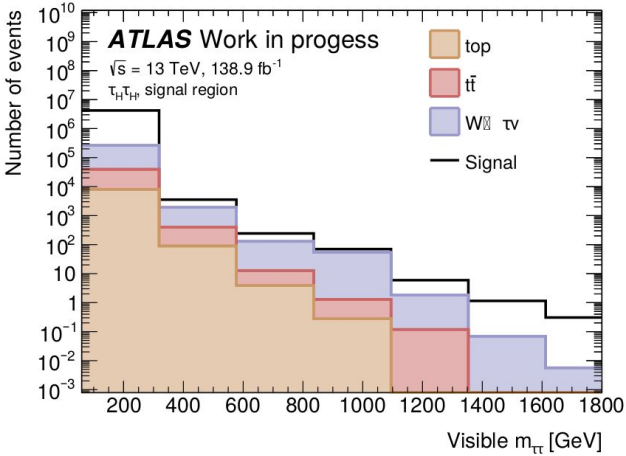
ONGOING - EB soon

Measurements of high-mass production of τ-lepton pairs at $\sqrt{s}$ = 13 TeV with the ATLAS detector

- **Few LHC analysis on 3rd lepton generation,**
  - **but many BSM scenarios sensitive to 3rd generation**
- **High priority for understanding the $b \rightarrow l$ anomalies**
  - **Search for DY processes mediated by a leptoquark**
  - **EFT interpretations**
- Full Run-2 data (139 fb^{-1}), on semi-lep and fully hadronic decay modes of the tau pair
- Analysis on the pole and high mll mass region (>120 GeV)





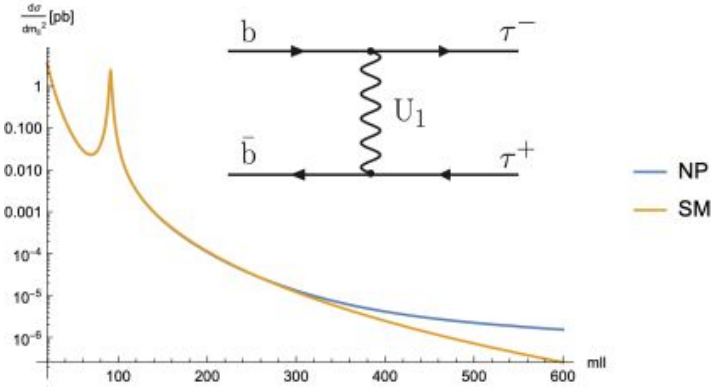


Data is blinded in visible high mass region

WG-2: High pT probes for b-anomalies studies

- Investigate the production of Leptoquarks as source of Lepton Flavor Universality violation
- Motivated by flavor physics results (LHCb, Belle)

$$R_{K^{(*)}} = \frac{\mathcal{B}\left(B \to K^{(*)}\mu\mu\right)}{\mathcal{B}\left(B \to K^{(*)}ee\right)} \quad \text{(NC)} \qquad R_{D^{(*)}} = \frac{\mathcal{B}\left(B \to D^{(*)}\tau\nu\right)}{\mathcal{B}\left(B \to D^{(*)}\ell\nu\right)} \quad \text{(CC)}$$



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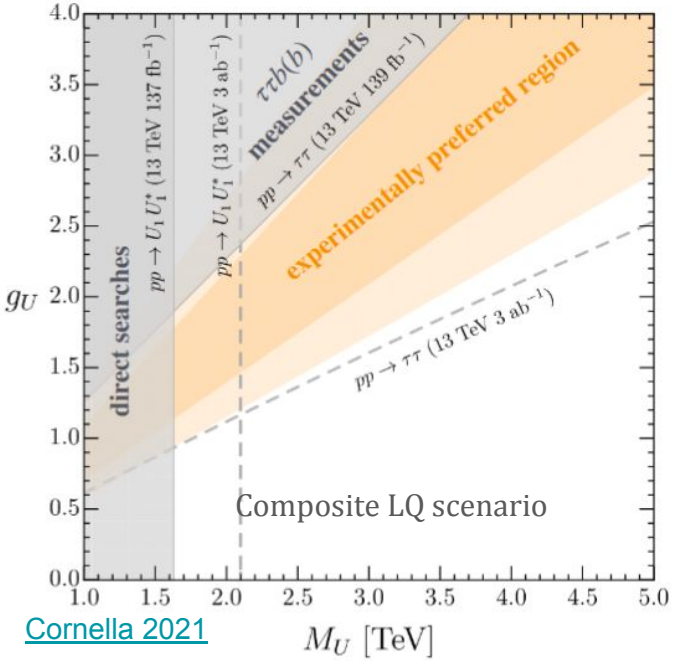


Cornella 2021

- Signal generation using Madgraph
- Test and set exclusion limits
- Sensibility in the high mass region of Z→$\tau\tau$
  - Look for the associated 1(2) b production
- Analysis will also include charge current DY
  - W→$\tau\nu$
  - W→$\tau\nu$+ 1(2)b
- Add 13.6 Run-3 dataset

WG-2: Search for Higgs boson pair production: HH → bb ττ channel

ATLAS Note

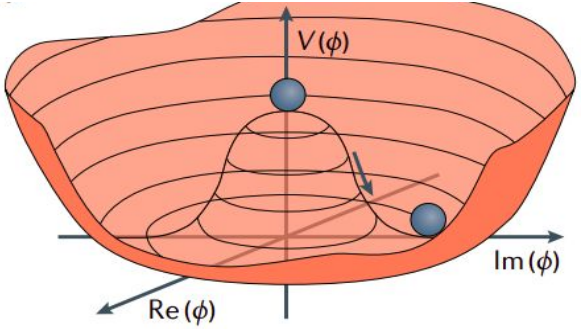
ANA-HDBS-2019-27-INT1

8th August 2022

Draft version 0.1

ONGOING - EB soon

Search for non-resonant ggF and VBF $HH \rightarrow bb\tau\tau$ production using the full Run-2 dataset



$$V(\phi) = \frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda\phi^4$$

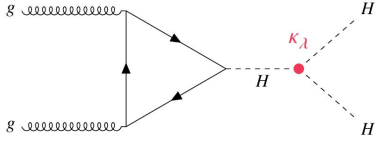
Higgs scalar potential is still largely unconstrained - could give direct insight into the structure of the Higgs potential

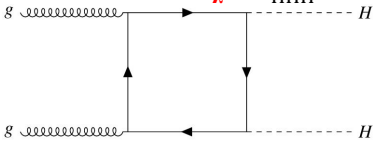
Higgs can interact with itself, producing a pair of Higgs bosons

Known m_H (~ 125 GeV) , SM predicts λ(~ 0.13)

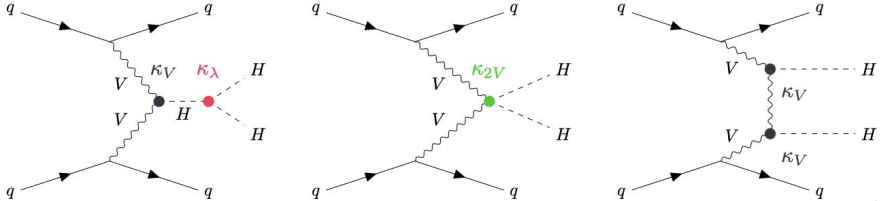
New physics can alter this number!

- Gluon-Gluon Fusion (**ggF**)
  - Dominant process at LHC
  - Destructive interference between triangle and box diagram makes the cross-section tiny (1000 smaller than single Higgs)
  - Anomalous deviations of the coupling strength $\kappa_\lambda = \lambda_{HHH} / \lambda^{SM}_{HHH}$





- Vector Boson Fusion (**VBF**)
  - Second most abundant production mode
  - VBF topology provides a clean signature
  - Direct handle to vector boson coupling modifiers κ_{2V} and κ_V



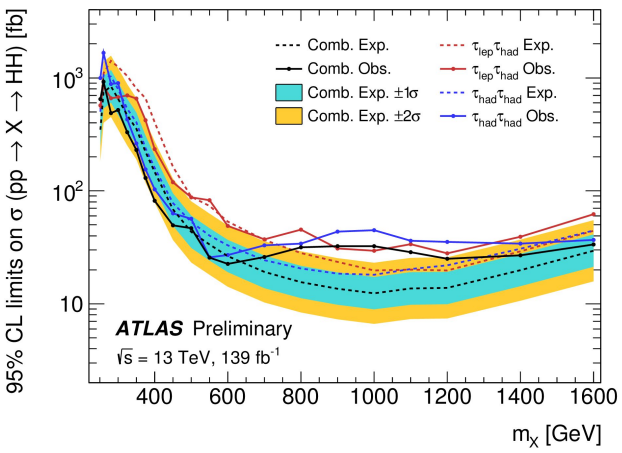
WG-2: HH → bb $\tau\tau$ channel in Run-3

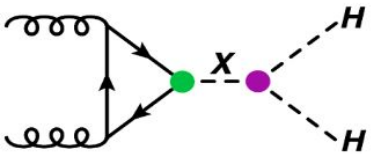
- **Profit from higher luminosity and cross section**
  - bb**ττ** has the 3rd largest BR of all accessible channels
- **Will require careful trigger studies (new systems in place)**
- HH final states can be a signal of Beyond Standard Model resonances
  - Test/exclude BSM models predicting heavy particles decaying into 2 Higgs bosons

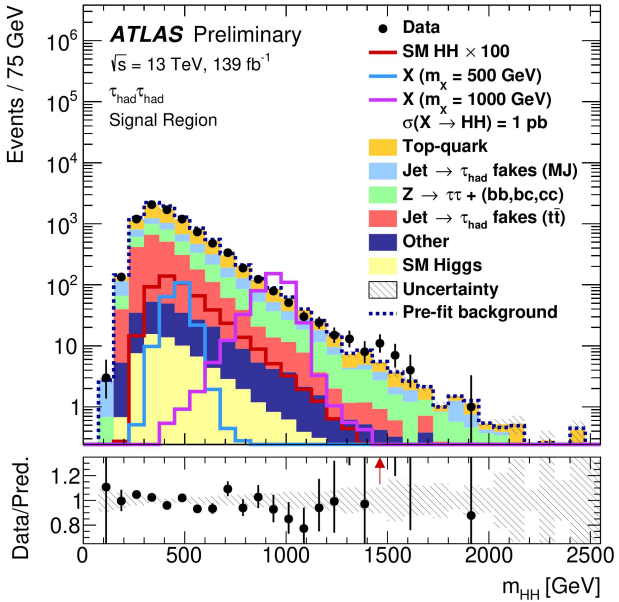
$BR(HH \to XXYY)$

	bb	WW	gg	ττ	cc	ZZ	γγ	Zγ	μμ
bb	33%								
WW	25%	4.6%							
gg									
ττ	7.4%								
cc									
ZZ	3.1%								
γγ	0.26%	0.1%							
Zγ									
μμ									

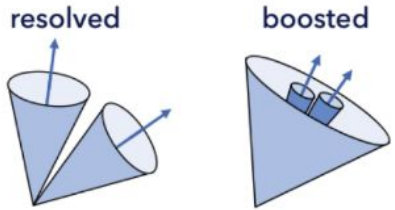
= results from ATLAS







Full exploration of resolved and boosted topologies



WG-2: Interpretations

Standard Model Effective Field Theory Framework→ accounts for BSM effects at a mass scale Λ that is large in comparison to the EWK scale.

- The theory provides predictions for experimental observables in terms of an expansion in E/Λ, where E is the typical energy exchanged in the process.
- SMEFT interpretation turns a hadron collider in a competitive tool for EWK precision measurements
- Measurements of observables sensitive to the effect of SMEFT operators allow to constrain $c^{(d)}{}_i / \Lambda^{d-4}$, where $c^{(d)}{}_i$ are the Wilson coefficients associated to the dimension-d operator O (d)

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(5)}}{\Lambda} O_i^{(5)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \dots .$$

- Ignoring odd-dimensional operators (responsible for lepton and baryon number violation) and stopping at dimension-6 :

$$\mathcal{L}_{\text{SMEFT}} \approx \mathcal{L}_{\text{SM}}^{(4)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)}$$

- Studies on-going (HMTW) for SMEFT interpretations
- Studies planned for Z→$\tau\tau$ + 1(2) b analysis (LFU violation)
- Higgs can also use the same approach, or Higgs EFT

WG-2: Person-power

Current ATLAS Team :

- Marco Leite (IFUSP)
- Marisilvia Donadelli (IFUSP, Run-2, Run-3 Di-Higgs)
- Márcia Begalli (UERJ, Run-3 Di-Higgs)
- Yara A. Coutinho (UFRJ, Run-3 Di-Higgs)
- Caio Daumann (IFUSP, MS, Run-2 $Z \rightarrow \tau\tau$)
- Rafael Azevedo (IFUSP, MS, Run 2 $Z \rightarrow \tau\tau$)
- Rodrigo Estevam (Poli-IFUSP, IC, LAr Phase-I commissioning)
- PD (IFUSP, Di-Higgs Run-3, + WG5.2.1)
- DD (IFUSP, precision SM, Run 2+3, + WG5.2.1)
- DD (IFUSP,Di-Higgs Run-3, + WG5.2.1)

Organization

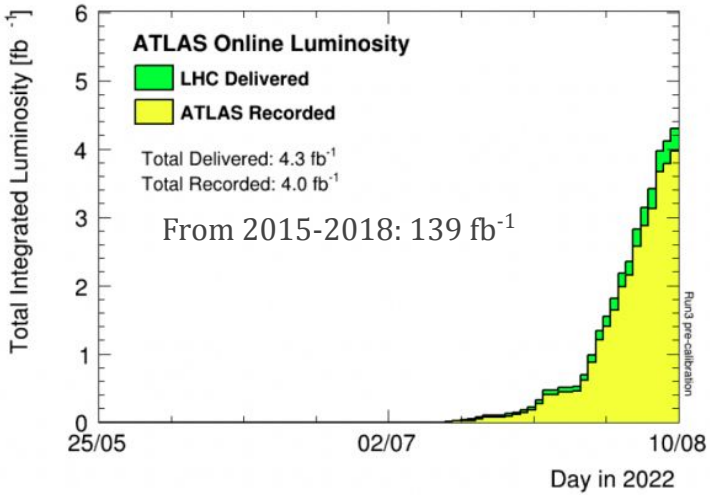
- Nothing much to invent here …
- Follow the ATLAS analysis group pace
- Weekly/Bi-weekly meetings
- Early Run-3 data studies
  - Trigger
  - Lepton Isolation
  - τ ID
  - Signal validation (HH, ΓW)
  - Interpretations (HH BSM, LFU SMEFT)

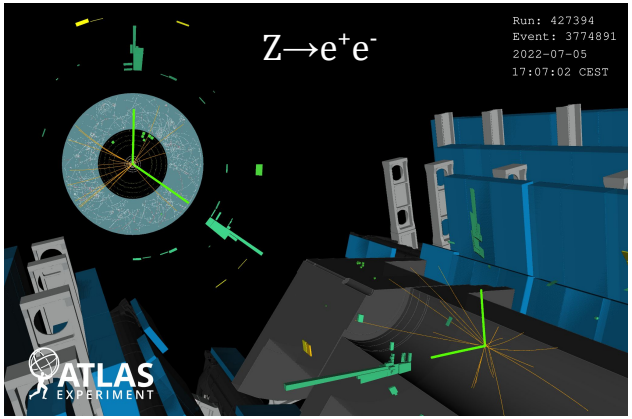
PD-2: *Searching for double Higgs pair production in the HH → bbττ channel at the ATLAS experiment*
DD–5: *Precision measurements in the electroweak sector with the ATLAS detector*
DD–6: *Exploring the fully hadronic di-τ decay channel in the search for HH → bb ττ production in the ATLAS*
IC–6: *Monte Carlo predictions for Electroweak Physics Analyses*

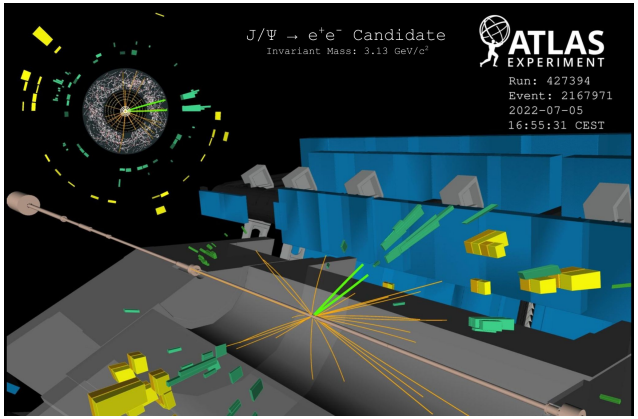
WG-2: Data is already coming fast !!

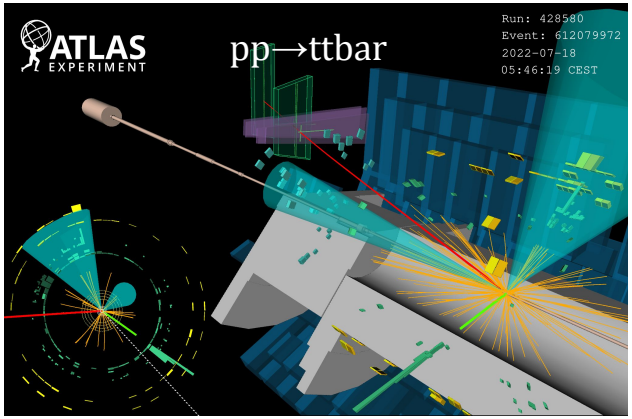
ATLAS Operations

- ATLAS is already taking collision data since ~ May
- **Groups are expected to help on data-taking**
- To be performed as Class-1 and Class-2 shifts @ CERN
- These **are not** related to upgrade activities (HGTD)
- Starting as early as this September









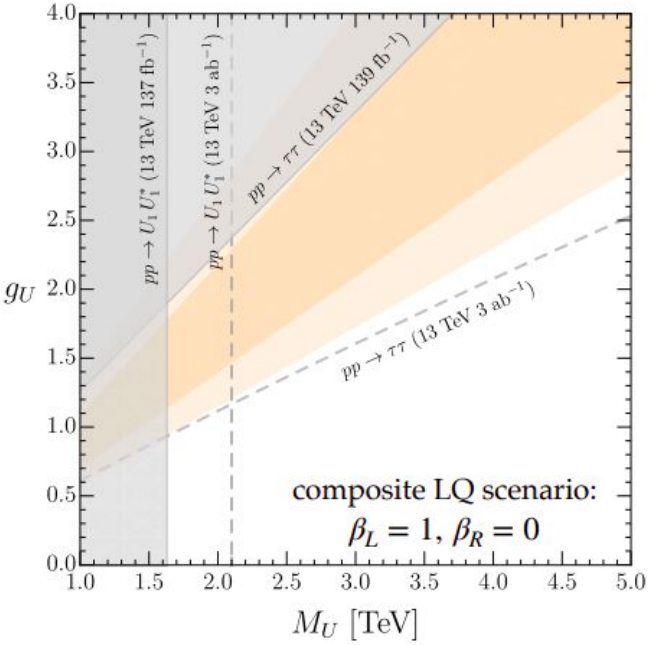
WG-2: $Z \to \tau\tau$ + 1(2)b, $W \to \tau\nu$, $W \to \tau\nu$+ 1(2)b

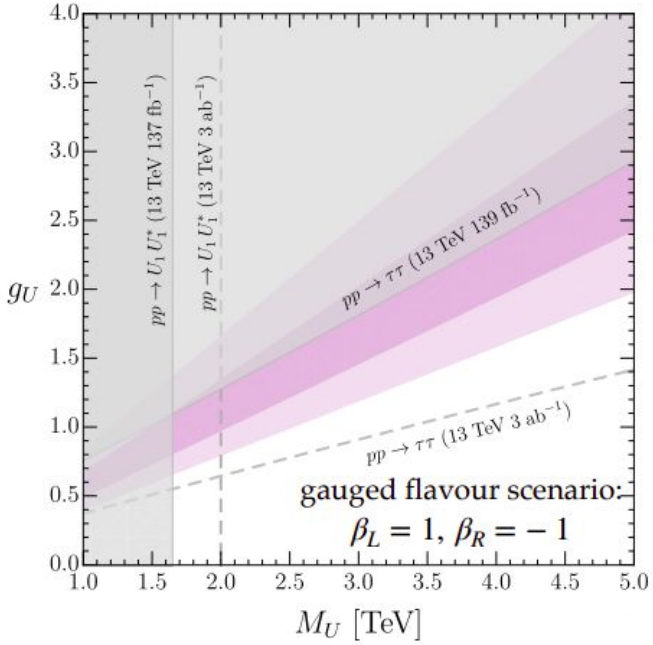
- Lagrangian for U1 vector leptoquark coupling to SM particles:

$$\mathcal{L}_U = -\frac{1}{2} U^\dagger_{\mu\nu} U^{\mu\nu} + M_U^2 U^\dagger_\mu U^\mu - i g_s (1-\kappa_c) U^\dagger_\mu T^a U_\nu G^{\mu\nu,a} - \frac{2i}{3} g_Y (1-\kappa_Y) U^\dagger_\mu U_\nu B^{\mu\nu} + \frac{g_U}{\sqrt{2}} (U^\mu J^U_\mu + \text{h.c.}),$$

- Current mediating U1 and SM fermions :

$$J^U_\mu = \beta^{i\alpha}_L (\bar{q}^i_L \gamma_\mu \ell^\alpha_L) + \beta^{i\alpha}_R (\bar{d}^i_R \gamma_\mu e^\alpha_R)$$

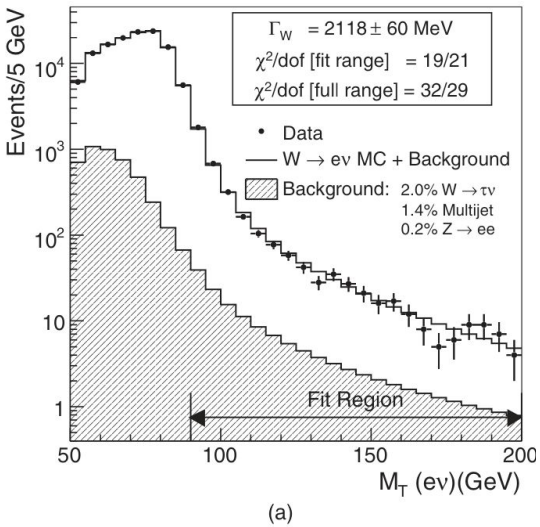




WG-2: Studies in the electroweak sector of the Standard Model

Direct Measurement of W width (Γ_W) in proton-proton collisions @13 and 13.6 TeV

CDF



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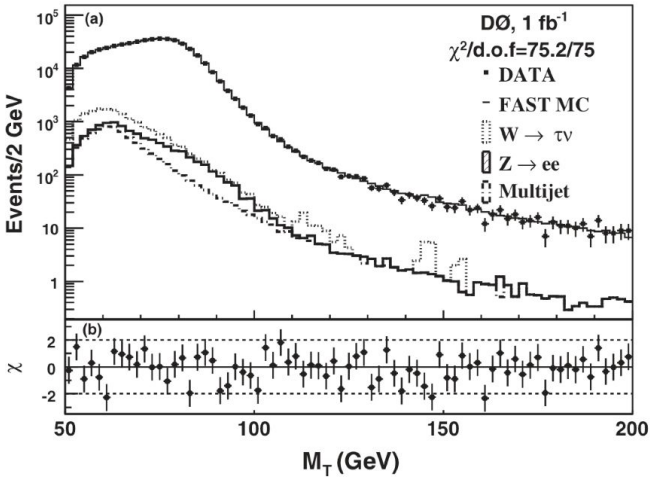
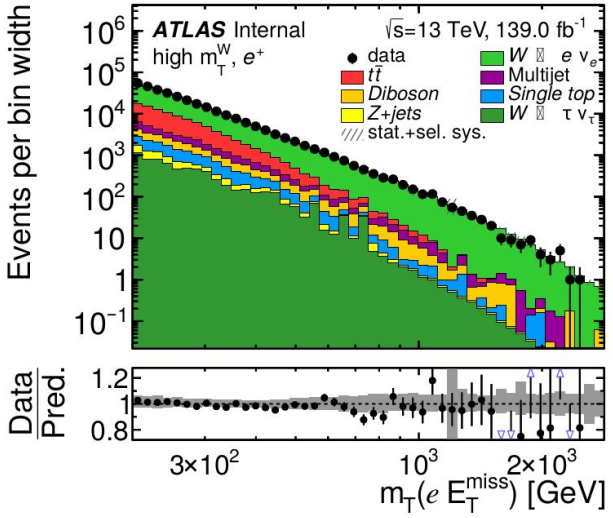


ATLAS



- Most of the heavy lifting done fby HMTW analysis
- Ask for MC validation samples with ΓW scan
- Do a likelihood fit in the signal spectrum and find the best ΓW
- Test if we have sensitivity
- Separate by lepton flavor and charge
- There is a limited-scope analysis on low <μ> for W mass measurement (limited mass range, limited stats)