$B \to \tau\nu_\tau$, $B \to \overline{D}^{(*)}\tau\nu_\tau$, and Charm CP at BaBar

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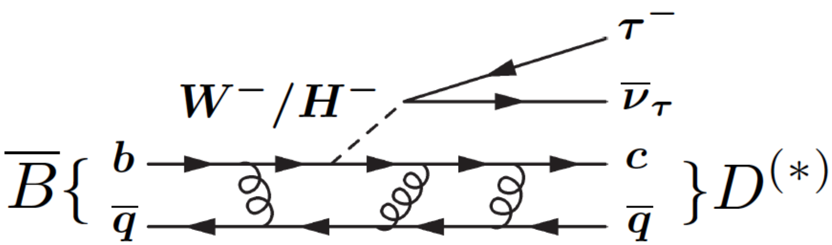
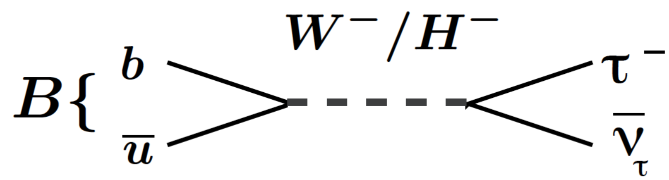
Outline

- Motivation for $B \to \overline{D}^{(*)}\tau\nu$ and $B \to \tau\nu$.
- $B \to \overline{D}^{(*)}\tau\nu$. (arxiv: 1303.0571)
  - Analysis Overview and Results.
  - Interpretation.
- $B \to \tau\nu$. (arxiv: 1207.0698)
  - Analysis Overview and Results.
- Charm CP:
  - $D^0 - \overline{D}^0$ mixing and CP violation. (arxiv: 1209.3896)
  - Direct CP violation search in $D^\pm \to K^+K^-\pi^\pm$. (arxiv: 1212.1856)
  - CP violation in $D^\pm \to K_S^0 K^\pm$, $D_s^\pm \to K_S^0 K^\pm$, and $D_s^\pm \to K_S^0 \pi^\pm$. (arxiv: 1212.3003)

MOTIVATION FOR MEASURING $B \to \tau\nu$ AND $B \to \overline{D}^{(*)}\tau\nu$





- Third generation leptons couple more strongly to the electroweak symmetry breaking sector. Their decays, therefore, are suitable to probe physics beyond the Standard Model (SM).
- One popular scenario for New Physics is the two Higgs doublet model (2HDM). It enhances the decay rates of $B \to \tau\nu$ and $B \to \overline{D}^{(*)}\tau\nu$ through the contribution of a charged Higgs boson.

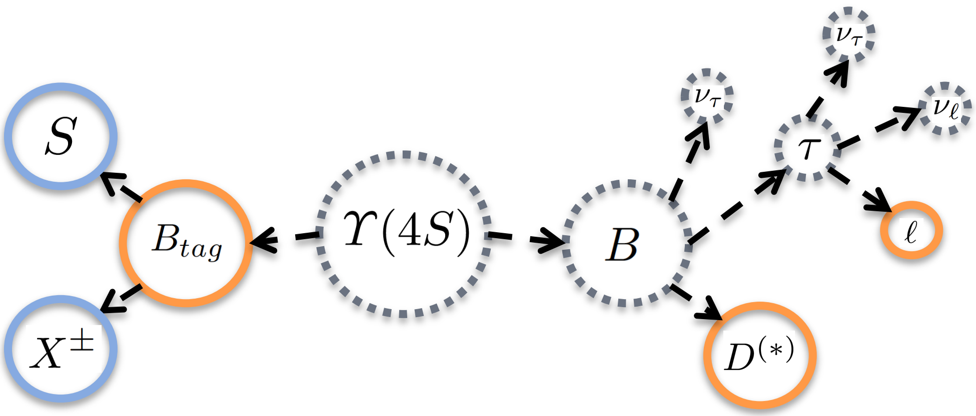
MEASUREMENT OVERVIEW FOR $B \to \overline{D}^{(*)}\tau\nu$

- We measure ratios of branching fractions:

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(B \to \overline{D}^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \to \overline{D}^{(*)}\ell\nu_\ell)}$$

- Reduces theoretical uncertainties.
  - Independent of $|V_{cb}|$.
  - Mostly independent of form factor parameterization.
- Reduces experimental uncertainties. In this analysis, both decay modes in the ratio are reconstructed in the same final states.
  - Cancels multiplicative uncertainties; e.g., lepton PID, detection and reconstruction efficiencies.

Event Reconstruction and Selection



- For each event, reconstruct $B_{tag}D^{(*)}\ell$.
- Signal efficiency is 3 times more than previous BABAR analysis. (arxiv: 0709.1698)
- Due to the presence of three neutrinos, our ability to fully reconstruct the rest of the event is critical.

Fitting Yields and Extracting Results

- Define signal ($\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau$) and normalization ($\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell$) events.

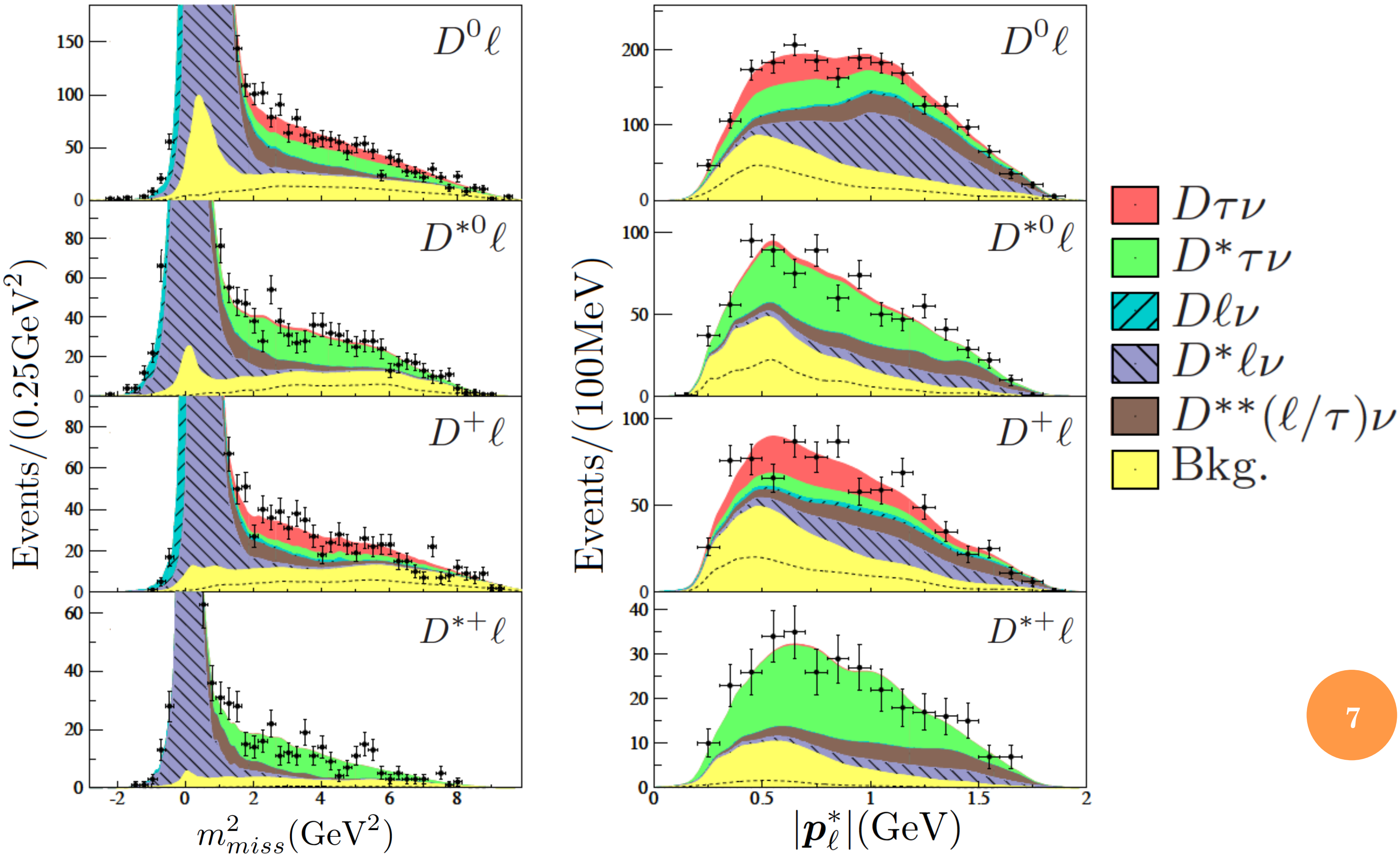
- The signal and normalization yields are determined in an unbinned maximum-likelihood fit to the 2D distribution in m^2_{miss} vs $|\boldsymbol{p}^*_\ell|$.

- Take the quotient of signal and normalization yields and scale with their efficiencies determined in MC to get the desired ratios.

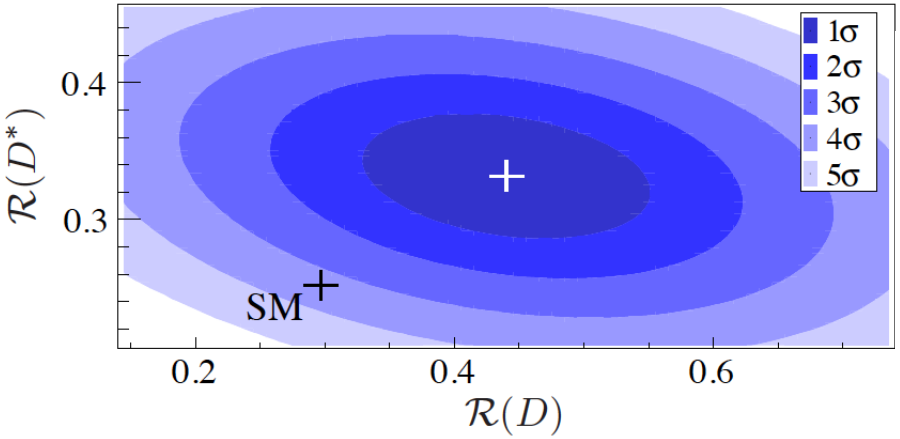
$$\mathcal{R}(D^{(*)}) = \frac{N_{\text{sig}}}{N_{\text{norm}}} \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\text{sig}}}$$

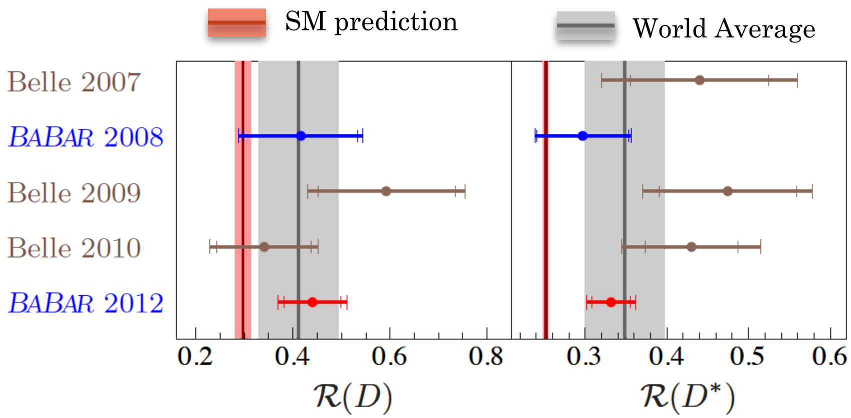
RESULTS

Decay	$\mathcal{R}(D^{(*)})$	N_{sig}	N_{norm}
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	$0.440 \pm 0.058 \pm 0.042$	489 ± 63	2981 ± 65
$\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau$	$0.332 \pm 0.024 \pm 0.018$	888 ± 63	11953 ± 122



Comparison with Standard Model





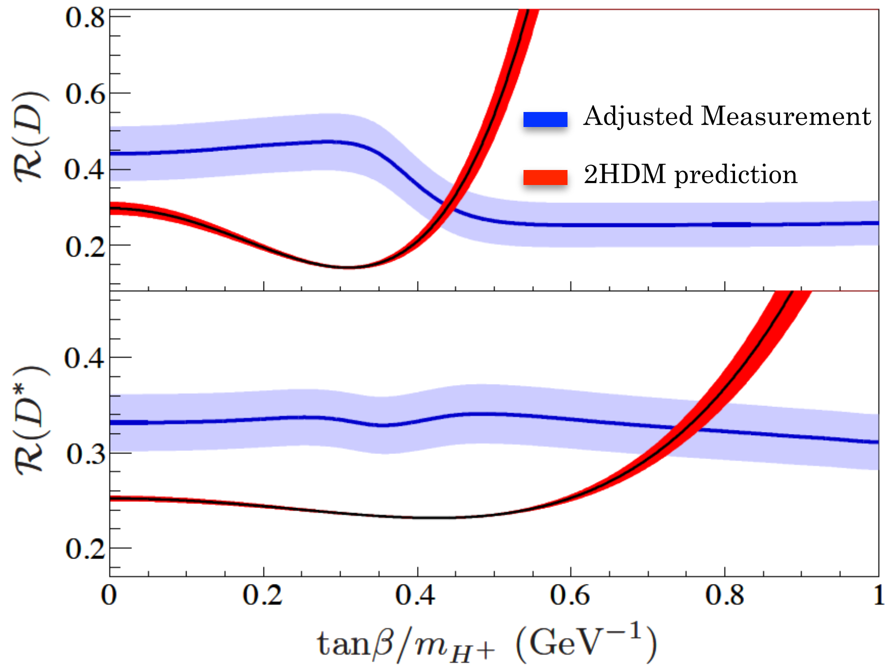
- Our results compared to SM predictions:

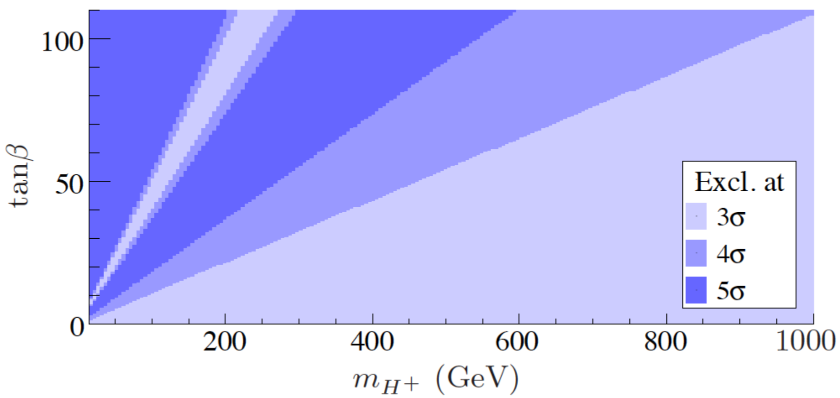
$$\mathcal{R}(D)_{\rm exp} = 0.440 \pm 0.072 \quad \mathcal{R}(D^*)_{\rm exp} = 0.332 \pm 0.030$$
$$\mathcal{R}(D)_{\rm SM} = 0.297 \pm 0.017 \quad \mathcal{R}(D^*)_{\rm SM} = 0.252 \pm 0.003$$

(SM predictions see arxiv: 1203.2654)

- Combining these ratio measurements and taking correlations into account, we exclude the possibility that SM predictions agrees with both at 3.4σ.

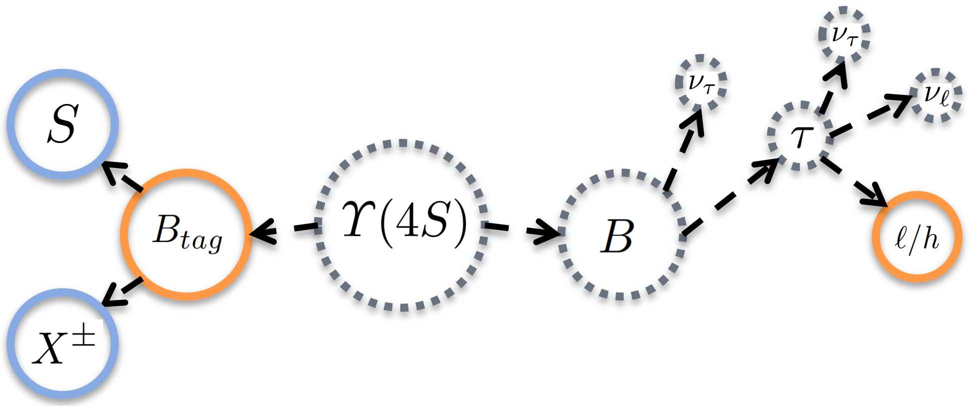
Comparison with Type-II 2HDM





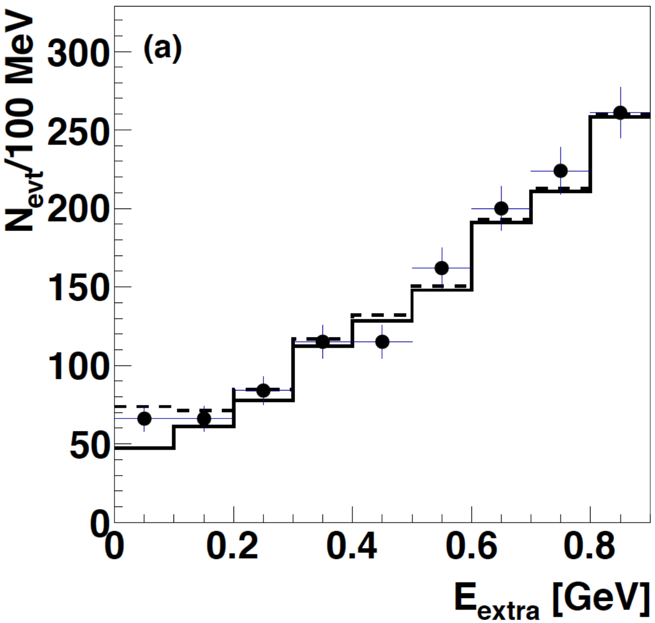
- To determine whether type-II 2HDM is consistent with the observed excess, we plot our results as a function of $\tan\beta/m_{H^+}$.
- Together with $B \to X_s\gamma$ measurements, we exclude the type-II 2HDM at 99.8% confidence level in the full $\tan\beta/m_{H^+}$ parameter space.

Measurement Overview: $B \to \tau\nu$



- Limited precision on $|V_{ub}|$ is the main source of uncertainty. The ratio trick does not work experimentally as the lighter leptons are helicity suppressed.
- SM predicts the branching fraction differently depending on which experimentally determined $|V_{ub}|$ is used:
  - Using $|V_{ub}|$ measured from exclusive B decays:
    $$\mathcal{B}_{SM}(B^+ \to \tau^+\nu) = (0.62 \pm 0.12) \times 10^{-4}$$
  - Using $|V_{ub}|$ measured from inclusive B decays:
    $$\mathcal{B}_{SM}(B^+ \to \tau^+\nu) = (1.18 \pm 0.16) \times 10^{-4}$$

Results for $B \to \tau\nu$



Reconstructed τ mode	$\mathcal{B}(B \to \tau\nu) \times 10^{-4}$
$\tau^+ \to e^+\nu\overline{\nu}$	$0.35^{+0.84}_{-0.73}$
$\tau^+ \to \mu^+\nu\overline{\nu}$	$1.12^{+0.90}_{-0.78}$
$\tau^+ \to \pi^+\nu$	$3.69^{+1.42}_{-1.22}$
$\tau^+ \to \rho^+\nu$	$3.78^{+1.65}_{-1.45}$
Combined	$1.83^{+0.53}_{-0.49}$

Belle 2012: $0.72^{+0.27}_{-0.25} \pm 0.11$

(arxiv: 1208.4678)

- Excludes no signal hypothesis at 3.8σ.
- Exceeds SM predictions by 2.4σ and 1.6σ for using exclusive and inclusive values of $|V_{ub}|$ respectively.

$D^0 - \overline{D}^0$ MIXING AND CP VIOLATION

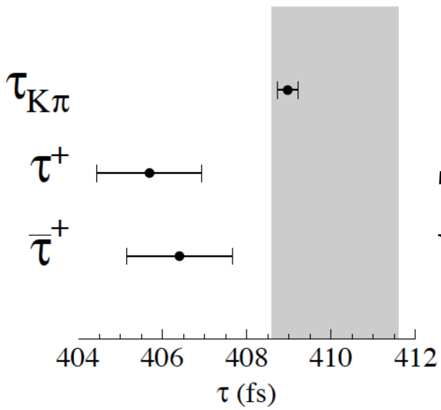
- One manifestation of $D^0 - \overline{D}^0$ mixing is differing D^0 decay time distributions to different CP eigenstates.
- From the decay widths, we compute the mixing and CP violation (CPV) parameters:

$$\boxed{y_{CP} = \frac{\Gamma^+ + \overline{\Gamma}^+}{2\Gamma} - 1, \quad \Delta Y = \frac{\Gamma^+ - \overline{\Gamma}^+}{2\Gamma},}$$

they are zero for no mixing and no CPV hypotheses respectively.

$D^0 - \overline{D}^0$ MIXING AND CP VIOLATION

- We measure the effective D^0 lifetimes in three modes:
  - $D^0 \to K^\mp \pi^\pm$: This final state is CP mixed. We assume its decay width is described by the average D^0 width Γ.
  - $D^0(\overline{D}^0) \to \pi^- \pi^+$: This final state is CP even, and its lifetime is Γ^+ $(\overline{\Gamma}^+)$.
  - $D^0(\overline{D}^0) \to K^- K^+$: This is also CP even. We assume it has the same decay width as the mode above.
- The results are:



$$y_{CP} = [0.72 \pm 0.18(\text{stat}) \pm 0.12(\text{syst})]\%$$
$$\Delta Y = [0.09 \pm 0.26(\text{stat}) \pm 0.06(\text{syst})]\%$$

This excludes the no mixing hypothesis at 3.3σ.
We find no evidence for CPV in mixing.

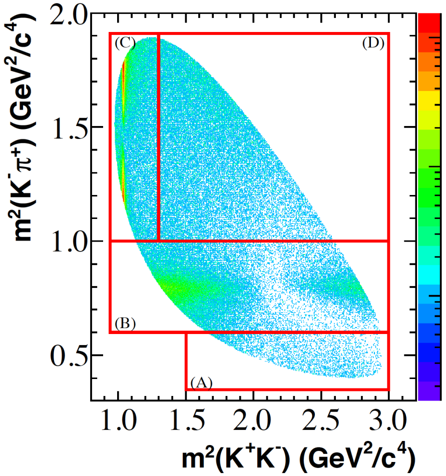
DIRECT *CP* VIOLATION IN $D^{\pm} \to K^{+}K^{-}\pi^{\pm}$

- We reconstruct the 3-body decay $D^{\pm} \to K^{+}K^{-}\pi^{\pm}$ and perform integrated *CP* asymmetry measurements as well as Dalitz plot analyses to search for direct *CPV*.
- Integrated *CP* Asymmetry: Fitting for the yields in $D^{\pm} \to K^{+}K^{-}\pi^{\pm}$, we get:

$$A_{CP} = (0.37{\pm}0.30{\pm}0.15)\%$$

- We also compute asymmetries in different regions of the Dalitz plot:

Dalitz plot region	A_{CP} [%]
(A) Below $\bar{K}^{*}(892)^{0}$	$-0.7 \pm 1.6 \pm 1.7$
(B) $\bar{K}^{*}(892)^{0}$	$-0.3 \pm 0.4 \pm 0.2$
(C) $\phi(1020)$	$-0.3 \pm 0.3 \pm 0.5$
(D) Above $\bar{K}^{*}(892)^{0}$ and $\phi(1020)$	$1.1 \pm 0.5 \pm 0.3$



No evidence of direct *CPV*.

CP ASYMMETRY IN $D^{\pm} \rightarrow K_S^0 K^{\pm}$, $D_s^{\pm} \rightarrow K_S^0 \pi^{\pm}$, AND $D_s^{\pm} \rightarrow K_S^0 K^{\pm}$

- The CP asymmetry

$$A_{CP} = \frac{\Gamma(D^+_{(s)} \to f) - \Gamma(D^-_{(s)} \to \overline{f})}{\Gamma(D^+_{(s)} \to f) + \Gamma(D^-_{(s)} \to \overline{f})}$$

is measured in modes $D^{\pm} \rightarrow K_S^0 K^{\pm}$, $D_s^{\pm} \rightarrow K_S^0 K^{\pm}$, and $D_s^{\pm} \rightarrow K_S^0 \pi^{\pm}$.

- After accounting for detector asymmetries and the forward backward asymmetry:

Decay Mode	A_{CP} final value
$D^{\pm} \rightarrow K_S^0 K^{\pm}$	$(0.46 \pm 0.36 \pm 0.25)\%$
$D_s^{\pm} \rightarrow K_S^0 K^{\pm}$	$(0.28 \pm 0.23 \pm 0.24)\%$
$D_s^{\pm} \rightarrow K_S^0 \pi^{\pm}$	$(0.3 \pm 2.0 \pm 0.3)\%$

These results are all consistent with SM predictions.

SUMMARY

- $B \to \overline{D}^{(*)}\tau\nu$:
  - Disagrees with SM predictions at 3.4σ.
  - Excludes Type-II 2HDM at 99.8% confidence level.
- $B \to \tau\nu$:
  - Branching fractions in excess of SM predictions.
- Charm CP :
  - $D^0 - \overline{D}^0$ mixing:
    - Observed mixing at 3.3σ .
    - No evidence of CPV in mixing.
  - No evidence of direct CPV in $D^\pm \to K^+K^-\pi^\pm$.
  - No evidence of CPV in $D^\pm \to K^0_S K^\pm$, $D_s^\pm \to K^0_S K^\pm$, and $D_s^\pm \to K^0_S \pi^\pm$.

BACKUPS

Comparison with Type-III 2HDM

- In the type-III 2HDM, a right handed current is included. The relative contributions of the left and right handed currents are parameterized with S_L and S_R.
- In this model, the measured ratios take the form

$$\mathcal{R}(D) = \mathcal{R}(D)_{\rm SM} + A'_D \mathrm{Re}(S_R + S_L) + B'_D |S_R + S_L|^2,$$
$$\mathcal{R}(D^*) = \mathcal{R}(D^*)_{\rm SM} + A'_{D^*} \mathrm{Re}(S_R - S_L) + B'_{D^*} |S_R - S_L|^2.$$

- For real values of S_L and S_R, four regions are favored: