CP properties in 2HDM

Test of CP properties

- Suppose the signal at 125 GeV, h(125), actually consists of two states, a CP-even one and a CP-odd one. Consider the benchmark scenario in the 2HDM proposed by the LHCHiggsXSWG (see next slide)

- Apply the usual methods for testing CP properties to this scenario, in particular angular distributions in h(125) → 4 leptons. Can one distinguish the above scenario from a pure CP-even state in this way?

- Which other observables could one use to experimentally detect the presence of two degenerate states at 125 GeV?

Test of CP properties, 2HDM benchmark scenario

BP1: *Howard Haber, Oscar Stål*
Phenomenological benchmarks for the CP-conserving 2HDM with softly-broken Z_2-symmetry. https://twiki.cern.ch/twiki/pub/LHCPhysics/LHCHXSWG3Benchmarks2HDM/HH_OS_2HDM_Benchmarks.pdf

Scenario C ($\mathcal{CP}$-overlap)

In this work we have restricted ourselves to benchmarks for a 2HDM Higgs sector with $\mathcal{CP}$-conservation. Nevertheless, we consider one scenario where overlapping $\mathcal{CP}$-odd and $\mathcal{CP}$-even Higgs bosons simultaneously have mass close to 125 GeV [13]. Since the $\mathcal{CP}$-odd Higgs boson does not couple to vector bosons at tree level, there are surprisingly few channels where it is possible to distinguish this scenario from the case with a single light Higgs, h. The most important channel where the $\mathcal{CP}$-odd contribution to the total rate could reach $\mathcal{O}(1)$ is through gluon ($b\bar{b}$) fusion, followed by the decay $h/A \to \tau^+\tau^-$. Input parameters are given in the physical basis. Note that the choice of $\lambda_5 = 0$ in this scenario is equivalent to $m_{12}^2 = \frac{1}{2} m_A^2 \sin 2\beta$.

Scenario C ($\mathcal{CP}$-overlap)								
	m_h	m_H	m_A	$m_{H^\pm}$	$c_{\beta-\alpha}$	λ_5	$\tan\beta$	Type
C1	125	300	125	300	0	0	1 . . . 10	I
C2	125	300	125	300	0	0	1 . . . 10	II

2HDM

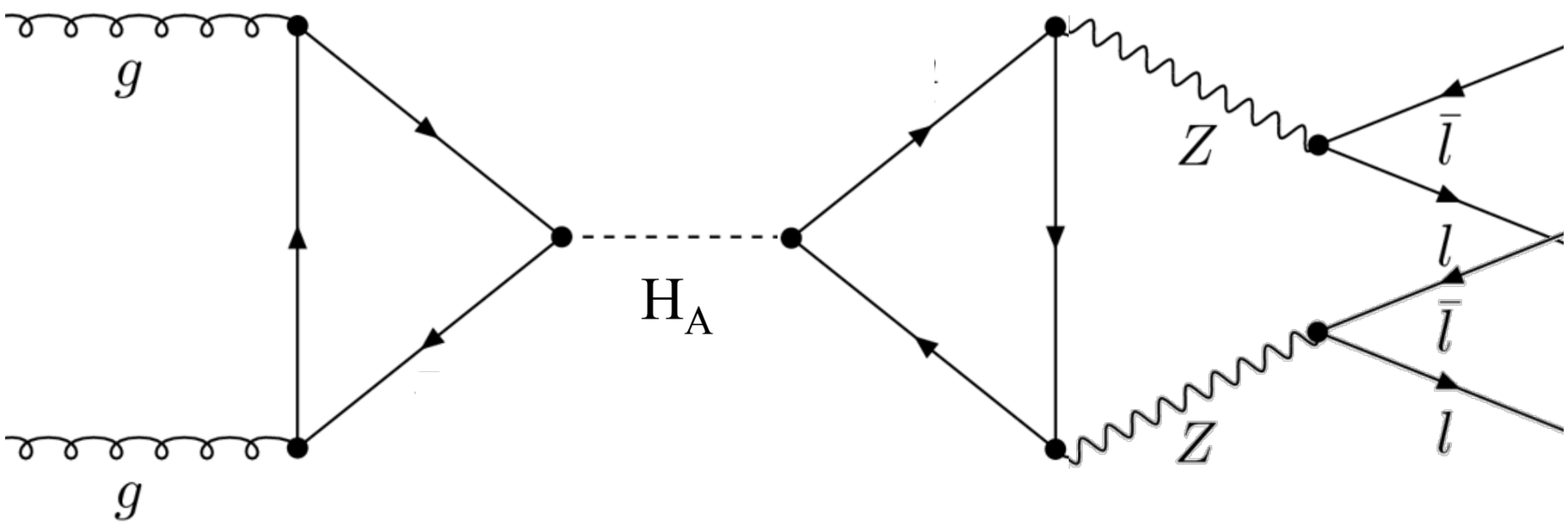
- SM with extra Higgs Doublet, leading to 5 bosons (h,H,A,$H^{\pm}$)
- Free parameters: Masses, Ratio of vacuum expectation values (tan β), Mixing angle between h,H (α)
- Alignment limit: cos(β - α) = 0: h is SM-like
- Our case: h,A mass degenerate (125 GeV) and alignment limit
  - Type I: only one doublet couples to fermions (Fermiophobic)
  - Type II: one doublet couples to down quarks, charged leptons; other couples to up quarks (MSSM-like). Coupling ratio: tan β

Properties of a pseudoscalar Higgs

- Spin 0, pseudoscalar interaction with fermions
- Parity conservation: coupling to vector bosons allowed only at loop level via fermions
- In type I: All fermionic interactions suppressed by $\tan^2 \beta$
- In type II: Up-quarks coupling suppressed by $\tan^2 \beta$ compared to down-quarks, leptons
- Two signatures:
  - Angular dependence in $h \rightarrow VV$
  - Branching fractions of $h \rightarrow bb$ or $h \rightarrow \tau\,\tau$

Angular dependence

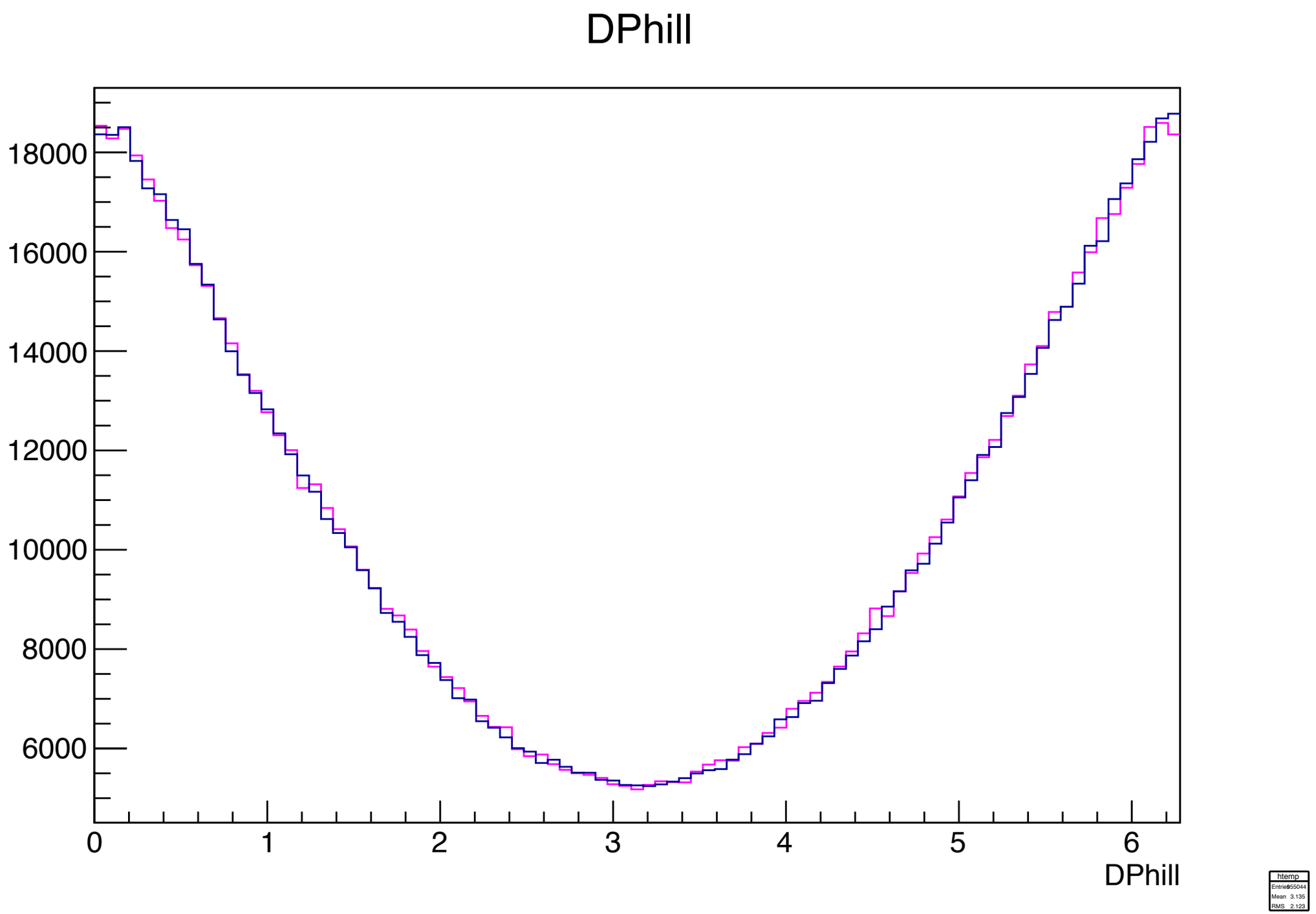
- For h,A → VV→ 4 ℓ, angular distributions of final state leptons dependent on CP-state



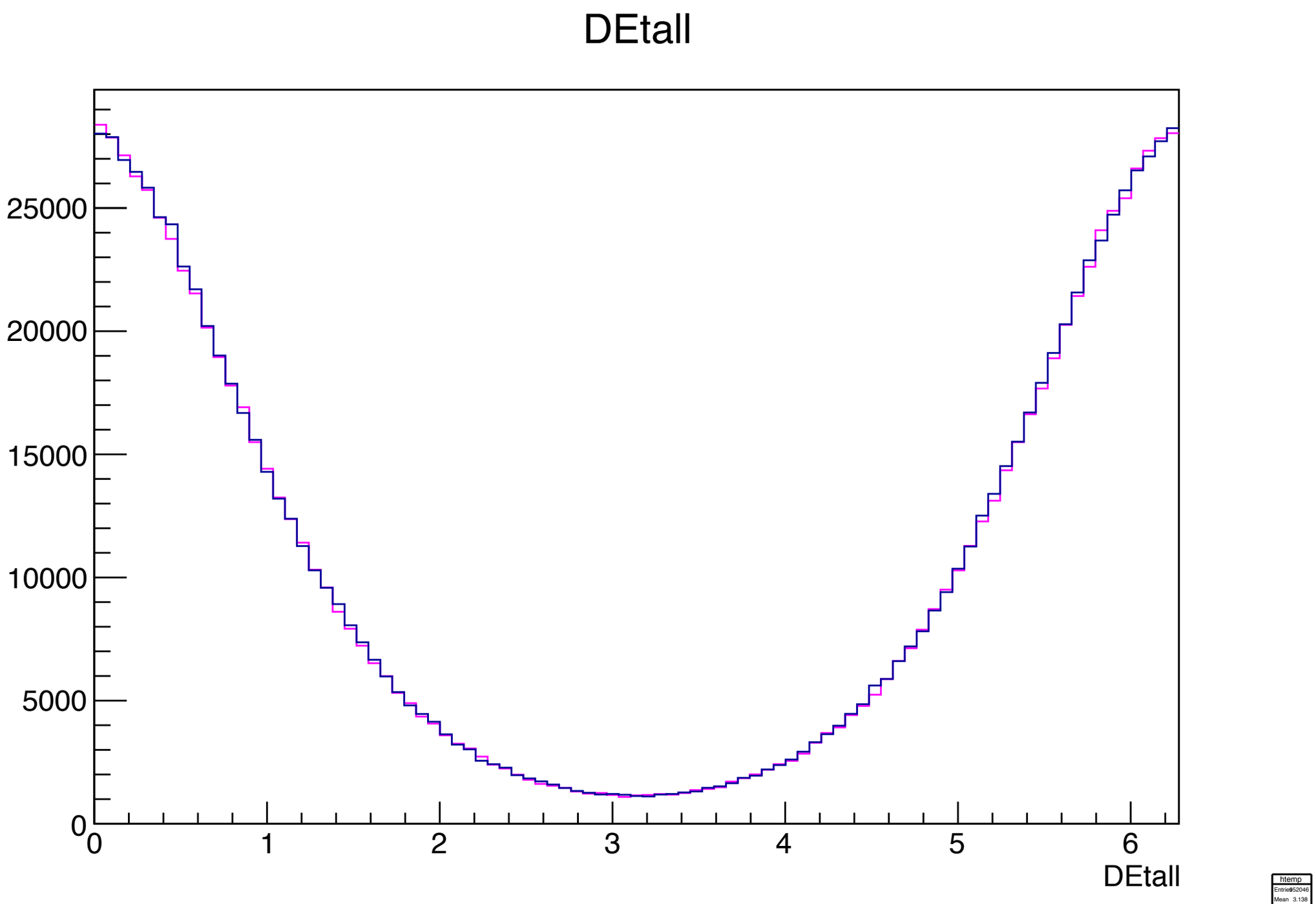
MadGraph

- Generate events for both CP even and CP odd Higgs
- In this case h,A → WW→ 2ℓ2v

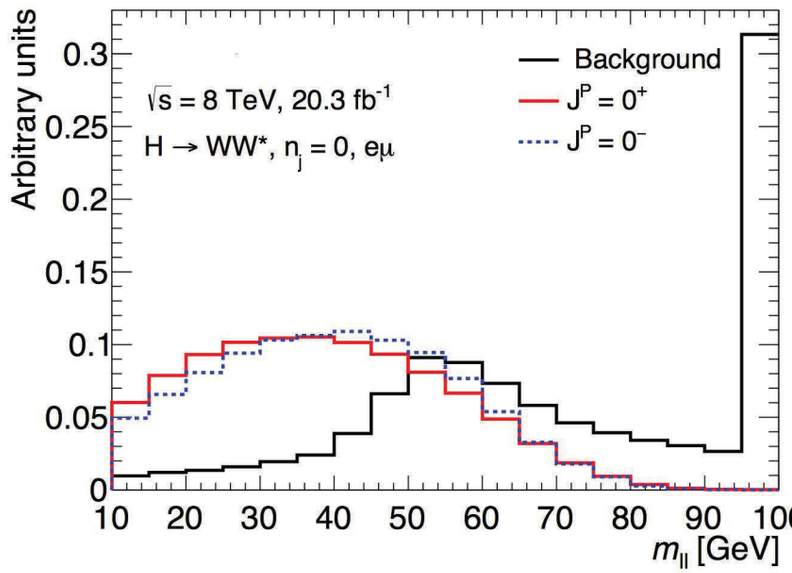
Angular distributions
h,A → WW

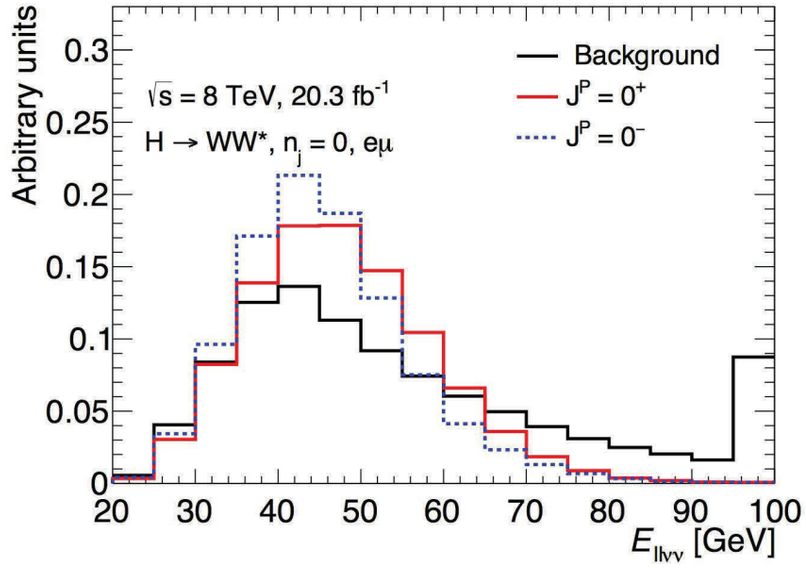


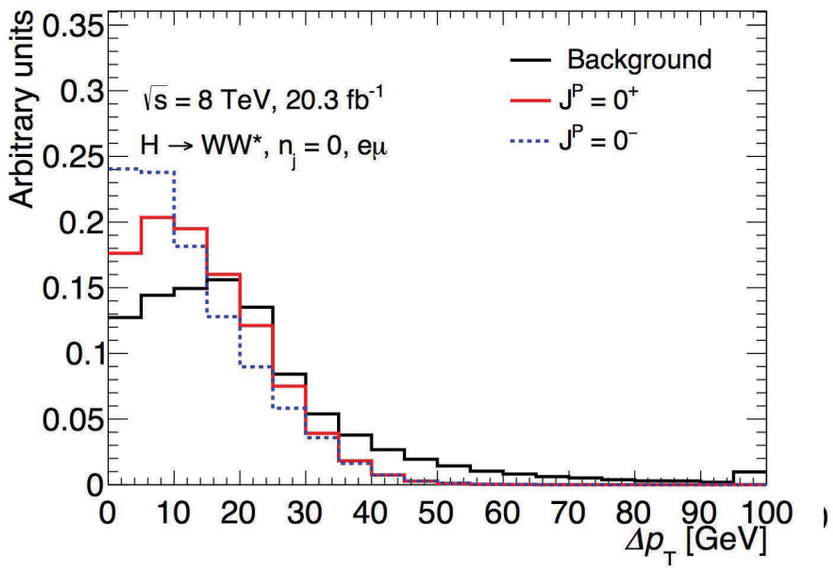
Angular distributions
h,A → WW

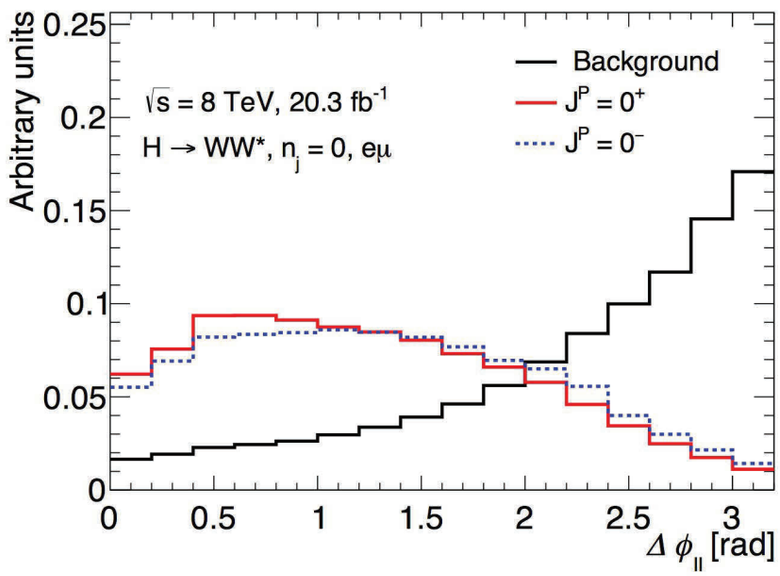


Distributions
h,A → WW





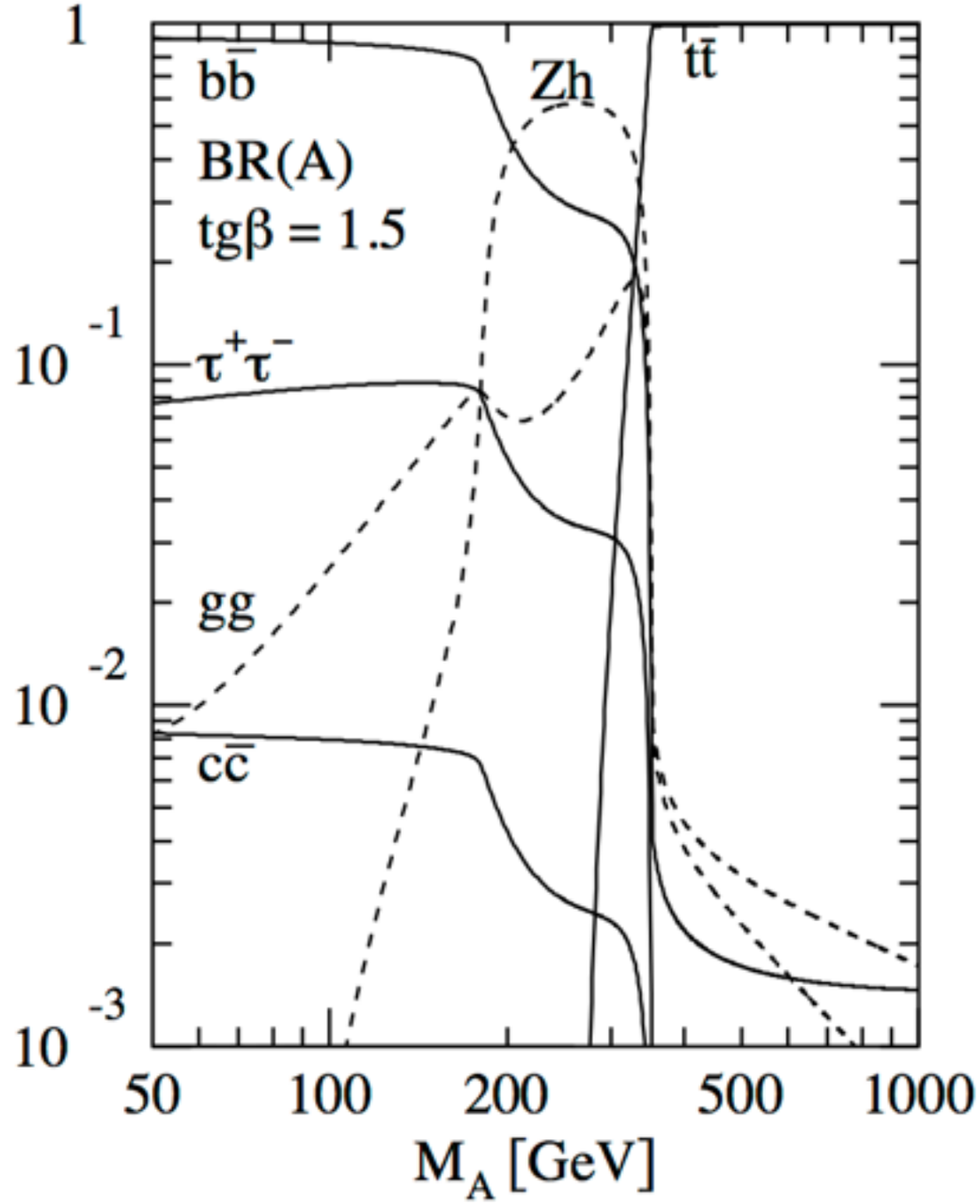




Decay modes of a pseudoscalar Higgs

- Loop contributions from $A \rightarrow VV$ possible at O(0.1%)

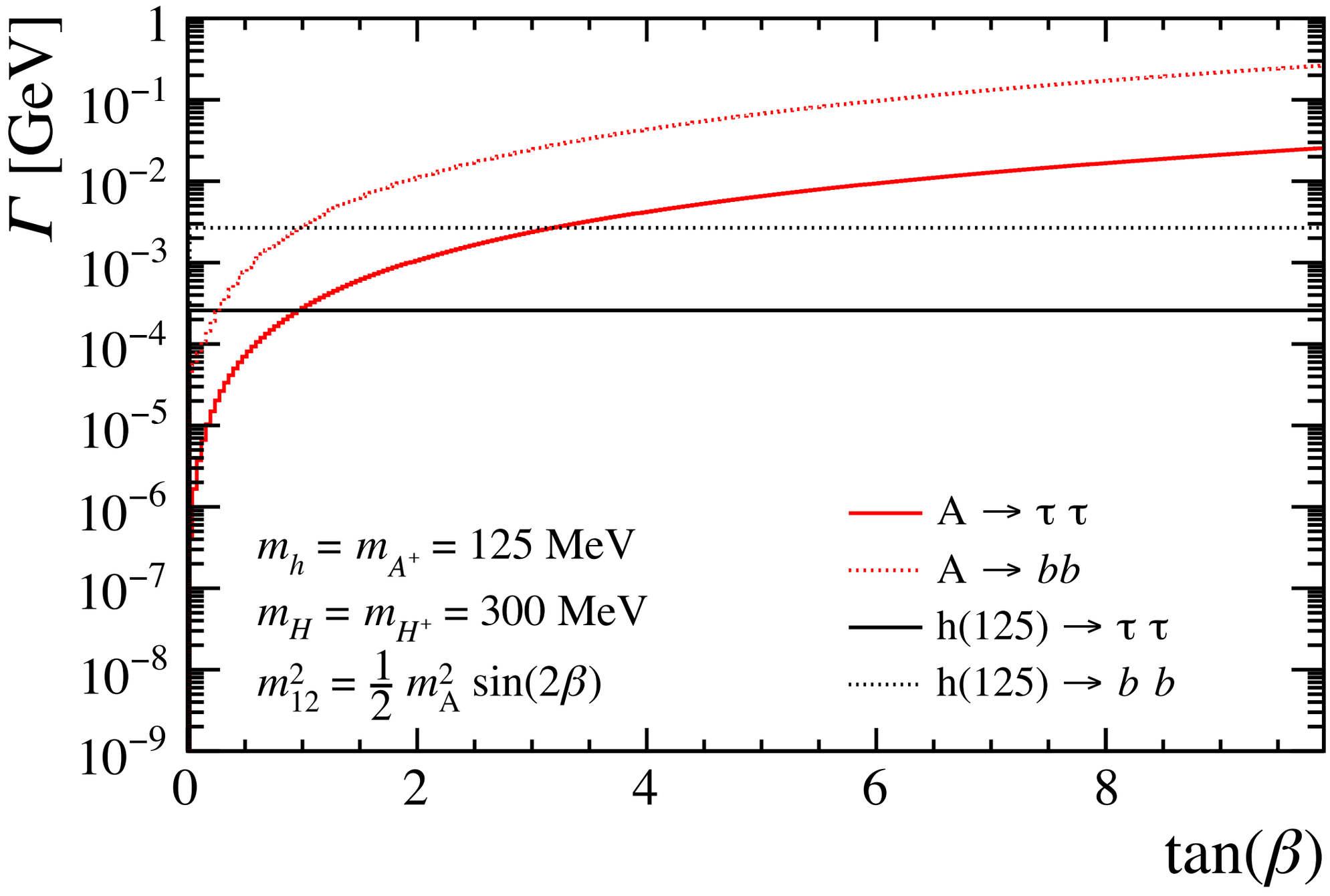
- At tree level $h \rightarrow bb$ and $h \rightarrow \tau\,\tau$ the most promising candidates



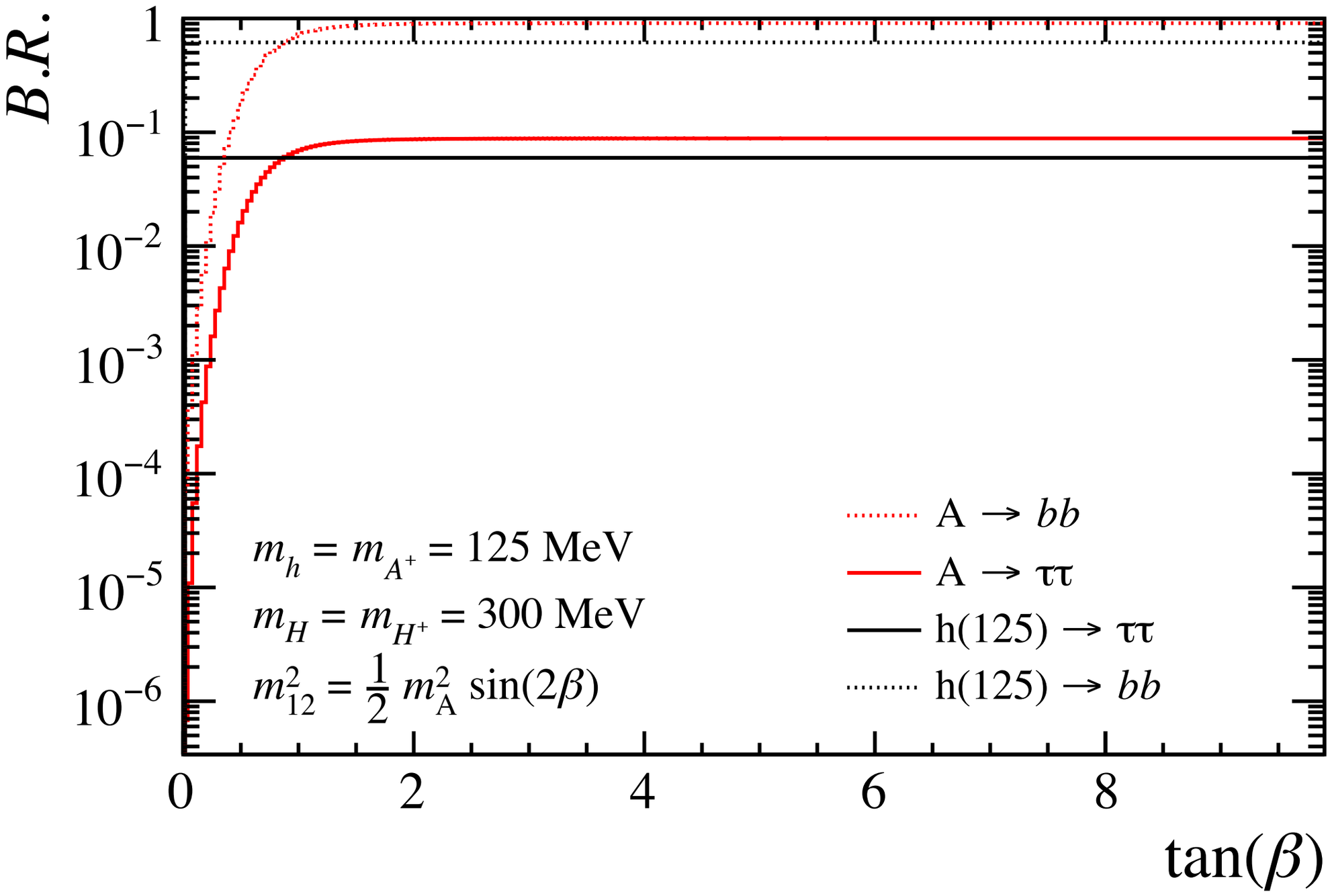
2HDMC

- Package for C++ to calculate branching fractions and decay widths for 2HDM
- See https://2hdmc.hepforge.org
- Used output to plot BR, decay width as function of tan β

Decay widths of h,A

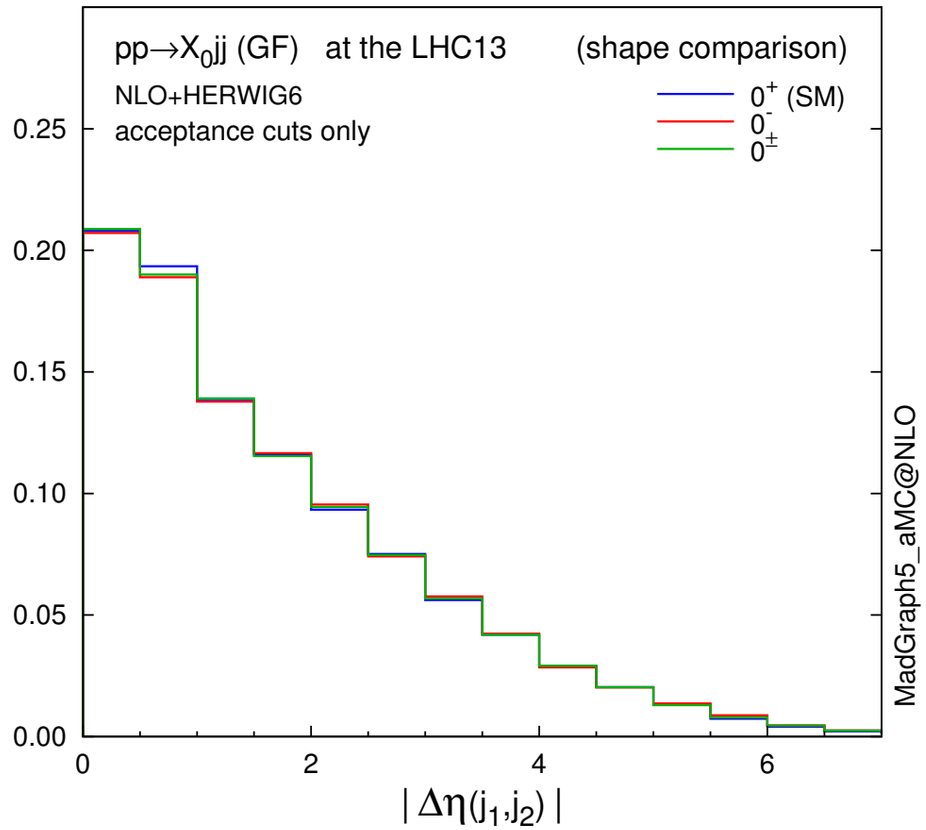


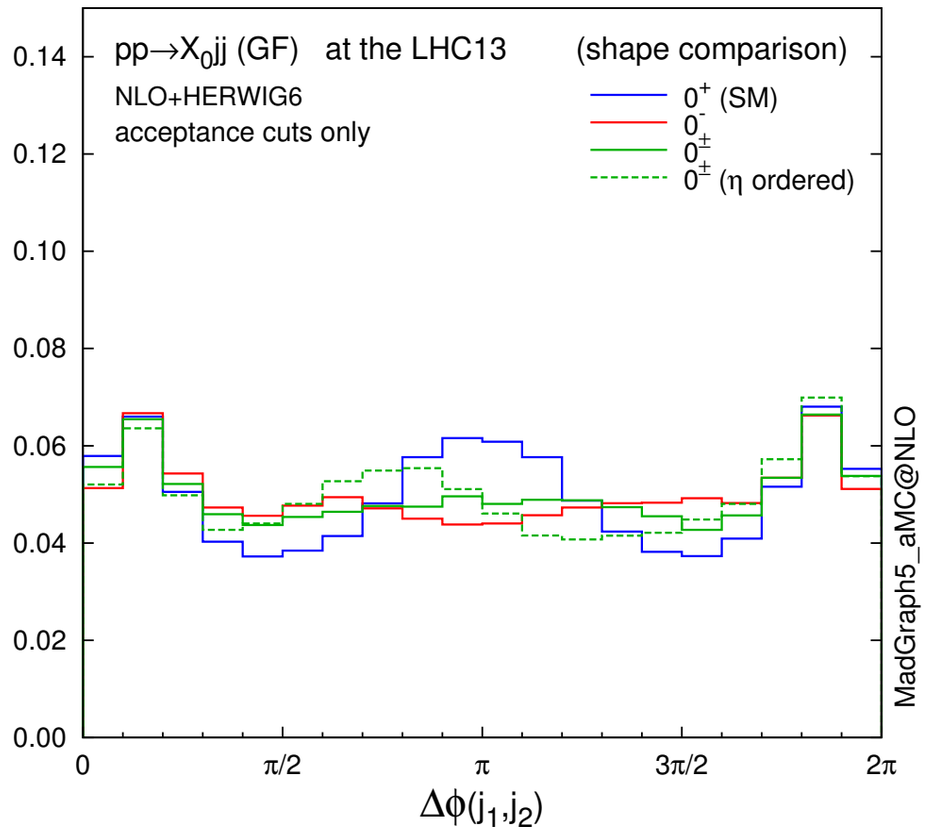
Branching Ratios of h,A



ggF+2jets

- When concerning two jets a clear separation in angular jet distributions between scenario's is possible





Conclusion

- Angular distributions between leptons do not show a clear separation between even and odd

- Deviation in bb or tau tau branching fraction measurements could be explained by pseudoscalar contribution

- Angular distributions between jets do show a separation between even and odd

“Type a quote here.”

–Johnny Appleseed