Upper limits and bands for an interference search for Higgs bosons

Interference searches



Statistical treatment of interference

> Observable is mass of $t\bar{t}$ pair (sensitive to interference) > Likelihood is quadratic in the parameter of interest (POI= $\sqrt{\mu}$)

$$L = \prod_{\text{bins}} \mathscr{P}(n \mid \nu), \nu = \mu S + \sqrt{\mu}I + B$$

- Interference template has negative bins
- Offset method: sum an offset histogram and subtract it as a counter term

$$> \nu = \mu S + \sqrt{\mu}(I+O) - \sqrt{\mu}O + I$$

- > Double minimum feature in NLL scan
 - > Independent of offset
 - > Can cause upper limit on $\sqrt{\mu}$



Variations on POI upper limits

>*N* ocontours:



Toy model comparison of bands and contours

- > Band edges are the correct way to report upper limit variations
- Contours coincide with the band edges if the Poisson expectations depend linearly on POI
- > Define two toy models with two Poisson bins each:
- > Linear model : $\nu_1 = \mu + b_1$, $\nu_2 = \mu + b_2$
- > Quadratic model : $\nu_1 = \mu^2 + b_1$, $\nu_2 = \mu + b_2$ (mimicking interference)
- > In the quadratic model, calculating A_N by solving the equation

>Widely used in ATLAS

- > Upper limit on POI with Asimov dataset A_N representing the $N\sigma$ fluctuation under the B-only hypothesis
- $>A_N$ is supposed to represent the dataset yielding a MLE of the POI $N\sigma$ far from its expected value under the B-only hypothesis
- > Calculated by finding value of POI such that profile likelihood ratio of B-only Asimov is N^2 , i.e. $t_{\mu}(A_0) = N^2$

$>N\sigma$ bands:

- > New recommended approach
- > Interval of POI values with exclusion rate between $\Phi(-N)$ and $\Phi(N)$ [Standard Gaussian CDF]
 - > Exclusion rate is the probability under the B-only hypothesis of the POI being excluded at 95% CL
- > Band edges calculated by using values of the test statistics yielding

$$p_{alt} = \int_{t_{\mu}}^{\infty} f\left(x \mid b - \text{only}\right) dx = \Phi(\pm N)$$

$t_{\mu}(A_0) = N^2$ does not give the $N\sigma$ variation on the MLE $\hat{\mu}$ > Limit contours do not approximate band edges



References

- > [1] LHC Dark Matter Working Group: Next-generation spin-0 dark matter models, Physics of the Dark Universe, Volume 27, 2020
- > [2] Search for Heavy Higgs Bosons A/H Decaying to a Top Quark Pair in pp Collisions at $\sqrt{s}=8$ TeV with the ATLAS Detector, ATLAS Collaboration, Phys. Rev. Lett. 119, 191803
- > [3] Will Buttinger

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