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D semi-leptonic and leptonic decays at BESIII

BESIII Collaboration

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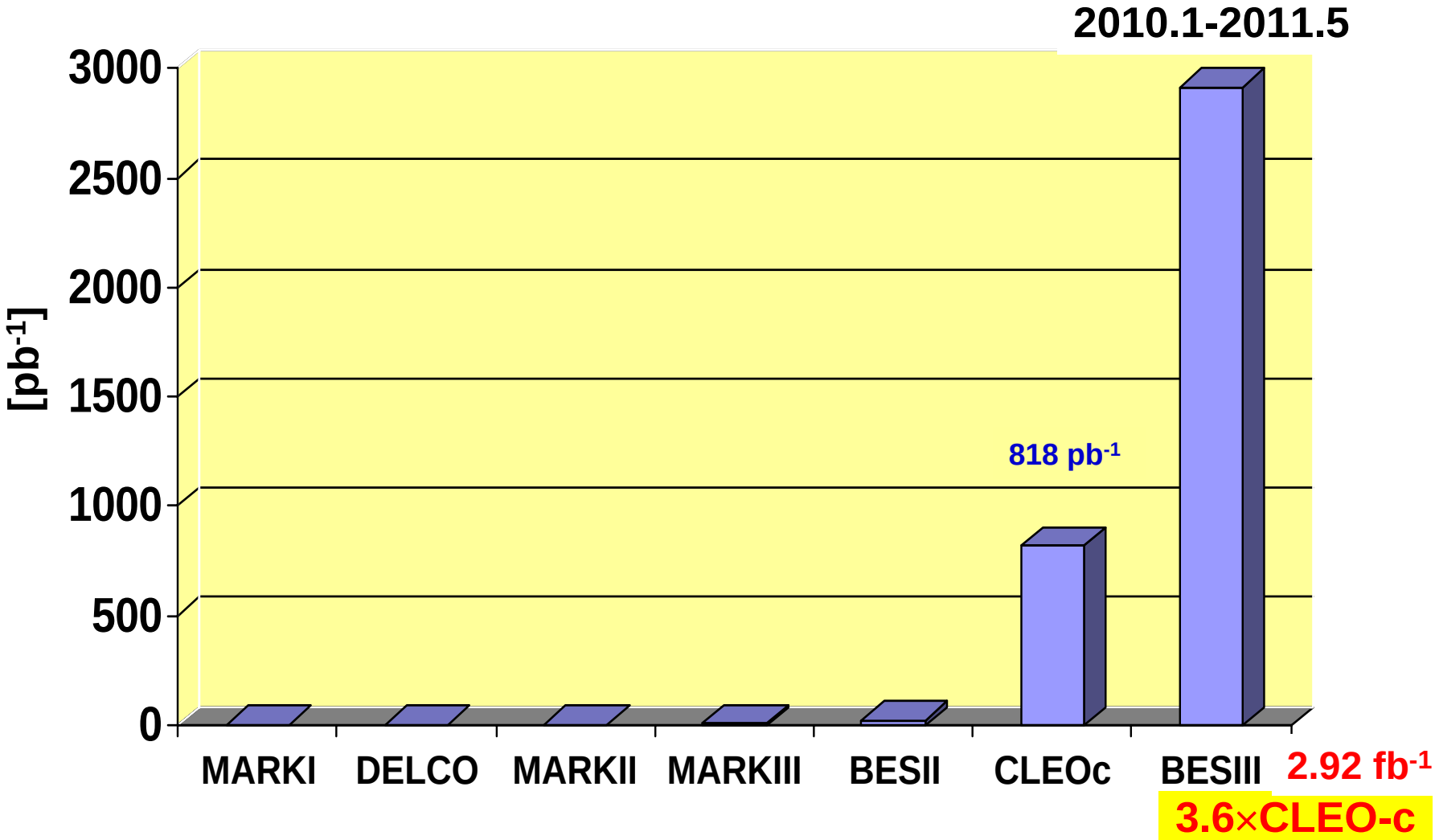
Outline

Key words: BESIII/BEPCII, precision measurement, D meson purely and semi-leptonic decays, decay constant f_{D+}, form factors $f^{+}_{K/\pi}(q^2)$, CKM matrix elements $|V_{cs}|$ and $|V_{cd}|$.

- Data and D meson production
- $D^{+} \rightarrow \mu^{+}\nu$, f_{D+} and $|V_{cd}|$
- $D^{0} \rightarrow K/\pi^{-}e^{+}\nu$, $f^{+}_{K/\pi}(q^2)$ and $|V_{cs/d}|$
- Summary

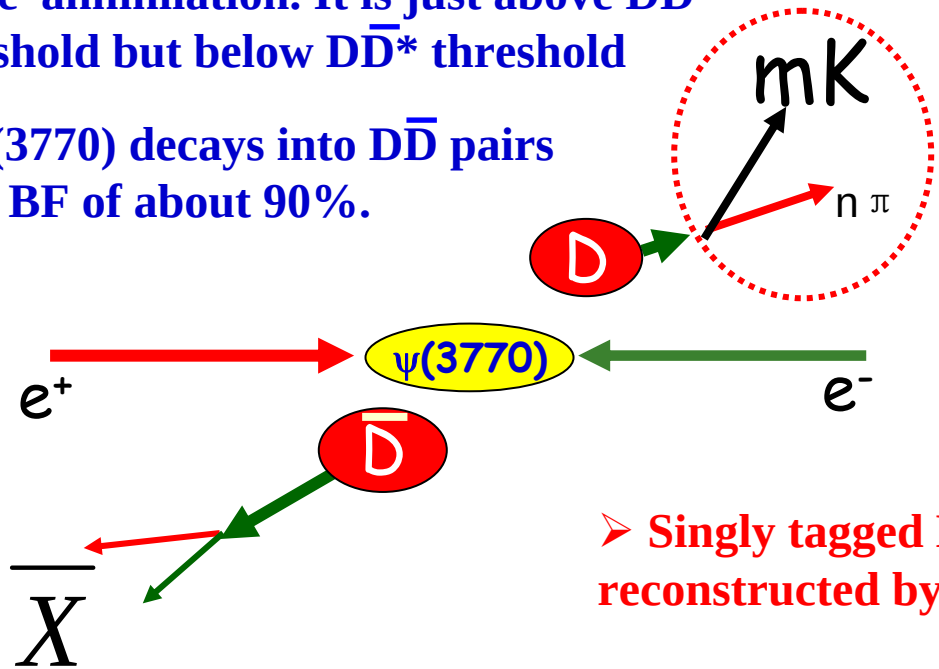
Data and D meson production

e^+e^- collision data taken at ~3.773 GeV



D meson production at 3.773 GeV

- At 3.773 GeV, ψ(3770) is produced in e^+e^- annihilation. It is just above $D\bar{D}$ threshold but below $D\bar{D}^*$ threshold
- ψ(3770) decays into $D\bar{D}$ pairs with BF of about 90%.



Singly tagged $\bar{D}$ sample

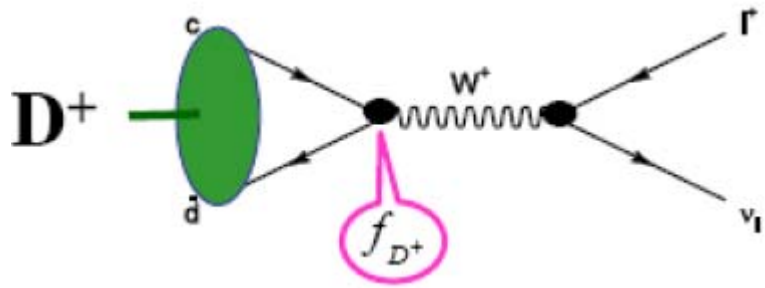
$$B(D \to X) = \frac{N(D \to X)}{N_{\bar{D}\text{tag}} \times \varepsilon_{D \to X}}$$

- Singly tagged $\bar{D}^0$ and D^- mesons can be fully reconstructed by hadronic decays.
- With the singly tagged $\bar{D}^0$ and D^- mesons, we can measure the branching fraction for purely leptonic decays and semi-leptonic decays absolutely, and study their decay mechanism.

Purely-leptonic decay

$D^+ \rightarrow \mu^+ \nu$, f_{D+} and $|V_{cd}|$

$D^+ \rightarrow \mu^+ \nu$ and decay constant f_{D+}



$$\Gamma(D^+ \rightarrow \mu^+ \upsilon_\mu) = \frac{G_F^2}{8\pi} f_{D^+}^2 \, |V_{cd}|^2 \, m_l^2 \left(1 - \frac{m_l^2}{m_{D^+}^2}\right) m_{D^+}$$

- **All strong interaction effect between the two quarks within D^+ meson is simply factorized into the decay constant f_{D+}.**
- **Improved f_{D+} can accurately test LQCD calculation of f_{D+}.**
- **In current LQCD calculations, the ratio f_{D+}:f_{Ds+}:f_{B+} has a significantly better precision than their individual values. Once the measured f_{D+} pass the test on LQCD, f_{B+} can be improved. As a result, $|V_{td}|$ can also be improved in the of $B^0\bar{B}^0$ mixing experiment.**

Isospin symmetry expects $f_B = f_{B0} = f_{B+}$. The well $B^0\bar{B}^0$ mixing parameter x_B relates to $|V_{td}|$ and f_B. The decay constant f_{B+} relates to $|V_{td}|$ via $B^+ \rightarrow l^+ \nu$.

$|V_{cd}|$ measured via $D^+ \rightarrow \mu^+ \nu$

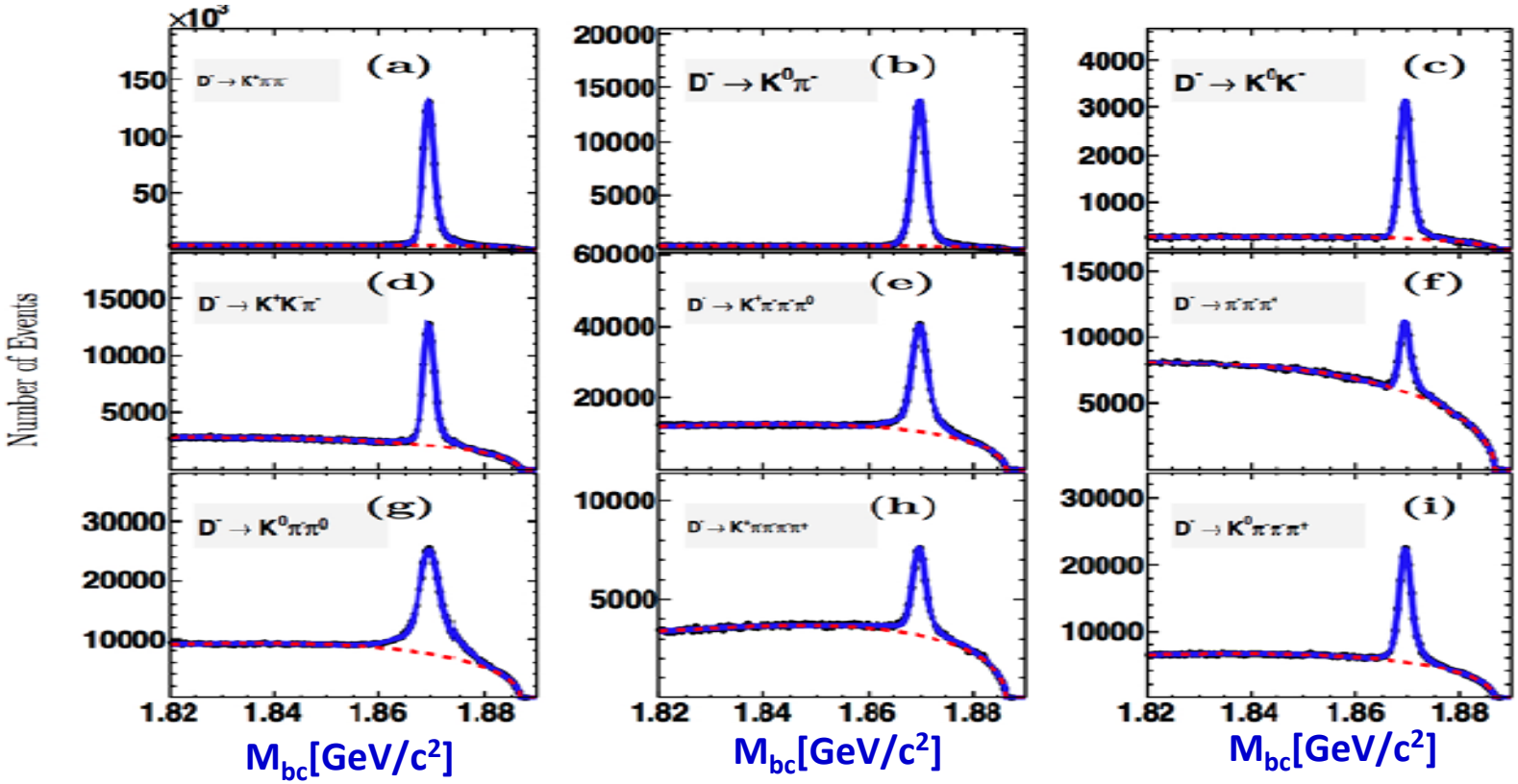
- **In history, $|V_{cd}|$ was usually measured by**
  - **D meson decay $D \rightarrow \pi e^+ \nu$, which suffers 11% uncertainty of theoretical calculation of form factor;**
  - **neutrino and anti-neutrino interaction, which suffers 4.8% uncertainty.**

- **A recent un-quenched LQCD of f_{D+} reaches ~2% precision, thus provides an opportunity to accurately measure $|V_{cd}|$ by $D^+ \rightarrow \mu^+ \nu$.**

- **More accurate measurements of $|V_{cd}|$ and $|V_{td}|$ will improve the stringency of unitarity constraints on CKM matrix and provide improved test on the Standard Model.**

Single tag D⁻ mesons

Preliminary results

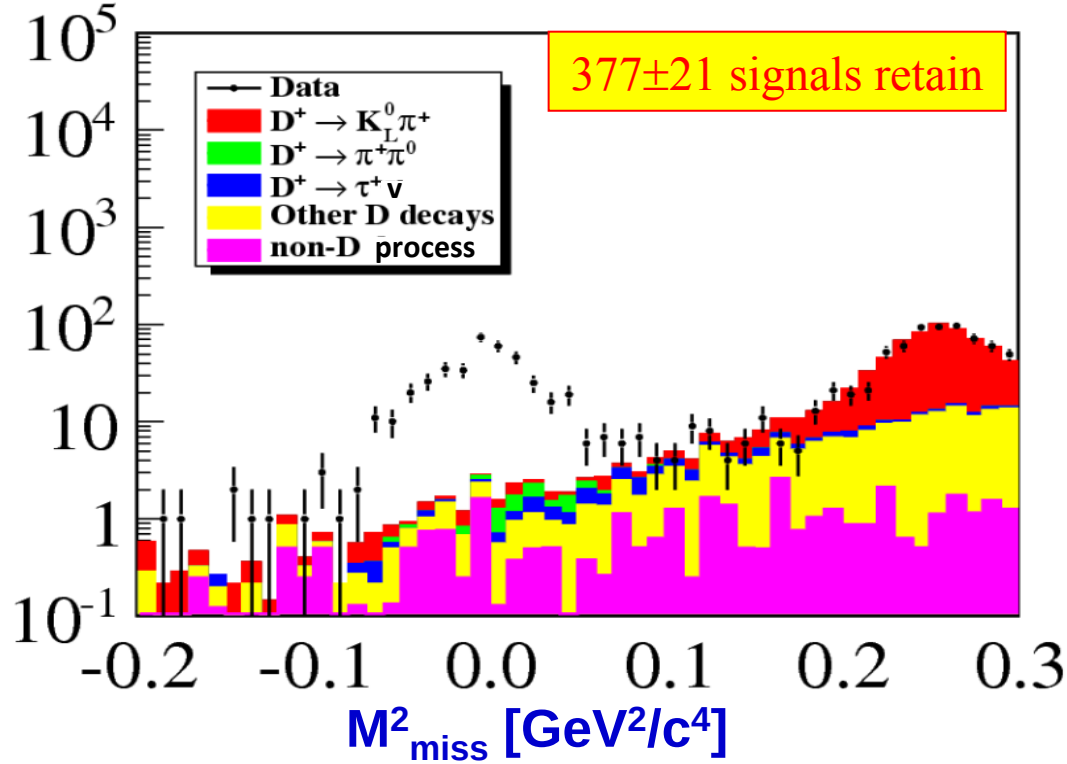


$$N_{D^-_{tag}} = (1.566 \pm 0.002) \times 10^6$$

Preliminary results on f_{D+} and $|V_{cd}|$

In the recoil side, we select the purely leptonic decays $D^+ \rightarrow \mu^+\nu$ by defining

$$E_{miss} = E_{cms} - \sum_i E_i$$
$$\vec{p}_{miss} = -\sum_i \vec{p}_i$$
$$M^2_{miss} = E^2_{miss} - P^2_{miss}$$



M^2_{miss} for the events of the singly tagged D^- vs. $D^+ \rightarrow \mu^+\nu$ should be ~0

$B[D^+ \rightarrow \mu^+\nu] = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$

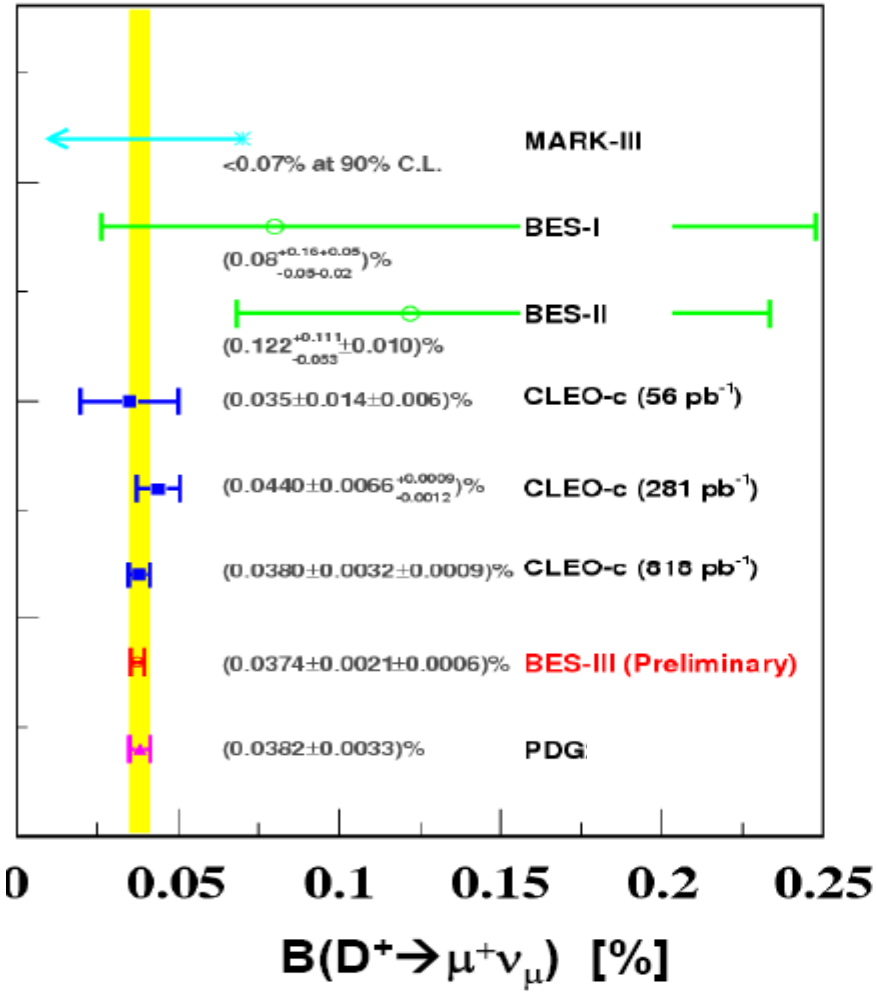
Input t_{D+}, m_{D+}, $m_{\mu+}$ on PDG and $|V_{cd}|$ of CKM-Fitter

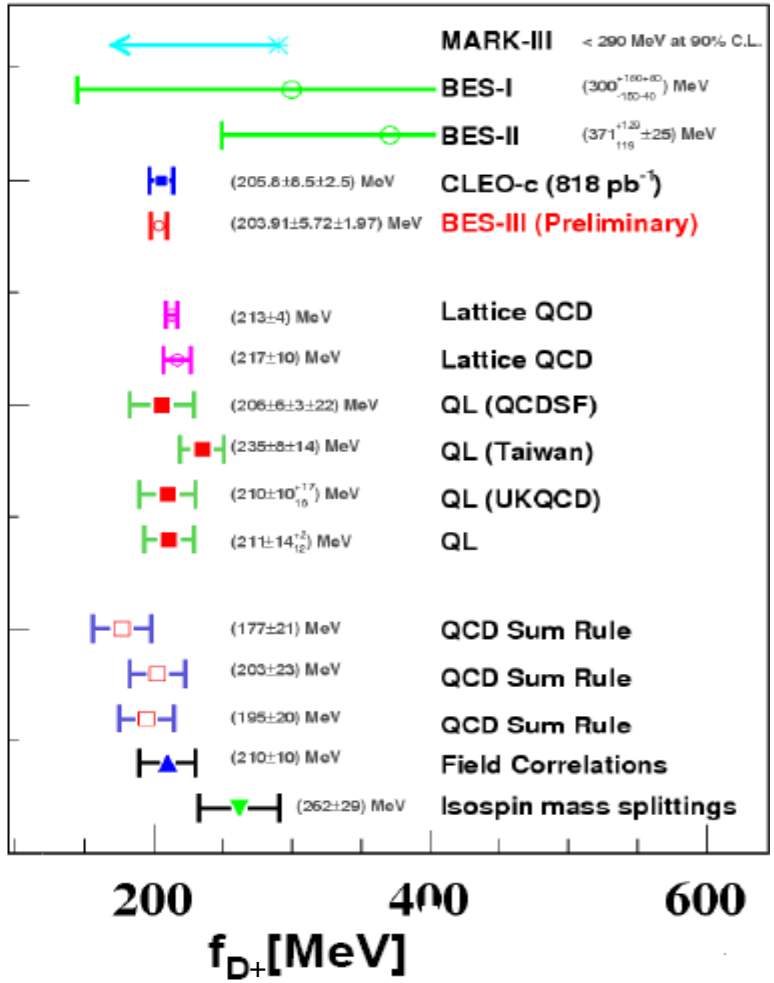
$f_{D+} = (203.91 \pm 5.72 \pm 1.97)$ MeV

Input t_{D+}, m_{D+}, $m_{\mu+}$ on PDG and LQCD calculated $f_{D+} = 207 \pm 4$ MeV[PRL100(2008)062002]

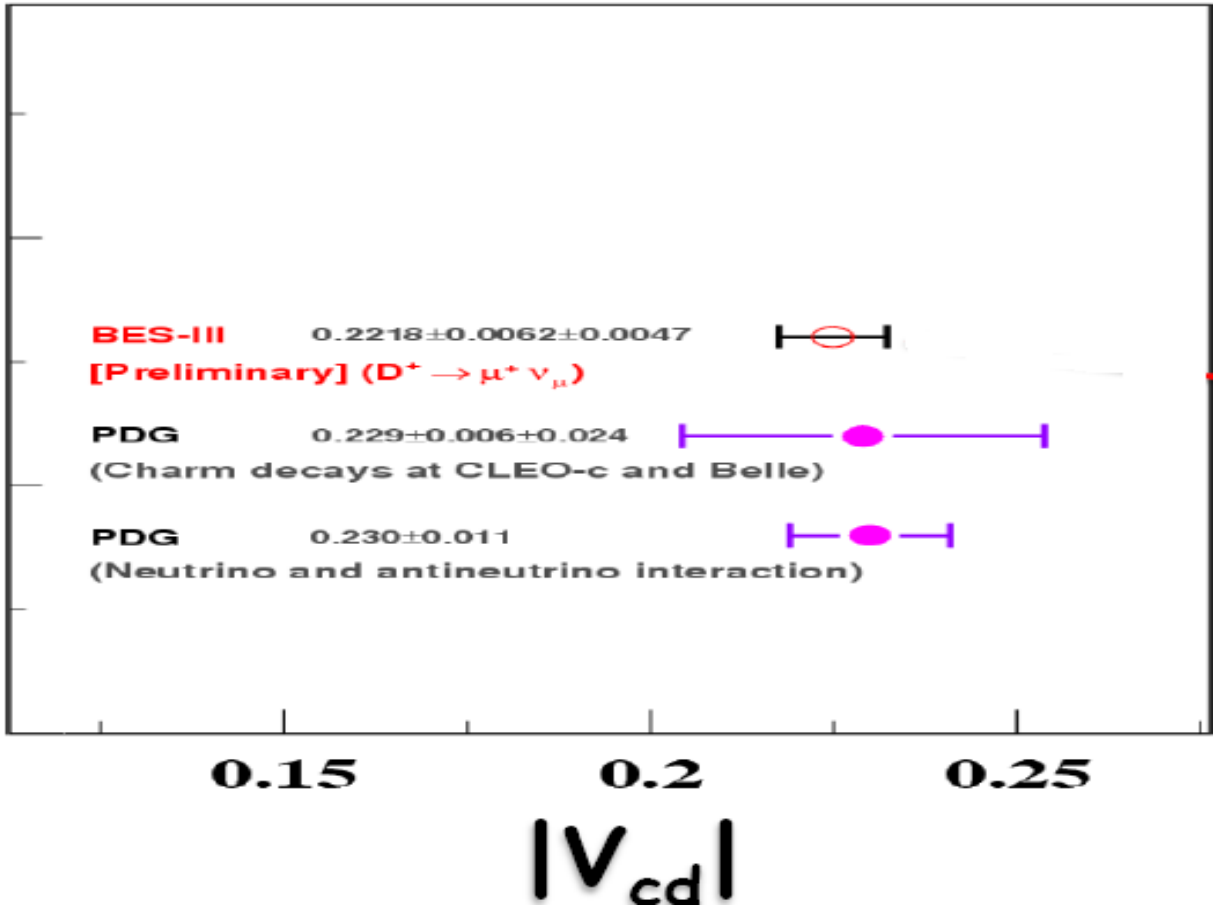
$|V_{cd}| = 0.222 \pm 0.006 \pm 0.005$

Comparisons of $B[D^+ \to \mu^+ \nu_\mu]$ and f_{D+}





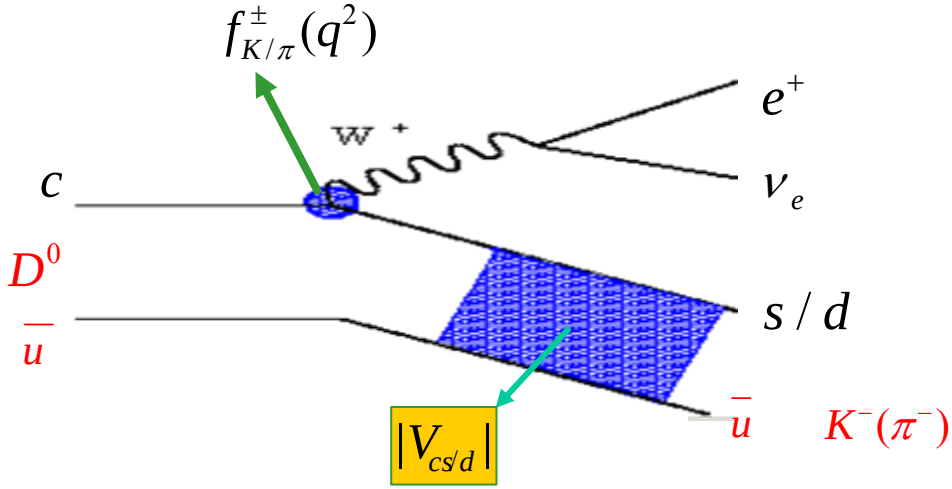
Comparisons of the measured $|V_{cd}|$



Semi-leptonic decay

$D^0 \rightarrow K/\pi^- e^+ \nu$, $f^+_{K/\pi}(q^2)$ and $|V_{cs/d}|$

$D^0 \rightarrow K/\pi^- e^+ \nu$ and form factor $f^+_{K/\pi}(q^2)$



$$\frac{\Delta\Gamma(D^0 \rightarrow K/\pi^- e^+ \upsilon_e)}{dq^2} = \frac{G_F^2 \, |V_{cs(d)}|^2}{24\pi^3} p^3 \left| f_+^2(q^2) \right|^2$$

- **The strong interaction effect between the two quarks within D^0 meson is simply factorized into the form factor $f^+_{K/\pi}(q^2)$.**
- **$|V_{cs/d}|$ parameterizes the mixing between the quark mass eigenstates and the two weak eigenstates.**

$f^+_{K/\pi}(q^2)$ and $|V_{cs/d}|$ from D semileptonic decay

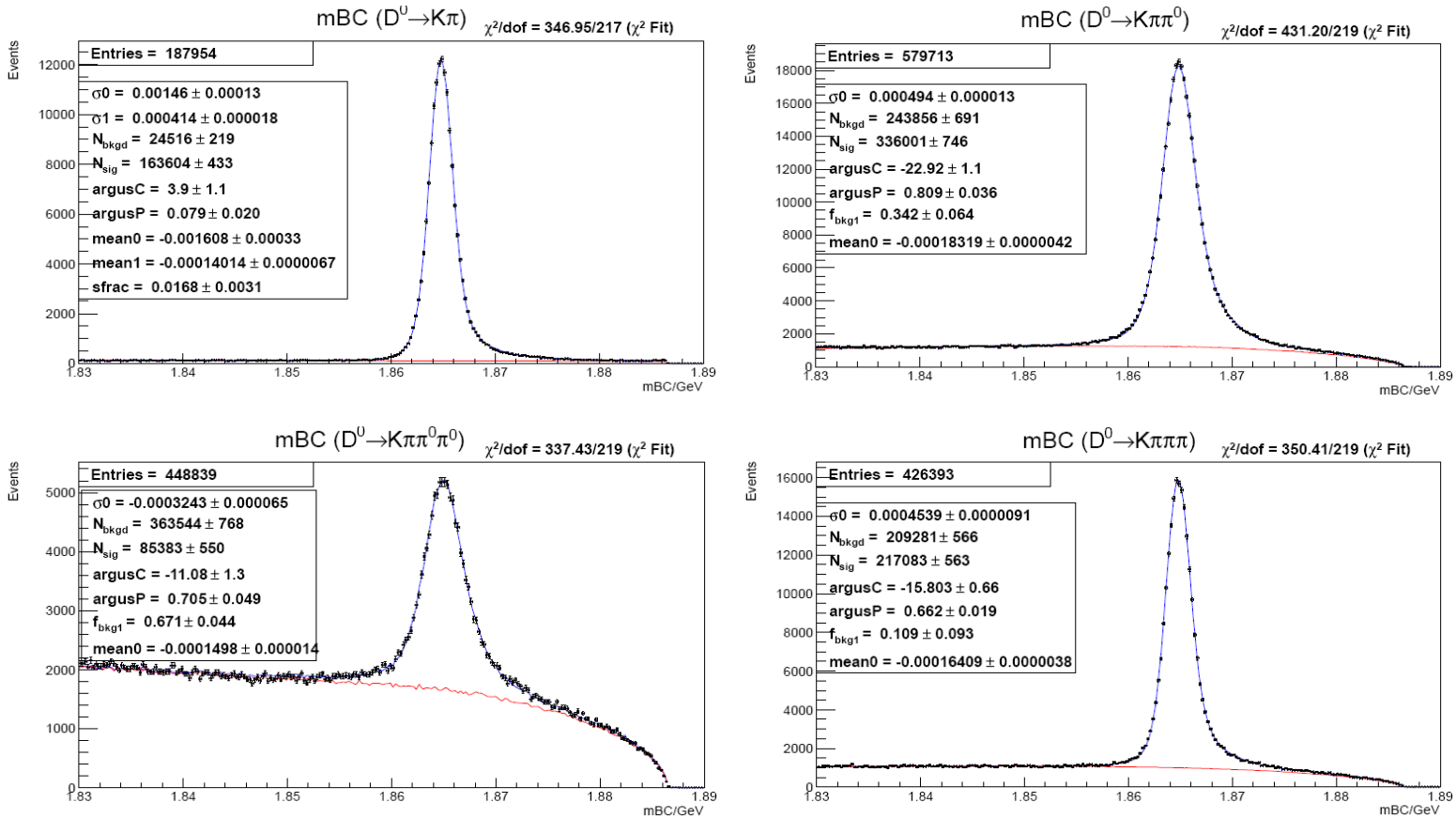
- **In experiment, studies of $D^0 \rightarrow K/\pi^- e^+ \nu$ can provide**
  - **form factors of hadronic current $f^+_{K/\pi}(q^2)$**
    - **Single pole form**
    - **Modified pole model**
    - **ISGW2 model**
    - **Series expansion model**
  - **CKM matrix elements $|V_{cs}|$ and $|V_{cd}|$**

- **The improved $f^+_{K/\pi}(q^2)$ can be used to validate the LQCD calculations on $f^+_{K/\pi}(q^2)$**

- **More accurate measurements of $|V_{cs}|$ and $|V_{cd}|$ can more precisely test the SM.**

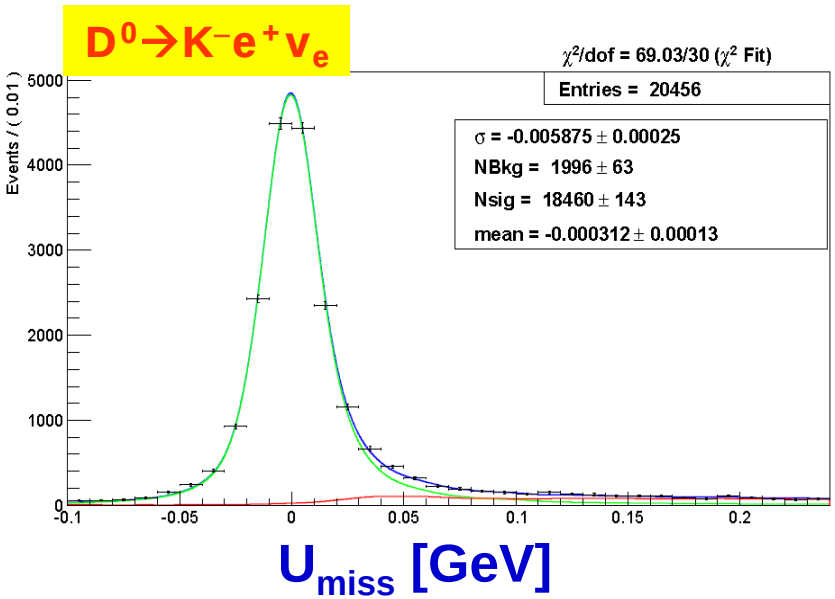
Single tag $\overline{D}^0$ mesons

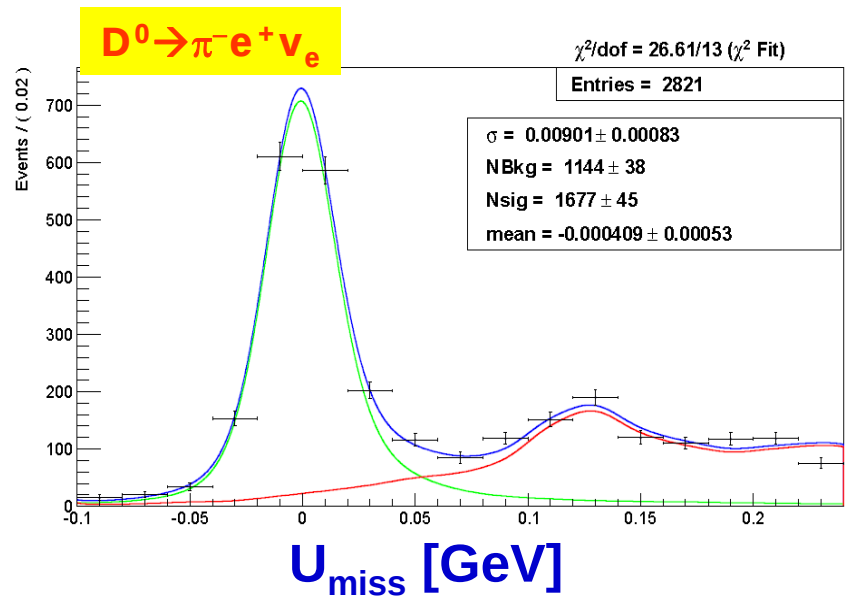
Preliminary results with 0.928fb^{-1} data@ 3.773 GeV



$$N_{\overline{D}^0_{tag}} = (0.774 \pm 0.001) \times 10^6$$

Preliminary results





$$E_{miss} = E_{cm} - \sum_i E_i$$

$$\vec{p}_{miss} = \left| -\sum_i \vec{p}_i \right|$$

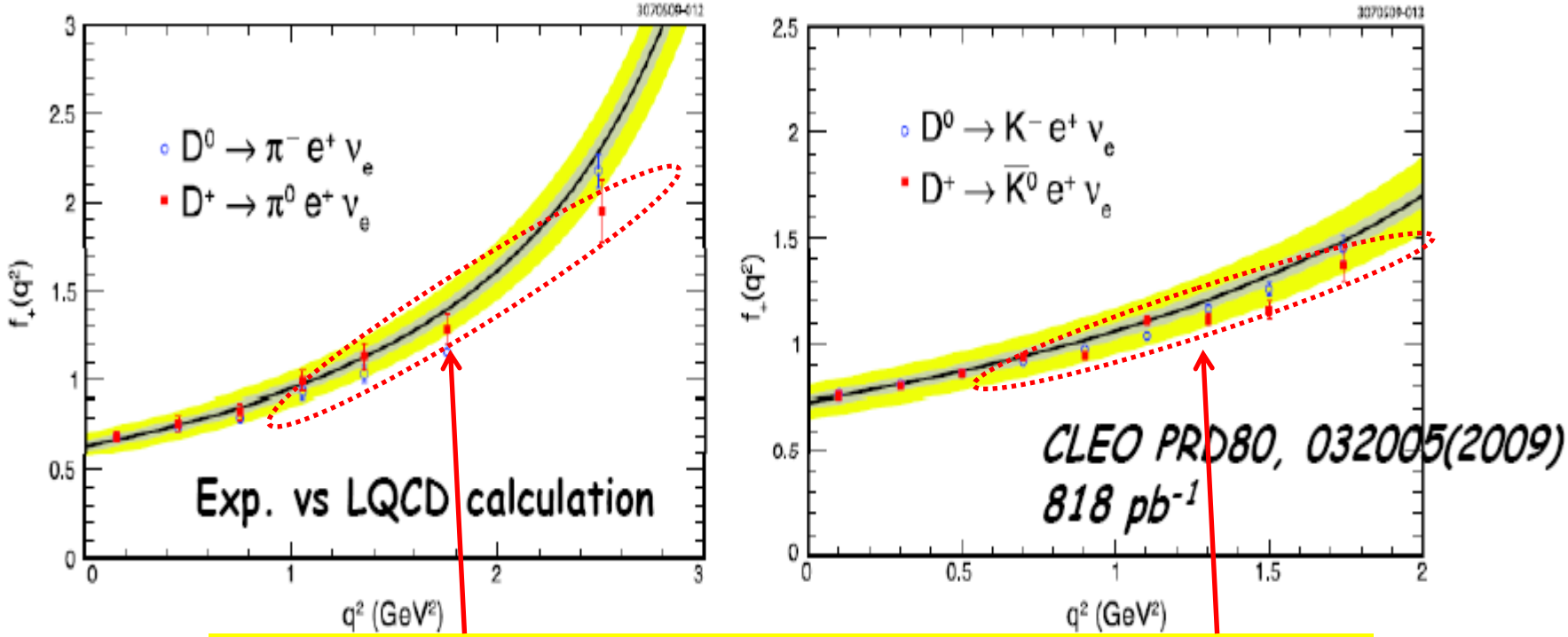
$$U_{miss} = E_{miss} - p_{miss}$$

U_{miss} for the events of the singly tagged $\bar{D}^0$ vs. $D^0 \to K/\pi^- e^+ \nu$ should be ~0

B [%]	BESIII (0.928 fb^{-1})	CLEO-c (0.818 fb^{-1})	PDG
$D^0 \to K^- e^+ \nu_e$	3.542±0.030±0.046	3.50±0.03±0.04	3.55±0.04
$D^0 \to \pi^- e^+ \nu_e$	0.288±0.008±0.004	0.288±0.008±0.003	0.289±0.008

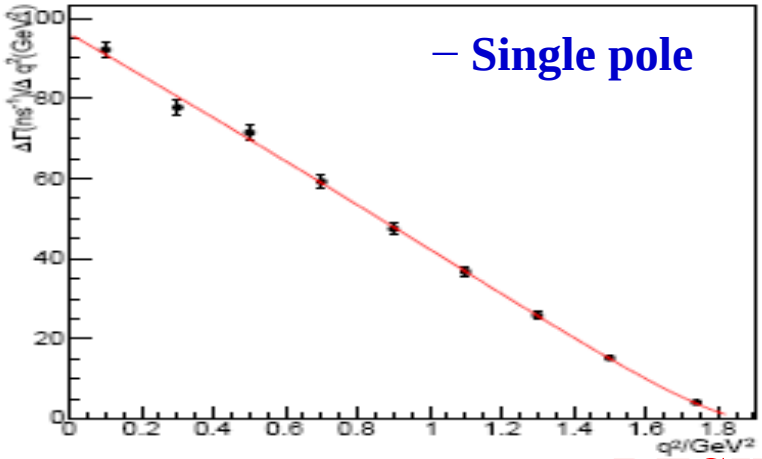
Form factors at CLEO-c

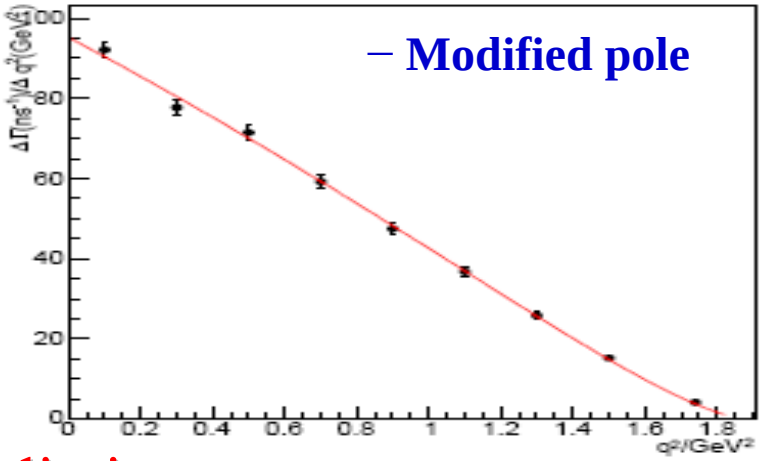
Form factor studies from CLEO-c experiment



Experimental measurements will calibrate LQCD calculation.

Form factor fits for $D^0 \rightarrow K^- e^+ \nu$





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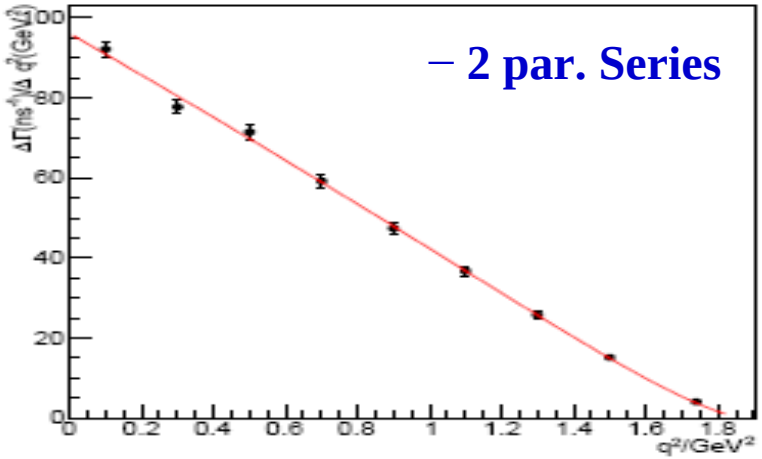
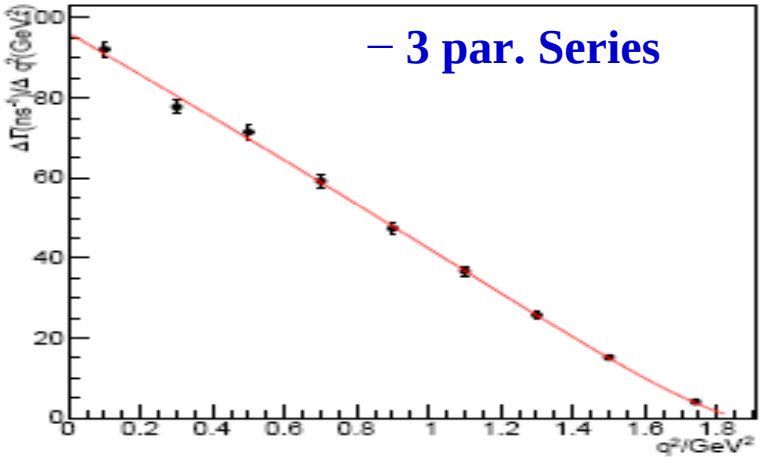
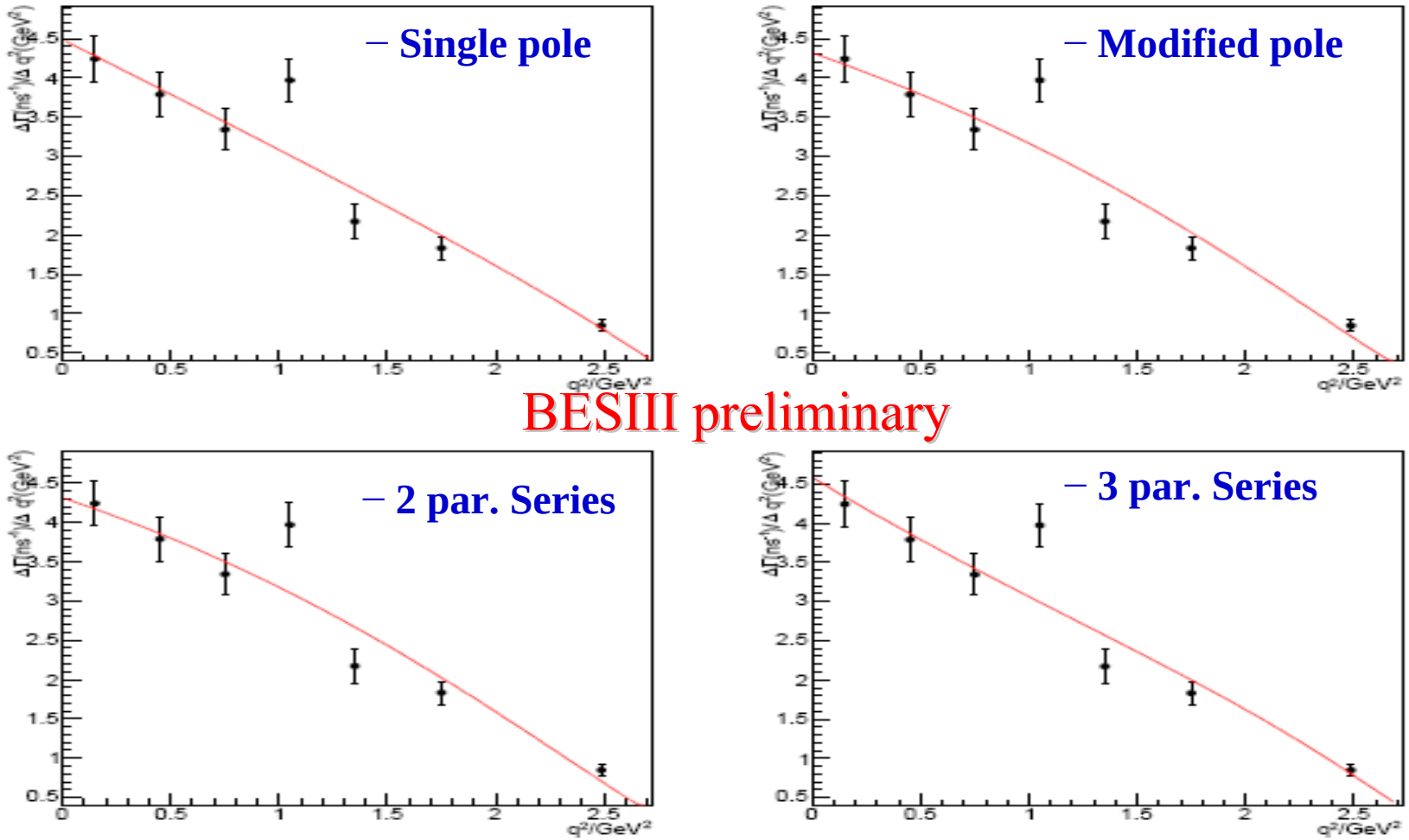




Form factor fits for $D^0 \rightarrow \pi^- e^+ \nu$



Form factor fit results

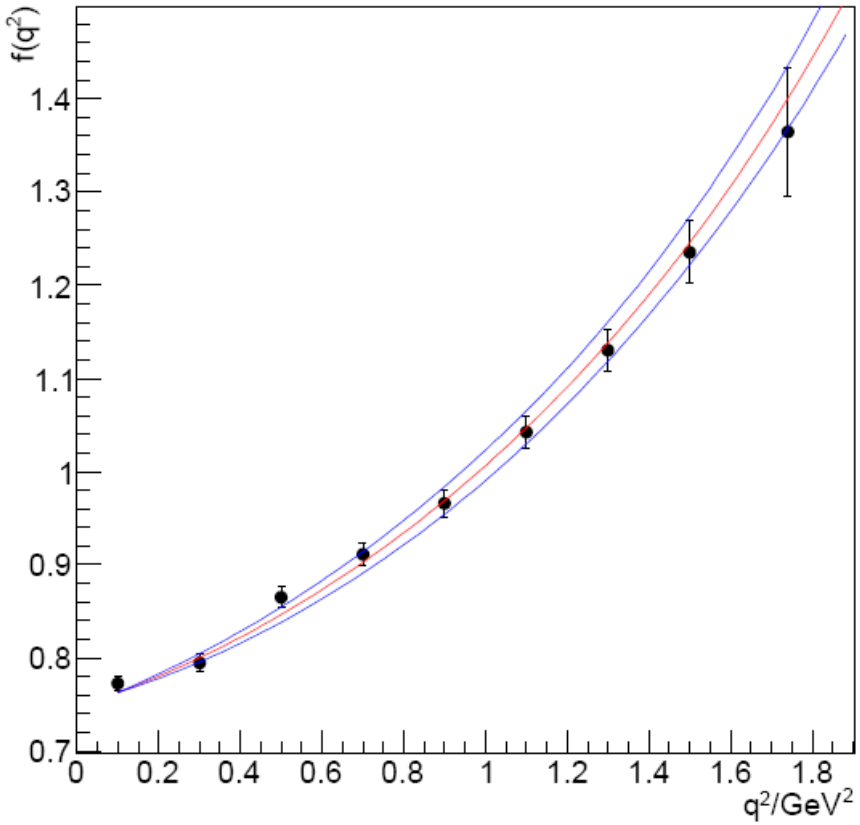
Simple Pole	$f_+(0)\|V_{cd(s)}\|$	m_{pole}	
$D^0 \to Ke\nu$	0.729±0.005±0.005	1.943±0.025±0.003	
$D^0 \to \pi e\nu$	0.142±0.003±0.001	1.876±0.023±0.003	
Modified Pole	$f_+(0)\|V_{cd(s)}\|$	α	
$D^0 \to Ke\nu$	0.725±0.006±0.005	0.265±0.045±0.006	
$D^0 \to \pi e\nu$	0.140±0.003±0.001	0.315±0.071±0.011	
2 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	
$D^0 \to Ke\nu$	0.728±0.006±0.005	−1.235±0.201±0.025	
$D^0 \to \pi e\nu$	0.140±0.004±0.001	−2.117±0.163±0.023	
3 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	r_2
$D^0 \to Ke\nu$	0.729±0.008±0.005	-1.251±0.349±0.053	0.527±7.984±0.895
$D^0 \to \pi e\nu$	0.144±0.005±0.001	-2.728±0.482±0.031	4.194±3.122±0.237

TABLE XVII. Form factor fit results, center value from statistical only

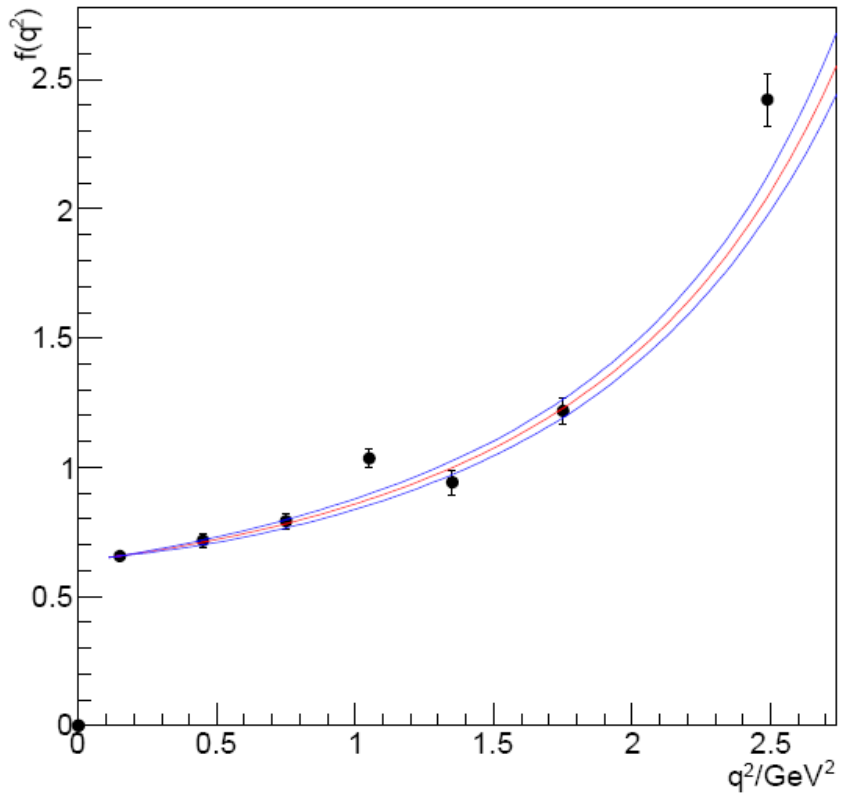
BESIII preliminary

Form factor comparisons

$D^0 \rightarrow K^- e^+ \nu$



$D^0 \rightarrow \pi^- e^+ \nu$



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Summary

- **BESIII collected 2.92 fb^{-1} data at 3.773 GeV.**

- **Purely leptonic decay $D^+ \rightarrow \mu^+ \nu$ and semi-leptonic decays of $D^0 \rightarrow K^-/\pi^- e^+ \nu$ were studied.**

- **These will significantly improve**
  - **Branching fractions for these decays**
  - **Decay constant f_{D+}**
  - **CKM matrix elements $|V_{cs}|$ and $|V_{cd}|$**
  - **form factors of hadronic current $f^+_{K/\pi}(q^2)$**

Thank you!