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

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3. Distinguishing Higgs boson of CP-mixture
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in collaboration with W. Bernreuther (RWTH)

1. Introduction

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

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

- Higgs mass will be measured

- $m_{\tau\tau}$ needs to be understood

- 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?

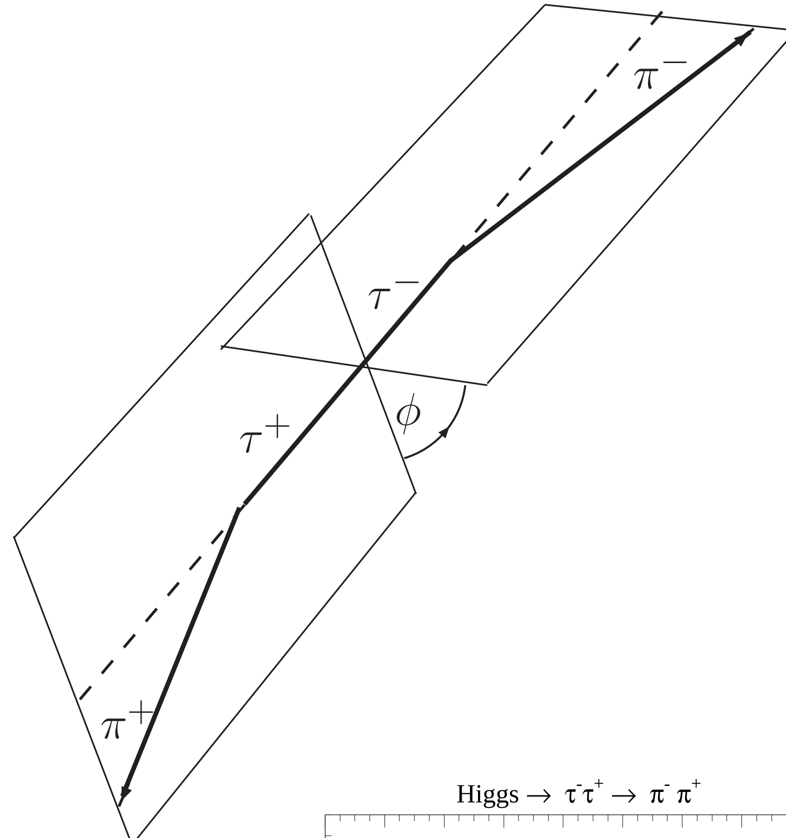
$$\Phi^0 \rightarrow \tau^-\tau^+ \rightarrow \pi^-\pi^+ \ + \ 2\nu$$

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

- Decay probability can be written as

  (Barger, Cheung, Djouadi, Kniehl, Zerwas, '79)

$$\Gamma(H, A \to \tau^- \tau^+) \;\sim\; 1 - \mathbf{s}_\mathbf{z}^- \, \mathbf{s}_\mathbf{z}^+ \;\pm\; \mathbf{s}_\mathbf{T}^- \, \mathbf{s}_\mathbf{T}^+$$



- Can be written as:

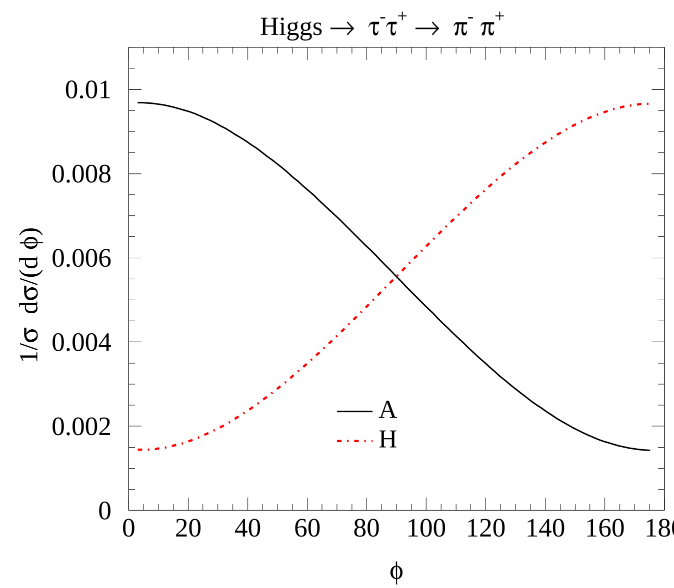
$$\frac{1}{\Gamma}\frac{d\Gamma(H,A \to \pi^+ \bar{\nu} \pi^- \nu)}{d\cos\theta_+ d\cos\theta_- d\varphi} =$$

$$\frac{1}{8\pi}[1 + \cos\theta_- \cos\theta_+ \mp \sin\theta_+ \sin\theta_- \cos\varphi]$$

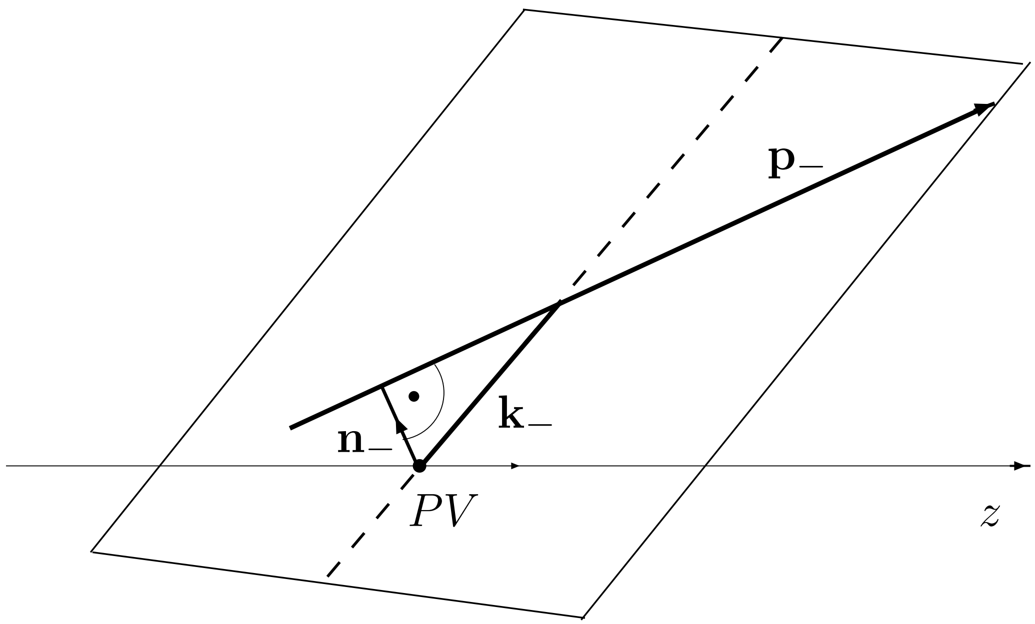
- Integrate out θ_-, θ_+

.

$$\frac{1}{\Gamma}\frac{d\Gamma(H,A)}{d\varphi} \;=\; \frac{1}{2\pi}\left[1 \mp \frac{\pi^2}{16}\cos\varphi\right]$$



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



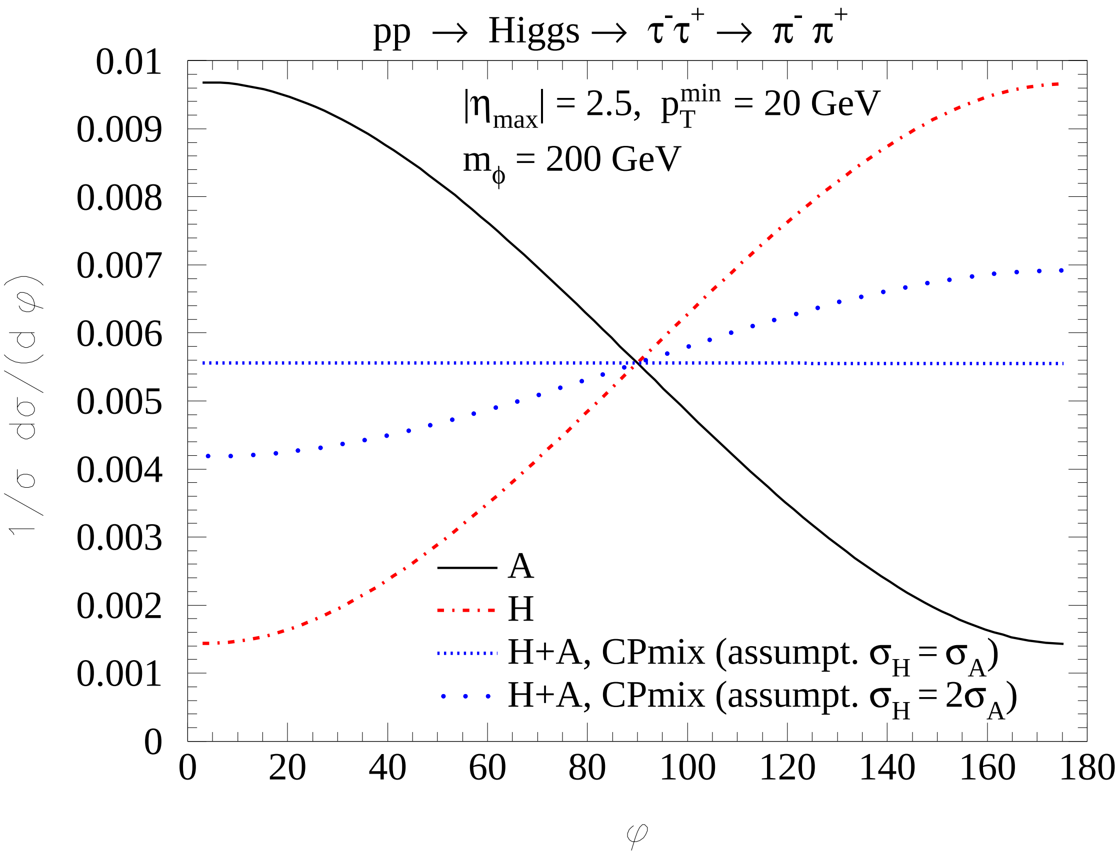
- $\rightarrow \varphi = acos(\hat{\vec{n}}_- \cdot \hat{\vec{n}}_+)$
- LHC: boost to $\tau\tau$ - ZMF
  requires τ-4-momenta
- Instead boost to $\pi^-\pi^+$ - ZMF
  Same φ distribution!
- Use n^μ with $|\vec{n}| = 1, \; n^\mu n_\mu = -1$

i) Measure π momenta and impact parameter to PV in Lab frame

ii) Boost to $\pi^-\pi^+$ - ZMF

$\rightarrow$ no τ-reconstruction needed; π^+ and π^- could be back-to-back

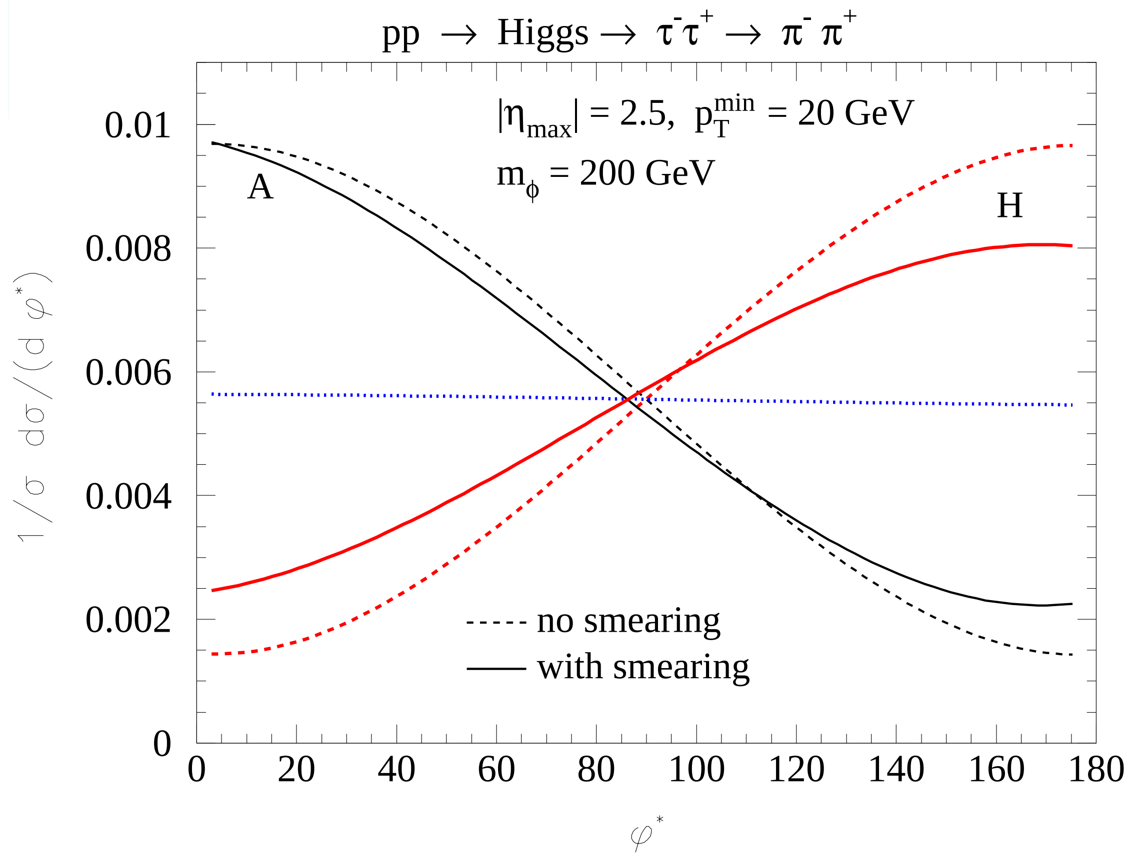
2. Determination of CP$= \pm 1$ states of Higgs bosons



$$\frac{1}{\Gamma}\frac{d\Gamma(H,A)}{d\varphi^*} = \frac{1}{2\pi}\left[1 \mp \frac{\pi^2}{16}\cos\varphi^*\right]$$

- No η dependence
- Small p_T and m_ϕ dependence
- Difference between H and A will be smaller for ll, $l\pi$ final states

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



- Smearing parameters, $l_\tau^{min} = 2\text{mm}$:

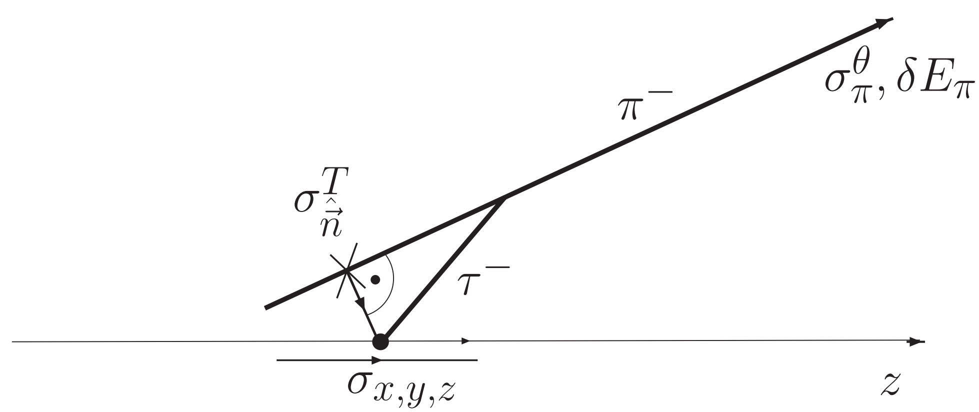
$$\sigma^T_{\hat{\vec{n}}} = 10\,\mu m$$

$$\sigma^\theta_{\vec{q}_\pi} = 1 \text{ mrad}$$

$$\delta E_\pi = 5\%$$

$$\sigma^{PV}_z = 30\,\mu m$$

$$\sigma^{PV}_{x,y} = 10\,\mu m$$



3. Distinguishing Higgs boson of CP-mixture

- φ^* can't distinguish between $H + A$ (CP eigenstates; A,H mass degenerated) and CPmix

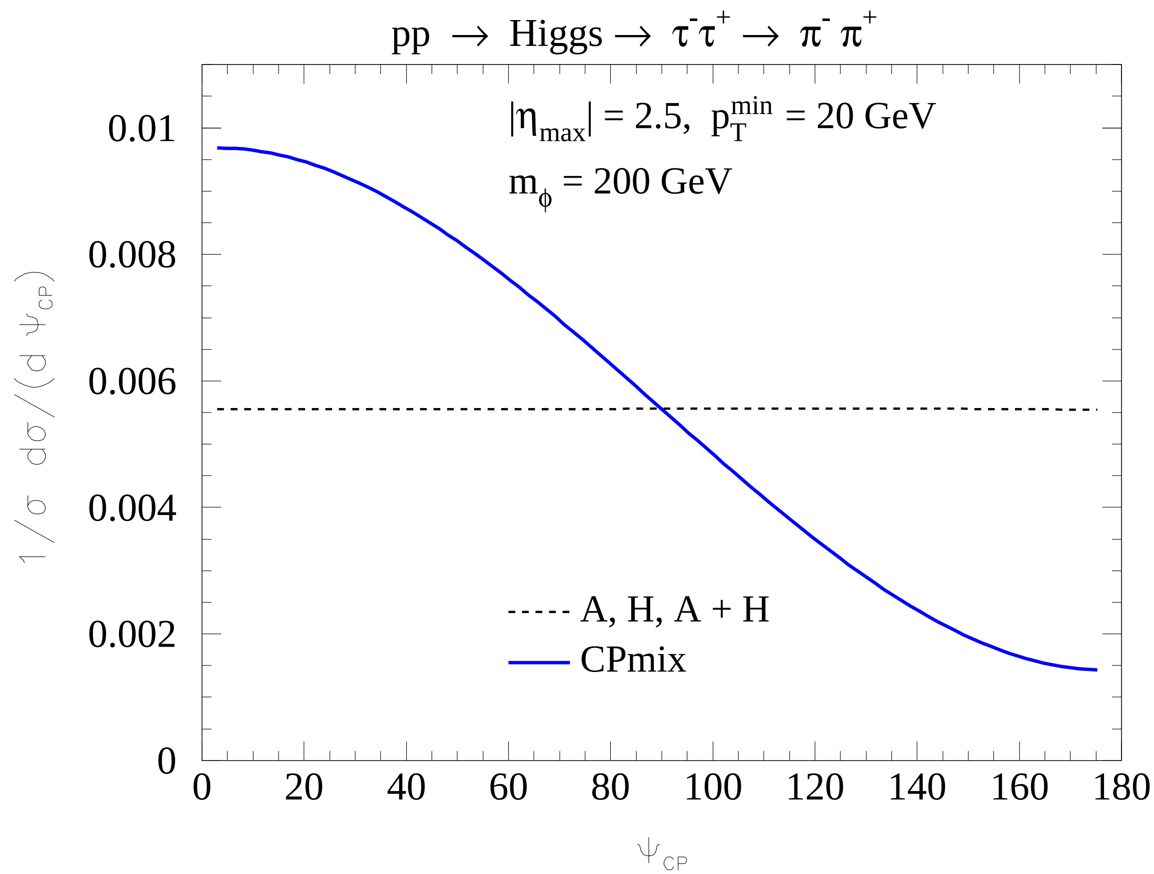
- Use CP-odd Observable:

  $$\psi^*_{CP} = acos(\hat{\vec{k}}_{\tau^-} \cdot (\vec{s}_{\tau^-} \times \vec{s}_{\tau^+}))$$

- $\rightarrow$ in $\pi^+\pi^-$ ZMF:

  $$\psi^*_{CP} = acos(\hat{\vec{q}}_{\pi^-} \cdot (\hat{\vec{n}}_{\pi^-} \times \hat{\vec{n}}_{\pi^+}))$$

- $< \psi^*_{CP} >$ may $\neq 0$ already at LO



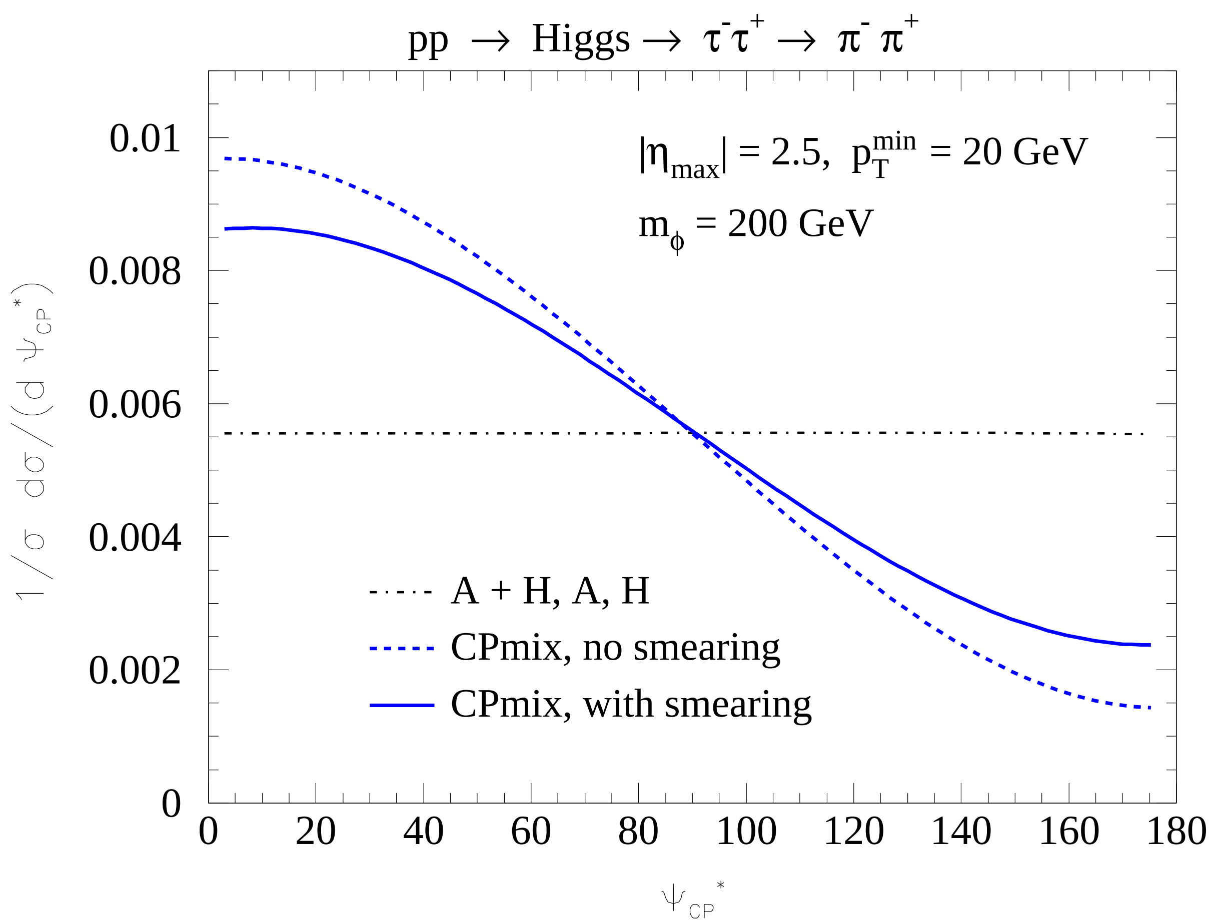
- Measurement of final particle charge required

3. Distinguishing Higgs boson of CP-mixture

- $\longrightarrow$ in $\pi^+\pi^-$ ZMF:
  $\psi^*_{CP} = acos(\hat{\vec{q}}_{\pi^-} \cdot (\hat{\vec{n}}_{\pi^-} \times \hat{\vec{n}}_{\pi^+}))$

- 'CPmix' for Φ with maximal CP-mixture ($a = b = 1$)

- study asymmetry:
  $N_{(\psi^*_{CP} < 90^o)} - N_{(\psi^*_{CP} > 90^o)}$



4. Conclusion

- Test of Higgs CP quantum number should be possible at the LHC for entire Higgs mass range ($m_\Phi \geq 114$ GeV) if:

  a) enough events can be recorded (production process, Higgs mass)

  b) resolution of Higgs production vertex better than $\sigma_{PV} \leq 40\,\mu m$, track $\sigma \leq 15 \mu m$

- Possible channels:

  a) $\cos(\phi)$, $\mathcal{O}_2$ distribution: $\tau\tau \to a_1 a_1 \;\; (a_1\pi, a_1 l, ...)$ *S.B., Bernreuther, Ziethe '08*

  b) φ^*, $\psi^*_{CP}-$distribution: $\tau\tau \to i + j + n\,\nu$
  $\{i,j\} = \{\pi, l, \rho, a_1\}$

- Results independent of Higgs production mechanism