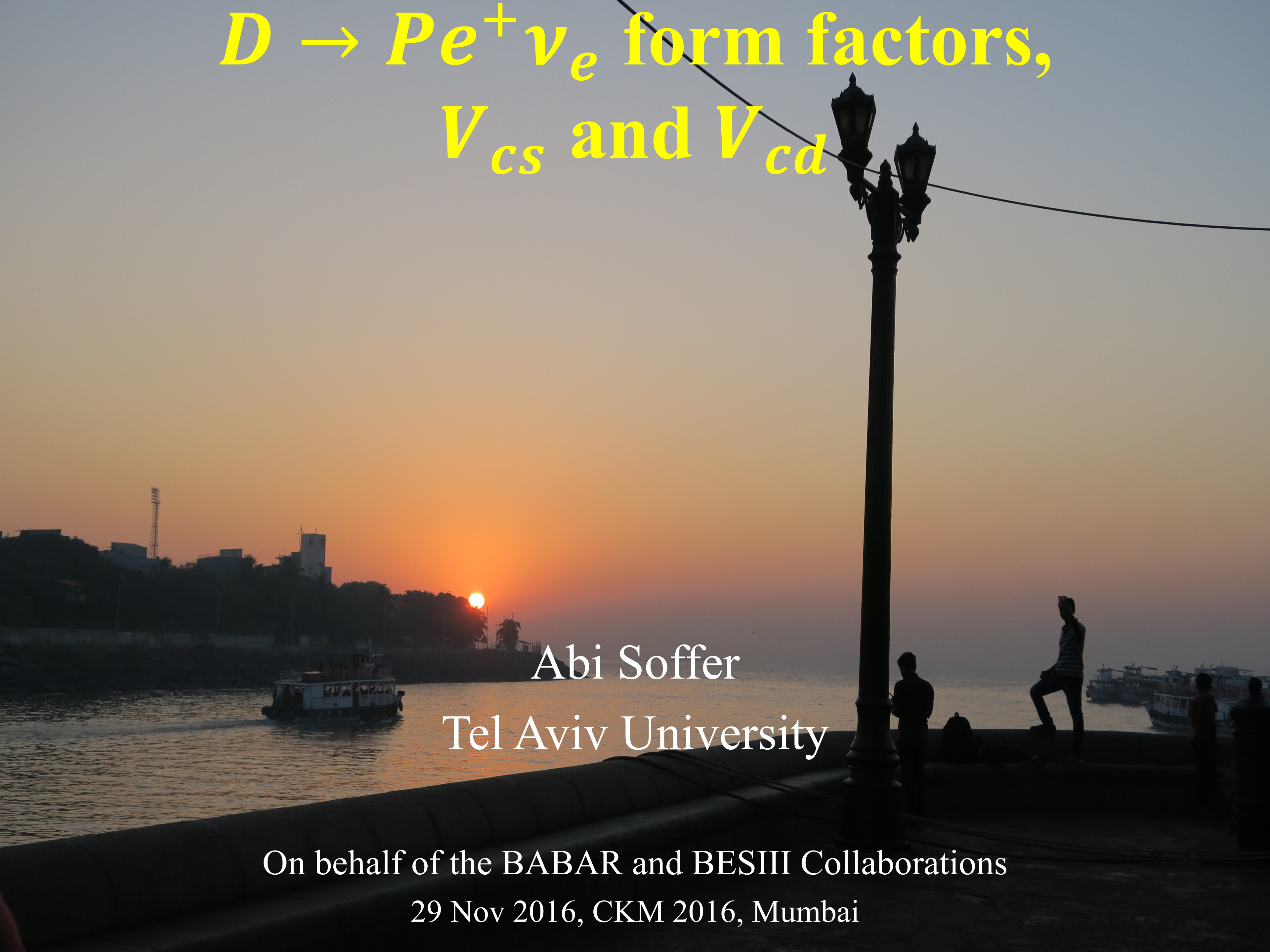
$D \to P e^+ \nu_e$ form factors, V_{cs} and V_{cd}



Abi Soffer
Tel Aviv University

On behalf of the BABAR and BESIII Collaborations

29 Nov 2016, CKM 2016, Mumbai

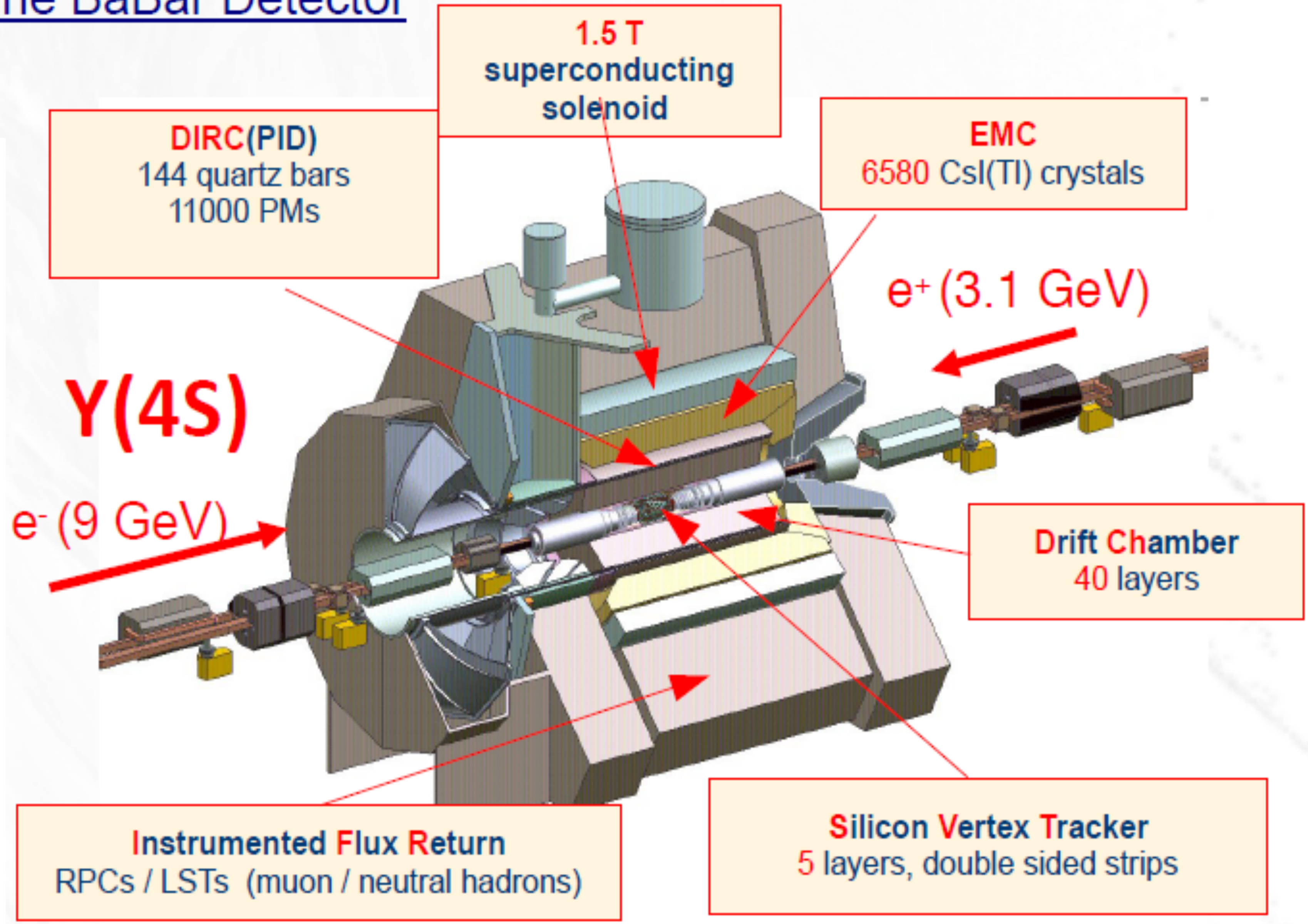
Outline

- BABAR: 347.2 fb^{-1} @ $\sqrt{s} = 10.59$ GeV
  - $D^0 \to \pi^- e^+ \nu_e$ (PRD91, 052022)
- BESIII: 2.92 fb^{-1} @ $\sqrt{s} = 3.770$ GeV
  - $D^0 \to K^- e^+ \nu_e$ & $D^0 \to \pi^- e^+ \nu_e$ (PRD92, 072012)
  - $D^+ \to K_L^0 e^+ \nu_e$ (PRD92, 112008)
- Conclusions

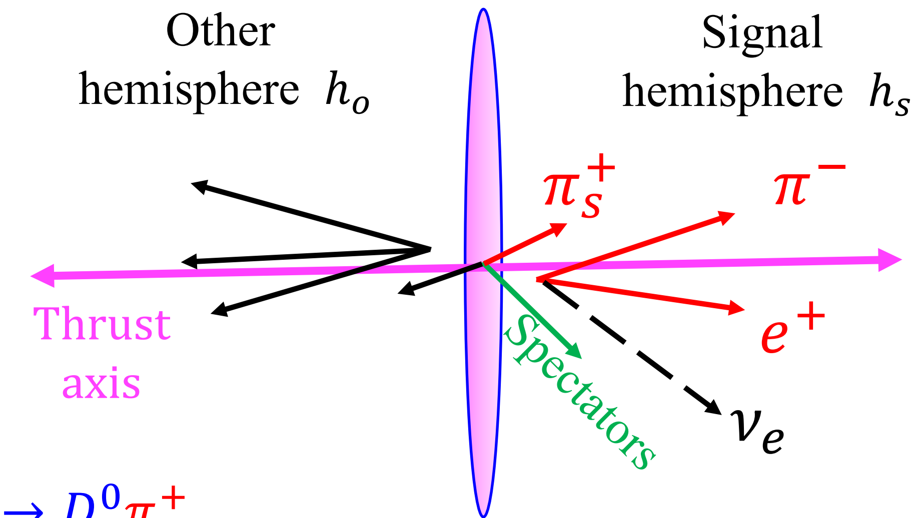
$D^0 \to \pi^- e^+ \nu_e$ from BABAR

(PRD91, 052022)

The BaBar Detector



$D^0 \to \pi^- e^+ \nu_e$ reconstruction



Use all info to reconstruct the ν_e:

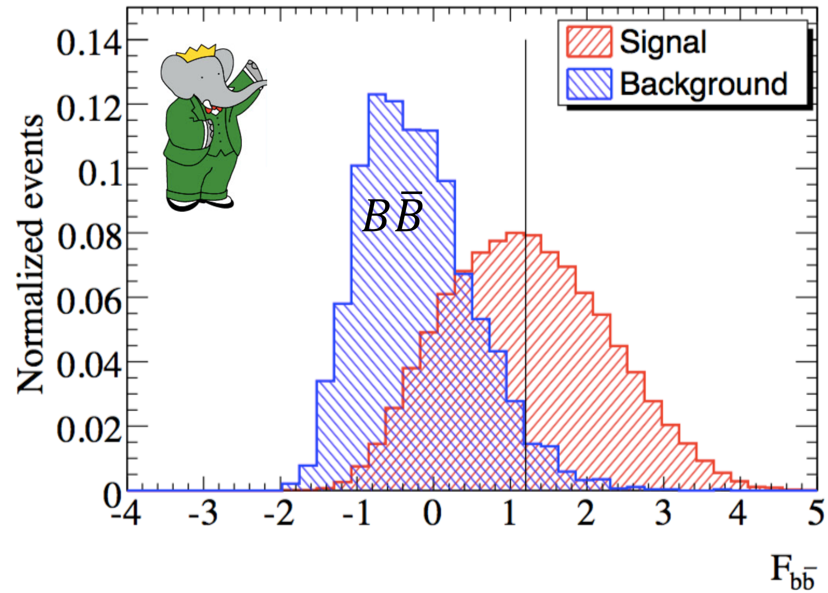
- Contain event: $|\cos\theta_{\text{thrust}}| < 0.6$
- Divide event to 2 hemispheres along thrust axis
- "Signal hemisphere" has candidate $D^{*+} \to D^0 \pi_s^+$
  $D^0 \to \pi^- e^+ \nu_e$

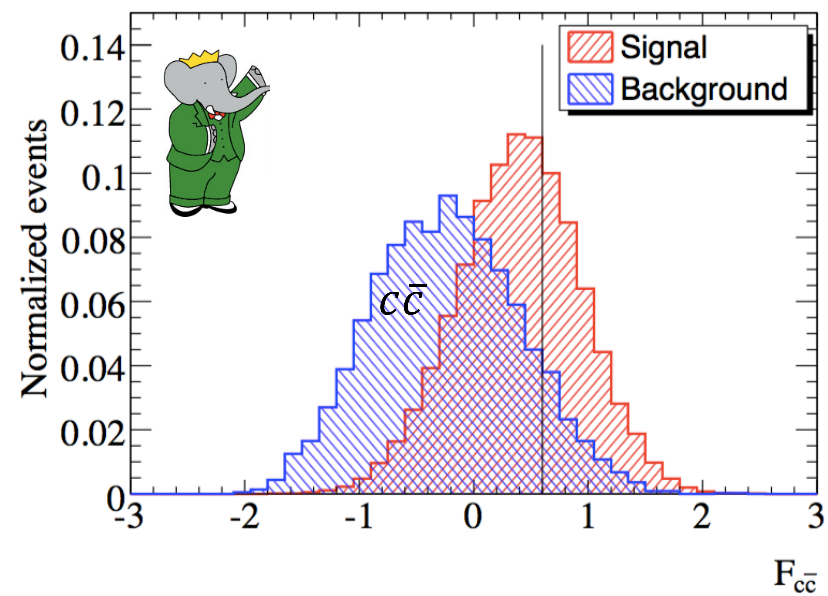
K^- probability < 0.4%

- For each hemisphere $h = s, o$:
  - $m_h^2 = (\sum_{i \in h} E_i)^2 - (\sum_{i \in h} \vec{p}_i)^2$
  - E_h from $e^+e^- \to h_s h_o$ kinematics
- Estimate neutrino energy $E_\nu = E_s - \sum_{i \in s} E_i$
- Take $\hat{p}_D$ = opposite sum of all momenta in the event, except those of $\pi^- e^+$
- Improve $\vec{p}_D$ with kinematic fit constraining D^0 mass, then a fit constraining D^{*+} mass

Background suppression Fishers

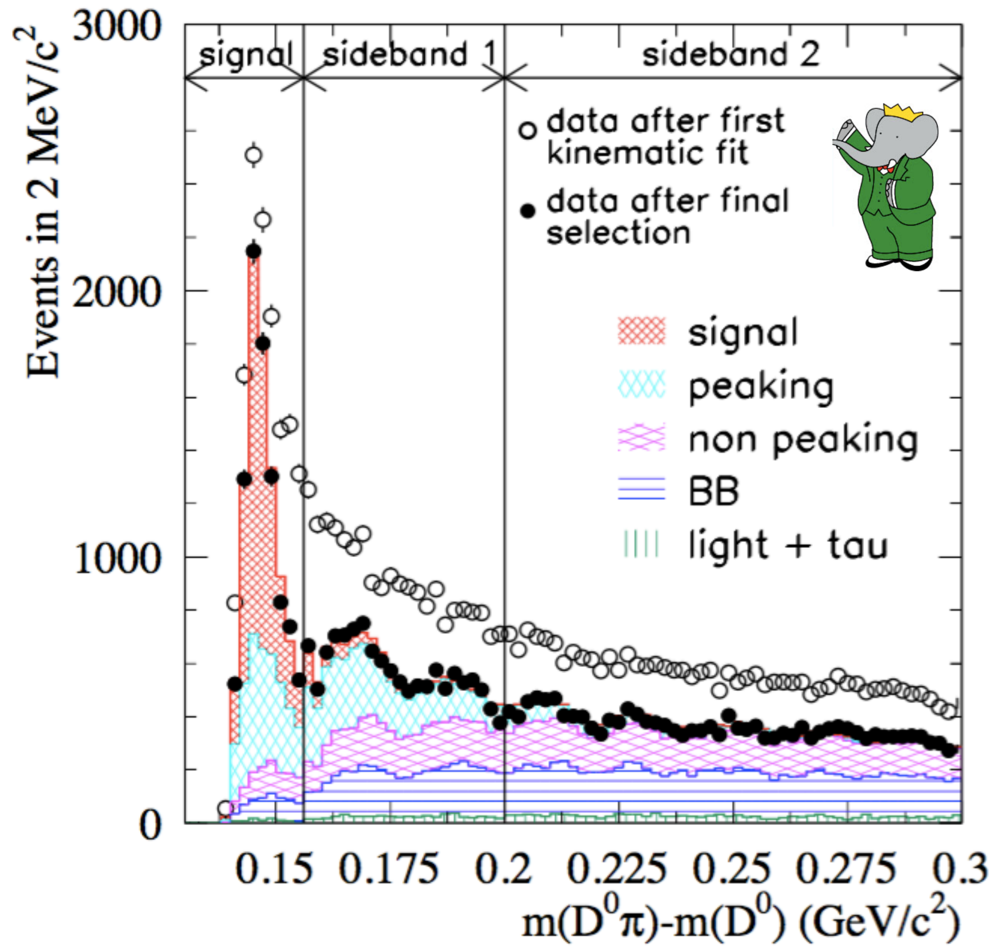
- $F_{b\bar{b}}$ suppresses $B\bar{B}$ bgd:
  - R_2
  - Particle multiplicity
  - $p_{\pi_s^+}$
- $F_{c\bar{c}}$ suppresses $c\bar{c}$ bgd:
  - p_D
  - Spectators mass
  - Spectators angle to thrust axis
  - Leading-spectator momentum
  - Leading-spectator angle to $\vec{p}_D$
  - Leading-spectator angle to thrust axis
  - $e^+ - \pi^-$ angle in $e^+\nu_e$ frame
  - p_{e^+}





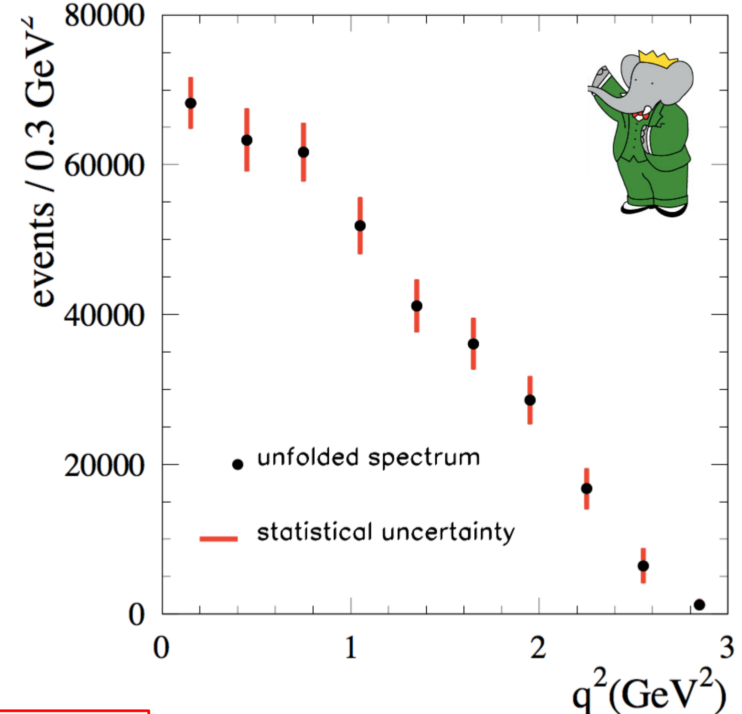
Observed signal

- Use $D^{*+} - D^0$ mass difference for final signal identification
- Peaking background from true $D^{*+} \rightarrow D^0\pi_s^+$ with other D^0 decays
- Sidebands used to correct background-MC distributions, improve background prediction in signal region
- Signal region has almost 10k events, 45% background.
- # of signal decays produced: $(375.4 \pm 9.2 \pm 10.1)\times 10^3$



Results1

- $$\frac{Br(D^0 \to \pi^- e^+ \nu_e)}{Br(D^0 \to K^- \pi^+)} = 0.0702 \pm 0.0017 \pm 0.002$$
- $$Br(D^0 \to \pi^- e^+ \nu_e) = (0.2770 \pm 0.068 \pm 0.092 \pm 0.037) \times 10^{-3}$$ ($\nearrow$ $Br(K\pi)_{WA}$)
- Unfolded q^2 distribution: →
- With z-expansion parameterization of the FF:



$$|V_{cd}| \times f^{\pi}_{+,D}(0) = 0.1374 \pm 0.0038 \pm 0.0022 \pm 0.0009$$

Lattice: $f^{\pi}_{+,D}(0) = 0.666 \pm 0.029$ → $|V_{cd}| = 0.206 \pm 0.007_{\text{exp.}} \pm 0.009_{\text{LQCD}}$

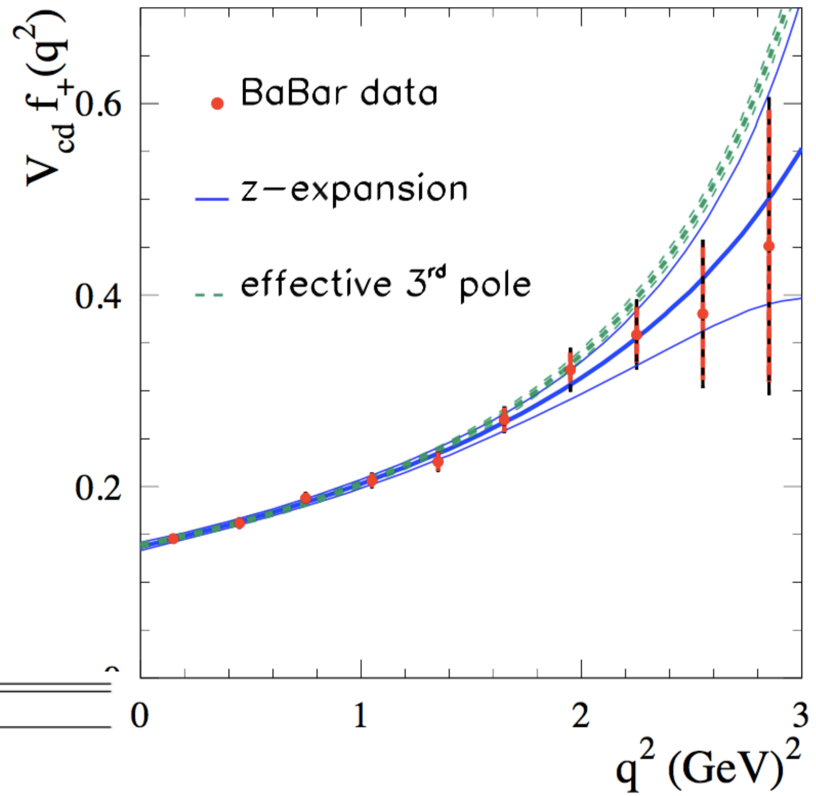
PRD84, 114505 (2011)

$|V_{cd}| = |V_{us}| = \lambda$ → $f^{\pi}_{+,D}(0) = 0.610 \pm 0.020_{\text{exp.}} \pm 0.005_{\text{other}}$

In most q^2 bins, dominant systematics are due to background

Results 2

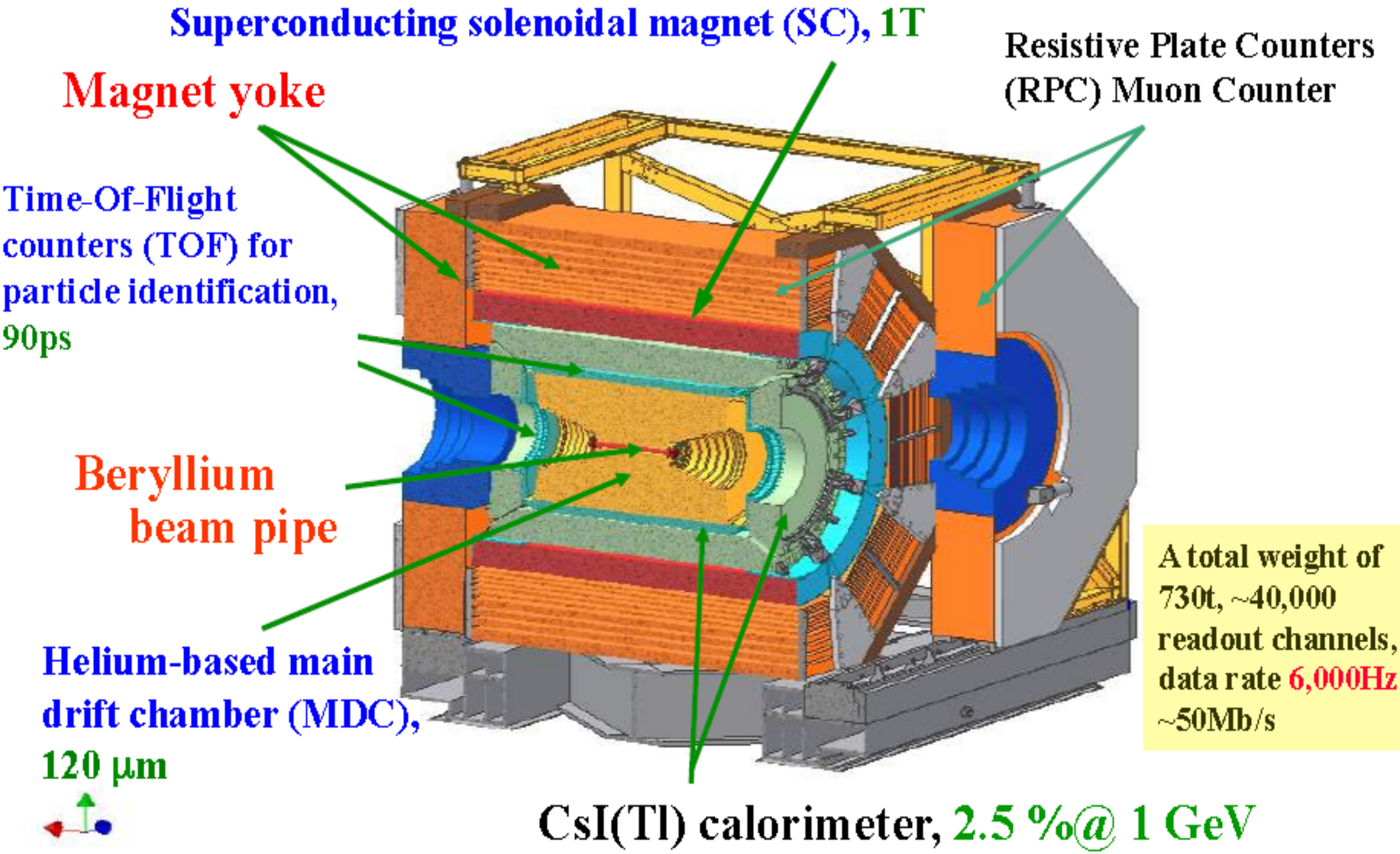
- $V_{cd} f_+^\pi(q^2)$ with z-expansion parameterization, floating $V_{cd} f_+^\pi(0)$ & shape parameters r_1, r_2



- Compare consistencies of different $f_+^\pi(q^2)$ parameterizations:

Ansatz	Fitted Parameters	χ^2/NDF	Predictions
z-expansion	$r_1 = -1.31 \pm 0.70 \pm 0.43$ $r_2 = -4.2 \pm 4.0 \pm 1.9$	2.0/7	
effective three-pole	$m_{\text{pole3}} = (3.55 \pm 0.30 \pm 0.05)$ GeV/c^2	4.8/9	$m_{\text{pole3}} > 3.1$ GeV/c^2
fixed three-pole	$c_2 = 0.17 \pm 0.06 \pm 0.01$ $c_3 = 0.15 \pm 0.09 \pm 0.06$	3.3/7	
two-pole	$b_2 = 1.643 \pm 0.060 \pm 0.035$ $b_3 = 0.68 \pm 0.13 \pm 0.11$	3.7/7	0.6
modified-pole	$\alpha_{\text{pole}} = 0.268 \pm 0.074 \pm 0.059$	3.0/8	< 0.6
single-pole	$m_{\text{pole}} = (1.906 \pm 0.029 \pm 0.023)$ GeV/c^2	5.5/8	2.010 GeV/c^2
ISGW2	$\alpha_I = (0.339 \pm 0.029 \pm 0.025)$ GeV^{-2}	2.1/8	0.104 GeV^{-2}

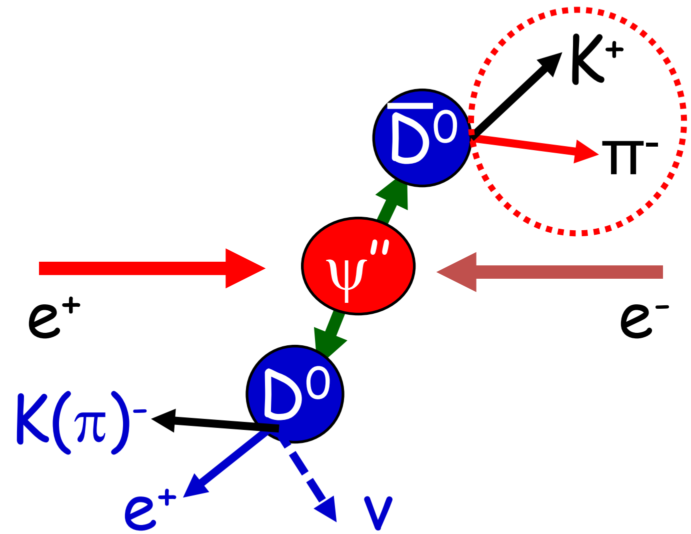
BESIII detector



Thanks to Hai-Bo Li and Hailong Ma

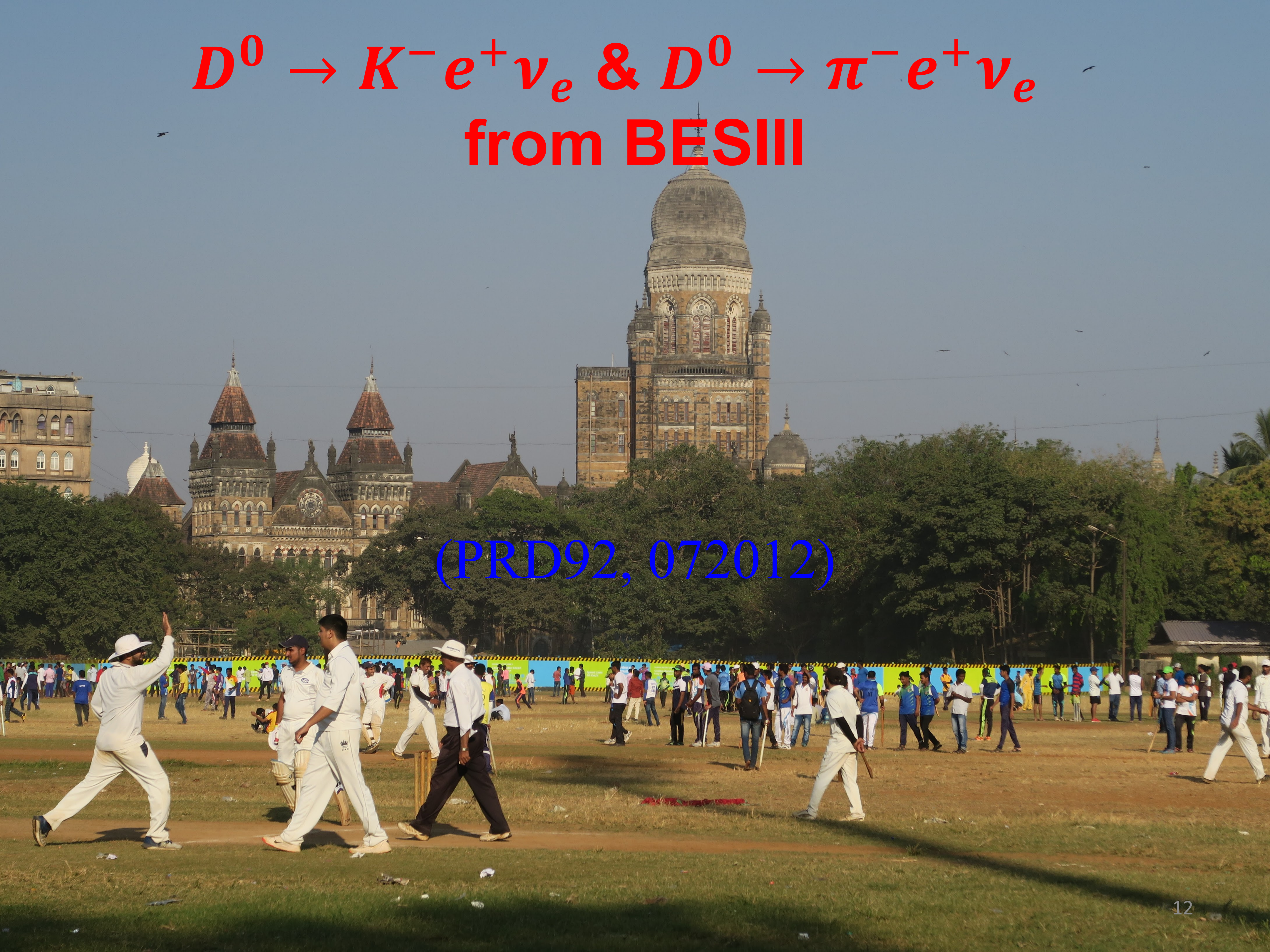
Hadronic tagging technique

- All presented analyses use $e^+e^- \to \psi(3770) \to D^0\overline{D}^0$ or D^+D^-
- Tag one meson in the decays
  - $D^0 \to K^+\pi^-,\ K^+\pi^-\pi^0,\ K^+\pi^-\pi^+\pi^-,$ $K^+\pi^-\pi^+\pi^-\pi^0,\ K^+\pi^-\pi^0\pi^0$
  - $D^+ \to K^+\pi^-\pi^-,\ K^+\pi^-\pi^-\pi^0,\ K_S^0\pi^-,$ $K_S^0\pi^-\pi^0,\ K_S^0\pi^+\pi^-\pi^-,\ K^+K^-\pi^-$
- Select good tag with
  - $M_{BC} = \sqrt{E_{\text{beam}}^2 - p_{\text{tag}}^2}$
  - $\Delta E = E_{\text{tag}} - E_{\text{beam}}$



- Reconstruct the semileptonic decay from the remaining events

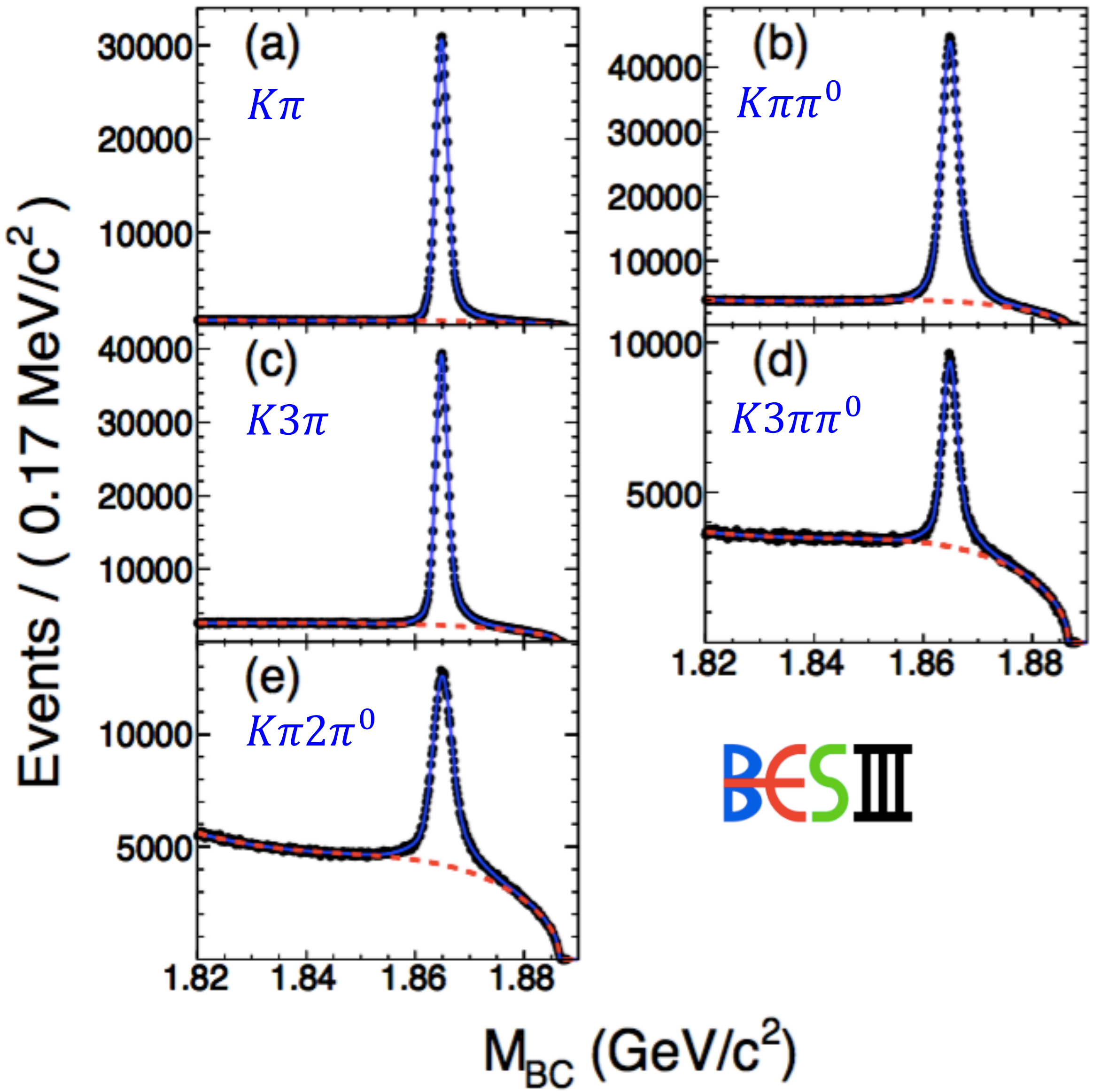
$D^0 \to K^- e^+ \nu_e$ & $D^0 \to \pi^- e^+ \nu_e$ from BESIII



(PRD92, 072012)

$\overline{D}^0$ tags

- Background shape: ARGUS × P3
- Signal shape: MC ⊗ 2G
- 2,793,317 ± 3684 tags



$D^0 \to h^- e^+ \nu_e$ reconstruction

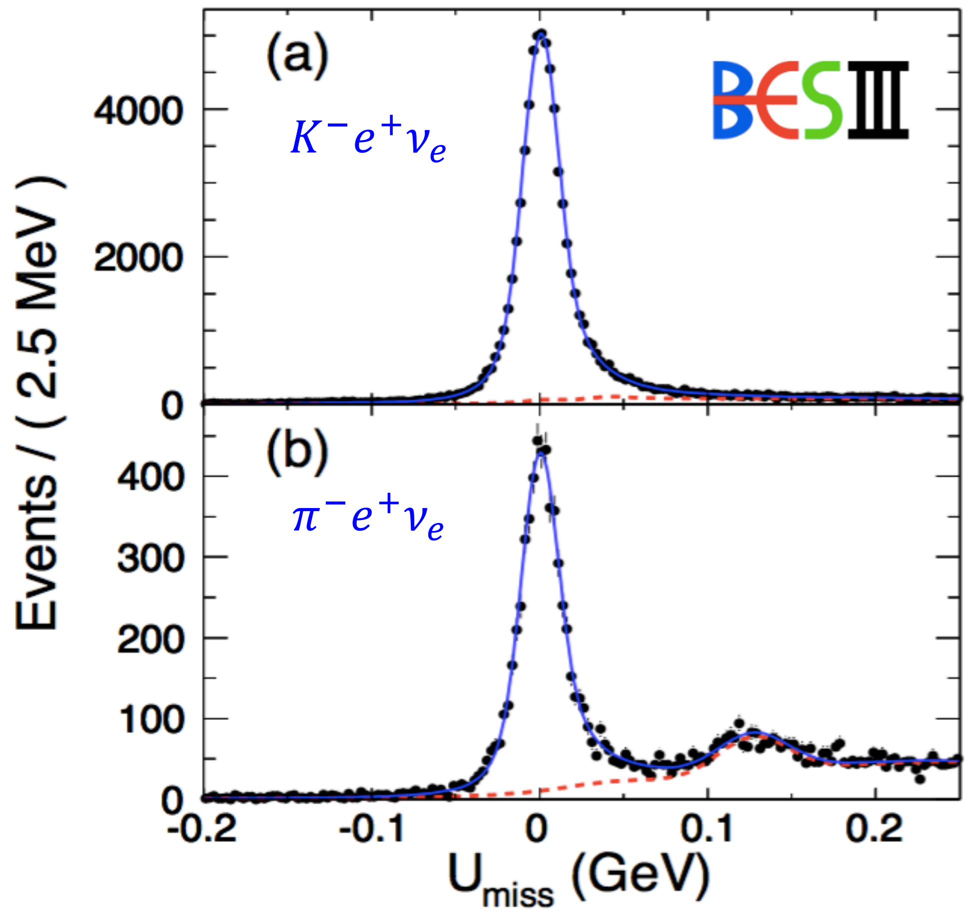
- Find h^- & e^+
- No unused tracks
- Unused γ: $E < 300$ MeV
- Apply $e^+e^- \to D^0\bar{D}^0$ kinematics:

$$U_{\text{miss}} \equiv E_{\text{miss}} - |\vec{p}_{\text{miss}}|$$

$$E_{\text{miss}} = E_{\text{beam}} - E_{h^-} - E_{e^+}$$

$$\vec{p}_{\text{miss}} = \vec{p}_{D^0} - \vec{p}_{h^-} - \vec{p}_{e^+}$$

$$\vec{p}_{D^0} = -\hat{p}_{\text{tag}}\sqrt{E_{\text{beam}}^2 - m_{D^0}^2}$$



- Fit U_{miss} to background (MC) + signal (Gaussian + power-law tails). Observed yields:

$$N_{\text{observed}}(D^0 \to K^-e^+\nu_e) = 70727.0 \pm 278.3$$

$$N_{\text{observed}}(D^0 \to \pi^-e^+\nu_e) = 6297.1 \pm 86.8$$

Results 1

- Granching fractions:

$$\mathcal{B}(D^0 \to K^- e^+ \nu_e) = (3.505 \pm 0.014 \pm 0.033)\%$$
$$\mathcal{B}(D^0 \to \pi^- e^+ \nu_e) = (0.295 \pm 0.004 \pm 0.003)\%$$

- $V_{cq} \times$ FFs (0):
  - Floating r_1 (2-param. expansion)
  - (Floating also $r_2 \to$ larger errors)

Decay mode	$f_+^{K(\pi)}(0)\lvert V_{cs(d)}\rvert$
$D^0 \to K^- e^+ \nu_e$	$0.7172 \pm 0.0025 \pm 0.0035$
$D^0 \to \pi^- e^+ \nu_e$	$0.1435 \pm 0.0018 \pm 0.0009$

- If take CKM elements from global fit:

$$f_+^K(0) = 0.7368 \pm 0.0026 \pm 0.0036$$
$$f_+^\pi(0) = 0.6372 \pm 0.0080 \pm 0.0044$$

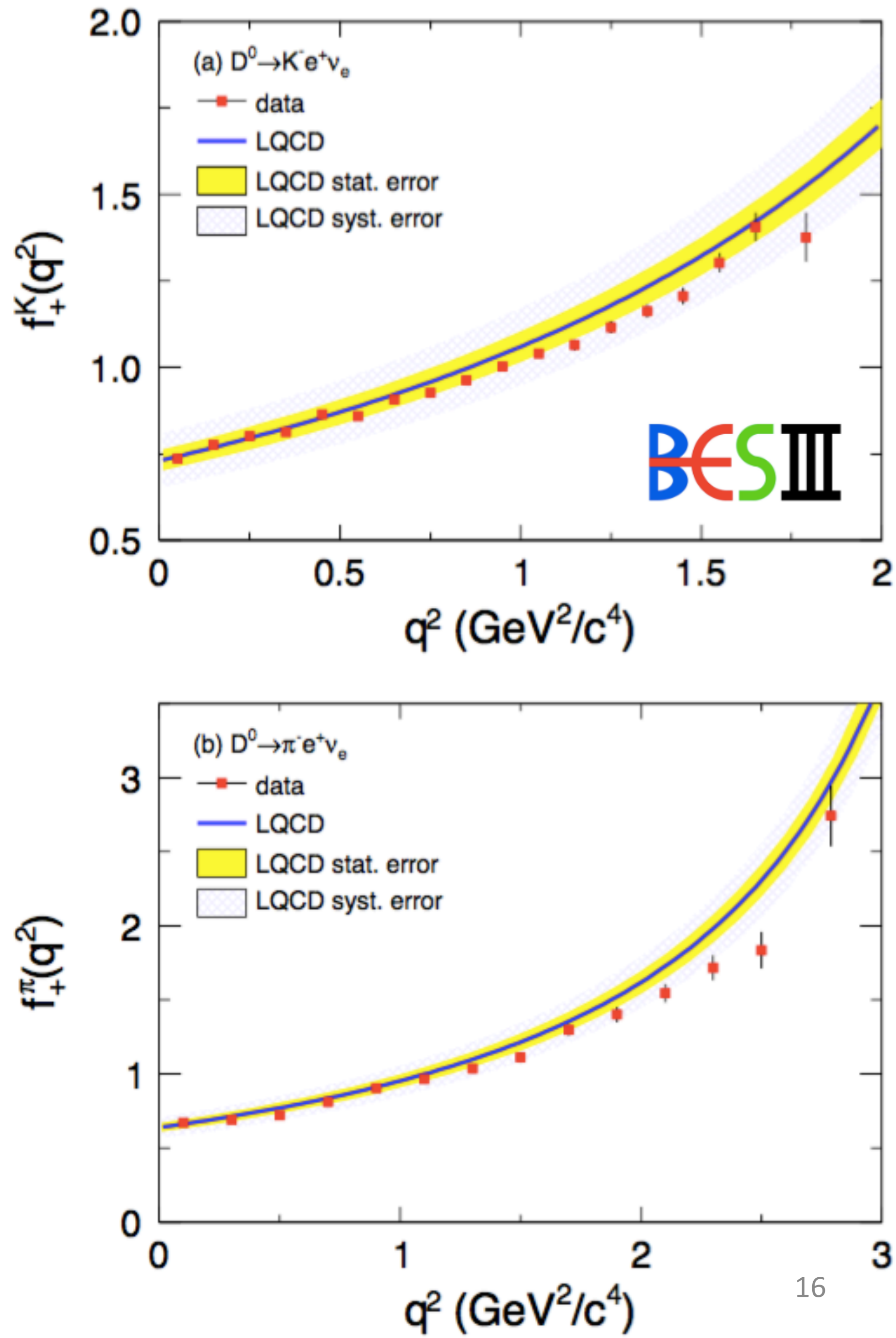
- If take FFs from lattice:
  - $f_+^K = 0.747 \pm 0.011 \pm 0.015$
  - $f_+^K = 0.666 \pm 0.020 \pm 0.021$

$$\lvert V_{cs}\rvert = 0.9601 \pm 0.0033 \pm 0.0047 \pm 0.0239$$
$$\lvert V_{cd}\rvert = 0.2155 \pm 0.0027 \pm 0.0014 \pm 0.0094$$

Dominant systematics are due to the # of tags, FSR recovery, and K tracking

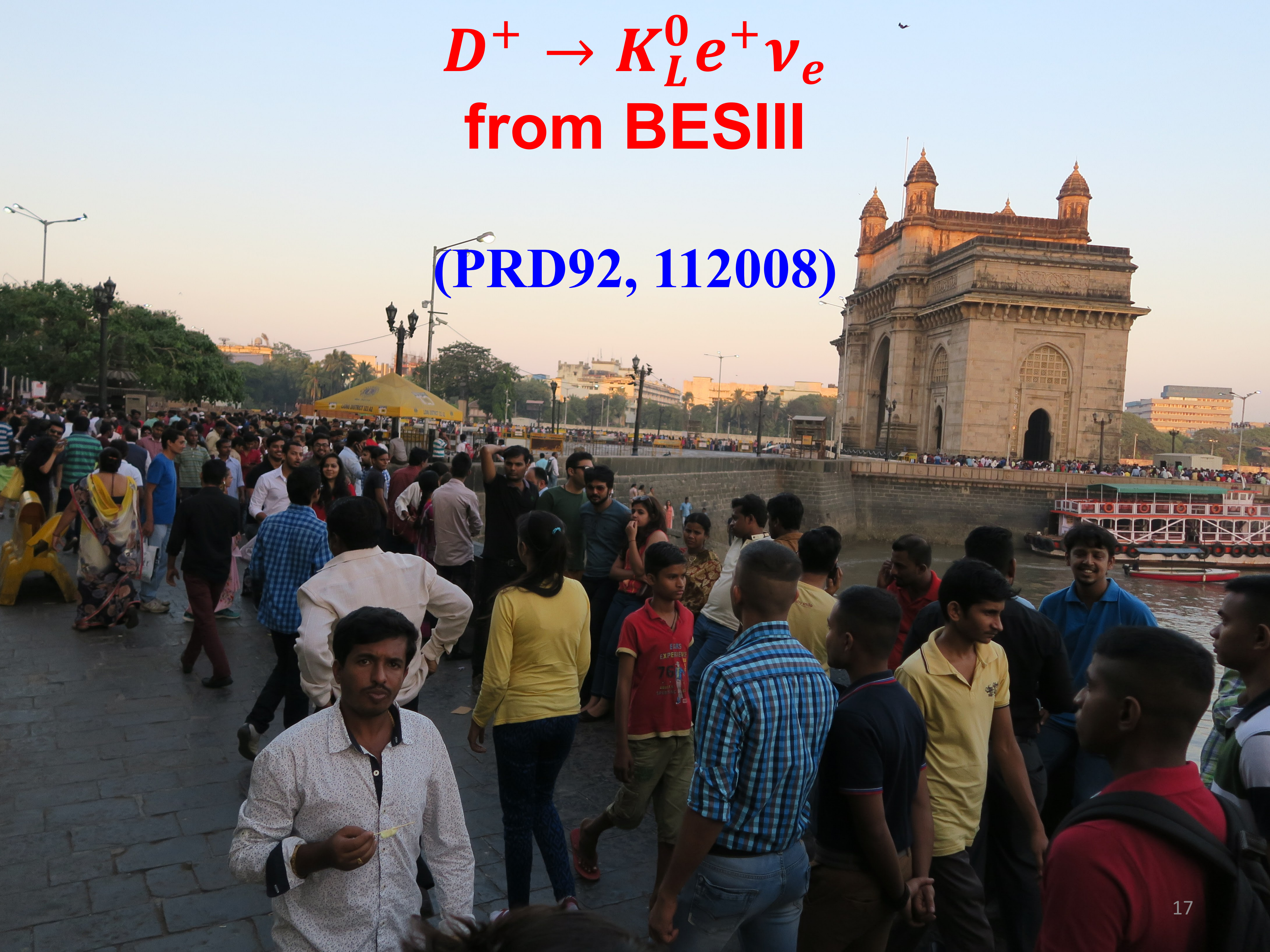
Results 2

- Compare FFs with LQCD predictions (PRL94, 01160)
- Deviations at high q^2
- The measurements are more precise than LQCD by ~3

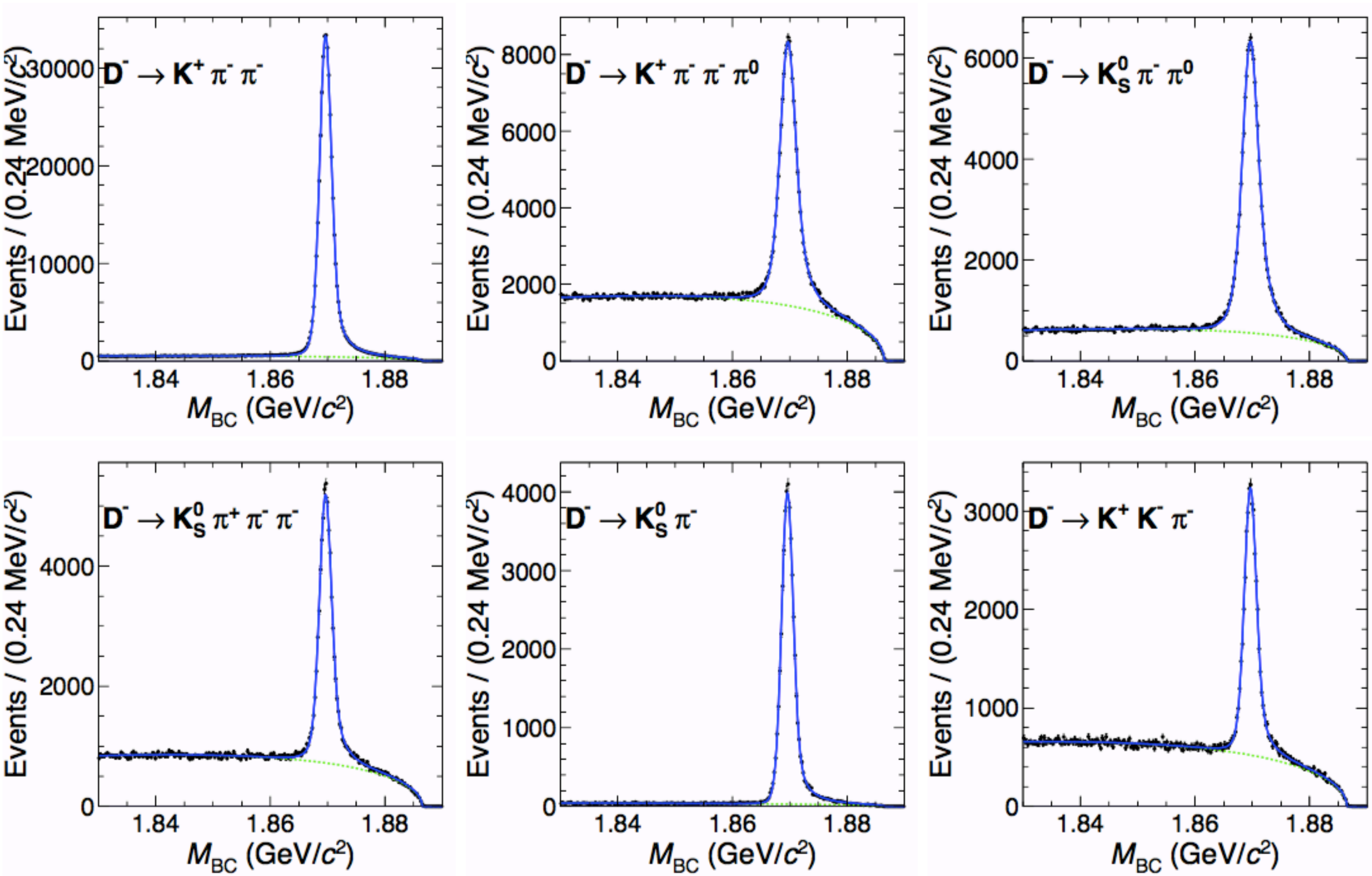


$D^+ \to K_L^0 e^+ \nu_e$ from BESIII

(PRD92, 112008)



D^- tags



- (Similar plots for D^+ tags)

$D^+ \to K_L^0 e^+ \nu_e$ reconstruction

- Find e^+
- Hardest unused calorimeter shower gives $\hat{p}_{K_L^0}$
- Use constraint $U_{\text{miss}} = E_{\text{miss}} - p_{\text{miss}} = 0$ to find $E_{K_L^0}$:

$$E_{\text{miss}} = E_{\text{tot}} - E_{\text{tag}} - \boxed{E_{K_L^0}} - E_e,$$
$$\vec{p}_{\text{miss}} = \vec{p}_{\text{tot}} - \vec{p}_{\text{tag}} - \boxed{\vec{p}_{K_L^0}} - \vec{p}_e;$$

- And then to get q^2: $q^2 = \frac{1}{c^4}(E_{\text{tot}} - E_{\text{tag}} - E_{K_L^0})^2 - \frac{1}{c^2}|\vec{p}_{\text{tot}} - \vec{p}_{\text{tag}} - \vec{p}_{K_L^0}|^2$

- Use MC to determine signal fraction:
  49% - 58%, depending on tag mode.

Results

$$Br(D^+ \to K_L^0 e^+ \nu_e) = (4.481 \pm 0.027 \pm 0.103)\%$$

$$A_{CP} = (-0.59 \pm 0.60 \pm 1.48)\%$$

$$V_{cs} f_+^K(0) = 0.728 \pm 0.006 \pm 0.011$$ (2-parameter expansion)

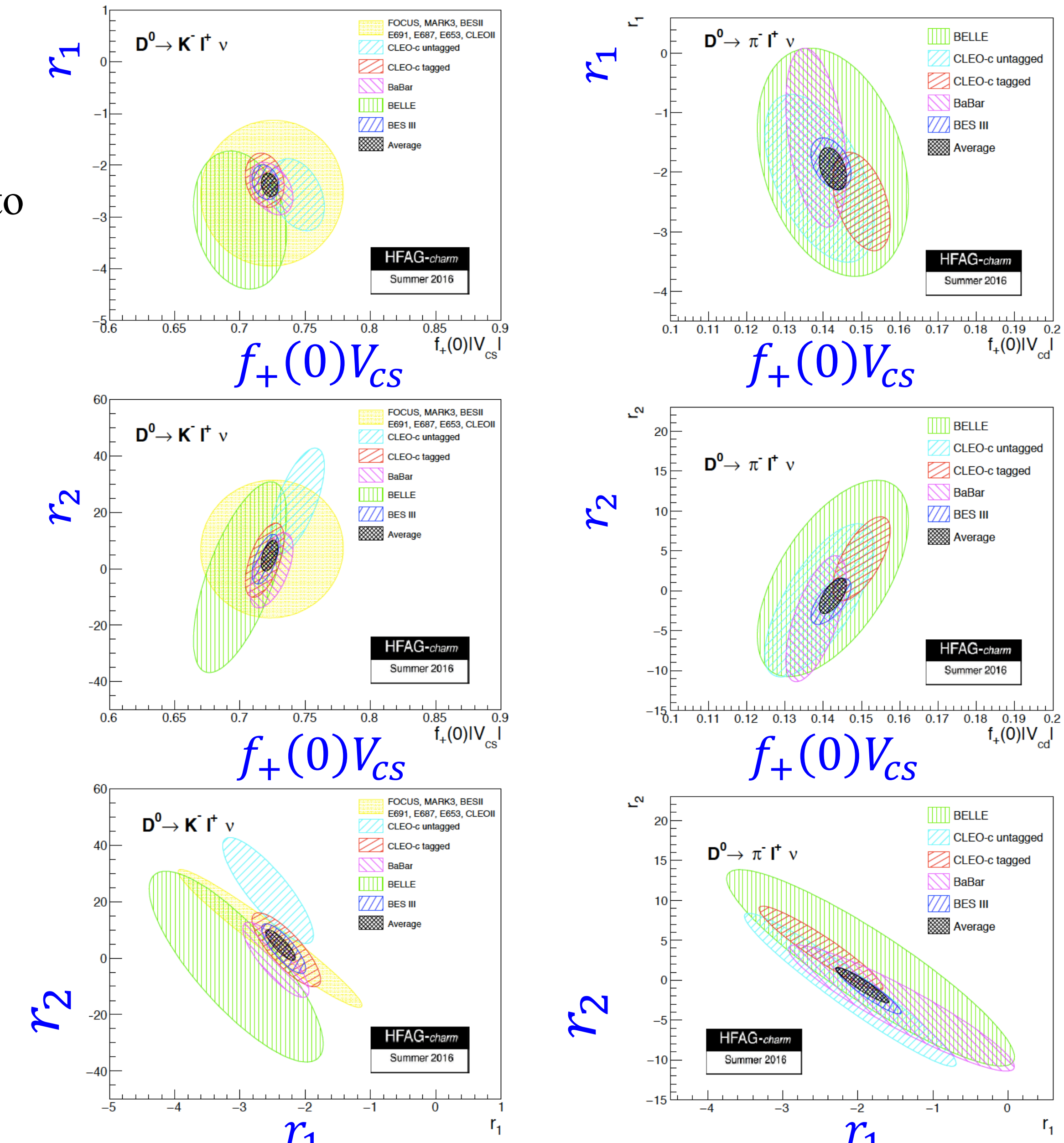
$|V_{cs}| = 0.97343 \pm 0.00015$ (PGD): $f_+^K(0) = 0.748 \pm 0.007 \pm 0.012$

$f_+^K(0) = 0.747 \pm 0.019$ (LQCD): $|V_{cs}| = 0.975 \pm 0.008 \pm 0.015 \pm 0.025$

Dominant systematics are due to peaking (signal-side) background and K_L efficiency

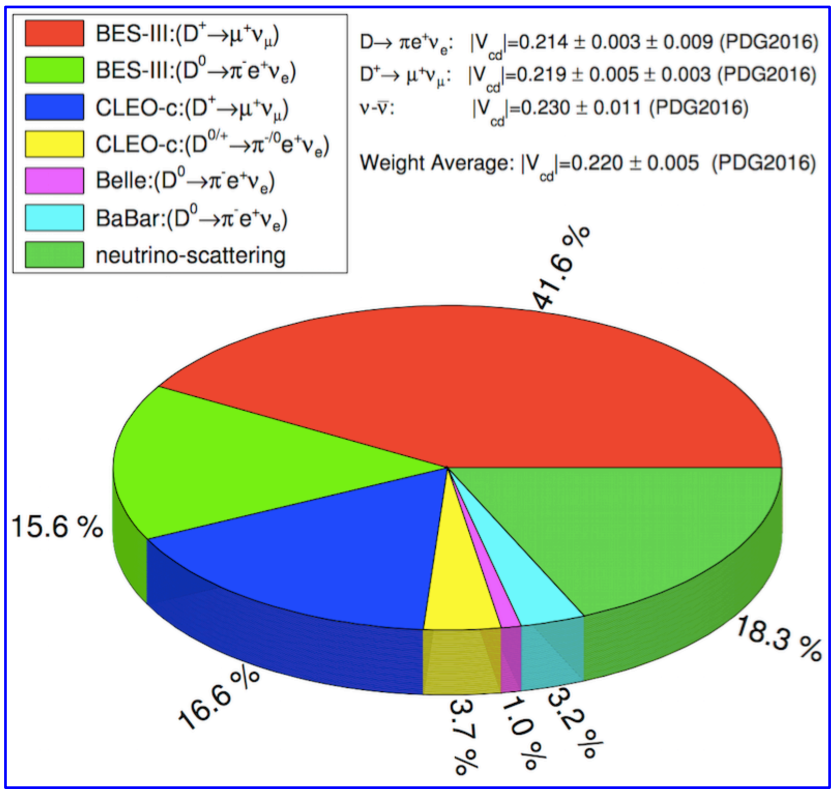
Conclusions 1

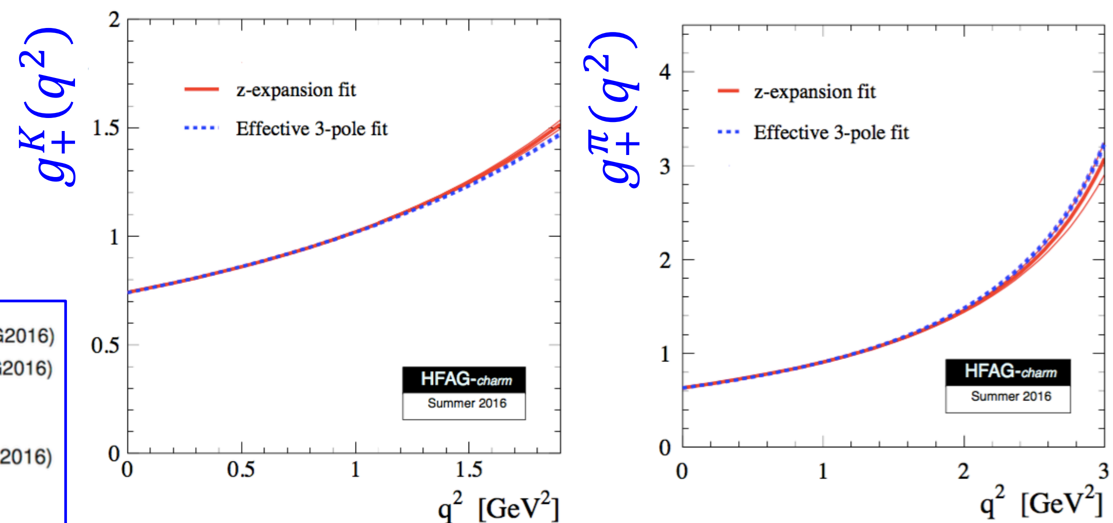
HFAG summary of contributions to expansion parameters & FFs from 3-parameter fits



Thanks:
Arantza Oyanguren Campos

Conclusions 2





FF dependence on q^2:
Extremely small experimental errors

Thanks: Hai-Bo Li, Gang Rong