D Meson Results at BESIII

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For BESIII Collaboration
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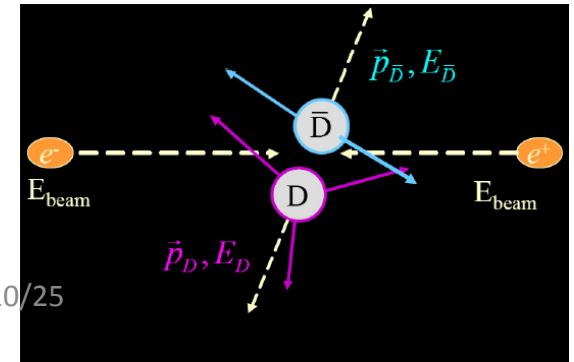
Outline

- Charm meson production at BESIII
- Leptonic decay $D^+ \rightarrow \mu^+ \nu_\mu$
  - Decays constant f_{D+}
  - CKM matrix element $|V_{cd}|$
- Semileptonic $D^0 \rightarrow K/\pi\ e\nu_e$
  - Form factor $f_+^K(0)$, $f_+^\pi(0)$
  - CKM matrix elements $|V_{cs(d)}|$
- Rare decay $D^0 \rightarrow \gamma\gamma$
  - FCNC
- Summary

Charm Meson Productions at Threshold

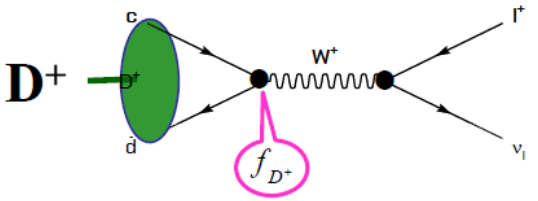
- At BESIII
  - World's largest $\psi(3770)$ sample $e^+e^- \to \psi(3770) \to D^0\bar{D}^0$
  - D^0D^0bar/D^+D^- are produced near threshold in pair.
  - Advantage: clean environment; kinematic constrains; quantum correlations
- Dtag technique
  - Fully reconstruct one *D* first, search for concerned final state at the recoiling side
  - Two variables: ΔE, beam-constrained mass M_{BC}



$$\Delta E = E_D - E_{\mathrm{Beam}}$$

$$M_{\mathrm{BC}} = \sqrt{E^2_{\mathrm{Beam}} - p^2_D}$$

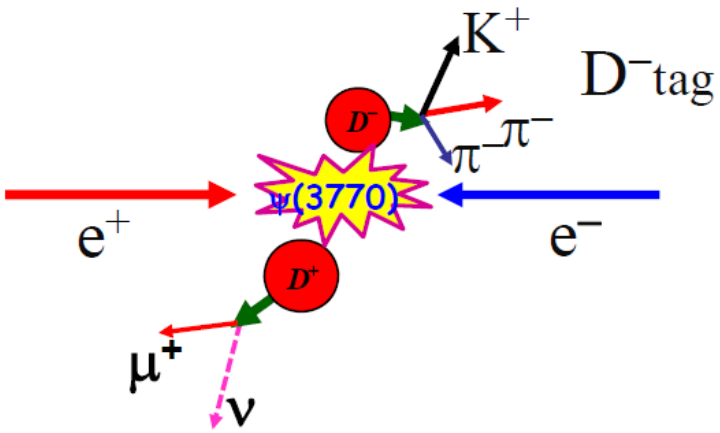
Leptonic Decay $D^+ \rightarrow \mu^+ \nu_\mu$



- Decay rate

$$\Gamma_{SM}(D^+_{(s)} \to l^+ \nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 |V_{cd(s)}|^2 f_{D^+_{(s)}}$$

  - Extract decay constant f_{D+}
  - Test LQCD calculations
  - Over-constrain CKM matrix
  - Sensitive to New Physics



- At BESIII:

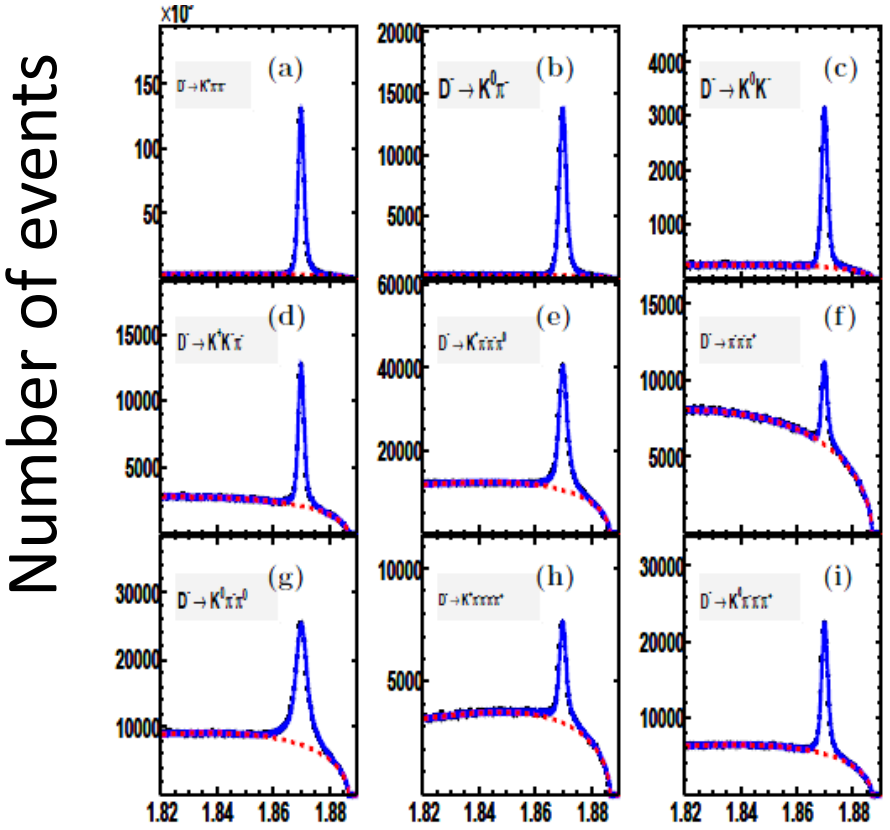
$$B(D^+ \to \mu^+ \nu) = \frac{N_{D^+ \to \mu^+ \nu}}{N_{D^-_{tag}} \varepsilon_{D^+ \to \mu^+ \nu}}$$

$D^+ \to \mu^+ \nu_\mu$ Tagging Side

Nine *D* tag modes:

$K^+\pi^-\pi^-$
$K^0_S\pi^-$
$K^0_S K^-$
$K^+K^-\pi^-$
$K^+\pi^-\pi^-\pi^0$
$\pi^+\pi^-\pi^-$
$K^0_S\pi^-\pi^0$
$K^+\pi^-\pi^-\pi^-\pi^+$
$K^0_S\pi^-\pi^-\pi^+$

BESIII Preliminary

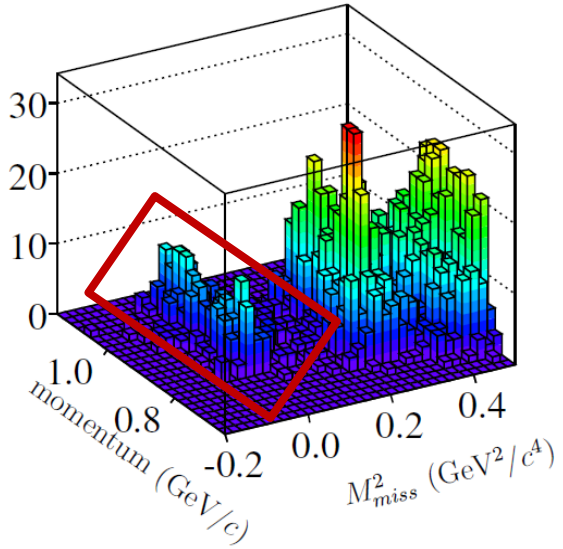


$N^{tag}_{D^-} = (1.566 \pm 0.002) \times 10^6$ in 2.9 fb^{-1}

$M_{BC}(GeV/c^2)$

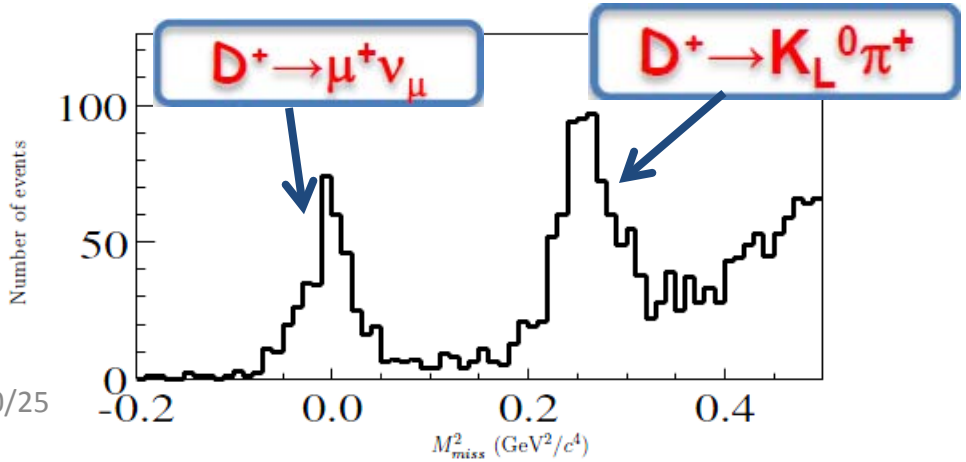
$D^+ \rightarrow \mu^+ \nu_\mu$ Signal Side

- At recoiling side:
  - Only one charged track
  - Identified as muon
  - No isolated photon

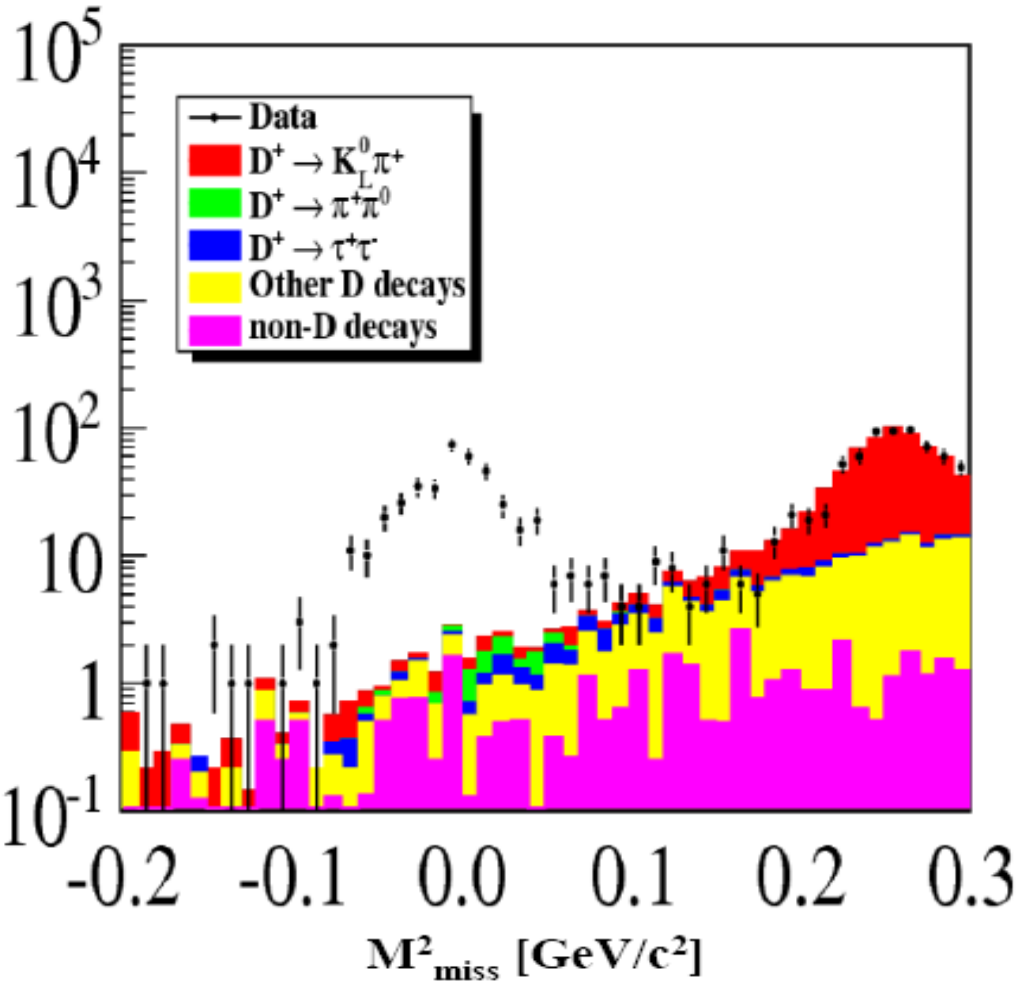


- Select on consistency with leptonic decay:

$$M^2_{\text{miss}} = \left(E_{\text{Beam}} - E_\mu\right)^2 - \left(-\vec{p}_{\text{tag}} - \vec{p}_\mu\right)^2 \approx 0$$



$D^+ \rightarrow \mu^+\nu_\mu$ Backgrounds



Event type	Number
$N(D^+ \to \mu^+\nu_\mu)^{\text{candidate}}$	425
N_b	$47.7 \pm 2.3 \pm 1.3$
$N(D^+ \to \mu^+\nu_\mu)$	$377.3 \pm 20.6 \pm 2.6$

- The number of backgrounds is also estimated with data.

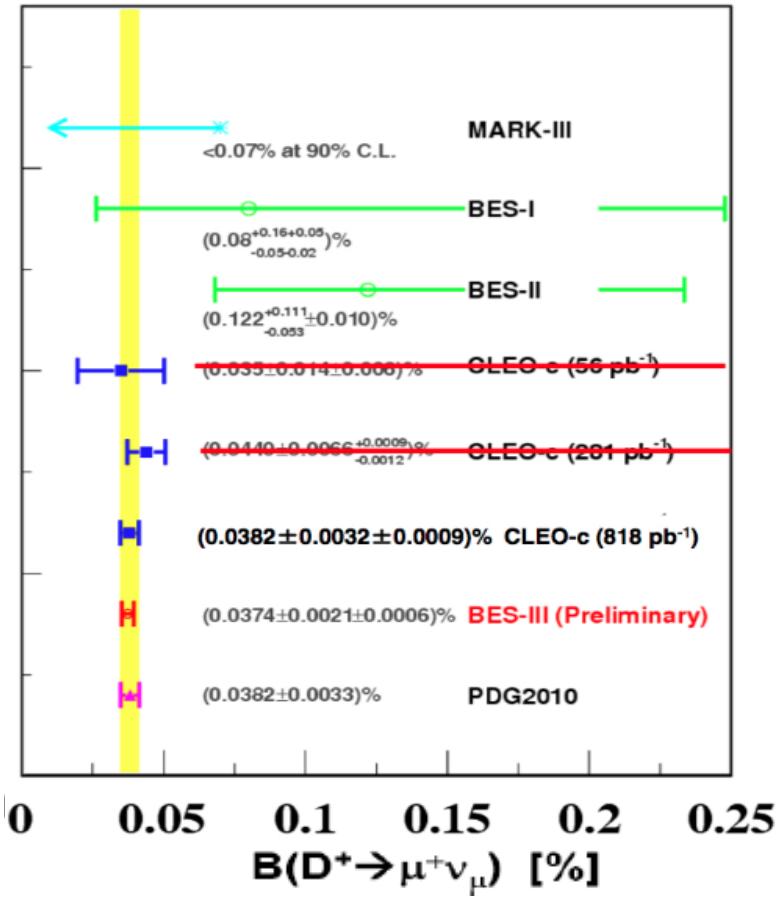
$$N_b^{\text{tot}} = 48.9 \pm 4.8$$

- Consistent within error with N_b estimated from MC

$D^+ \to \mu^+ \nu_\mu$ Results

- **Branching Fraction**

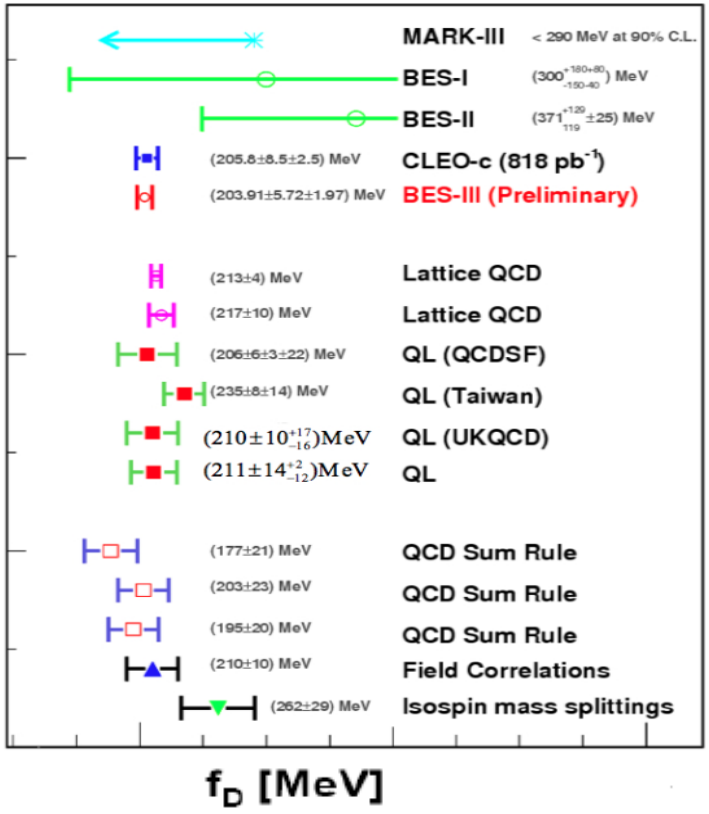
$$B(D^+ \to \mu^+ \nu_\mu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$$



- **Decay constant**

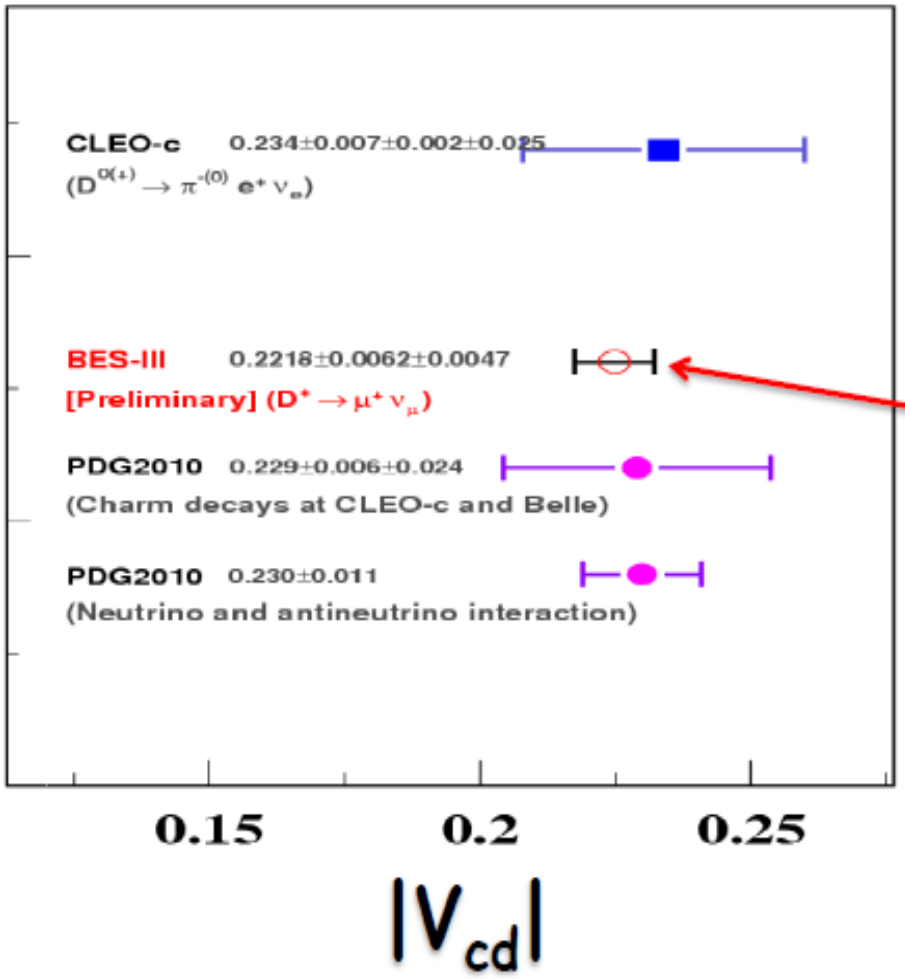
$$f_{D^+} = (203.91 \pm 5.72 \pm 1.97)\ \mathrm{MeV}$$

(Input τ_{D+}, m_{D+}, $m_{\mu+}$ of PDG10 and V_{cd} of CKM-Fitter)



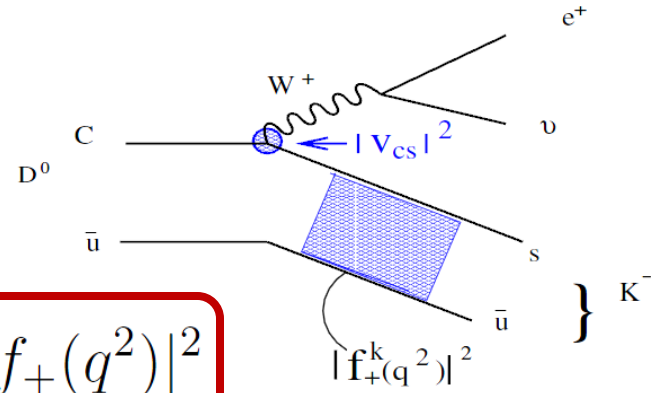
➢Still statistics limited.

$D^+ \rightarrow \mu^+ \nu_\mu$ Results



The most precise determination of |Vcd| is from the BESIII

$D^0 \to K/\pi\ e\ \nu_e$



- Differential decay rate

$$\frac{\Delta\Gamma(D \to \pi(K) e\nu)}{dq^2} = \frac{G_F^2 |V_{cd(s)}|^2}{24\pi^3} p^3 \boxed{|f_+(q^2)|^2}$$

$$q^2 = (E_\nu + E_e)^2 - |\vec{p}_\nu + \vec{p}_e|^2$$

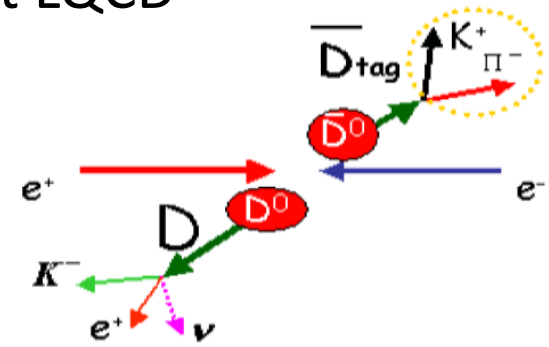
  - Form factor $f_+^{K(\pi)}(q^2)$ measure the probability to form the final state $K(\pi)$
  - CKM-unitarity $\Longrightarrow$ $|V_{cd(s)}|$, extract FF, test LQCD
  - Input LQCD FF to over-constrain CKM

- At BESIII:

$$N_{tag}^{obs} = 2N_{D\bar{D}} B_{tag} \epsilon_{tag}$$

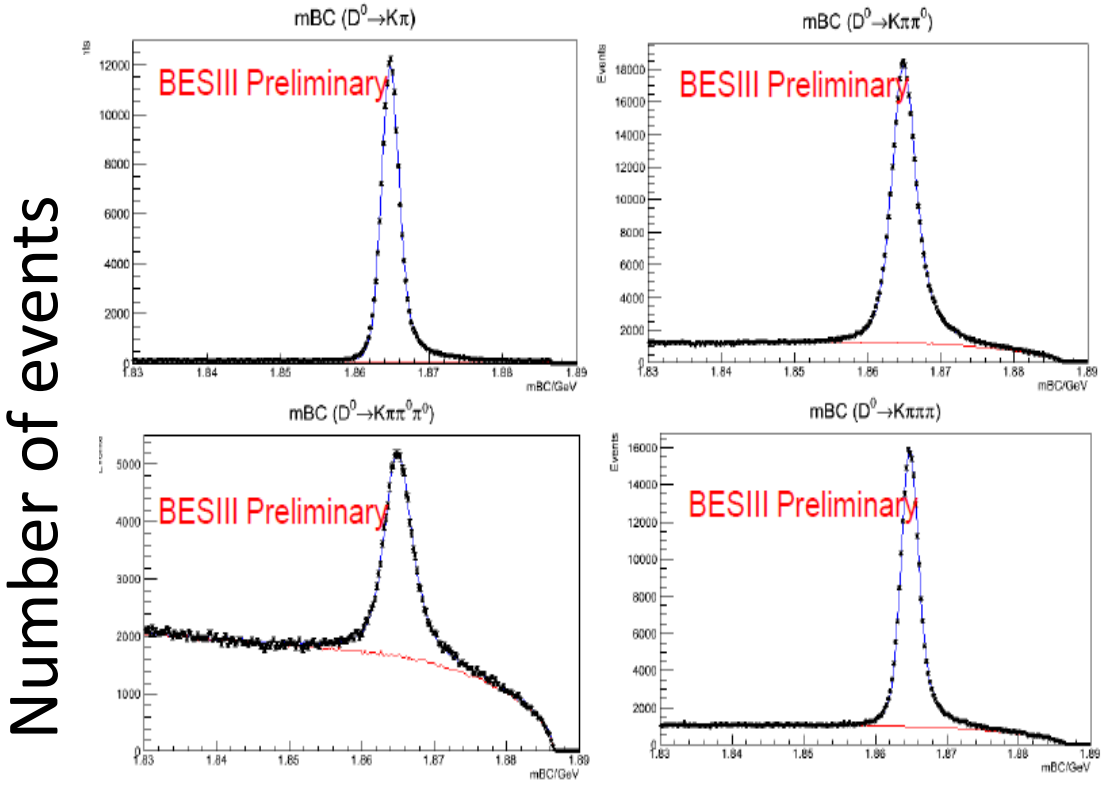
$$N_{sig}^{obs} = 2N_{D\bar{D}} B_{tag} B_{sig} \epsilon_{tag,sig}$$

$$\Rightarrow B_{sig} = \frac{N_{sig}^{obs} \epsilon_{tag}}{N_{tag}^{obs} \epsilon_{tag,sig}}$$



$D^0 \rightarrow K/\pi e \nu_e$ Tagging Side

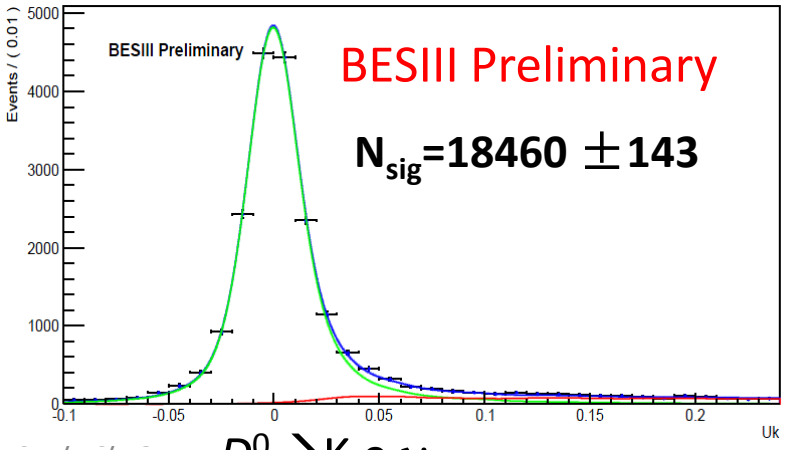
Mode
$D^0 \to K^-\pi^+$
$D^0 \to K^-\pi^+\pi^0$
$D^0 \to K^-\pi^+\pi^0\pi^0$
$D^0 \to K^-\pi^+\pi^-\pi^+$



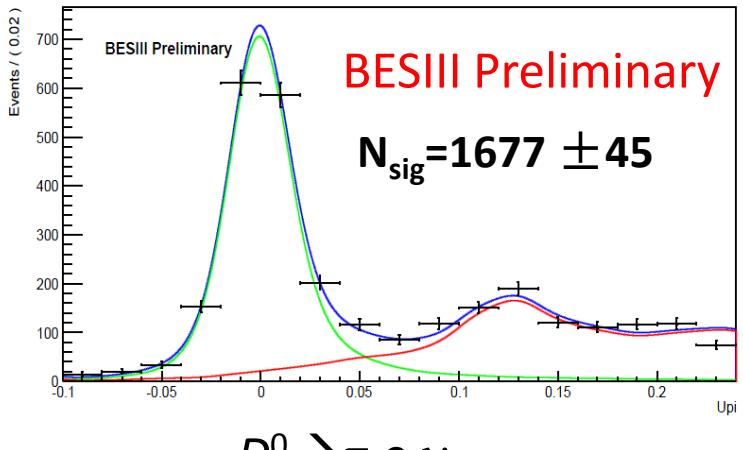
$$N_D^{tag} = (0.774 \pm 0.001) \times 10^6 \text{ in } 0.92\,\text{fb}^{-1}$$

$D^0 \rightarrow K/\pi e \nu_e$ Signal Side

- Selection:
  - Two oppositely-charged good tracks
  - K(π) and *e* are identified, right charged *e*
  - Veto extra EMC shower which is larger than 250MeV(suppress backgrounds with π^0)
- Missing neutrino: $U = E_{\mathrm{miss}} - c\left|\vec{P}_{\mathrm{miss}}\right| \approx 0$



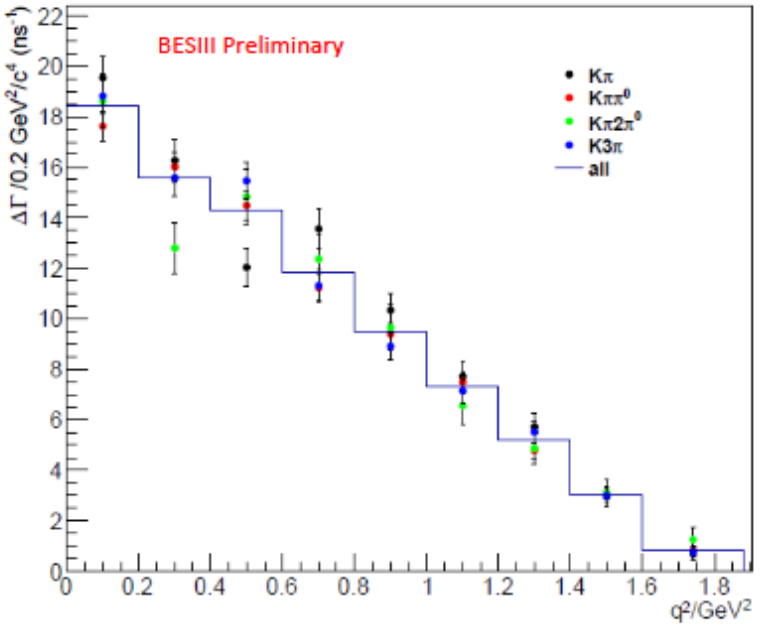
$D^0 \rightarrow K\ e\ \nu_e$



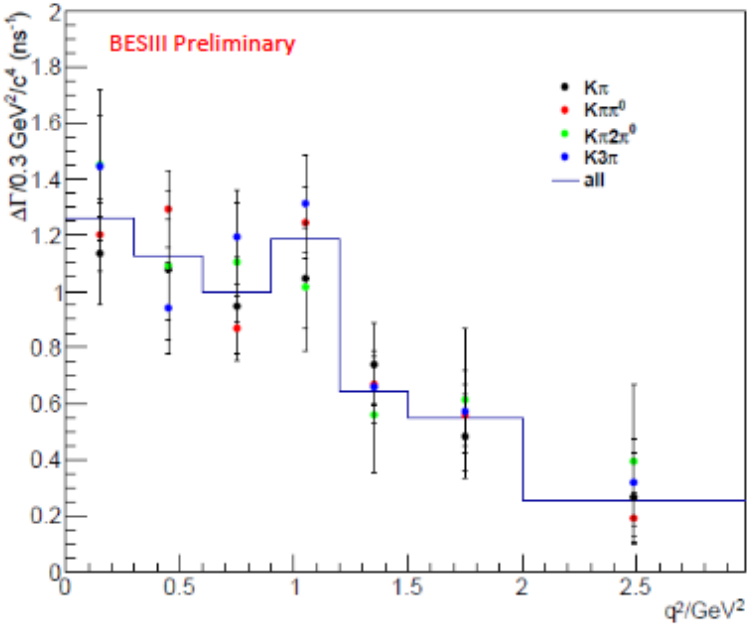
$D^0 \rightarrow \pi\ e\ \nu_e$

$D^0 \rightarrow K/\pi\, e\nu_e\ \Gamma(q^2)$

- Fit *U* distribution in each q^2 bin
- Compare results from each tag mode



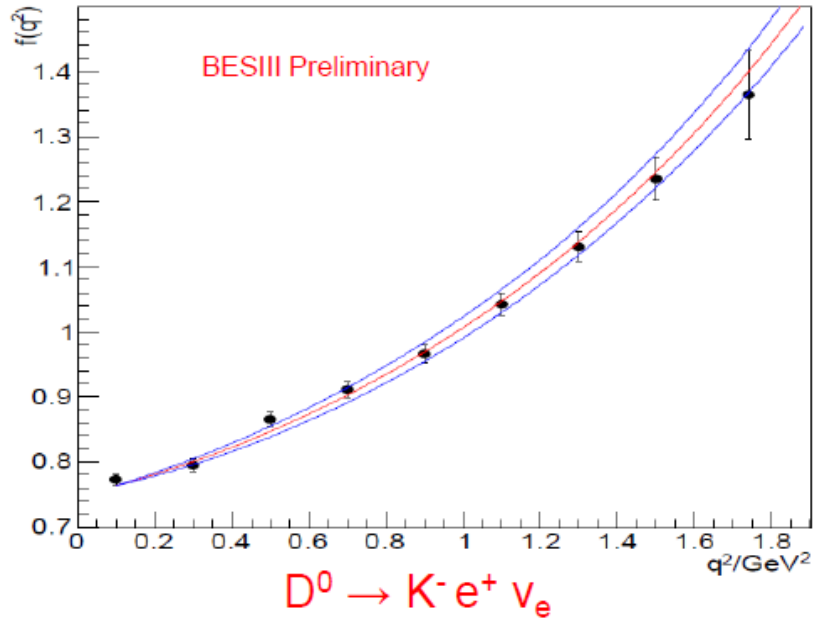
$D^0 \rightarrow K\, e\, \nu$

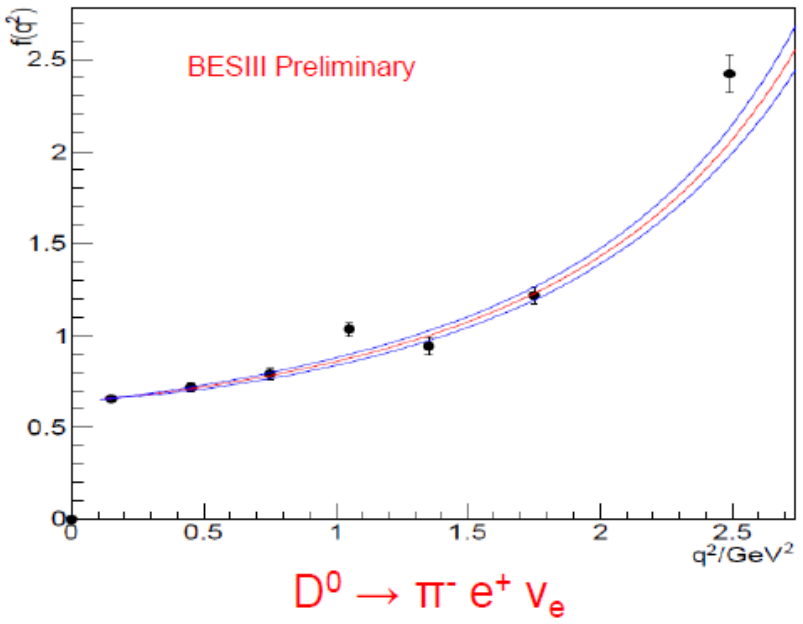


$D^0 \rightarrow \pi\, e\, \nu$

$D^0 \rightarrow K/\pi\, e\nu_e$ Extract $f(q^2)$

- Points are data with statistical errors only
- Curves are Fermilab-MILC (arXiv:1111.5417) with $\pm 1\sigma$ (statistical) bands
- Other theoretical work: HPQCD,arXiv:1111.0225
- Comparing shape only here($f_+(0)$ not known)





Form Factor Parameterization

Simple Pole Model

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{m_{H^*}^2}\right)}$$

Modified Pole Model

Becirevic and Kaidalov
PLB 478, 417 ('00)

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{m_{H^*}^2}\right)\left(1 - \alpha\frac{q^2}{m_{H^*}^2}\right)}$$

Series Expansion

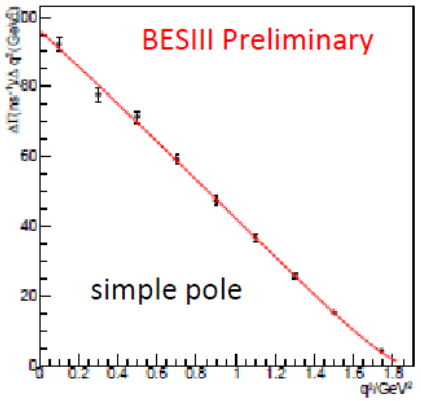
Becher and Hill
PLB 633, 61 ('06)

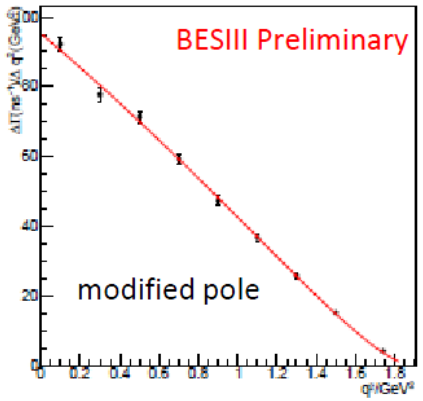
$$f_+(q^2) = \frac{1}{P(q^2)\phi(q^2,t_0)}\sum_{k=0}^{\infty} a_k(t_0)\left[z(q^2,t_0)\right]^k$$

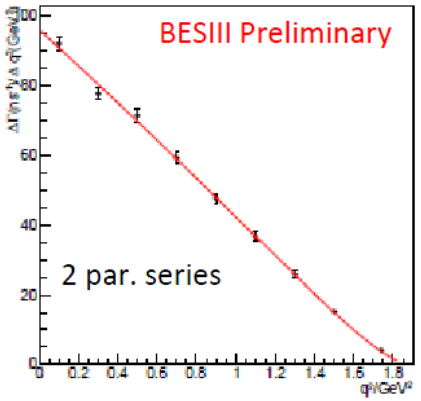
$$z(q^2,t_0) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}} \qquad t_\pm = \left(m_D \pm m_X\right)^2$$

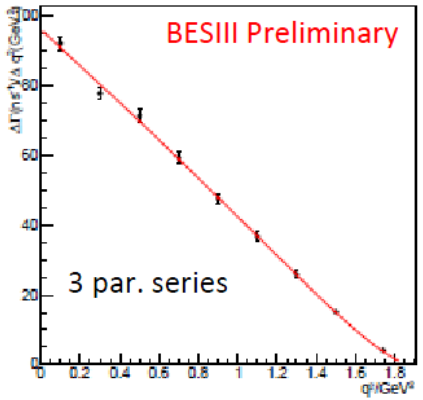
Form Factor $f(q^2)$ Fits

$$\chi^2 = \sum_{i,j=1}^{n} (\Delta\Gamma_i - \Delta G_i)\ C_{ij}^{-1}\ (\Delta\Gamma_j - \Delta G_j)$$

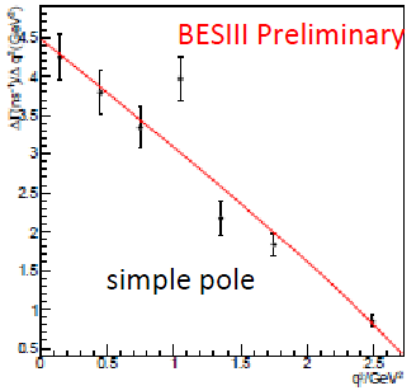


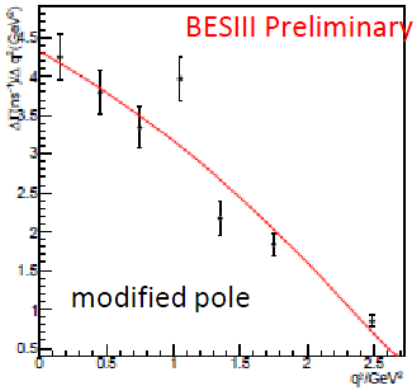


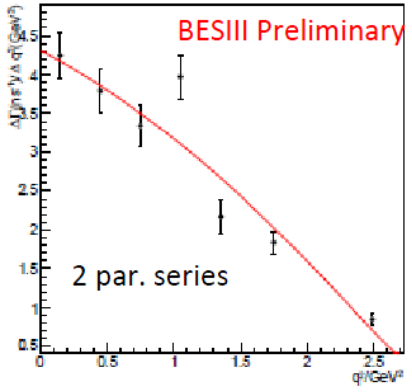


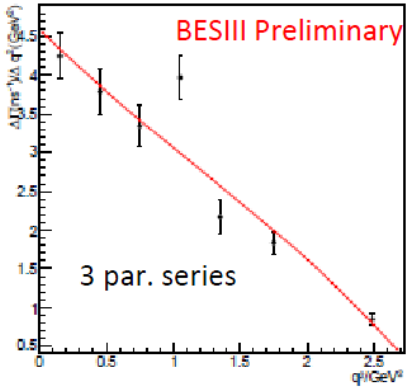


$D^0 \rightarrow K\ e\ \nu_e$









$D^0 \rightarrow \pi\ e\ \nu_e$

Form Factor Results

BESIII Preliminary

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

- Reasonable consistency with CLEO-c, comparable precision with 2/3 of data still to analyze

Rare Decay $D^0 \rightarrow \gamma\gamma$

- $D^0 \rightarrow \gamma\gamma$
  - Flavor Changing Neutral Current(FCNC) ($c \rightarrow u+\gamma$) is forbidden at tree level.
  - $D^0 \rightarrow \gamma\gamma$ is dominated by long-distance effect.
- Within SM:
  - Short distance: $B(D^0 \rightarrow \gamma\gamma) \sim 10^{-11}$
  - Long distance: $B(D^0 \rightarrow \gamma\gamma) \sim 10^{-8}$ (PRD 64,074008)
- Minimal super-symmetric standard model says the rate would be enhanced by a factor of 100 by exchanging gluino (PLB 500,304) or $B(D^0 \rightarrow \gamma\gamma) \sim 10^{-6}$

- CLEO-2 searched with 13.8fb^{-1} around $\Upsilon(4S)$
  - $B(D^0 \rightarrow \gamma\gamma) < 2.9 \times 10^{-5}$@90% C.L. (PRL90,01801)
- CLEO-c searched based on 818 pb^{-1} @$\psi(3770)$
  - $B(D^0 \rightarrow \gamma\gamma) < 8.63 \times 10^{-6}$@90%C.L. (Charm 2010)
- BaBar has a result with 470.5fb^{-1}@$\Upsilon(4S)$
  - $B(D^0 \rightarrow \gamma\gamma) < 2.2 \times 10^{-6}$@90%C.L.(arXiv:1110.6480)

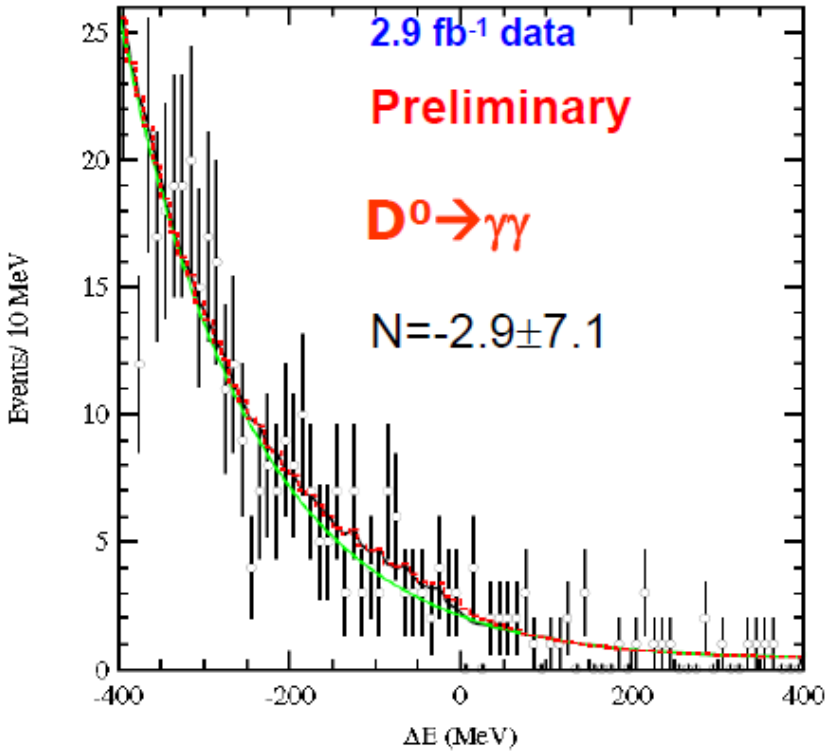
$D^0 \to \gamma\gamma$ at BESIII

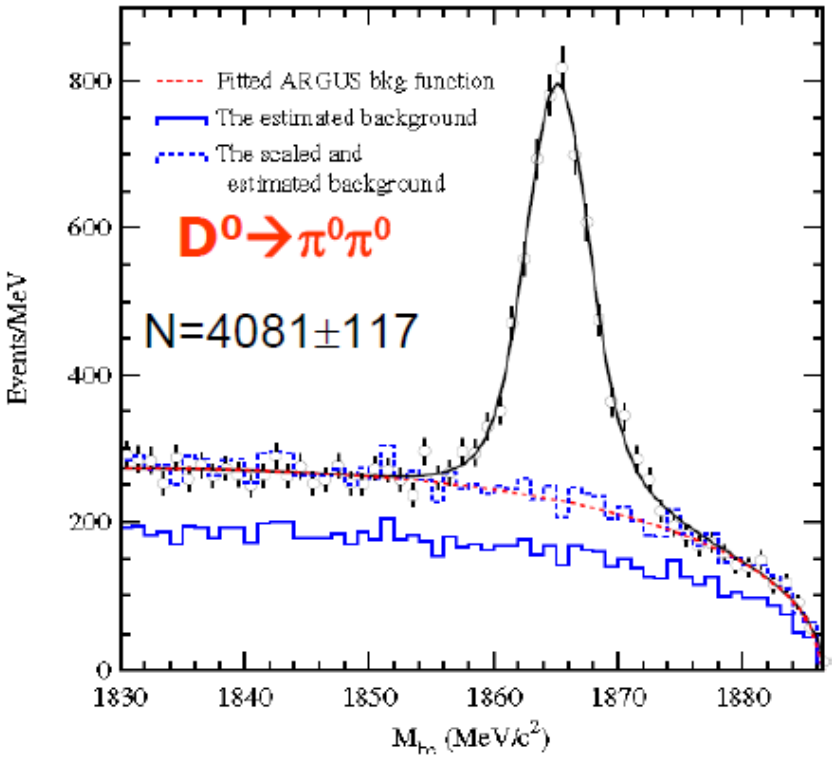
- As the main background components, we also study events from $D^0 \to \pi^0\pi^0$, and present preliminary results as:
  - $B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0)$
- Analysis method
  - Reconstruct one D with two γs or π^0s, where $\pi^0 \to \gamma\gamma$
  - Conservation of energy and momentum is required:

$$\Delta E \sim 0, \ M_{\mathrm{BC}} \sim M_{\mathrm{D0}}$$

- Details selection criteria are tuned based on MC

$D^0 \to \gamma\gamma$





$$B(D^0 \to \gamma\gamma) / B(D^0 \to \pi^0\pi^0) < 5.8 \times 10^{-3}$$ **@ 90% C.L.**

Experiments	BESIII	BABAR	CLEOc	PDG11
$B^{up}(D^0 \to \gamma\gamma)$ [$\times 10^{-6}$]	<4.6	<2.2	<8.63	<27

- Another double-tag technique is ongoing, which can reject most of backgrounds and reduce systematic errors

Summary

- BESIII has been successfully operated
- Some results on flavor physics have been obtained
  - Leptonic decay:
    - $B(D^+ \to \mu^+ \nu_\mu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$
    - $f_{D+} = (203.91 \pm 5.72 \pm 1.97)$ MeV
    - $|V_{cd}| = 0.222 \pm 0.006 \pm 0.005$
  - Semileptonic decay ($0.92 fb^{-1}$, will improve use full dataset)

Mode	measured branching fraction(%)	PDG	CLEOc
$\bar{D}^0 \to K^+ e^- \bar{\nu}$	$3.542 \pm 0.030 \pm 0.067$	3.55 ± 0.04	$3.50 \pm 0.03 \pm 0.04$
$\bar{D}^0 \to \pi^+ e^- \bar{\nu}$	$0.288 \pm 0.008 \pm 0.005$	0.289 ± 0.008	$0.288 \pm 0.008 \pm 0.003$

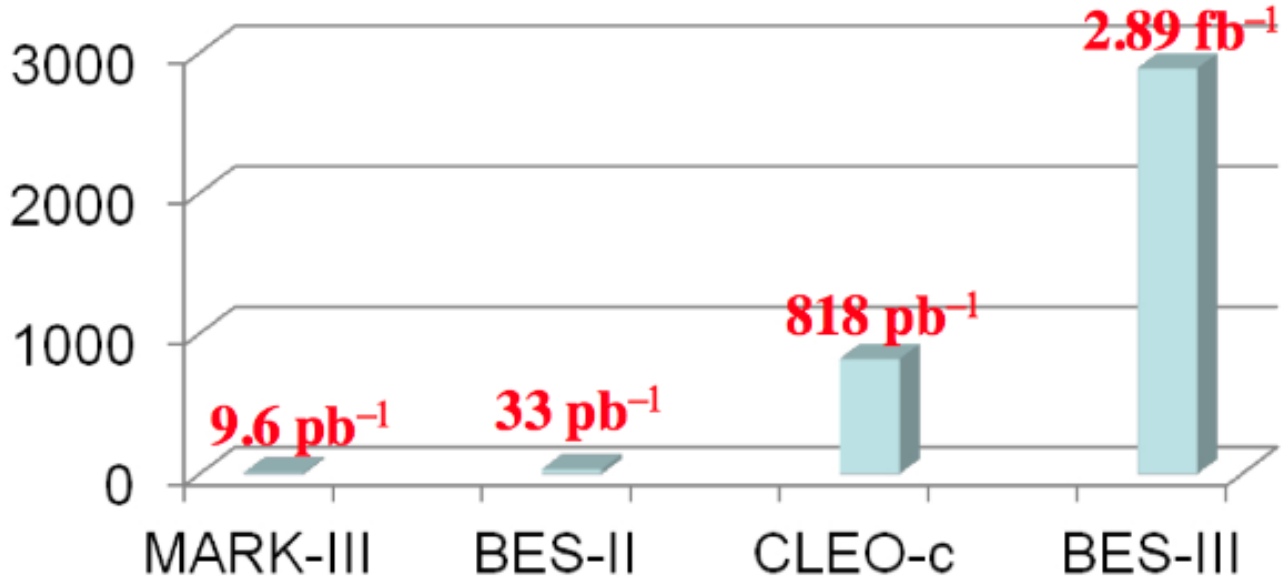
  - Rare decay: $B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 5.8 \times 10^{-3}$@90%C.L.
- Many other topics: D^0-D^0bar mixing, *CPV*, rare decay, Cabibbo suppress decay, other semileptonic decays are ongoing.

Thank you!

BACK UP

BESIII data

- World's largest ψ(3770) sample



Advantage of open charm at threshold

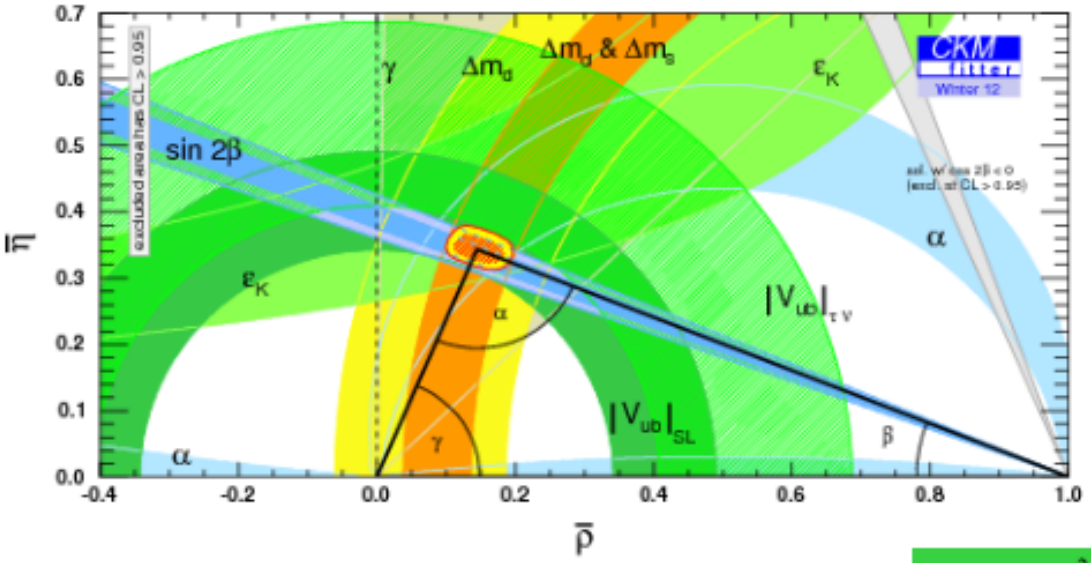
e^+e^- Colliders@threshold:

$e^+e^- \to \psi(3770) \to D^0\overline{D}^0$ [$C = -1$] OR $e^+e^- \to \gamma^* \to D^0\overline{D}^0\gamma$ [$C = +1$]

Good for charm flavor physics:

- Threshold production: clean
- Known initial energy and quantum numbers
- Both D and Dbar fully reconstructed (double tag)
- Absolute measurements

Charm's Role in the Big Picture



Flavor Physics:
* Over-constrain CKM matrix
* Search for New Physics

Difficulties:
* Mixing is not theoretically clean
* V_{ub} is not theoretically clean

Example: V_{ub} from $B \rightarrow \pi l \nu$

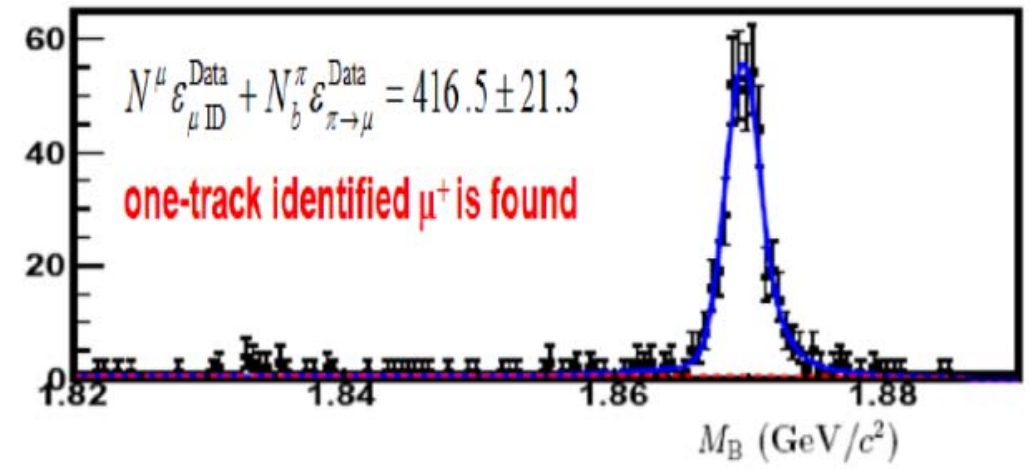
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

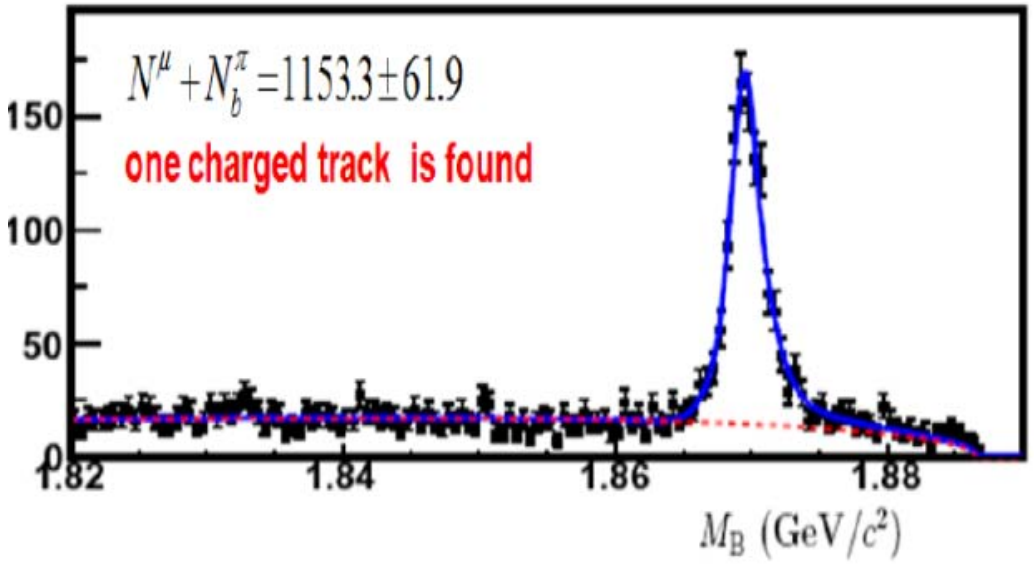
Latest result:

$V_{ub} \times 10^3 = 3.92 \pm 0.09(\text{exp}) \pm 0.45(\text{theory})$

* Needs inputs from Lattice QCD
* Charm physics provides perfect calibration

$D^+ \rightarrow \mu^+ \nu_\mu$ Backgrounds-data





- The number of backgrounds is also estimated with data.
- Examining number of events with only one charged track in recoiling side.
- Consistent within error with N_b estimated from MC

$D^+ \to \mu^+ \nu_\mu$ Results

- Branching fraction:
  $B(D^+ \to \mu^+ \nu_\mu) = (3.74 \pm 0.21 \pm 0.06) \cdot 10^{-4}$

All preliminary !

$$\Gamma_{SM}(D^+_{(s)} \to l^+ \nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 |V_{cd(s)}|^2 f_{D^+_{(s)}}$$

- Decay constant:
  $f_{D+} = (203.91 \pm 5.72 \pm 1.97)$ MeV $\Leftarrow$

$\tau_{D+} = (1040 \pm 7)$ fs,
$M_{D+} = (1896.60 \pm 0.16)$ MeV
$M_{\mu+} = (105.658 \pm 0.000)$ MeV
$V_{cd} = 0.2252 \pm 0.0007$ (CKM-Fitter)

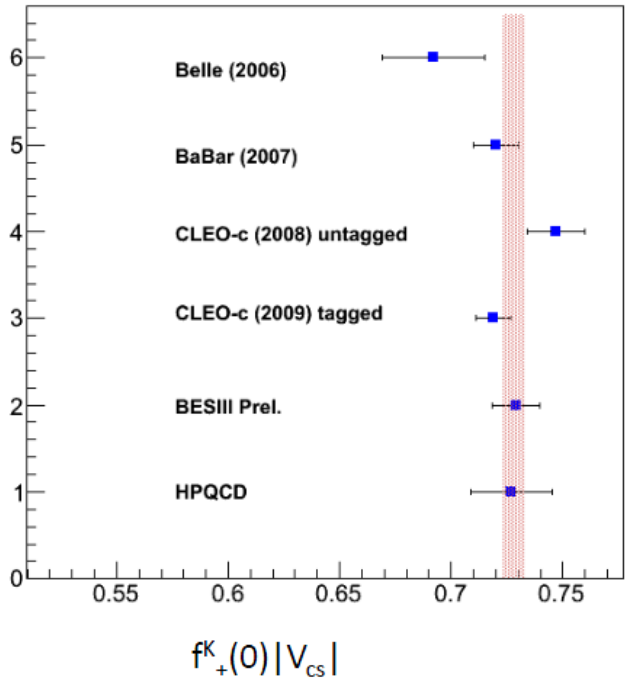
- Form factor:
  $|V_{cd}| = 0.222 \pm 0.006 \pm 0.005$ $\Leftarrow$

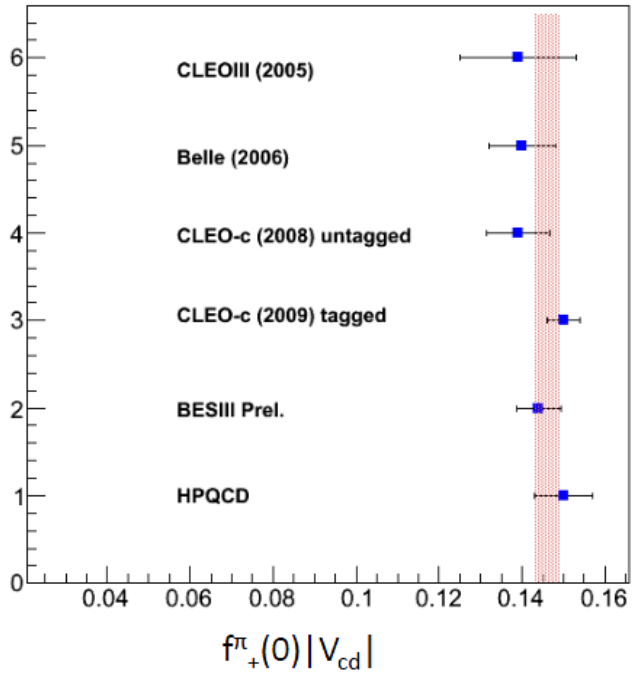
$\tau_{D+} = (1040 \pm 7)$ fs,
$M_{D+} = (1896.60 \pm 0.16)$ MeV
$M_{\mu+} = (105.658 \pm 0.000)$ MeV
$f_{D+} = 207 \pm 4$ MeV (from LQCD)

Cited:
CKM-Fitter: PDG 2010
LQCD: Phys. Rev. Lett. 100, 062002 (2008)

$D^0 \rightarrow K/\pi e \nu_e$ FF

Comparison (3 par. Model)





- Numbers are from HFAG 2012 report(**arXiv:1207.1158**)
- Error bar of BESIII prel. shrink with full data