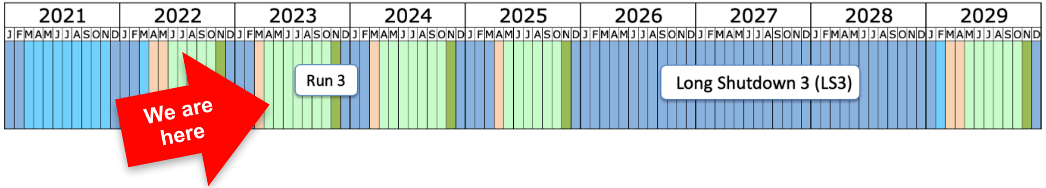
ATLAS Physics @ LIP

Inês Ochoa on behalf of LIP ATLAS

Fourth Joint Workshop IGFAE / LIP
April 13, 2023

The LIP ATLAS team

- Physics Analyses (this talk)
- ATLAS Upgrade (next by H. Santos)



Overview of the group’s Physics analyses

Standard Model Precision Measurements

- Higgs boson couplings (b,t,W) and spin/CP of ttH, HWW
- Top quark Vts vertex and global fits
- Triple and quartic gauge boson couplings
- EFT interpretations

Direct Searches for New Physics

- Vector-like quarks
- Diboson resonances
- FCNC in top quark interactions
- Dark Matter
- Anomaly detection

Heavy Ions

- Heavy quark production

Images generated by DALL.E

Recent Highlights

Higgs boson properties

- Higgs boson production in **association with top quarks**
- CP nature of **top-Higgs Yukawa coupling**
- **CP-odd couplings** in HWW vertex with new **inference methods**

Exotic searches

- **Heavy resonance** searches
- Resonant and non-resonant searches via **anomaly detection**
- **Higgs boson tagging** at high boosts

Heavy Ions

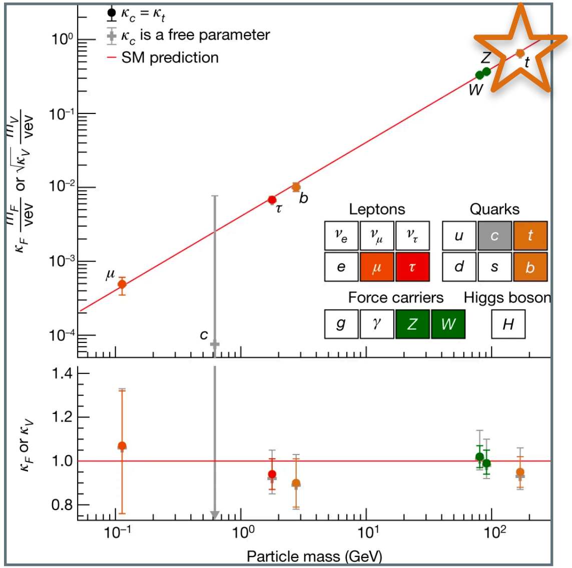
- Muon-jet **triggers** and **b-tagging** for the measurement of the nuclear modification factor of b-jets

Jet reconstruction and calibration

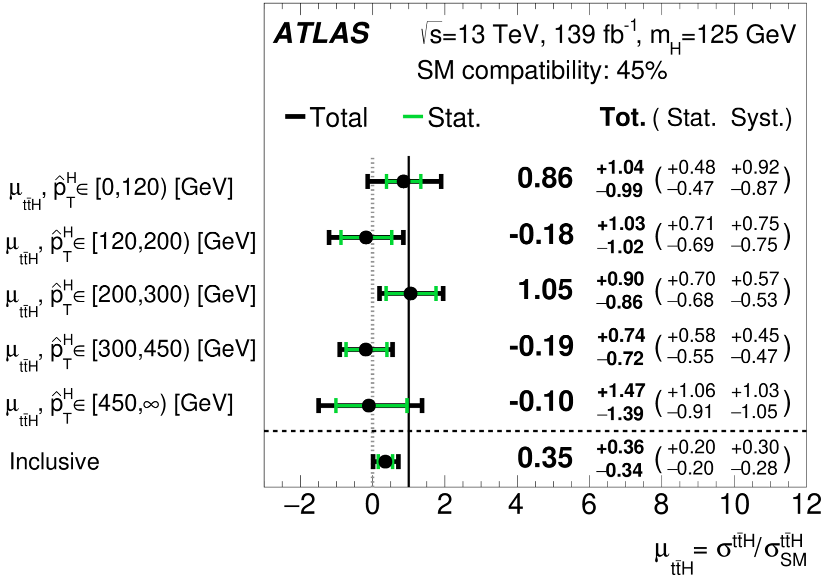
B-tagging & boosted boson tagging

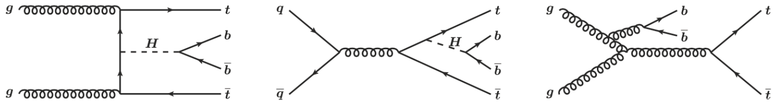
Machine learning **Trigger**

Higgs boson properties: top quark coupling strength



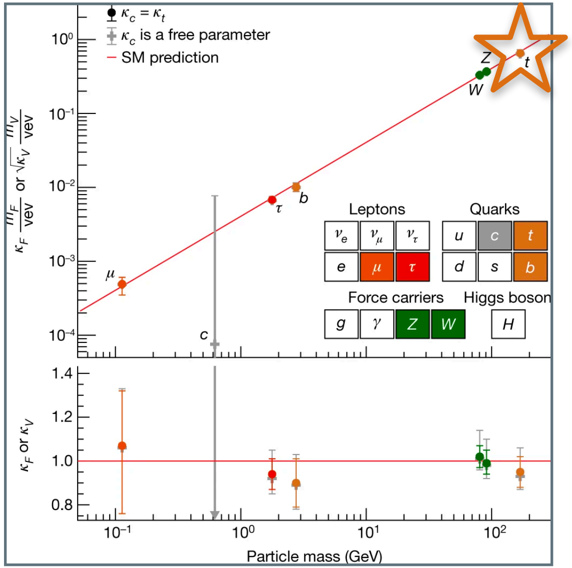
- Initially, indirectly observed via gg fusion and Higgs decay to ɣ ɣ.
- Direct ttH observation in 2018.
- Here, first **differential measurement** of $t\bar{t}H$ signal strength in bins of Higgs p$_T$: [JHEP 06 (2022) 097]





(a) $t\bar{t}H(b\bar{b})$ t-channel (b) $t\bar{t}H(b\bar{b})$ s-channel (c) $t\bar{t}+b\bar{b}$

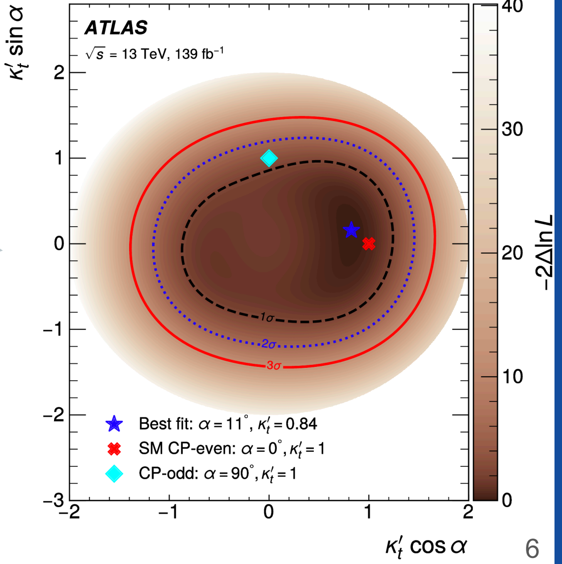
Higgs boson properties: CP nature of top-Higgs vertex



- Measuring **CP structure** of the top-Higgs Yukawa coupling in ttH and tH events (with H→bb).
- Beyond the SM extension of the top-Higgs interaction as:

$$\mathcal{L}'_{t\bar{t}H} = -\kappa'_t y_t \phi \bar{\psi}_t (\cos\alpha + i\gamma_5 \sin\alpha)\psi_t$$

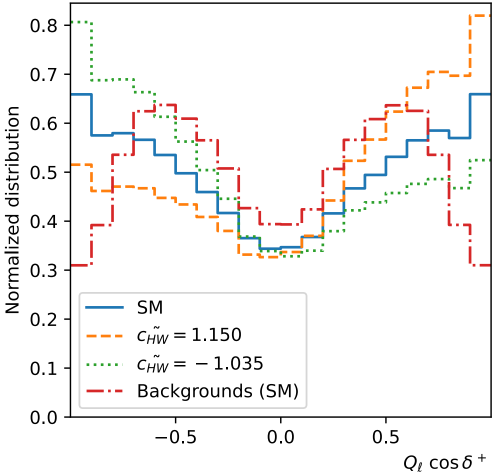
- Pure CP-odd coupling disfavoured at 1.2σ.

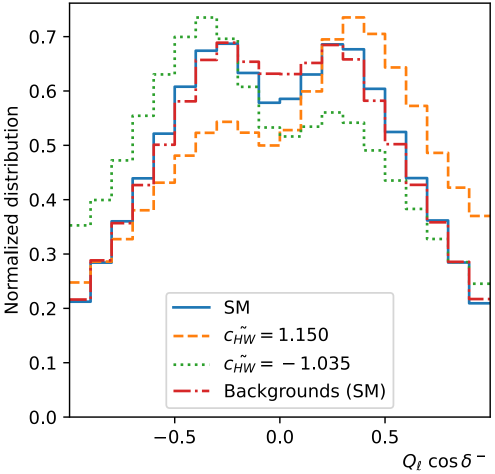


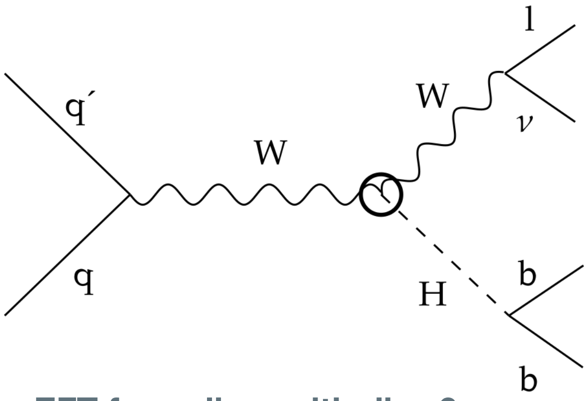
Submitted to PLB: arXiv:2303.05974

Higgs boson properties: CP nature of W-Higgs vertex (I)

- Search for **CP-odd couplings** in HWW vertex, considering the only dimension-6 CP-odd operator in the HWW vertex.
- New angular observables proposed to increase sensitivity to the coefficient of the CP operator:







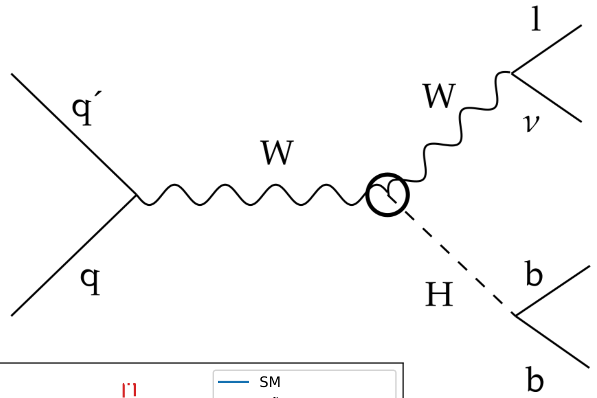
EFT formalism with dim-6 operator $c_{H\tilde{W}}$

$$\cos\delta^+ = \frac{\boldsymbol{p}_{l_1}^{(V)} \cdot (\boldsymbol{p}_h \times \boldsymbol{p}_V)}{|\boldsymbol{p}_{l_1}^{(V)}|\,|\boldsymbol{p}_h \times \boldsymbol{p}_V|}, \qquad \cos\delta^- = \frac{(\boldsymbol{p}_{l_1}^{(h-)} \times \boldsymbol{p}_{l_2}^{(h-)}) \cdot \boldsymbol{p}_V}{|(\boldsymbol{p}_{l_1}^{(h-)} \times \boldsymbol{p}_{l_2}^{(h-)})|\,|\boldsymbol{p}_V|}$$

arXiv:1409.5449

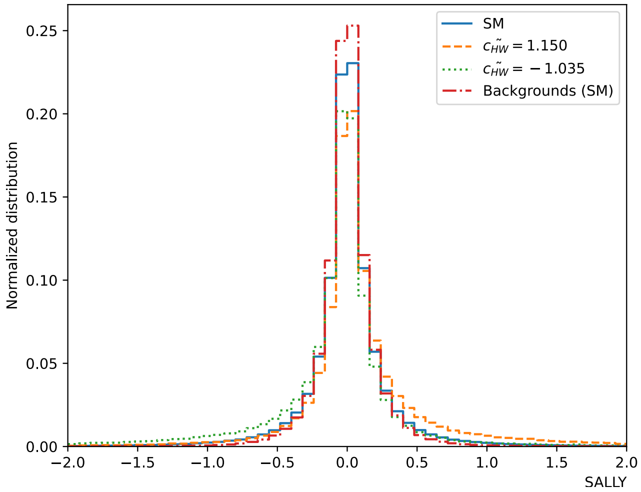
Higgs boson properties: CP nature of W-Higgs vertex (II)

- First implementation of **novel inference methods** taking advantage of machine-learning and matrix element information.
- Neural networks are trained to provide a "sufficient statistics" for this specific measurement, i.e. they converge to an estimate of the *score function:*
  - SALLY method introduced in arXiv:1805.12244



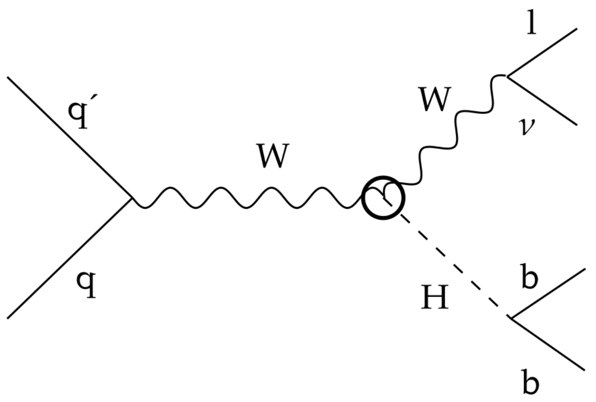
Score function:

$$t(x) = \nabla_\theta \log p(x|\theta)\Big|_{\theta_{\text{ref}}}$$



Higgs boson properties: CP nature of W-Higgs vertex (II)

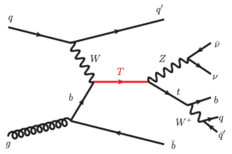
- First implementation of **novel inference methods** taking advantage of machine-learning and matrix element information:
  - SALLY outperforms traditional methods in sensitivity to interference terms.
  - In the presence of quadratic terms, 2D analysis yields best results.

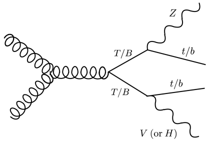


Observable	$c_{H\widetilde{W}}$ **S+B 95% CL (L= 300 fb^-1)**
1D: transverse momentum of W boson	[-1.62,1.62]
2D: W boson transverse momentum x transverse mass of WH system	[-1.4,1.4]
1D: $Q_\ell \times \cos\delta^+$	[-0.227,0.227]
2D: W boson transverse momentum x $Q_\ell \times \cos\delta^+$	[-0.088, 0.088]
MVA: SALLY, w/ final state particle 4 vectors	[-0.067, 0.067]
MVA: SALLY, w/ final state particle 4 vectors + 3 angular observables	[-0.062, 0.062]

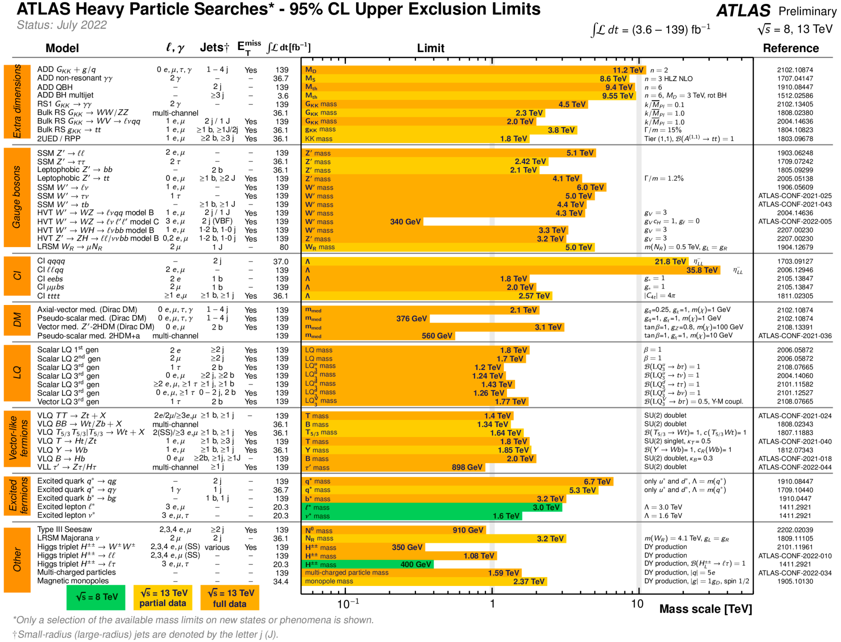
Preliminary results

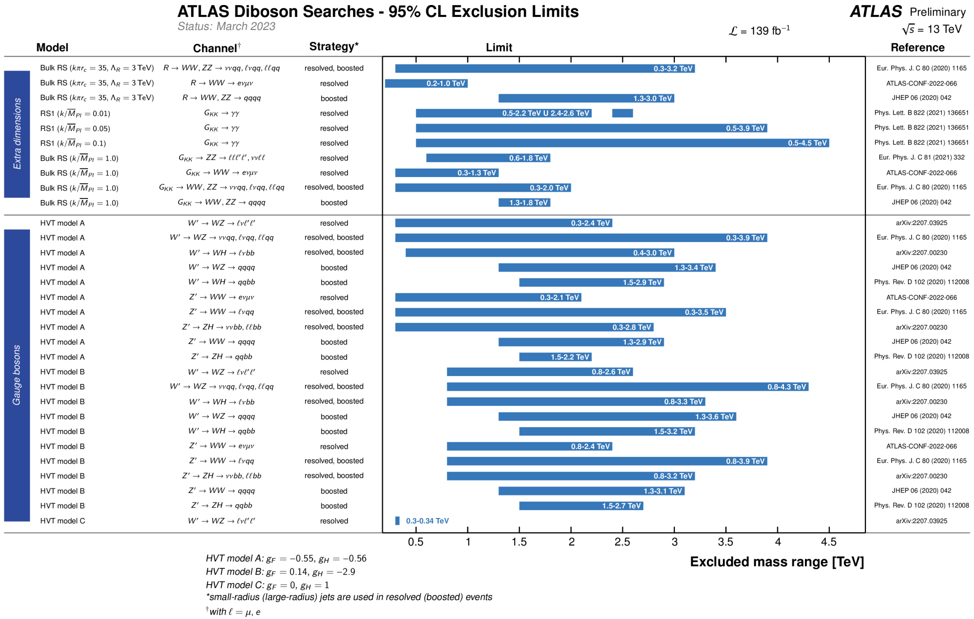
Exotics searches: a wide menu of searches



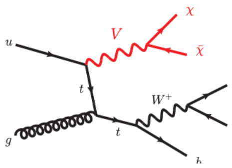


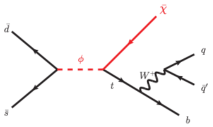
Vector-like quarks

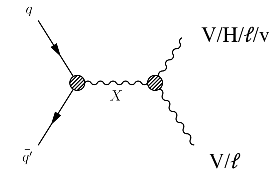




Diboson resonances

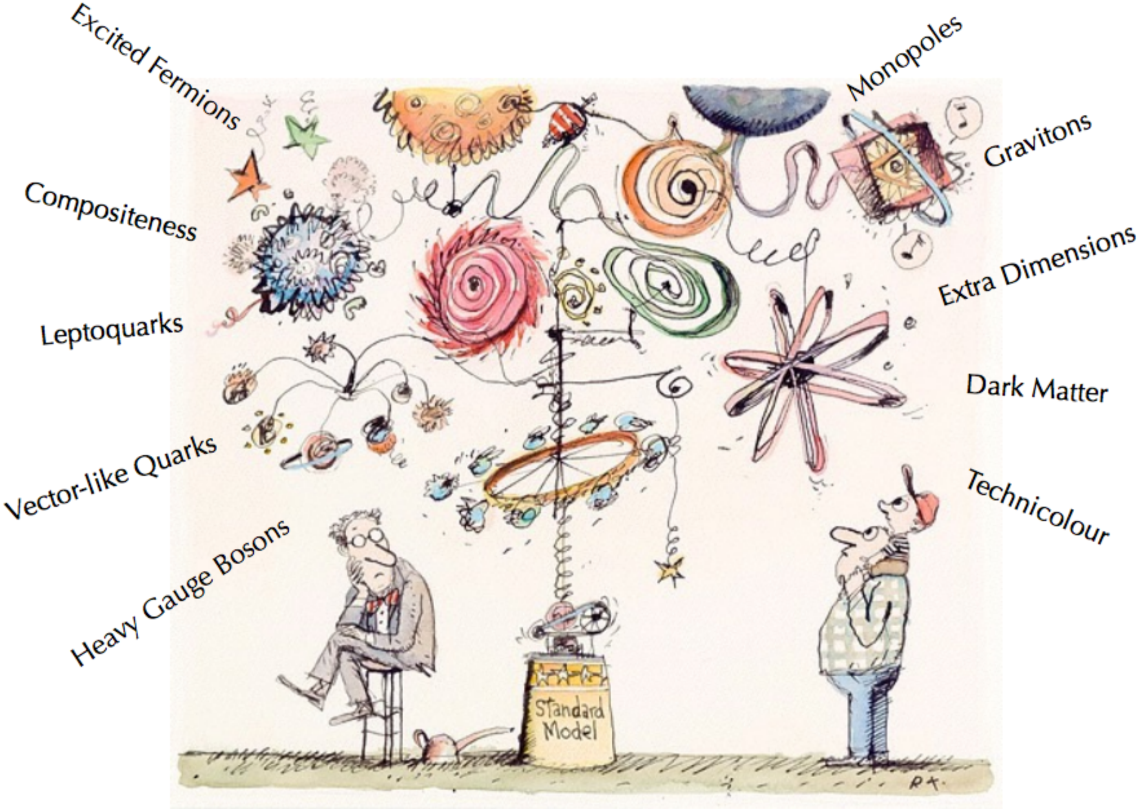






Dark matter

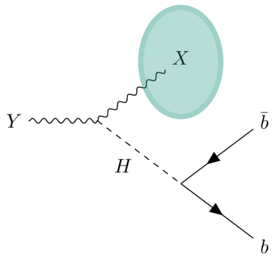
Too many to search for?



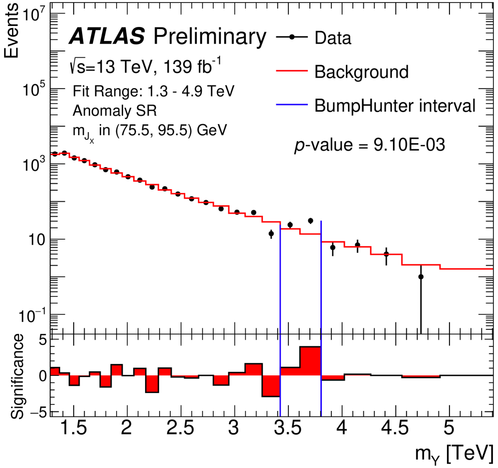
Exotics searches via anomaly detection

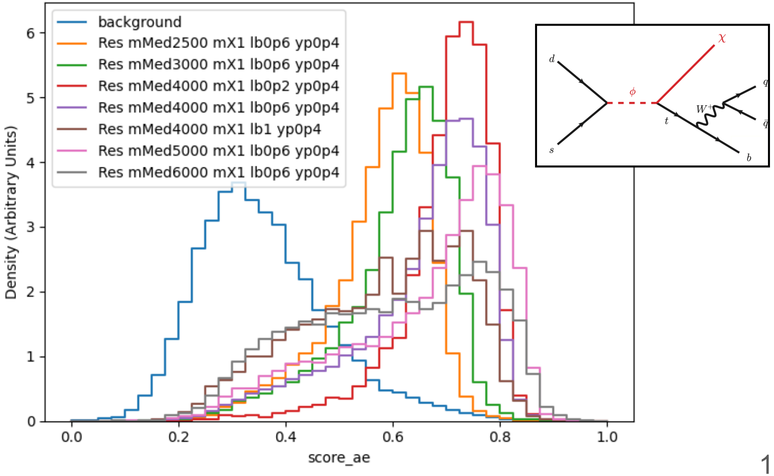
On the forefront of anomaly detection techniques

- Goal is to increase **generality of searches**.
- Mono-jet searches: train auto-encoder to learn SM background. Take reconstruction error as an **anomaly score**.
- $Y \to XH$ resonance search: "anomalous" X boson tagged via anomaly score, followed by bump-hunting in m_Y.



Preliminary results presented at ICHEP: ATLAS-CONF-2022-045

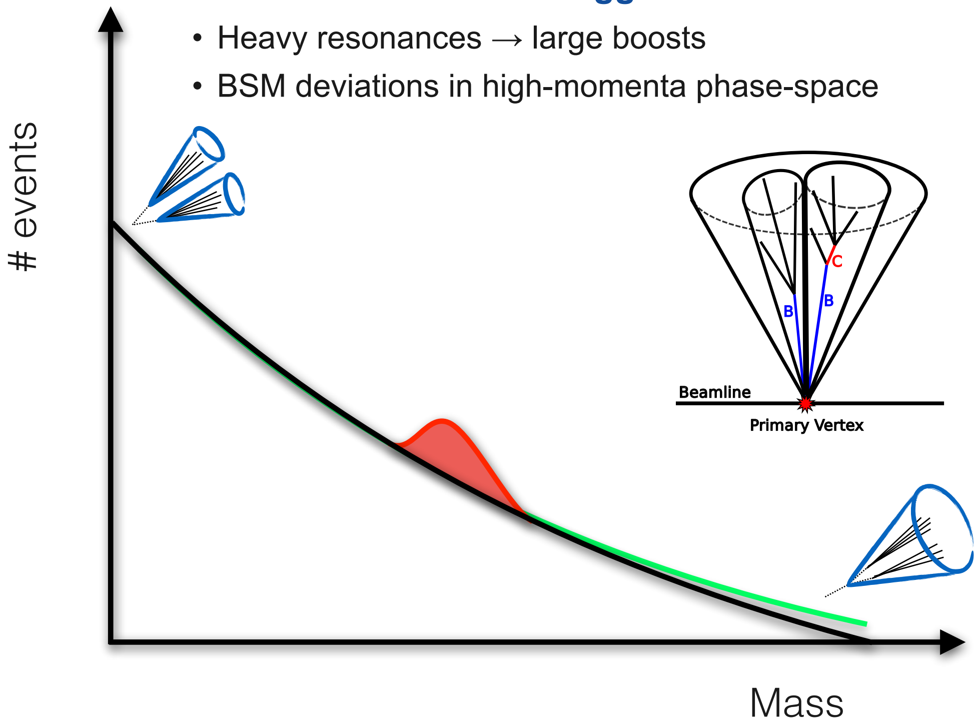


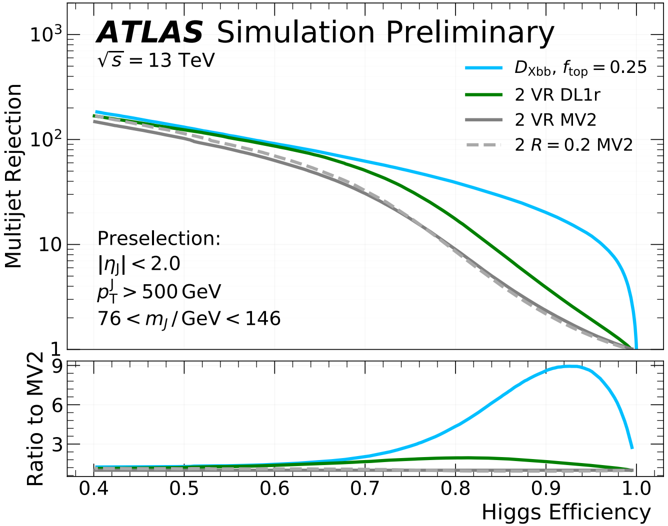


Improving b-jet and Higgs boson tagging

New boosted $H \rightarrow b\bar{b}$ taggers:

- Heavy resonances → large boosts
- BSM deviations in high-momenta phase-space





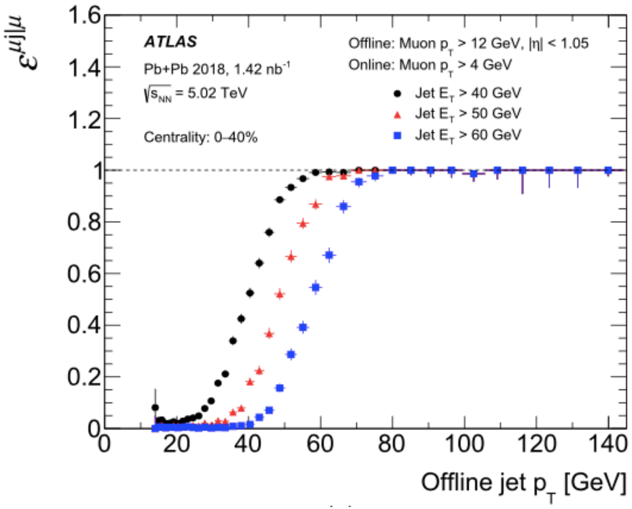
Differentiable secondary vertexing for b-tagging [new]

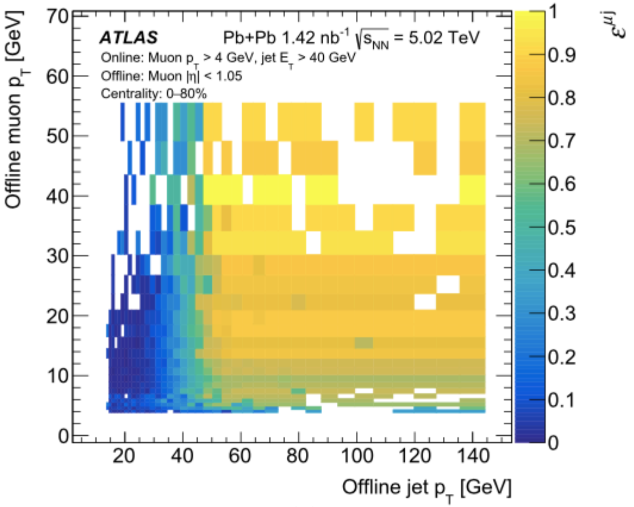
Introducing geometry information in ML based taggers

Improving b-jet trigger and tagging for heavy ions

Heavy flavour jet production in Pb+Pb collisions

- Measurement of nuclear modification factor of b-jets: probes of the Quark Gluon Plasma
- Development of **b-jet** and **muon-jet triggers**
- **NEW:** ML-based offline b-tagging in heavy ion collisions

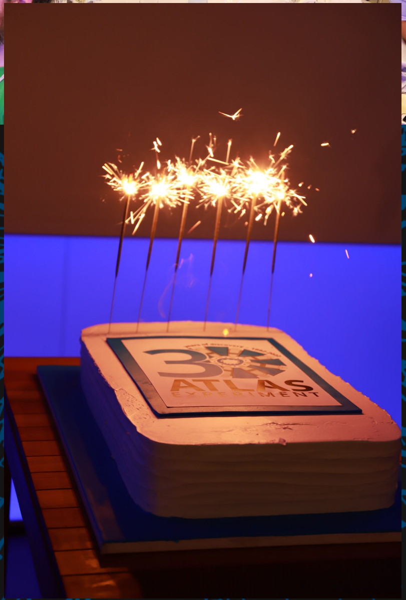




[2204.13530 (submitted to EPJC)](2204.13530)

Efficiency of *b*-jet trigger as a function of muon and jet p_T

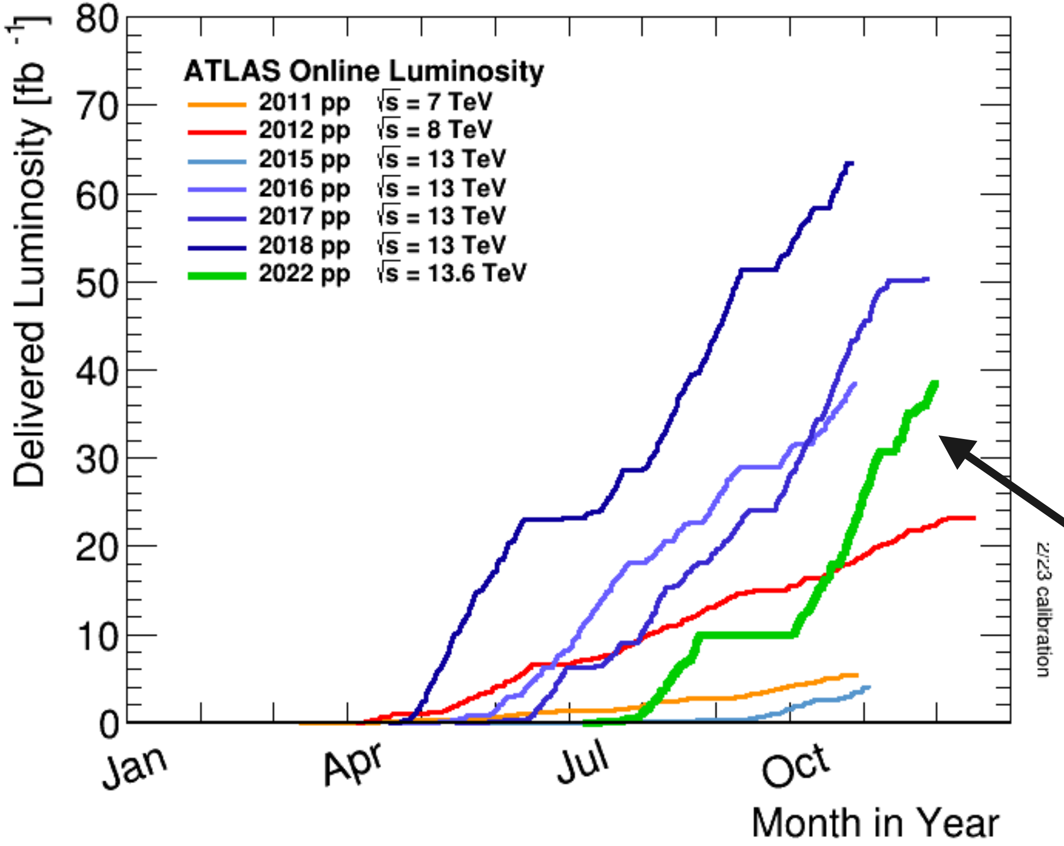
Last October we welcomed 250 members of ATLAS for a Collaboration Week in Lisbon



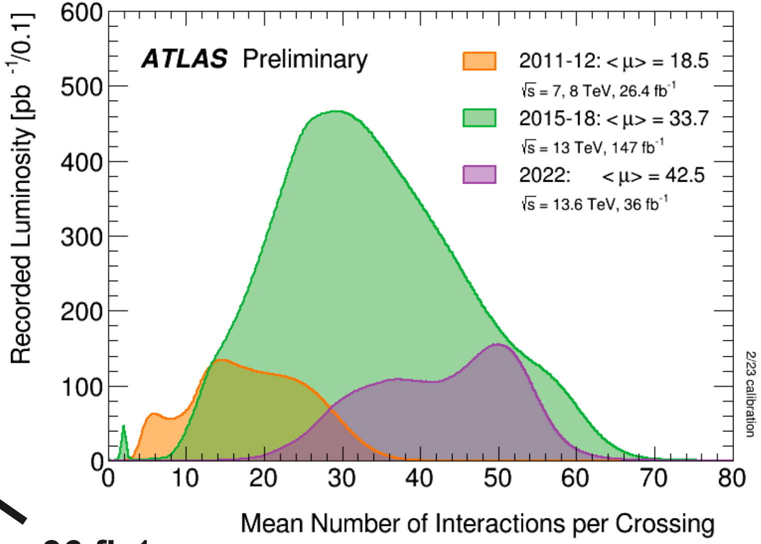
ATLAS WEEK

LISBON 10—14—OCTOBER——2022

Run 3 is restarting!

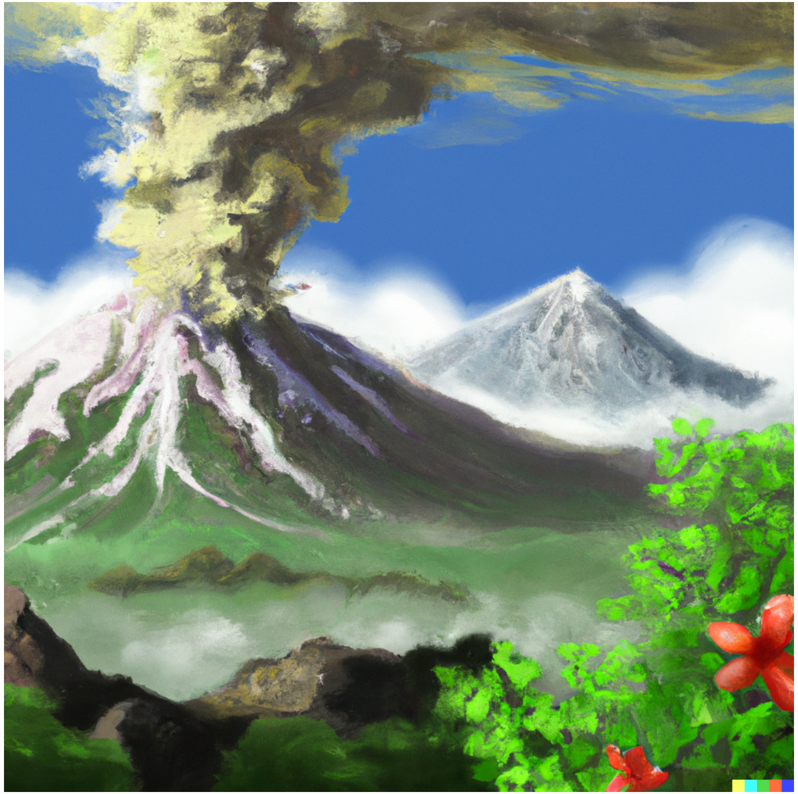


36 fb^{-1}



300 fb^{-1} projected by the end of Run 3 (2035)

Summary and conclusions



- From SM precision measurements, to probes of the quark-gluon plasma to direct searches for new physics, there is a wide physics program being carried out at LIP ATLAS.
- LIP is involved in the day-to-day detector operations, physics analyses and upgrade activities (more on this next).
- Looking forward to a successful Run 3 and to continue exploring all corners of the Standard Model and beyond.

Backup

Simulation-based inference

Score, $t(x)|_\theta = \nabla_\theta \log p(x|\theta)|_\theta$, is the statistically optimal observable in the vicinity of a parameter point θ (generally the SM, $\theta = 0$)

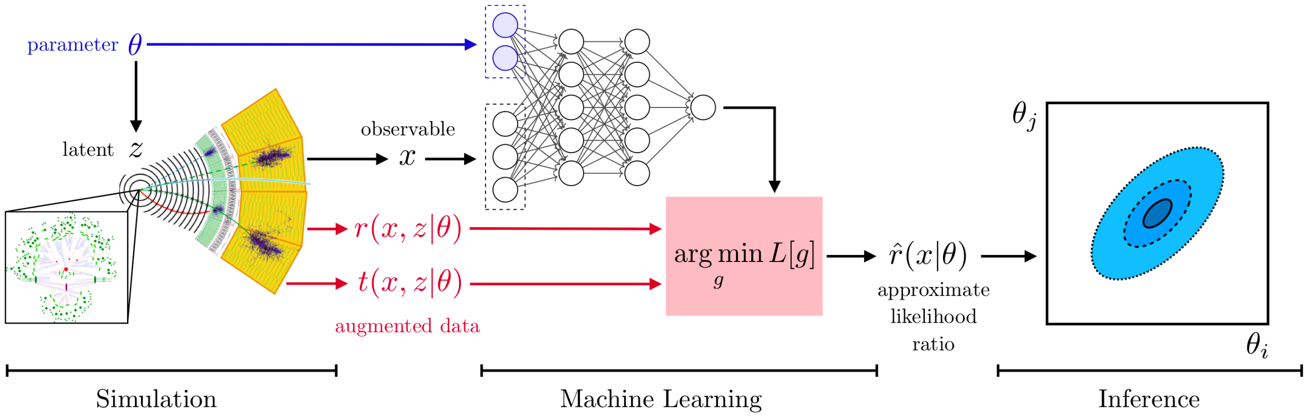
Idea: use the joint score $t(x, z_p|\theta)$ to approximate the score

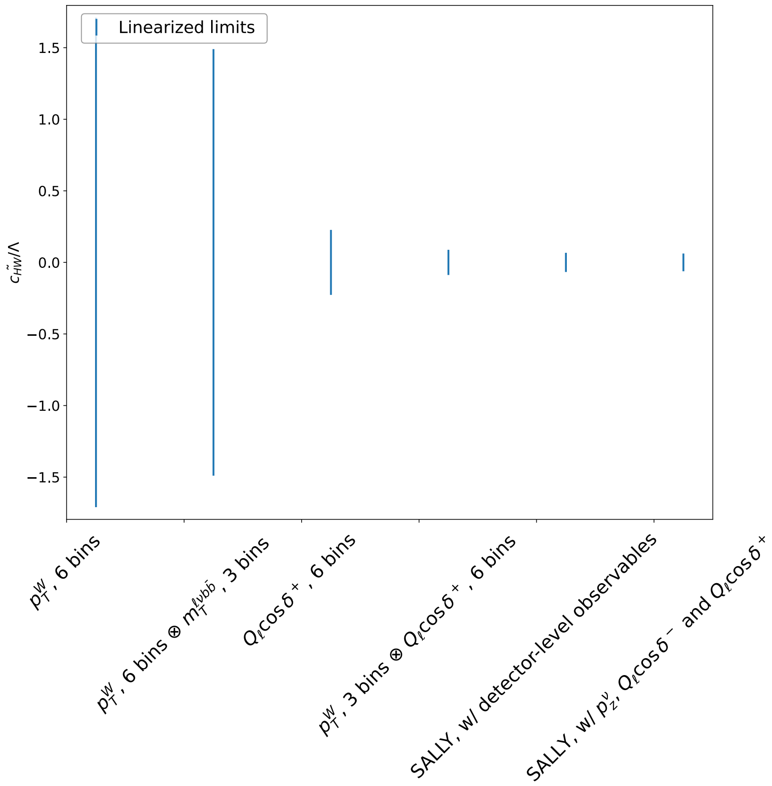
- used in analyses, but neglecting PS, had. and detector simulation ($z_p \equiv x$)

$$t(x, z_p) = \nabla_\theta \log p(z_p|\theta) = \frac{\nabla_\theta p(z_p|\theta)}{p(z_p|\theta)}|_\theta \approx \frac{\nabla_\theta |\mathcal{M}(z_p|\theta)|^2}{|\mathcal{M}(z_p|\theta)|^2} - \frac{\nabla_\theta \sigma(\theta)}{\sigma(\theta)}$$

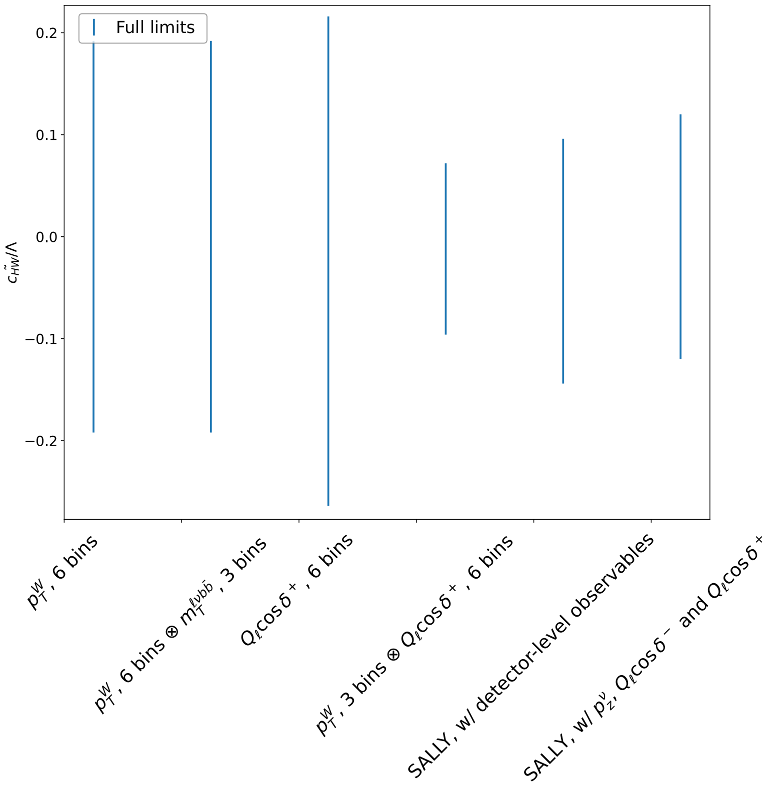
Alternative: use a NN with detector-level observables as inputs to extract $t(x|\theta)$, using joint score $t(x, z|\theta)$ in the loss

- SALLY: Score Approximates Likelihood LocallY





Linearized limits
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
$c_{H\tilde{W}}/\Lambda$
p_T^W, 6 bins
p_T^W, 6 bins ⊕ $m_T^{\ell\nu b\bar{b}}$, 3 bins
$Q_\ell \cos\delta^+$, 6 bins
p_T^W, 3 bins ⊕ $Q_\ell \cos\delta^+$, 6 bins
SALLY, w/ detector-level observables
SALLY, w/ p_z^ν, $Q_\ell \cos\delta^-$ and $Q_\ell \cos\delta^+$



Full limits
0.2
0.1
0.0
−0.1
−0.2
$c_{H\tilde{W}}/\Lambda$
p_T^W, 6 bins
p_T^W, 6 bins ⊕ $m_T^{\ell\nu b\bar{b}}$, 3 bins
$Q_\ell \cos\delta^+$, 6 bins
p_T^W, 3 bins ⊕ $Q_\ell \cos\delta^+$, 6 bins
SALLY, w/ detector-level observables
SALLY, w/ p_z^ν, $Q_\ell \cos\delta^-$ and $Q_\ell \cos\delta^+$