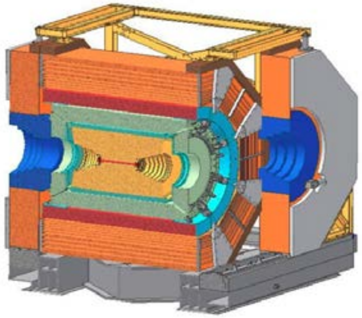
Recent charm results obtained at BESIII



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(on behalf of BESIII collaboration)

YongPyong-2013

YongPyong Winter Conference on Particle Physics

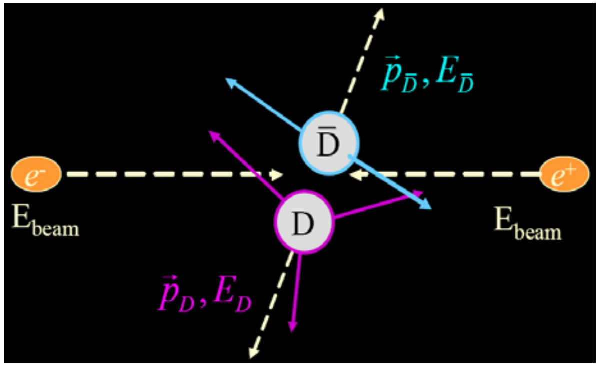
Feb. 24-28, 2013, Korea

Outline

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

Charm Meson Production at Threshold

- At $\psi(3770)$ charm production is D^+D^- and $D^0\overline{D}^0$
- Advantage:
  - Clean environment
  - Known initial energy and quantum numbers (quantum correlated for $D^0\overline{D}^0$ pair)
  - Both D and $\overline{D}$ fully reconstructed
  - Absolute measurements



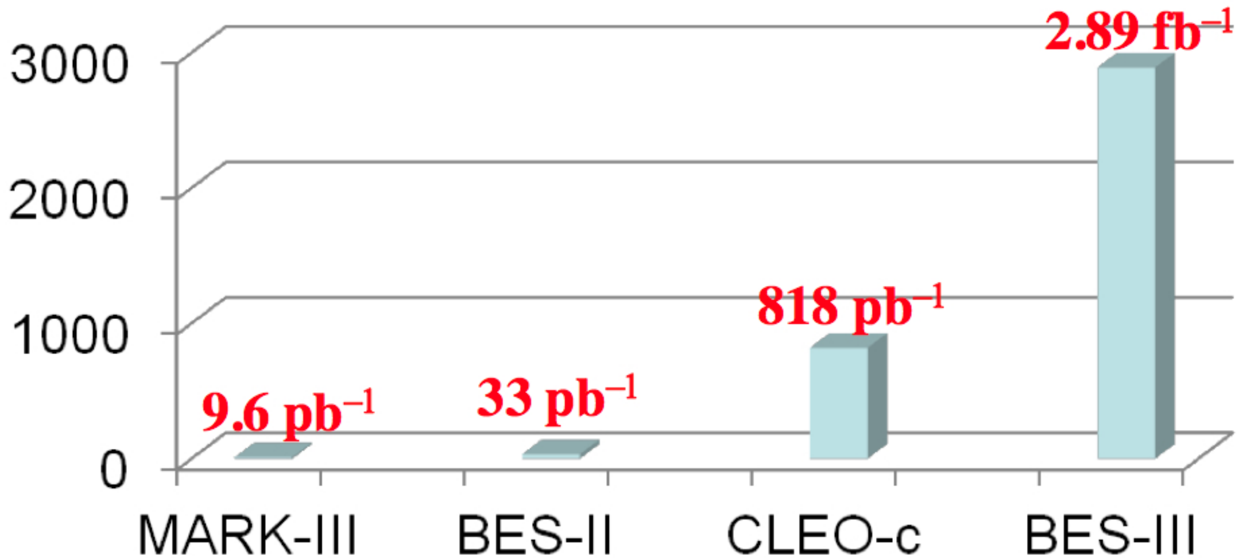
- Double-tag technique
  - Reconstruct D first, search for signal $\overline{D}$ on the other side
  - Two variables: ΔE & M_{BC}

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

$$M_{\mathrm{BC}} = \sqrt{E_{\mathrm{Beam}}^2 - p_D^2}$$

BESIII Data

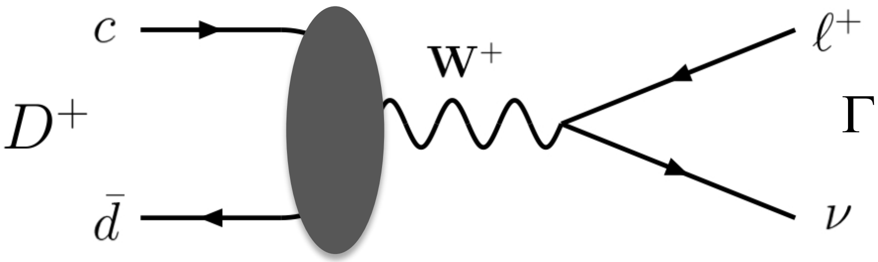
- World's largest $\psi(3770)$ sample



- Tools/techniques for precision charm physics still under development – all the following results are PRELIMINARY

Leptonic decay : $D^+ \to \mu^+ \nu_\mu$
Semileptonic decay : $D^0 \to K^-(\pi^-) e^+ \nu_e$
Rare decay : $D^0 \to \gamma\gamma$

Leptonic Decay



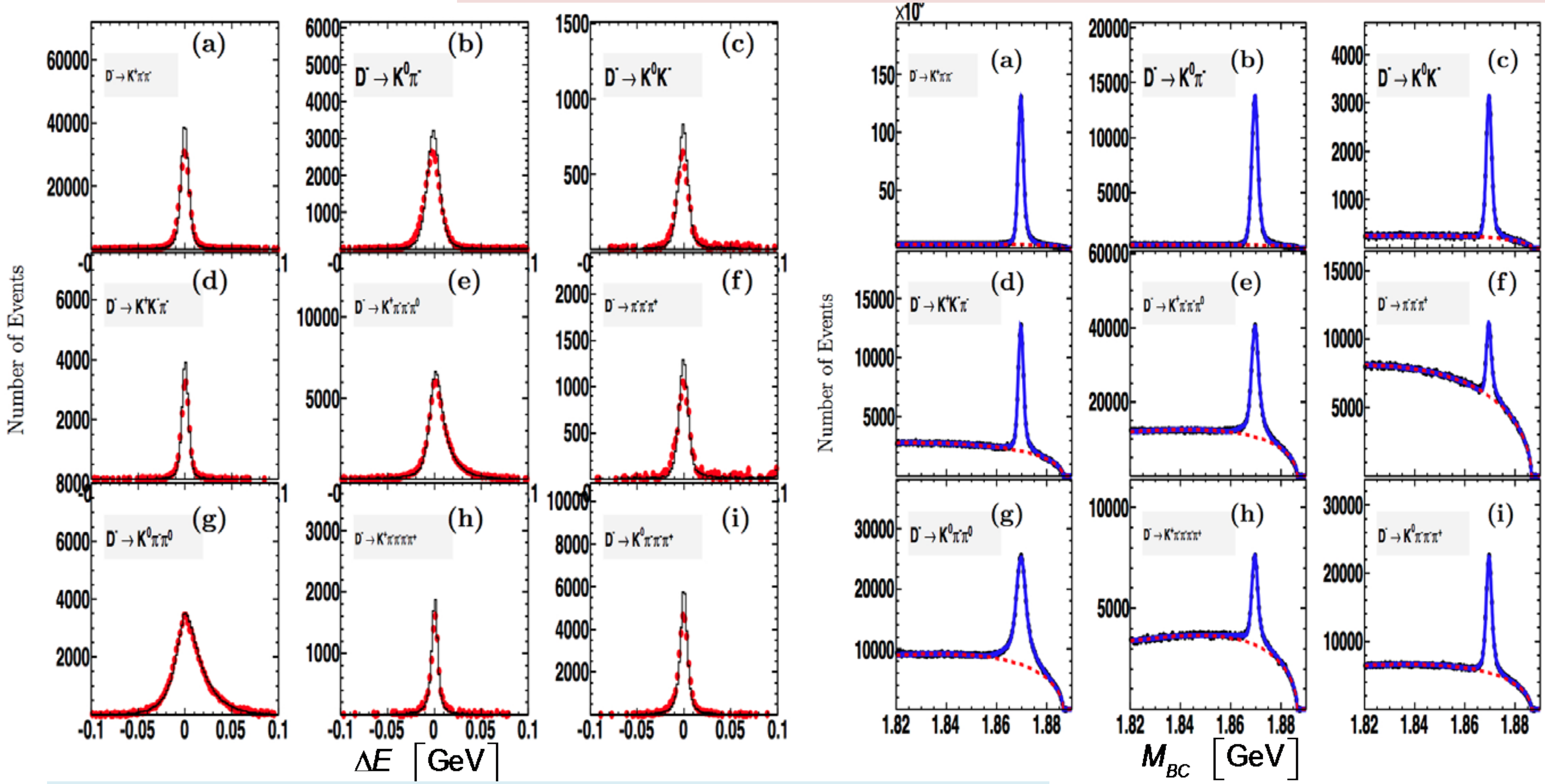
$$\Gamma\left(D^+ \to \ell^+ \nu_\ell\right) = \boxed{f_D^2}\left|V_{cd}\right|^2 \frac{G_F^2}{8\pi} m_D m_\ell^2 \left(1 - \frac{m_\ell^2}{m_D^2}\right)^2$$

- Decay constant f_D incorporates the strong interaction effects (wave function at the origin)
- Use charm leptonic decays to validate theory (LQCD) and apply to *B* mixing, which requires f_B
- Multiple tests with charm: f_D, f_{Ds}, and f_D / f_{Ds}
- Sensitivity to New Physics (charged Higgs contribution, …)

D^+ Leptonic Decays – Tag Selection

- Nine D^- tag modes

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



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

BESIII Preliminary

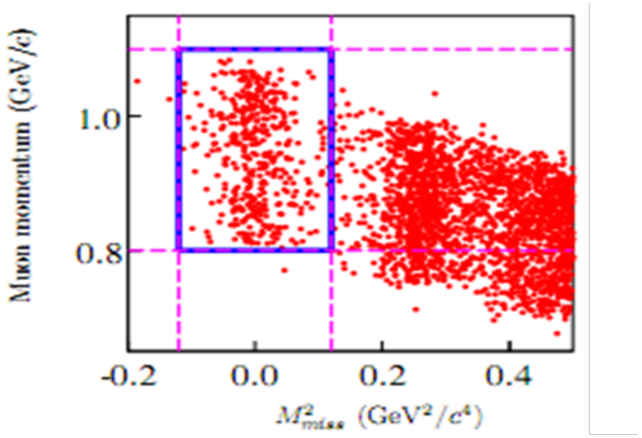
D^{+} Leptonic Decays – Signal Selection

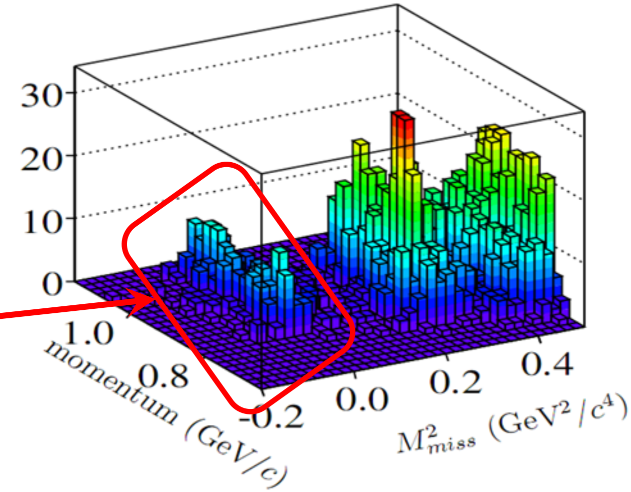
- Exactly one track in addition to tag, with the right charge
- Positive muon identification
- No extra photon
- Select on consistency with leptonic decay:

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

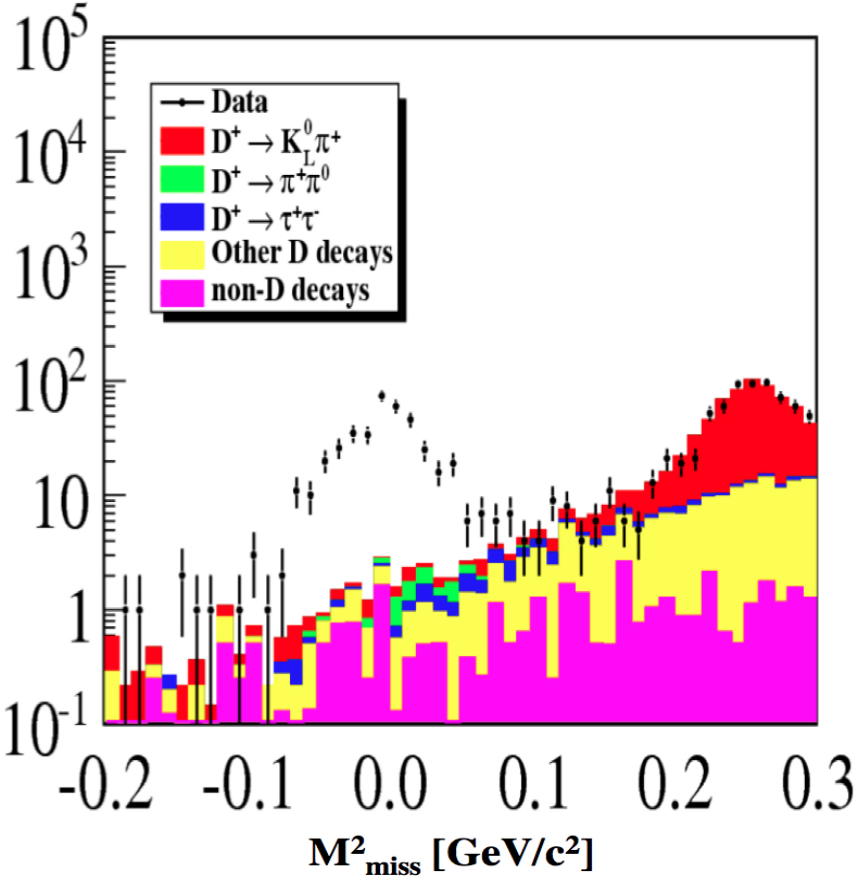
425 signal candidates

BESIII Preliminary





D^+ Leptonic Decays – Backgrounds



BESIII Preliminary

Estimated with Monte Carlo events

Source mode	Number of events
$D^+ \to K_L^0 \pi^+$	7.9 ± 0.8
$D^+ \to \pi^+ \pi^0$	3.8 ± 0.5
$D^+ \to \tau^+ \nu_\tau$	6.9 ± 0.7
Other decays of D mesons	17.9 ± 1.1
$e^+e^- \to \gamma\psi(3686)$	0.2 ± 0.2
$e^+e^- \to \gamma J/\psi$	0.0 ± 0.0
$e^+e^- \to light\ hadron$ (continuum)	8.2 ± 1.4
$e^+e^- \to \tau^+\tau^-$	1.9 ± 0.5
$\psi(3770) \to non - D\bar{D}$	0.9 ± 0.4
Total	47.7 ± 2.3

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

D^+ Leptonic Decays – Results

BESIII Preliminary

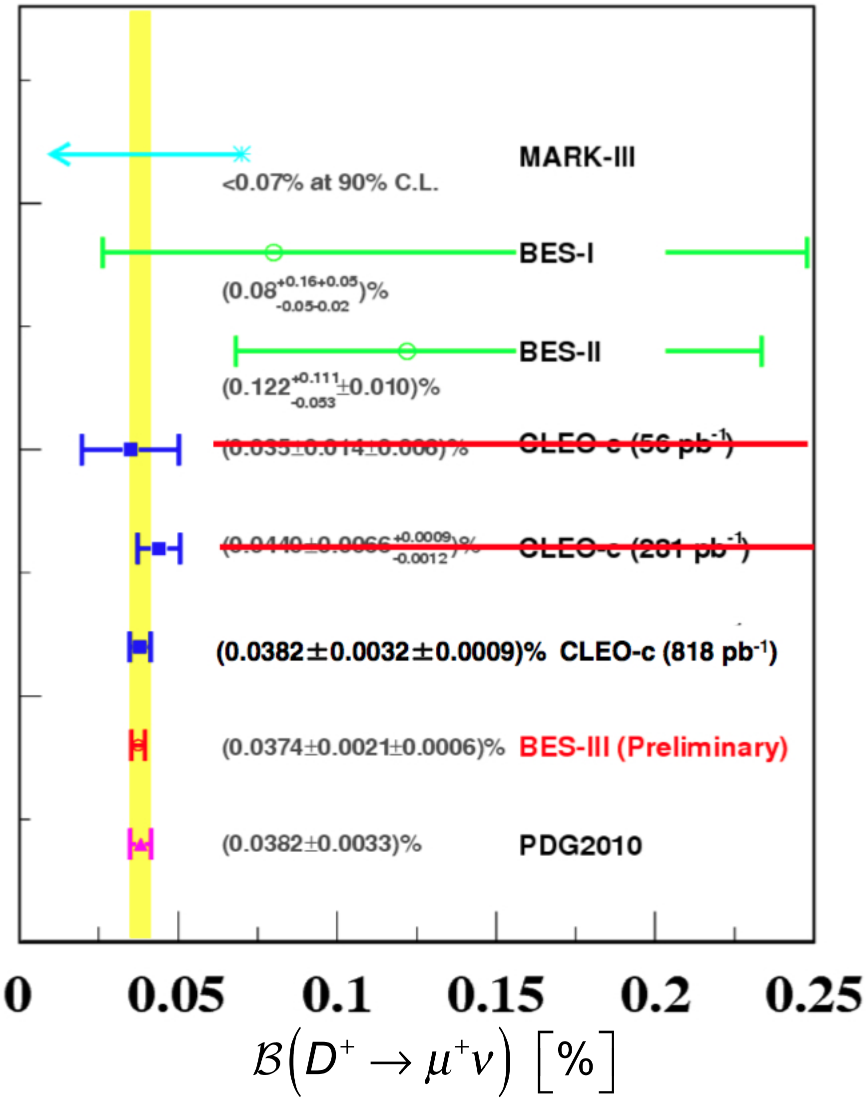
$$N\left(D^+ \to \mu^+ \nu\right) = 377.3 \pm 20.6$$

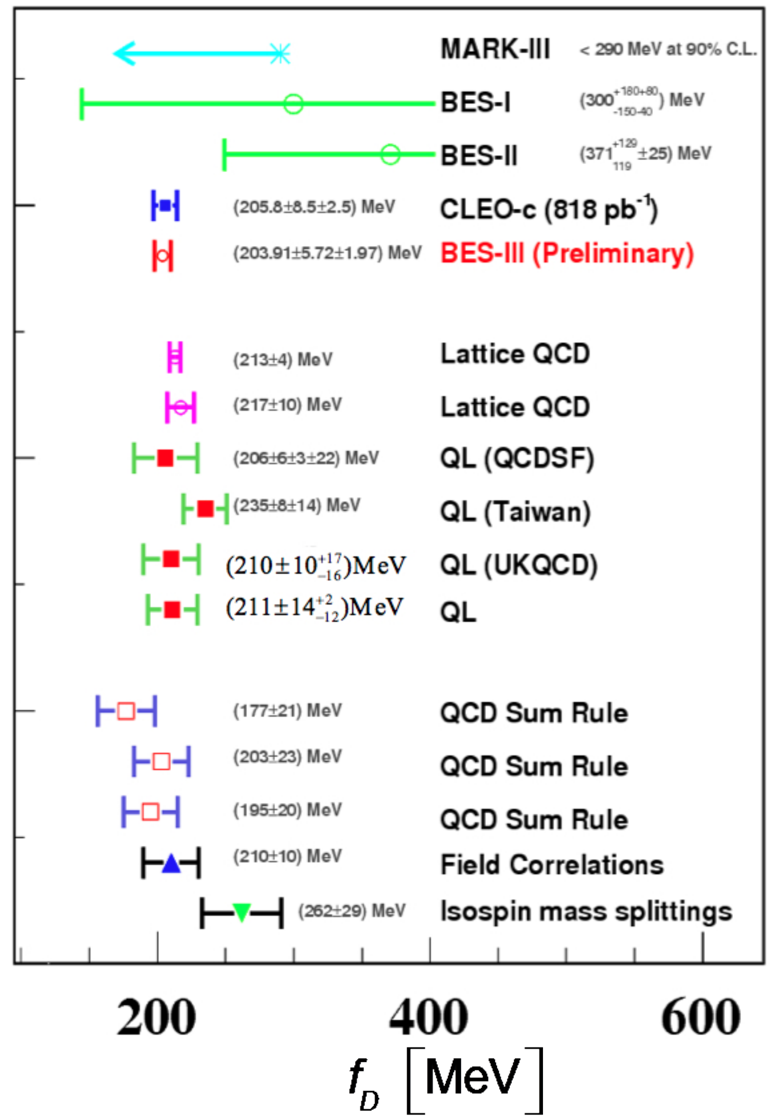
$$\mathcal{B}\left(D^+ \to \mu^+ \nu\right) = \left(3.74 \pm 0.21 \pm 0.06\right) \times 10^{-4}$$

$$f_{D^+} = \left(203.9 \pm 5.7 \pm 2.0\right) \text{ MeV}$$

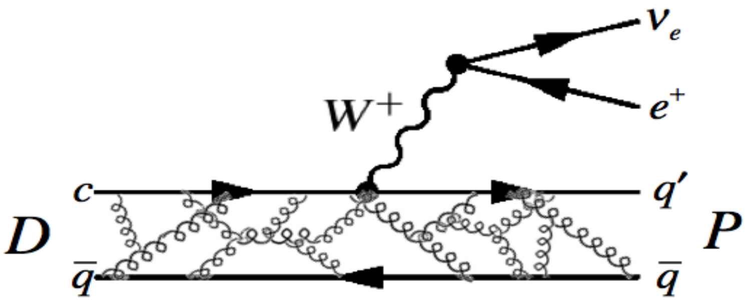
- Consistent with CLEO-c
- Still statistics limited – need more data!

D^+ Leptonic Decays – Comparisons (from G. Rong)





Semileptonic Decay



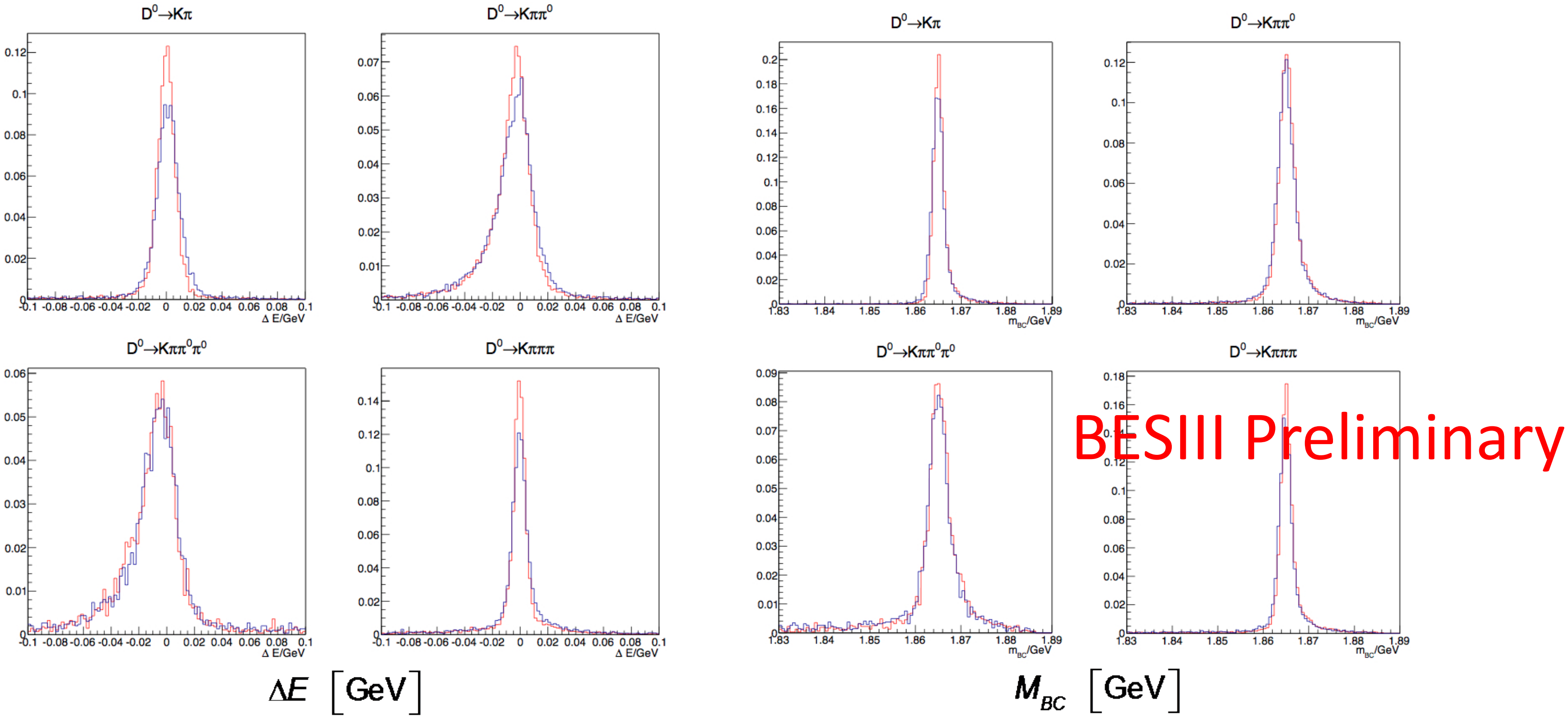
$$\frac{d\Gamma\left(D\to K(\pi)e\nu\right)}{dq^2} = \frac{G_F^2 \left|V_{cs(d)}\right|^2 P_{K(\pi)}^3}{24\pi^3} \boxed{\left|f_+\left(q^2\right)\right|^2}$$

- Use Strong Interaction theory (LQCD) for form factor, extract CKM
- Use other measurements and unitarity for CKM and test theory
- Theoretical uncertainties can be reduced in determinations of $|V_{ub}|$ if FF calculations can be validated with charm
- Multiple tests available, semileptonic *D* decays to pseudoscalar mesons are cleanest

D^0 Semileptonic Decays – Tag Selection

- Four D^0 tag modes

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



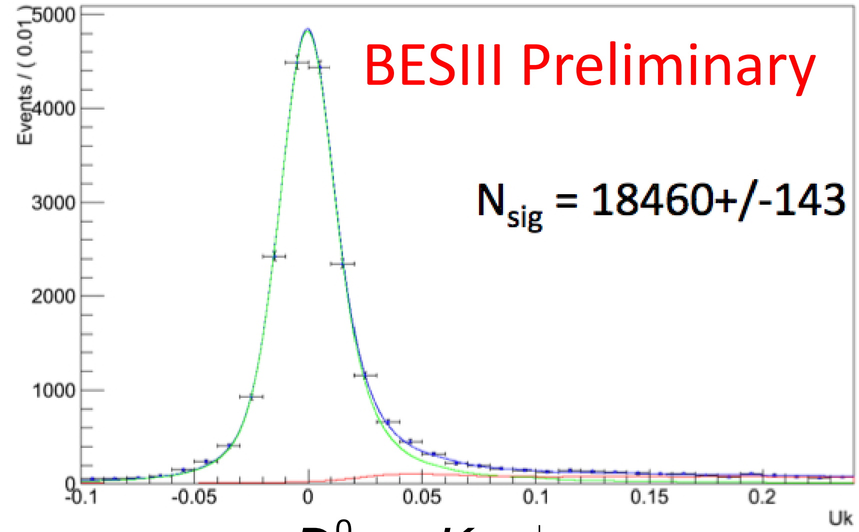
$$N_{D^-}^{\text{tag}} = (0.774 \pm 0.001) \times 10^6 \text{ in } 0.92\ \text{fb}^{-1}$$

D^0 Semileptonic Decays – Signal Selection

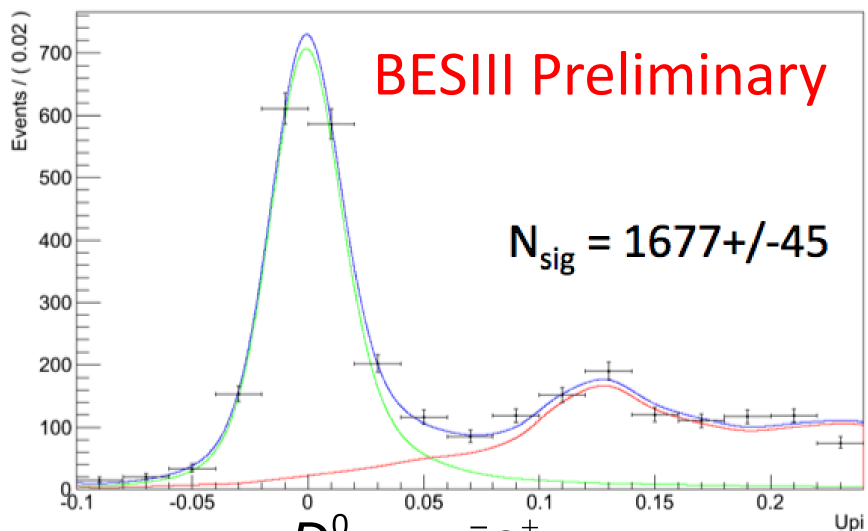
- Tag plus exactly two oppositely-charged tracks
- Kaon/pion/electron ID
- Electron has right charge
- No extra neutral energy
- Select on consistency with semileptonic decay

$$U = E_{miss} - \left|\vec{P}_{miss}\right| \approx 0$$

- Fit U distribution to extract yield



$D^0 \to K^- e^+ \nu_e$



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

D^0 Semileptonic Decays – Branching Fraction

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

$$\longrightarrow \quad B_{sig} = \frac{N_{sig}^{obs}}{\sum_\alpha N_{tag}^{obs,\alpha}\epsilon_{tag,sig}^{\alpha}/\epsilon_{tag}^{\alpha}}$$

BESIII Preliminary

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

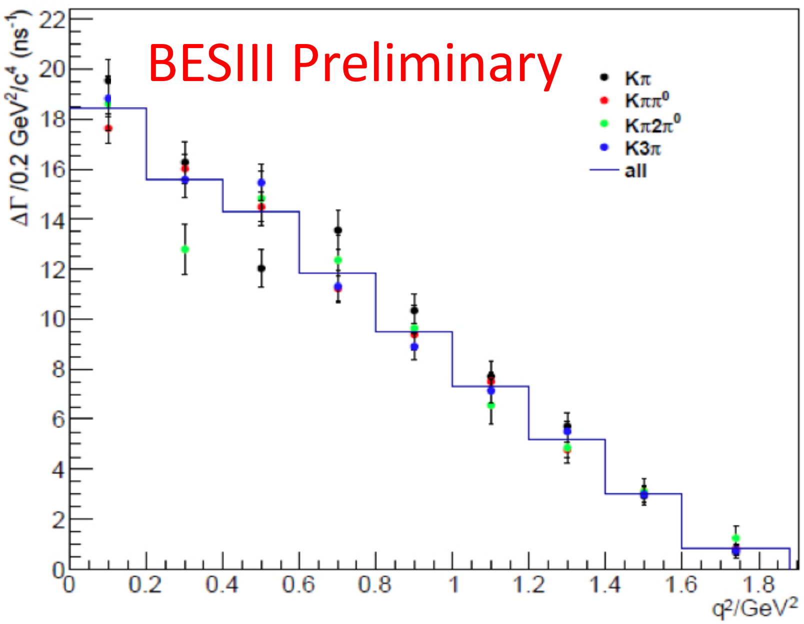
- Systematic uncertainties are preliminary
- Good consistency with CLEO-c, statistical precision is comparable with only 1/3 data analyzed

D^0 Semileptonic Decays – q^2 Distribution

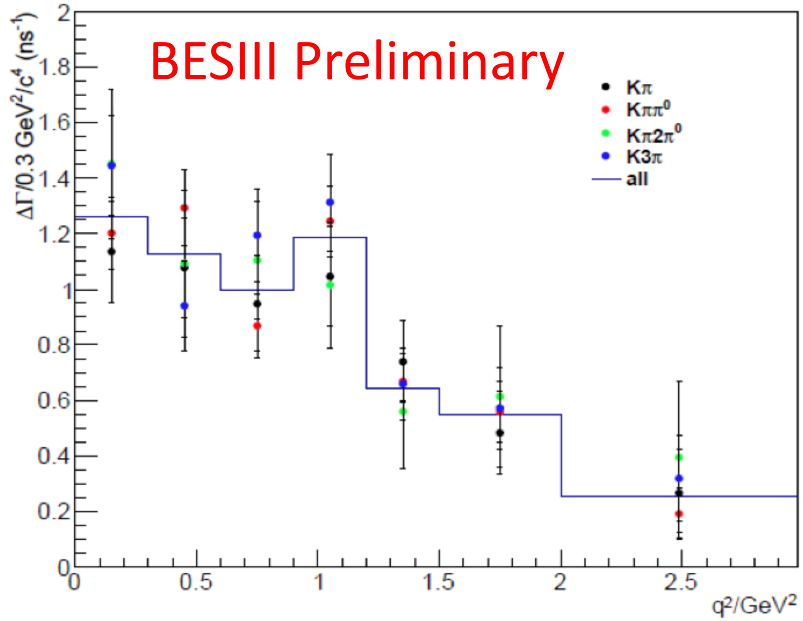
- Partition D^0 semileptonic candidates in bins of

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

- Fit U distribution in each q^2 bin



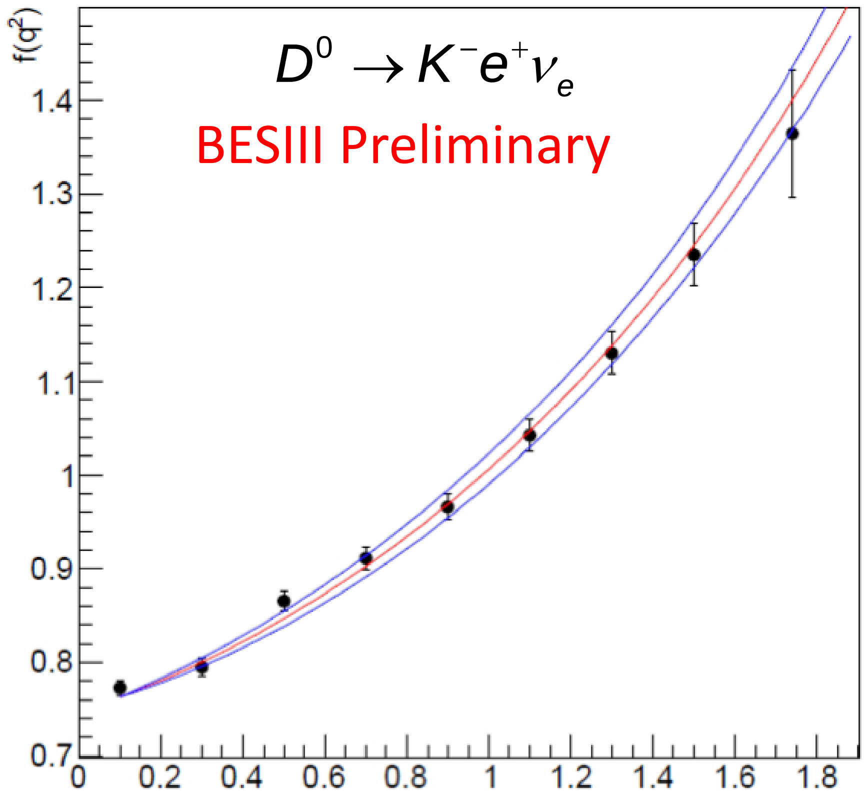
$D^0 \to K^- e^+ \nu_e$

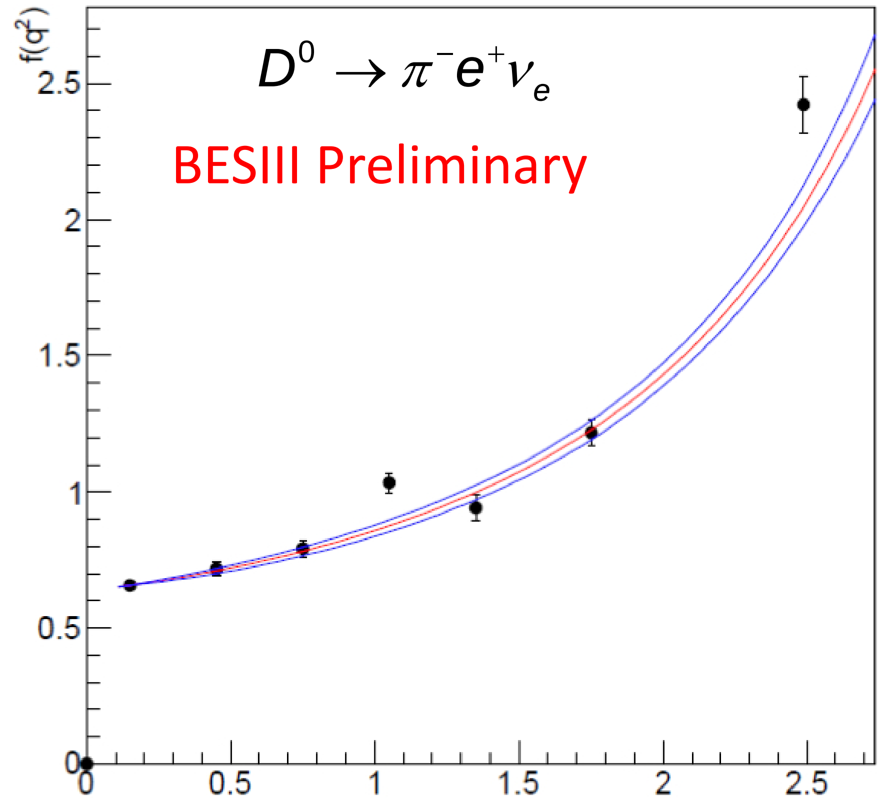


$D^0 \to \pi^- e^+ \nu_e$

D^0 Semileptonic Decays – extract $f(q^2)$

- Points are data with statistical errors only
- Curves are Fermilab-MILC (arXiv:1111.5471) with ±1σ (statistical) bands





D^0 Semileptonic Decays – Form Factor Parameterizations

Simple Pole Model

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

Modified Pole Model

Becirevic and Kaidalov
PLB 478, 417 (‘00)

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

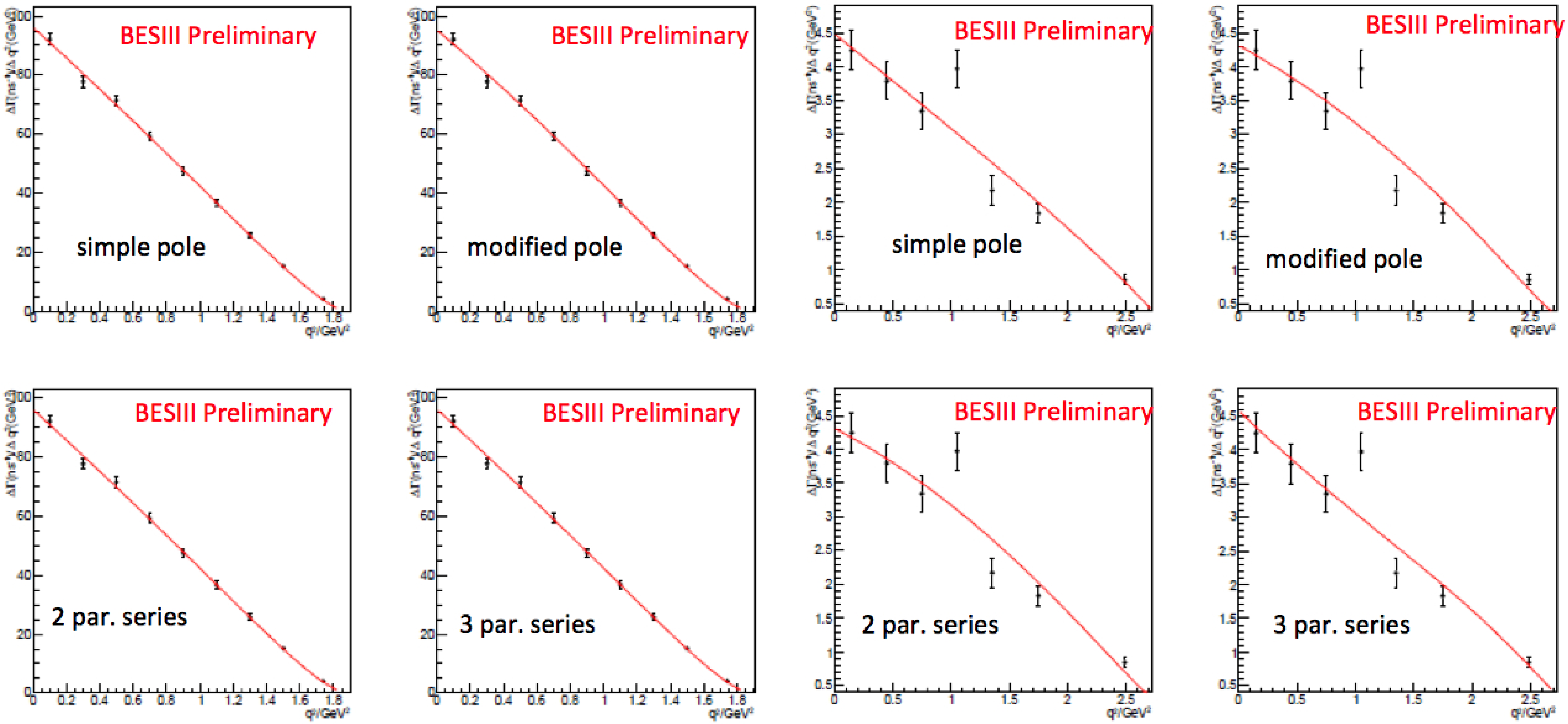
Series Expansion

Becher and Hill
PLB 633, 61 (‘06)

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

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

D^0 Semileptonic Decays – $f(q^2)$



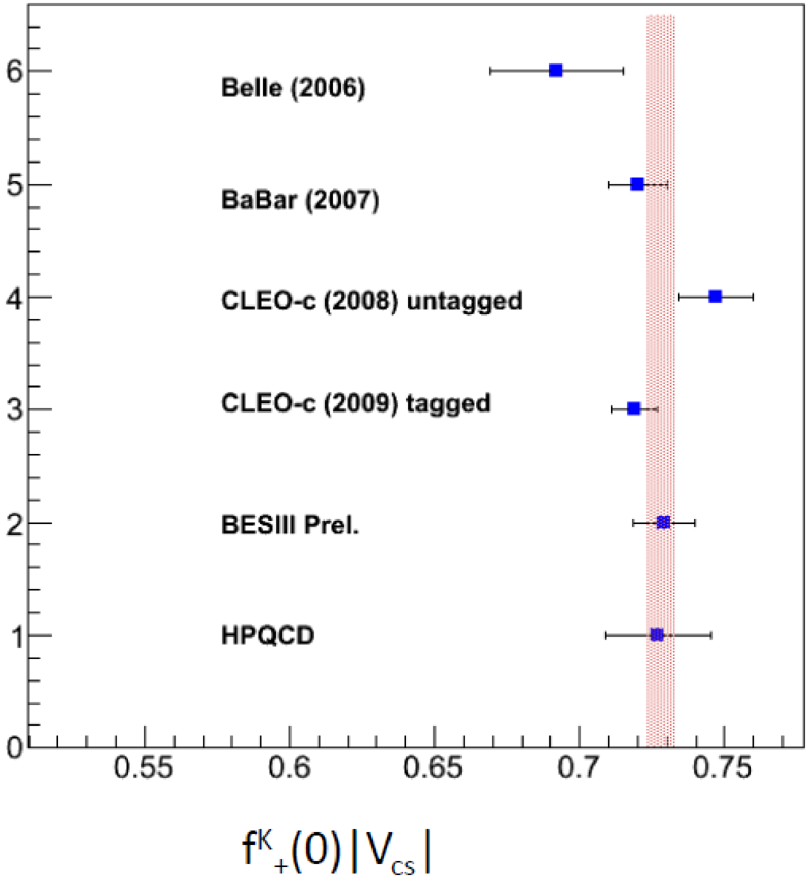
$D^0 \to K^- e^+ \nu_\mu$ $D^0 \to \pi^- e^+ \nu_\mu$

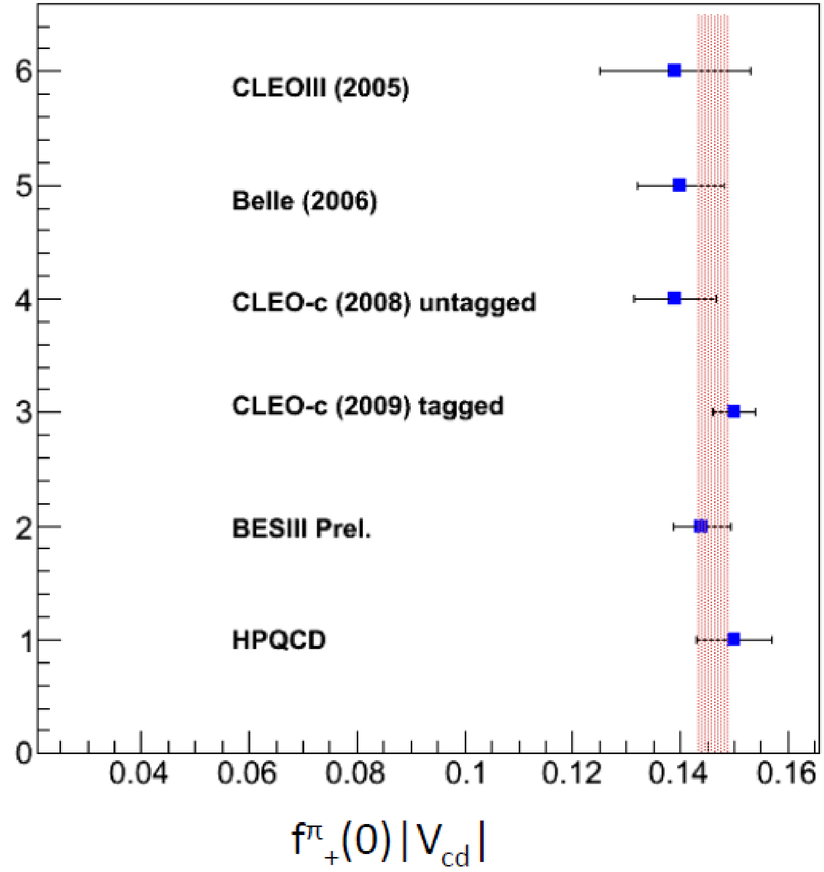
D^0 Semileptonic Decays – Form Factor Results

Simple Pole	$f_+(0)\|V_{cd(s)}\|$	m_{pole}	
$D^0 \to Ke\nu$	$0.729\pm0.005\pm0.007$	$1.943\pm0.025\pm0.003$	
$D^0 \to \pi e\nu$	$0.142\pm0.003\pm0.001$	$1.876\pm0.023\pm0.004$	
Modified Pole	$f_+(0)\|V_{cd(s)}\|$	α	
$D^0 \to Ke\nu$	$0.725\pm0.006\pm0.007$	$0.265\pm0.045\pm0.006$	
$D^0 \to \pi e\nu$	$0.140\pm0.003\pm0.002$	$0.315\pm0.071\pm0.012$	
2 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	
$D^0 \to Ke\nu$	$0.726\pm0.006\pm0.007$	$-2.034\pm0.196\pm0.022$	
$D^0 \to \pi e\nu$	$0.140\pm0.004\pm0.002$	$-2.117\pm0.163\pm0.027$	
3 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	r_2
$D^0 \to Ke\nu$	$0.729\pm0.008\pm0.007$	$-2.179\pm0.355\pm0.053$	$4.539\pm8.927\pm1.103$
$D^0 \to \pi e\nu$	$0.144\pm0.005\pm0.002$	$-2.728\pm0.482\pm0.076$	$4.194\pm3.122\pm0.448$

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

D^0 Semileptonic Decays – Comparisons(from C.L.Liu)





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

D^0 Rare Decay

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

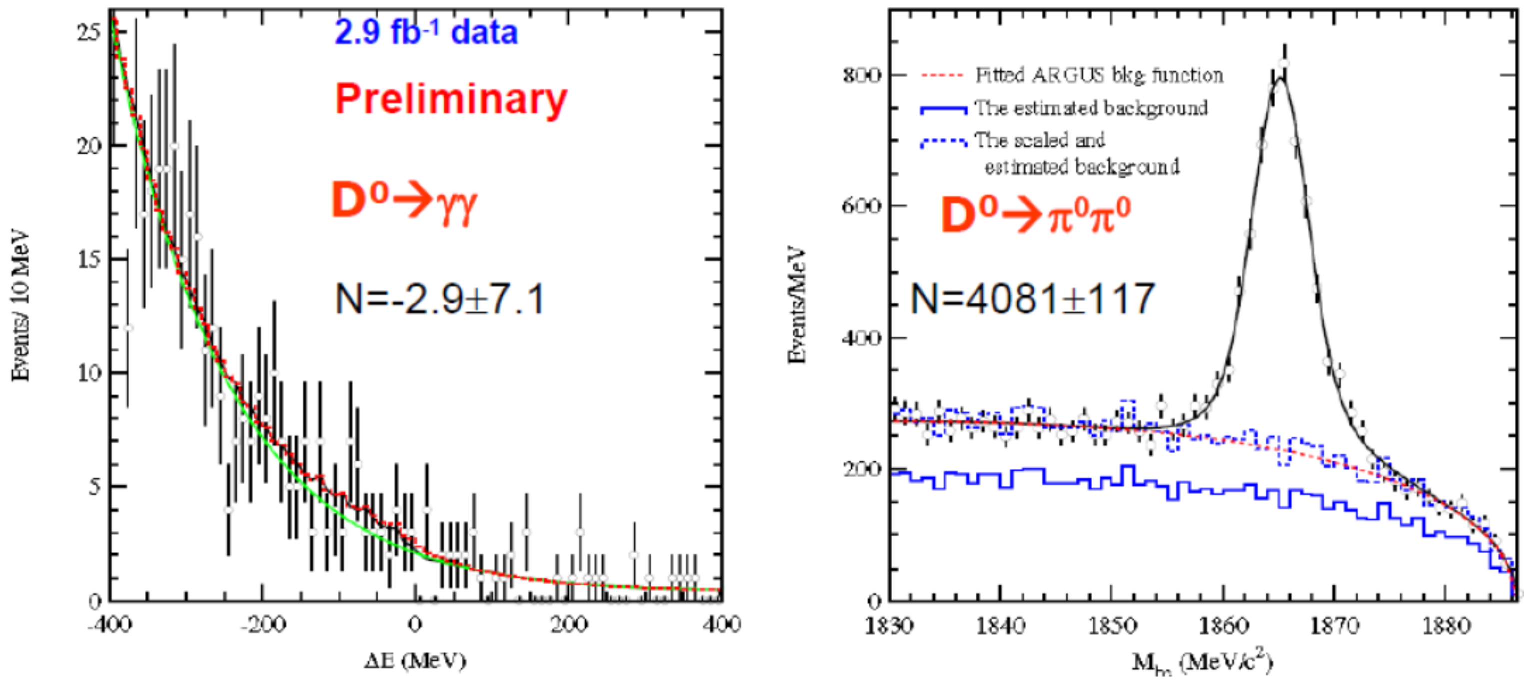
$D^0 \to \gamma\gamma$

- 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

$D^0 \rightarrow \gamma\gamma$



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

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

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

Summary

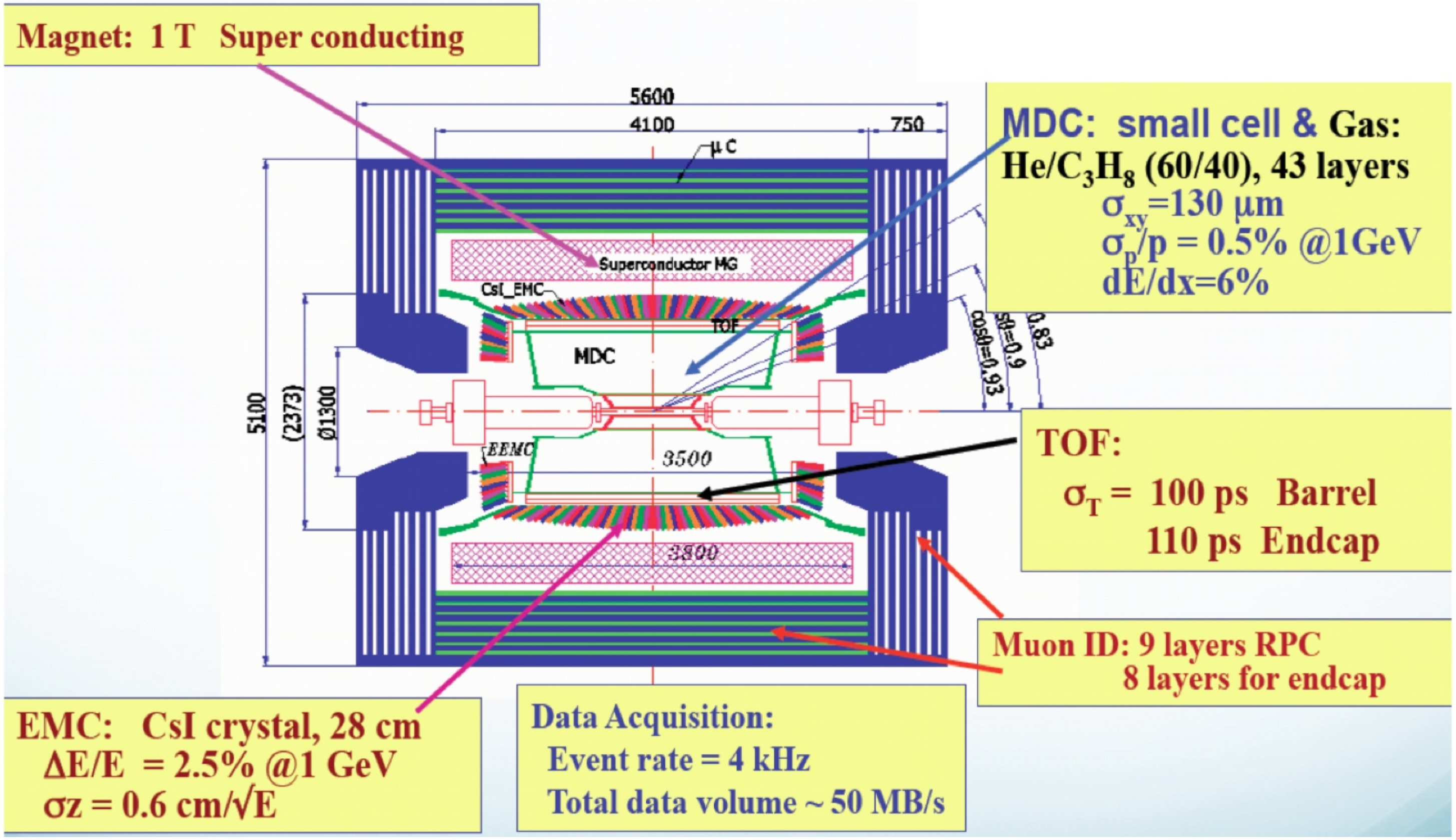
- First charm results from the BESIII experiment have been presented on
  - Leptonic decay:
    - $B(D^+ \to \mu^+ \nu_\mu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$
    - $f_{D+} = (203.91 \pm 5.72 \pm 1.97)$ MeV
    - $|V_{cd}| = 0.222 \pm 0.006 \pm 0.005$
  - Semileptonic decay (0.92fb^{-1}, will 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 $\pm$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 $\pm$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-$\overline{D}^0$ mixing, CP violation, rare decay and other semileptonic decays are ongoing.

Backup

BESIII at BEPCII



- Comparable capabilities to CLEO-c, plus muon ID
- The big advantage: BEPCII is a two-ring machine designed for charm
  - Design (achieved) luminosity at $\psi(3770)$: 1 (0.65) x 10^{33}