Determination of the CP quantum numbers of neutral Higgs bosons in the tau decay channels at the LHC

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1. Introduction
2. Determination of CP$= \pm 1$ states of Higgs bosons
3. Distinguish Higgs boson of CP-mixture
4. Conclusion

1.) Introduction

- LHC may discover one or several neutral boson resonances Φ including

$$pp \to \Phi \to \tau^+ \tau^-$$

- Spin may be extracted from polar angle distribution of τ's

- if spin-zero $\to$ CP quantum number ?

  MSSM: h^0, H^0, A^0 : scalar, pseudoscalar ?
  especially if mass degeneracy: CP mixture?

- 1. $\mathcal{O}_1 = s_{\tau^-} \cdot s_{\tau^+} \quad \to \quad$ CP $= +1$ or CP $= -1$

  2. $\mathcal{O}_2 = \hat{k}_{\tau^-} \cdot (s_{\tau^-} \times s_{\tau^+}) \quad \to \quad$ test if state of undefined CP

  (Bernreuther, Brandenburg, Flesch, '97,'98)

2.) Determine CP$= \pm 1$ states of Higgs bosons

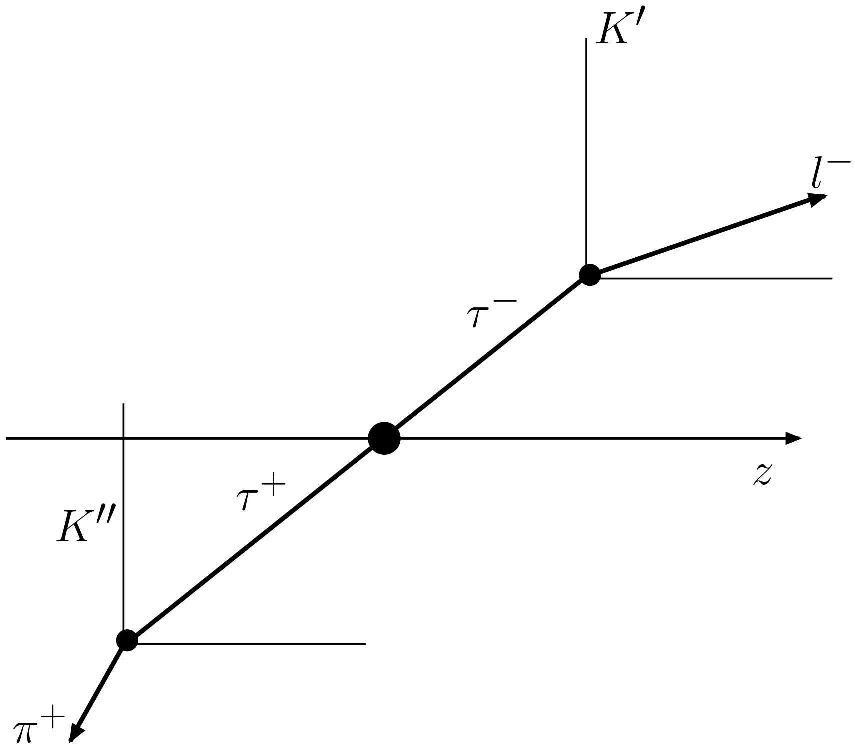
1.) $\mathcal{O}_1 = s_{\tau^-} \cdot s_{\tau^+}$

Φ scalar, $J^{PC} = 0^{++}$, $\rightarrow$ ${}^3P_0$ state $\rightarrow$ $< s_{\tau^-} \cdot s_{\tau^+} > = \frac{1}{4}$

Φ pseudoscalar, $J^{PC} = 0^{-+}$, $\rightarrow$ ${}^1S_0$ state $\rightarrow$ $< s_{\tau^-} \cdot s_{\tau^+} > = -\frac{3}{4}$

- Consider τ decays: $\tau^- \rightarrow \pi^- \nu_\tau,\ l^- \nu_\tau \bar{\nu}_l,\ \ldots$
  $\{a, b\} = \{l, \pi, \rho, \ldots\}$

$$pp \rightarrow \Phi \rightarrow \tau^+ \tau^- \rightarrow a(p_a) + \bar{b}(p_b)$$



$\rightarrow$ $\mathcal{O}_1$ propagates into distribution of

$\cos(\phi_{ab})$ with $\phi_{ab} = \angle(\hat{\vec{q}_a}, \hat{\vec{q}_b})$

2.) Numerical Results, LO

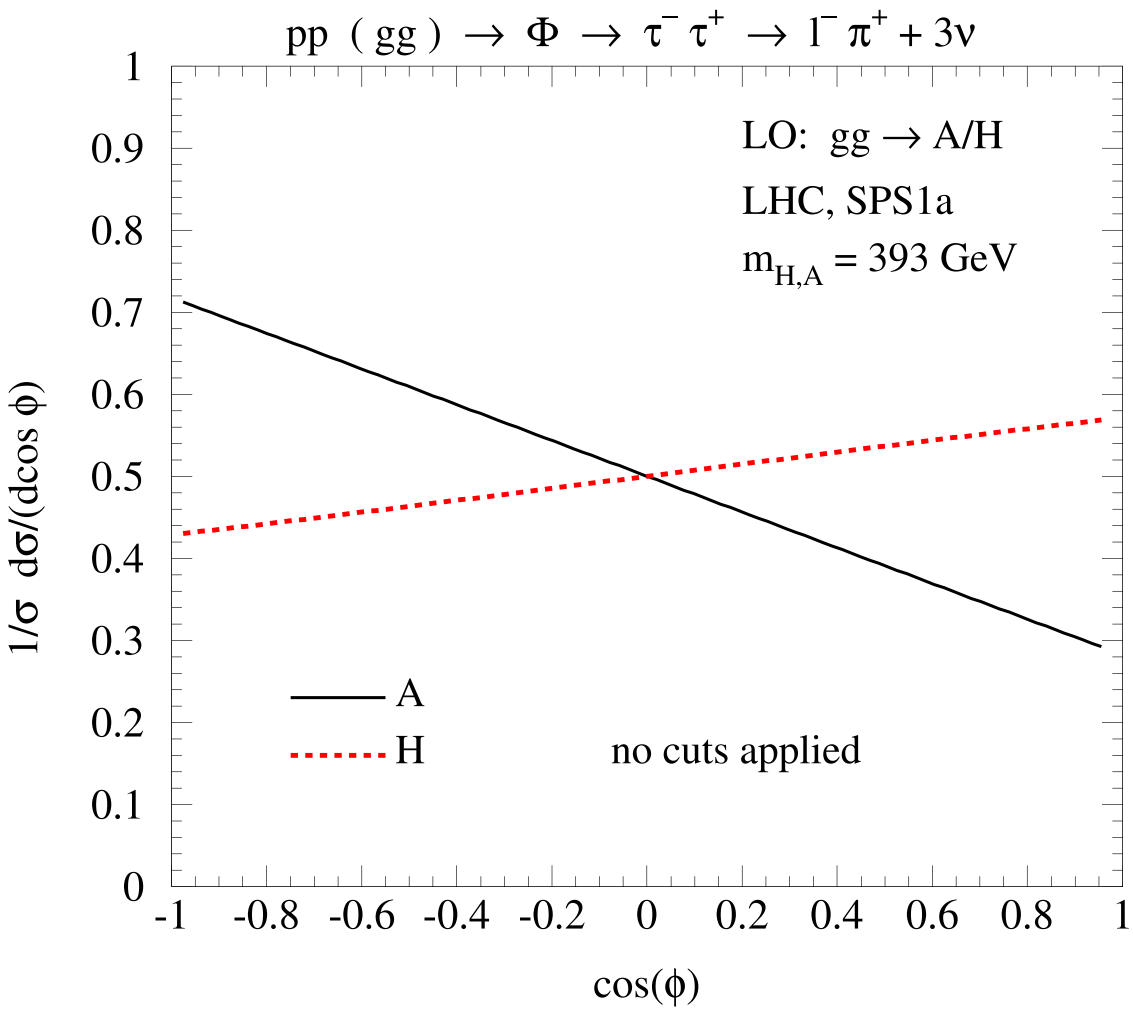
$$\frac{1}{\sigma_{ab}}\frac{d\sigma_{ab}}{d\cos\phi_{ab}} = \frac{1}{2}(1 - D_{ab}\cos\phi_{ab})$$

with

$$D_{ab} = \frac{4}{3}c_a c_b < s_{\tau^-} \cdot s_{\tau^+} >$$

e.g.

$\tau\tau \to$	πl	ρl
$\Phi(0^{++})$:	-0.11	-0.05
$\Phi(0^{-+})$:	0.33	0.15



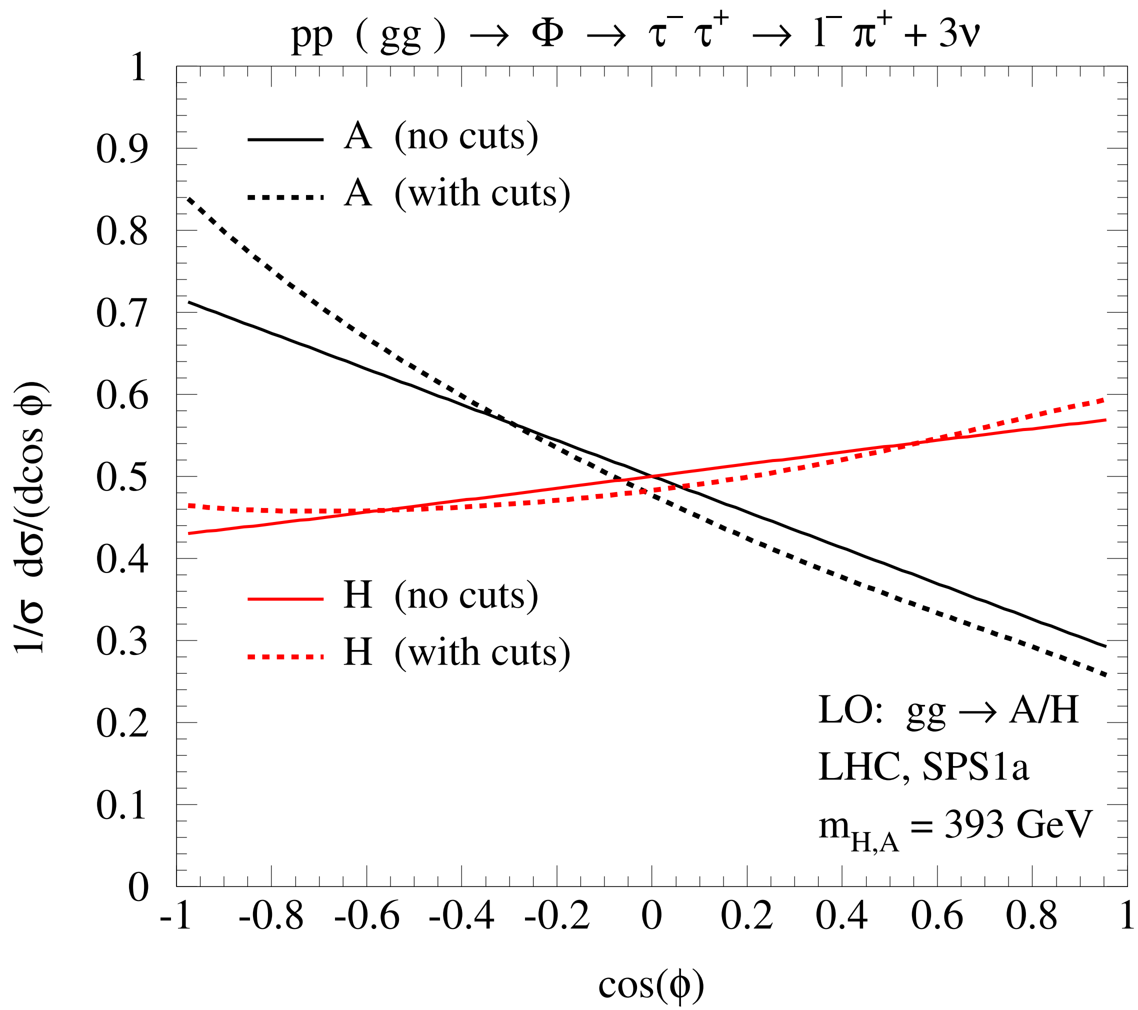
2.) Numerical Results at LO: Detector cuts

- Effect of detector cuts:

$p_{Tl} > 20$ GeV

$p_{T\pi} > 40$ GeV

$\eta_{l,\pi} \leq 2.5$



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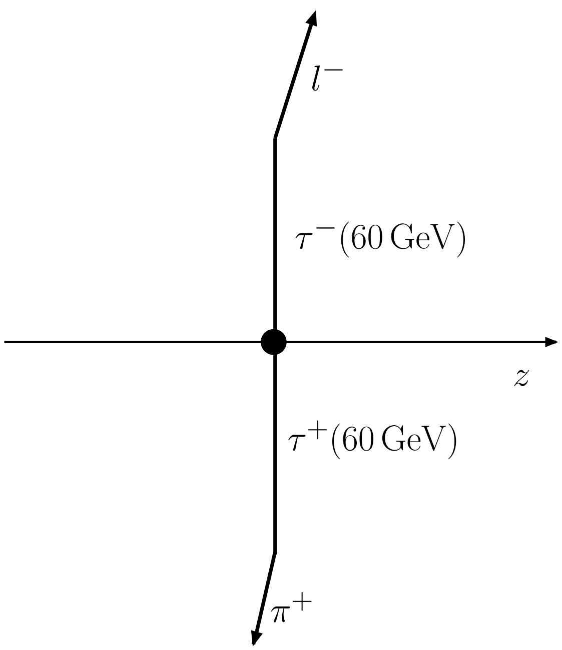
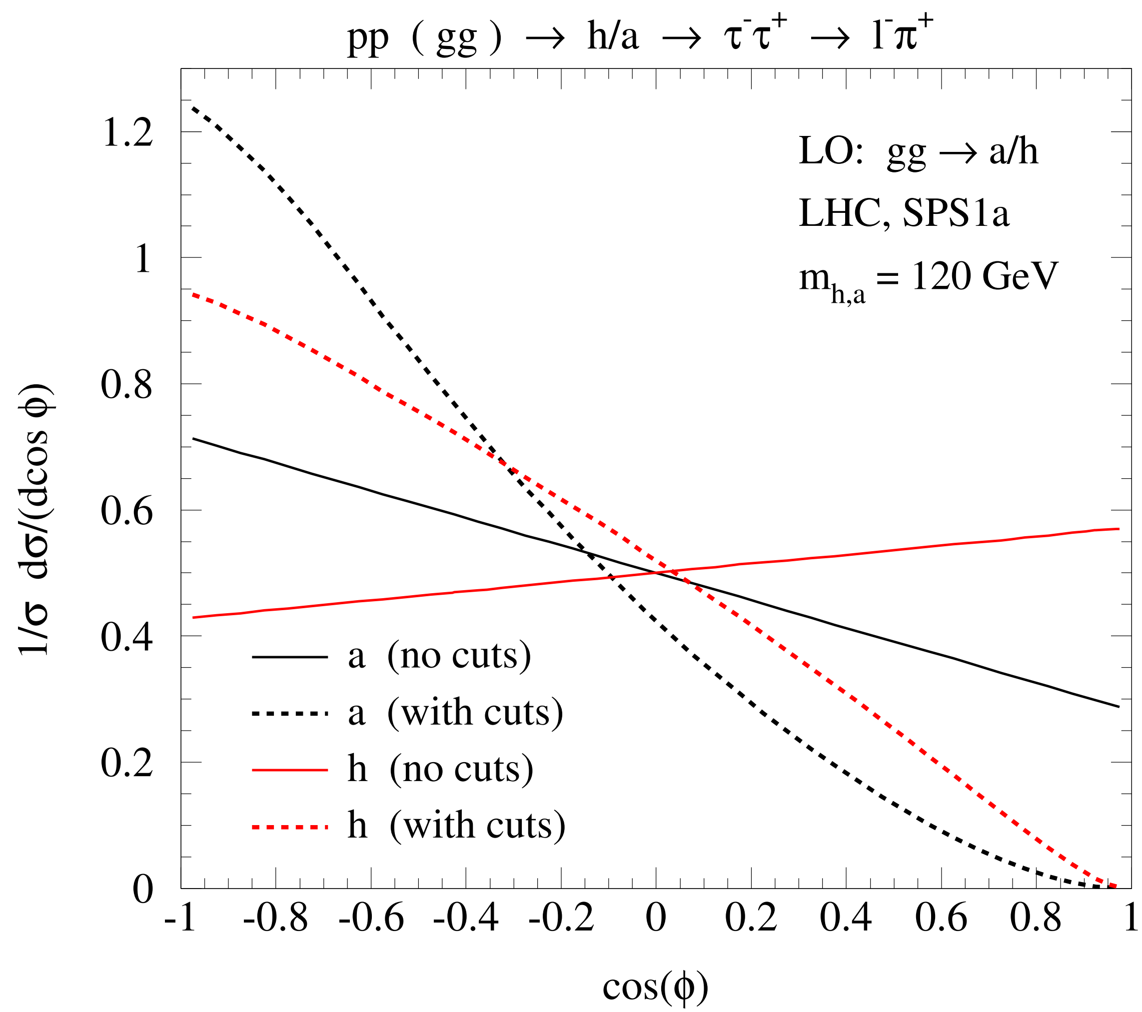




2.) NLO QCD corrections

- Partonic $\tau^+\tau^-$ production process:

$$|\overline{M}_{gg\to\Phi\to\tau\tau}|^2 \quad = \quad Tr\left[R_{gg\to\Phi\to\tau\tau}\big(\rho^{\tau^+}\otimes\rho^{\tau^-}\big)\right]$$

- factorizes for QCD-corrections

$$|\overline{M}_{gg\to\Phi\to\tau\tau}|^2 \quad = \quad |\mathcal{T}(gg\to\Phi)|^2|D^{-1}(\Phi)|^2\cdot Tr\left[\widetilde{R}_{\Phi\to\tau\tau}\big(\rho^{\tau^+}\otimes\rho^{\tau^-}\big)\right]$$

- Use effective Higgs-Gluon interaction (top-quark, squarks, gluinos integrated out)

$$\mathcal{L}_{eff} \quad = \quad \frac{-1}{4v}\,\Phi\,G^a_{\mu\nu}G^{a,\mu\nu}\cdot C^i$$

$$C_{SM} \quad = \quad \sum_{n=1}^{4} C^{(n)}_{SM}\cdot\left(\frac{\alpha_s}{\pi}\right)^n$$

Spira et al.; Chetyrkin et al., hep-ph/9807241

$$C_{MSSM} \quad = \quad C^{(1)}_{MSSM}\left(\frac{\alpha_s}{\pi}\right)+C^{(2)}_{MSSM}\cdot\left(\frac{\alpha_s}{\pi}\right)^2$$

Dawson et al.; Harlander and Steinhauser, hep-ph/0307346

2.) Numerical Results at NLO QCD

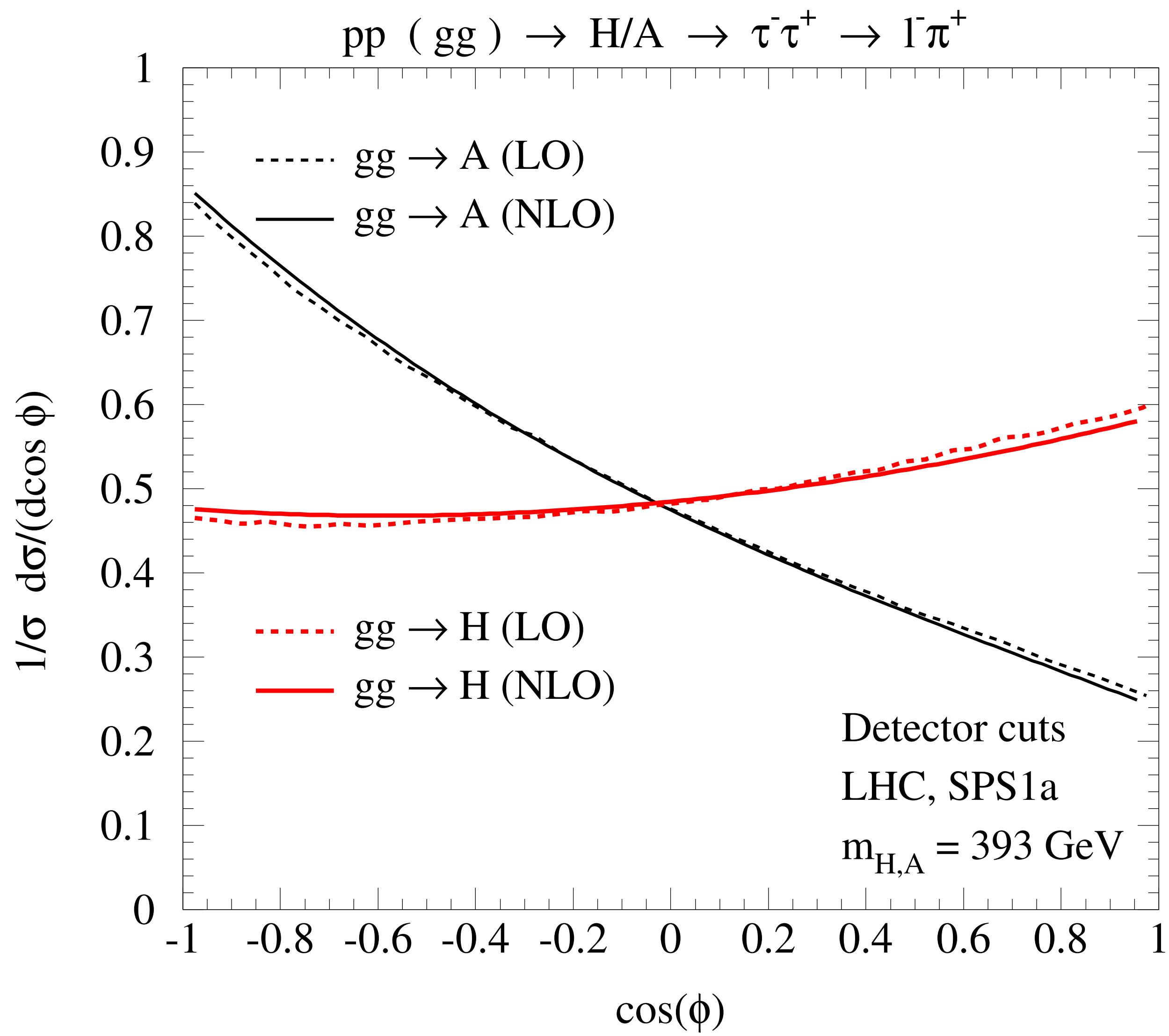
- NLO QCD corrections in eff. theory:

- MSSM, SPS1a
  $m_H = m_A \approx 400$ GeV

- Corrections are small

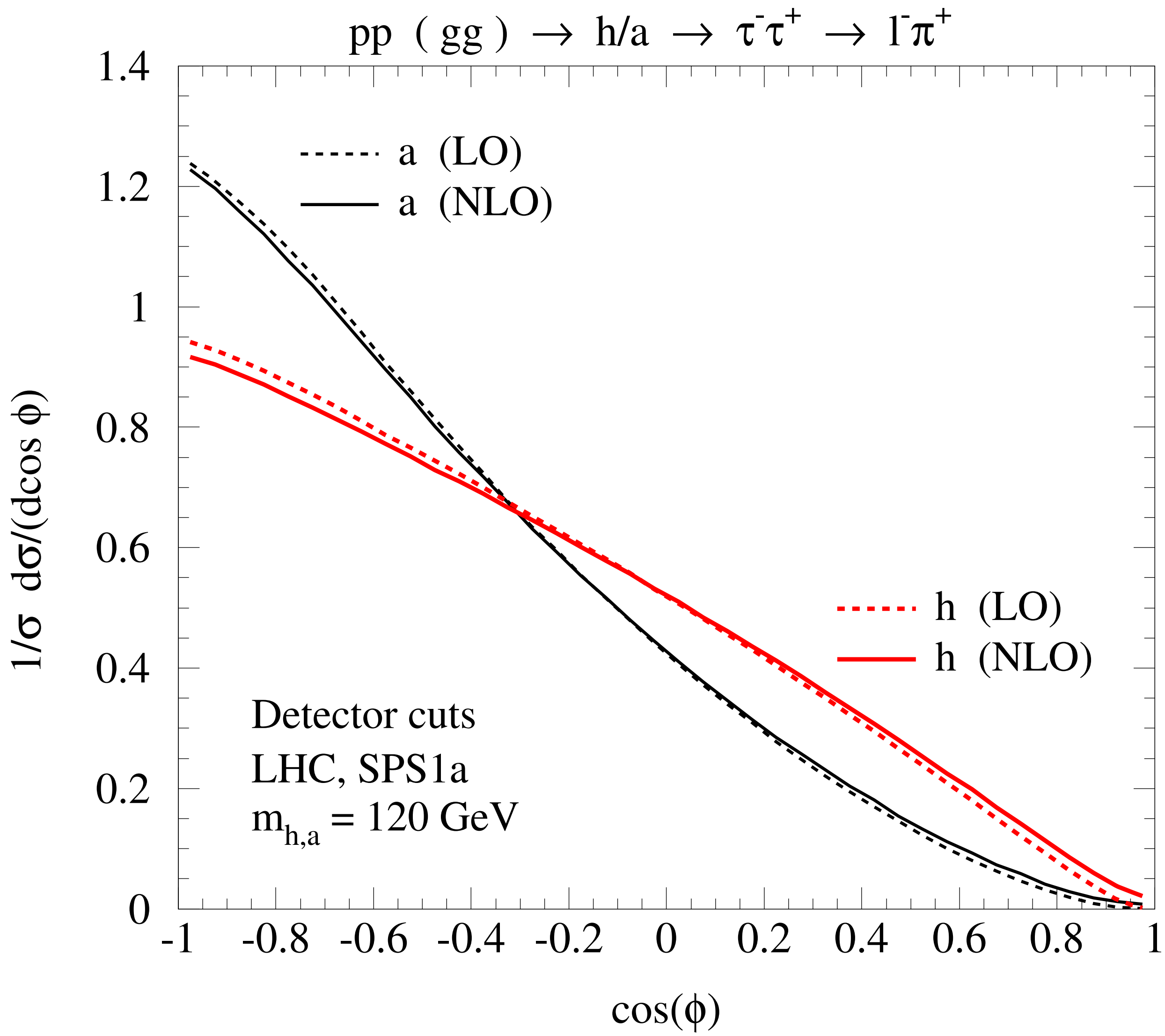
- Detector Cuts
  $p_{Tl} > 20$ GeV
  $p_{T\pi} > 40$ GeV
  $\eta_{l,\pi} \leq 2.5$

- Similar size or smaller for $bb \to \Phi(g)$



2.) Numerical Results at NLO QCD

- NLO QCD corrections in eff. theory
- for SM-like Higgs boson
  $m_h = m_a \approx 120$ GeV



3.) Distinguish Higgs boson of CP-mixture

- $\mathcal{O}_1$ can't distinguish between $H + A$ (CP eigenstates; A,H mass degenerated) and CPmix

- Use $\quad \mathcal{O}_2 = \hat{k}_{\tau^-} \cdot (s_{\tau^-} \times s_{\tau^+})$

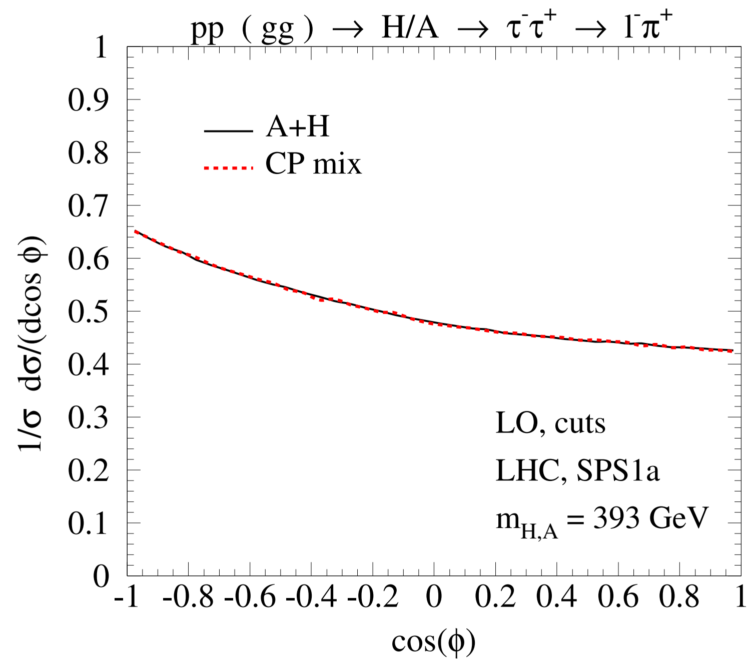
- CP-odd

- $\mathcal{O}_2$ measures correlation of τ^+ and τ^- Spins transverse to direction of flight

- $< \mathcal{O}_2 >$ may $\neq 0$ already at LO

- Measurement of final particle charge required

- Final state dependence: *(Bernreuther et al., '97,'98)*



$$Q_2 = (\hat{k}_{\tau^-} - \hat{k}_{\tau^+}) \cdot (\hat{\vec{p}}_{l^-} \times \hat{\vec{p}}_{\pi^+})/2$$

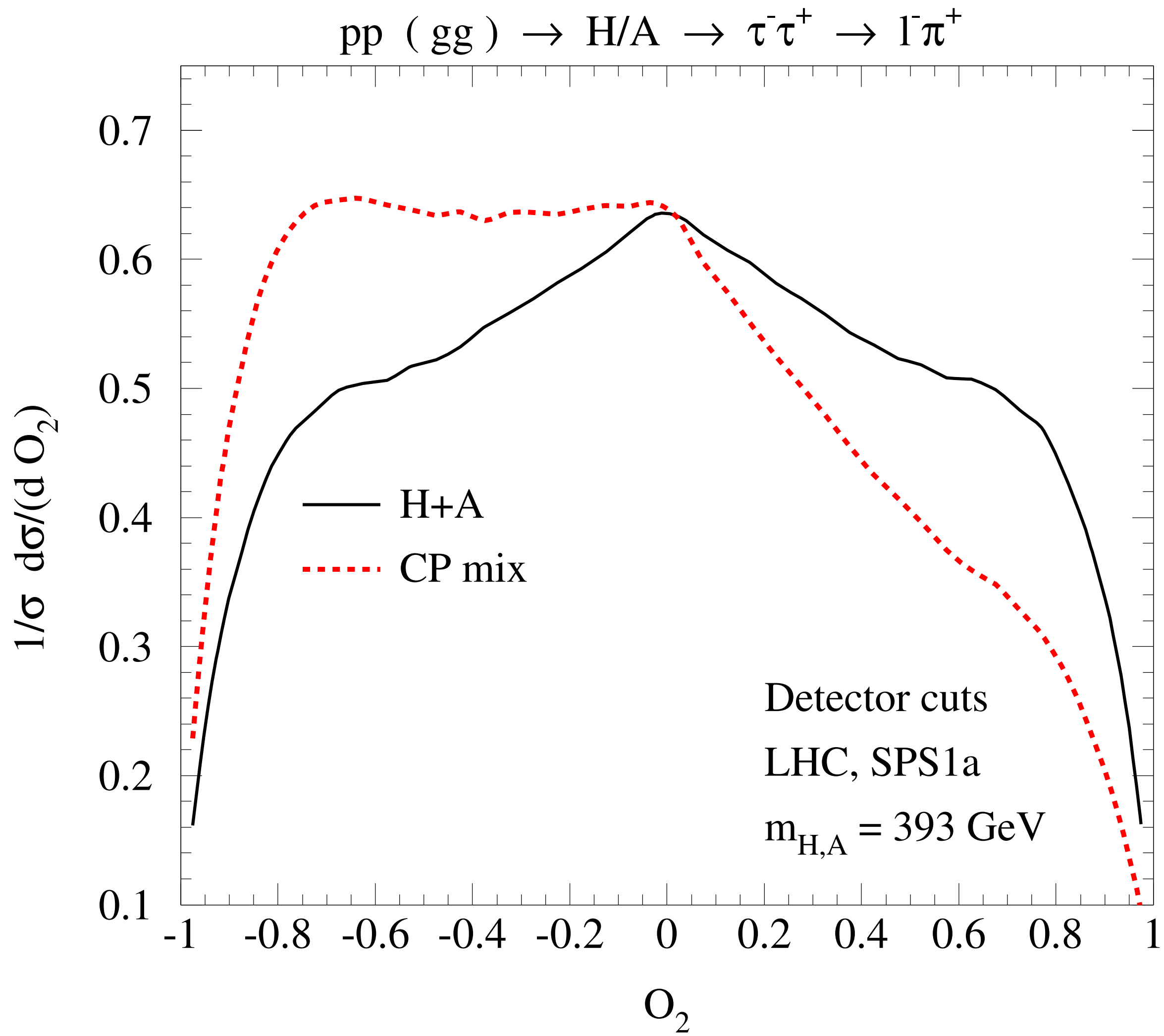
3.) Higgs boson of CP-mixture, Numerical Results

- $O_2 = (\hat{k}_{\tau^-} - \hat{k}_{\tau^+}) \cdot (\hat{\vec{p}}_{l^-} \times \hat{\vec{p}}_{\pi^+})/2$

- $\hat{k}$ defined in $\tau^+\tau^-$ -ZMF ;
  $\hat{\vec{p}}_{l^-}$ $(\hat{\vec{p}}_{\pi^+})$ in τ^- (τ^+)
  rest frame

- 'CPmix' for Φ with maximal CP-mixture $(a = \tilde{a} = 1)$

- study asymmetry: $N_{(O_2<0)} - N_{(O_2>0)}$

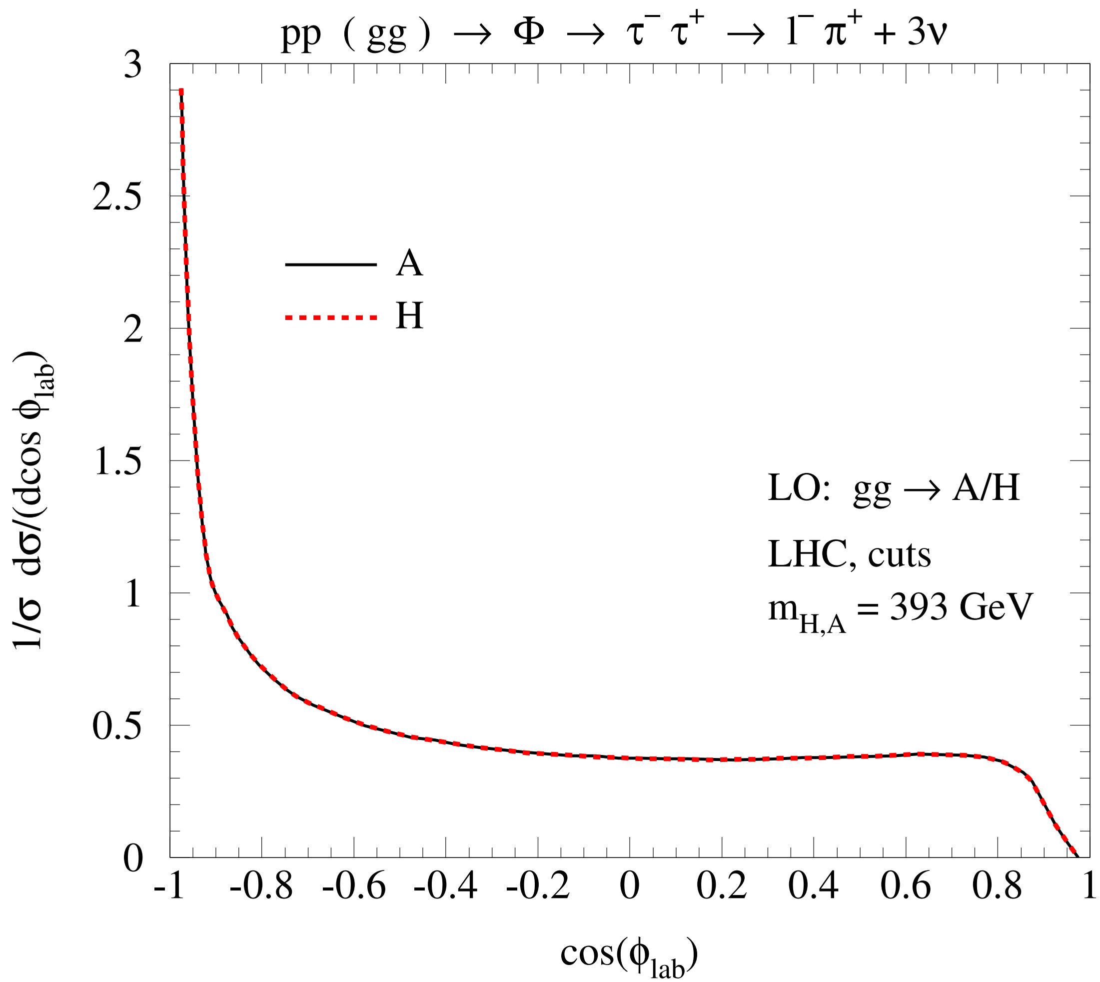


$\cos(\phi_{lab})$ and total cross section

- total cross section [fb]:

$\tau\tau \to$	πl	$l(\rho \to \pi)$
H^0:	3.9	3.7
A^0:	2.6	2.5

- $\to$ LHC: for $100\ fb^{-1}$ leads to typically $\mathcal{O}(1000)$ events including cuts, all channels



4.) Conclusion

- sudied Observables in the $pp \to \Phi + X \to \tau^+\tau^- + X \to l^- + \pi^+ X$ production channels
  - $\cos(\phi_{\hat{p}_l,\hat{p}_\pi})$ distribution can distinguish between scalar and pseudoscalar Higgs state
  - O_2 gives information if Higgs boson(s) is(are) a CP-mixture or in CP eigenstates

- Outlook:
  - include QED final state corrections
  - find pseudo-restframe of the τ-leptons, which are easier experimental accessible