D^+ Leptonic and D^0 Semileptonic Decays First Results from BESIII

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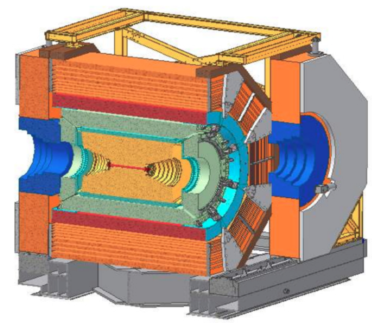

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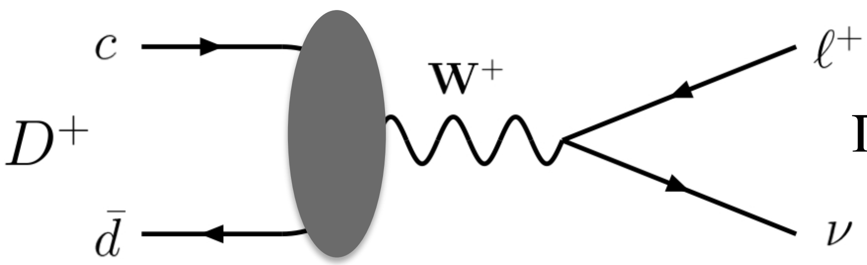
Window on Weak and Strong Physics

Leptonic Decay

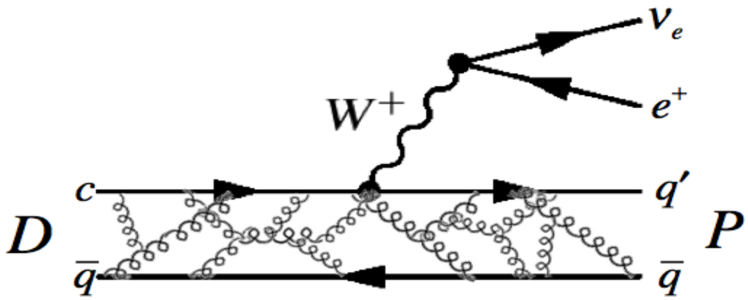


$$\Gamma\left(D^+ \to \ell^+ \nu_\ell\right) = \boxed{f_D^2} \left|V_{cd}\right|^2 \frac{G_F^2}{8\pi} m_D m_\ell^2 \left(1 - \frac{m_\ell^2}{m_D^2}\right)^2$$

- 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_{D_s} (esp. ratios)
- Sensitivity to New Physics

Window on Weak and Strong Physics

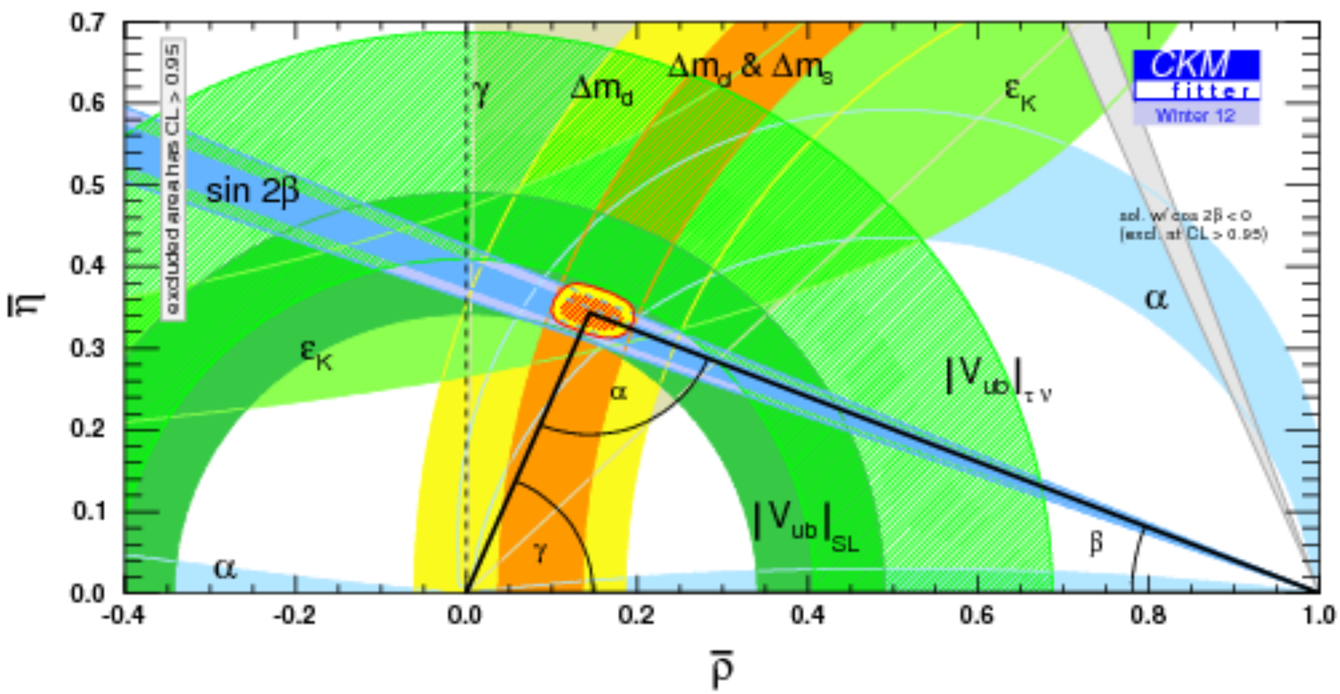
Semileptonic Decay



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

- 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

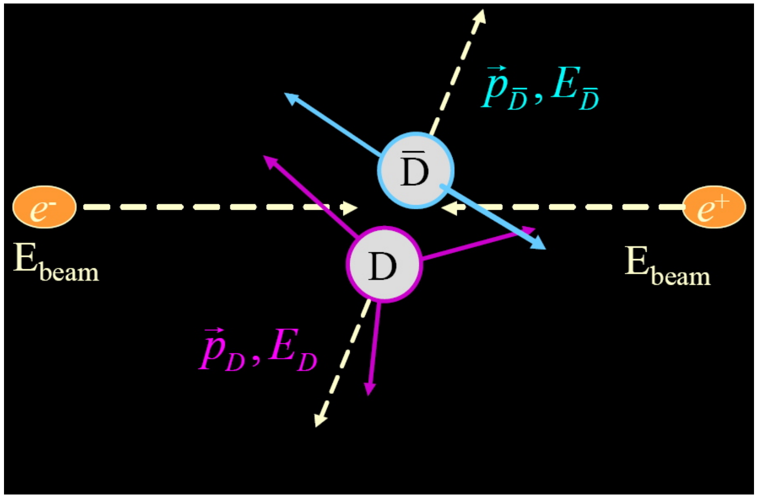
Window on Weak and Strong Physics



- Widths of mixing and $|V_{ub}|$ bands will be reduced as charm validates LQCD
- Long-term goal: Over-constrain CKM and search for New Physics

Charm Physics at Threshold

- At ψ(3770) charm production is $D^0\bar{D}^0$ and D^+D^-
- Fully reconstruct about 15% of *D* decays

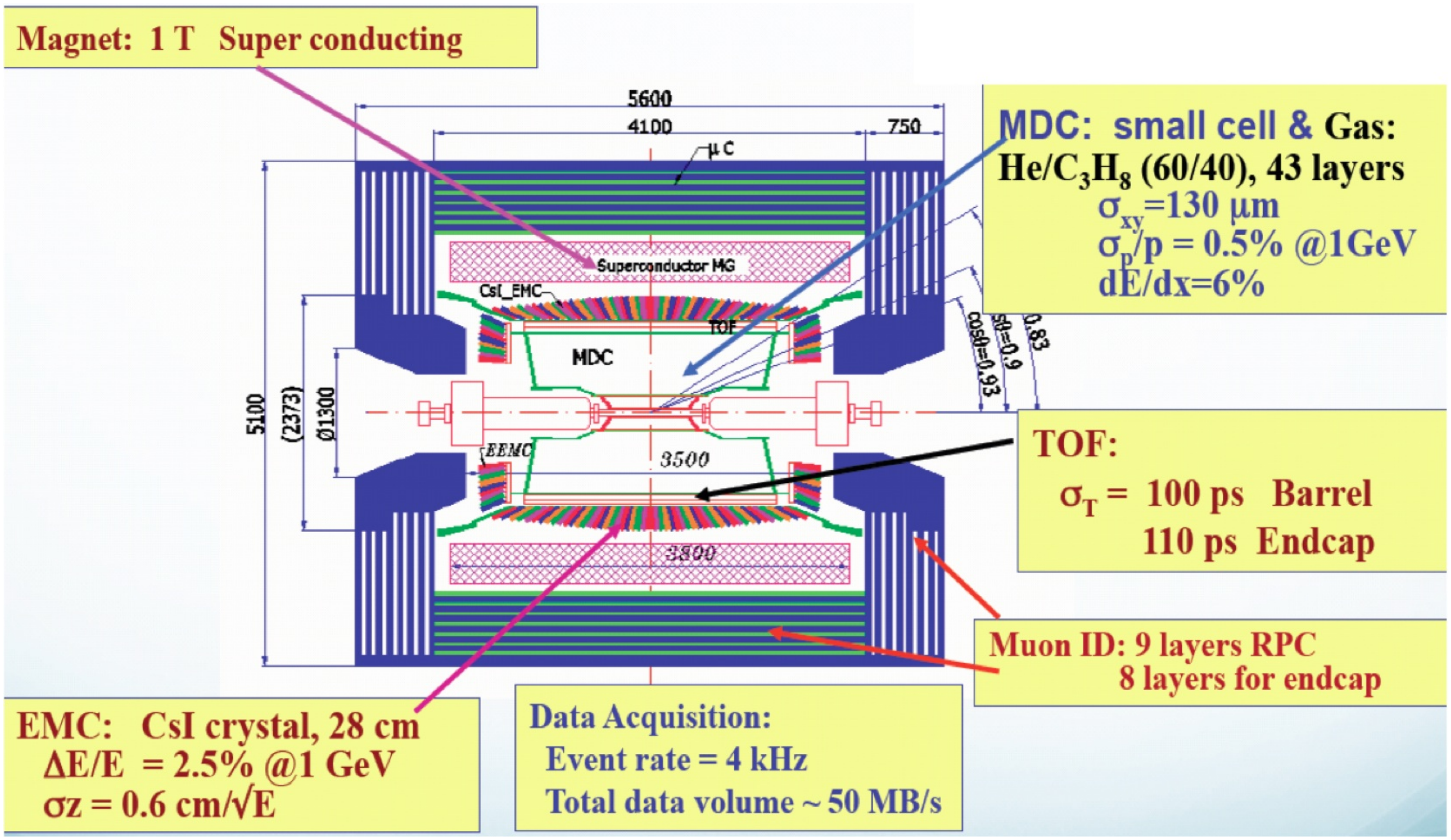


$$\Delta E = E_D - E_{\mathrm{Beam}}$$

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

- Hadronic tag on one side gives "beam" of D^0 or D^+ on the other side for leptonic/semileptonic studies. Neutrino is reconstructed from missing energy and momentum

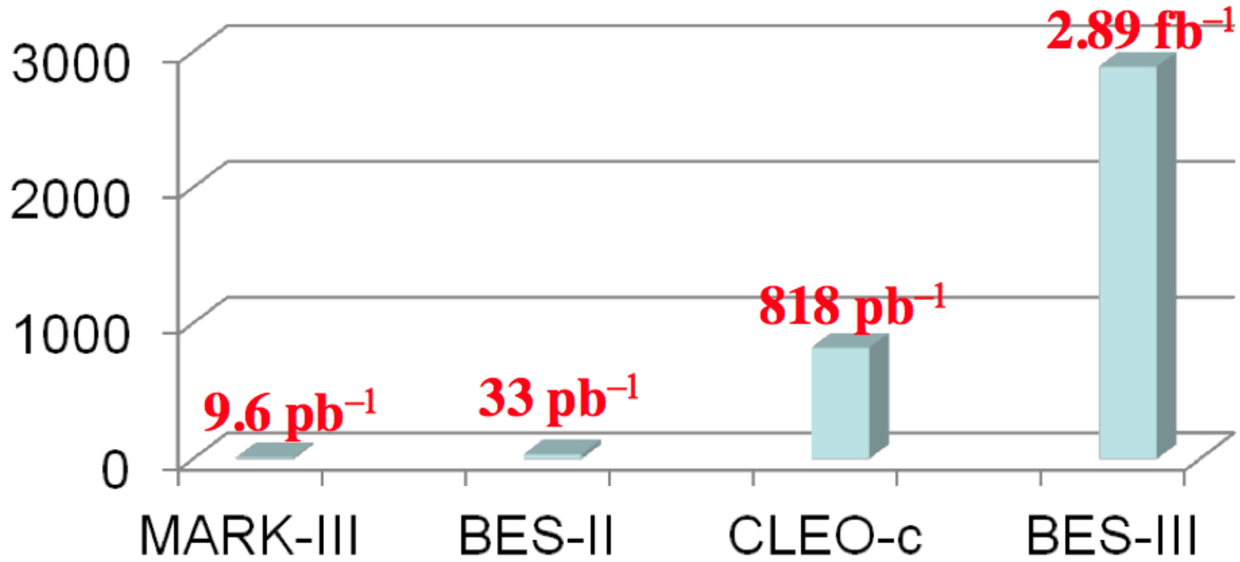
BESIII at BEPCII



- 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}

BESIII Data

- World's largest ψ(3770) sample

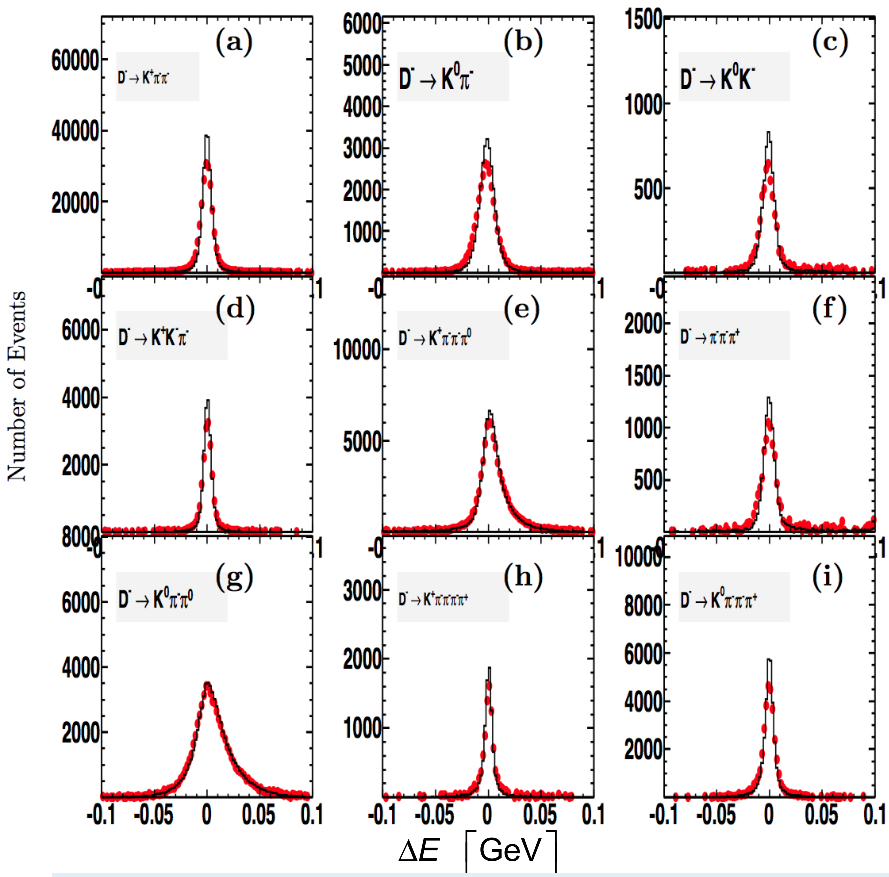


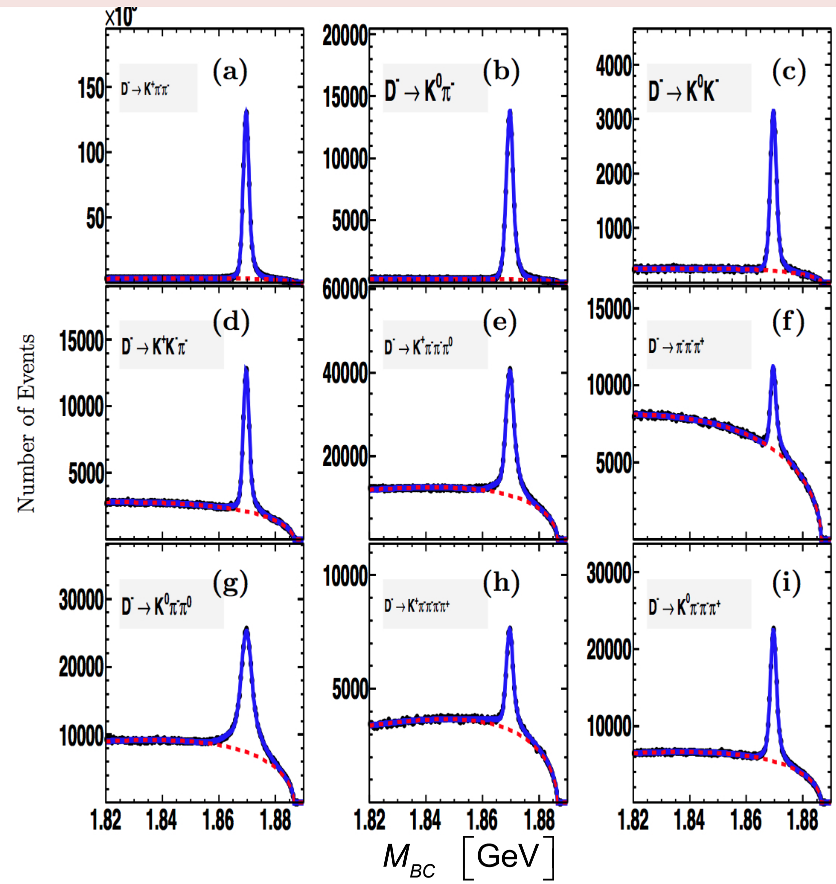
- Tools/techniques for precision charm physics still under development – all results are PRELIMINARY
  - $D^+ \to K^0\left(\pi^0\right)e^+\nu_\mu$ analysis is "partially blind" – 0.92 fb^{-1} analyzed so far. Full 2.9 fb^{-1} later for final results

D^+ Leptonic Decays – Tag Selection

- Nine D^- tag modes

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





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

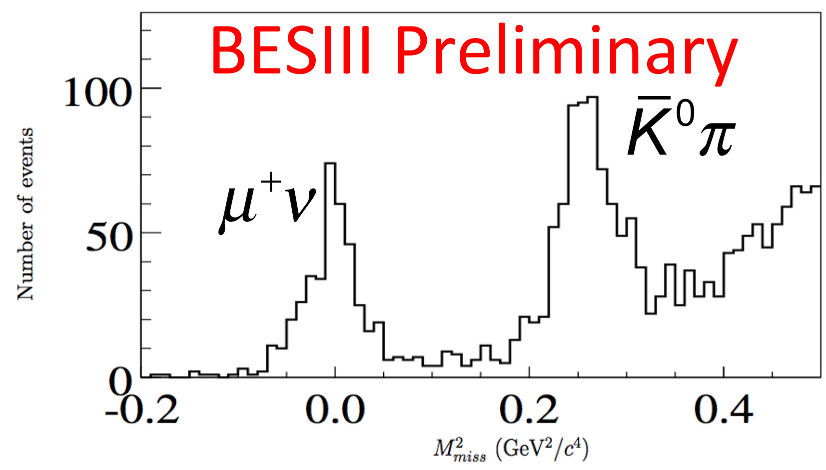
BESIII Preliminary

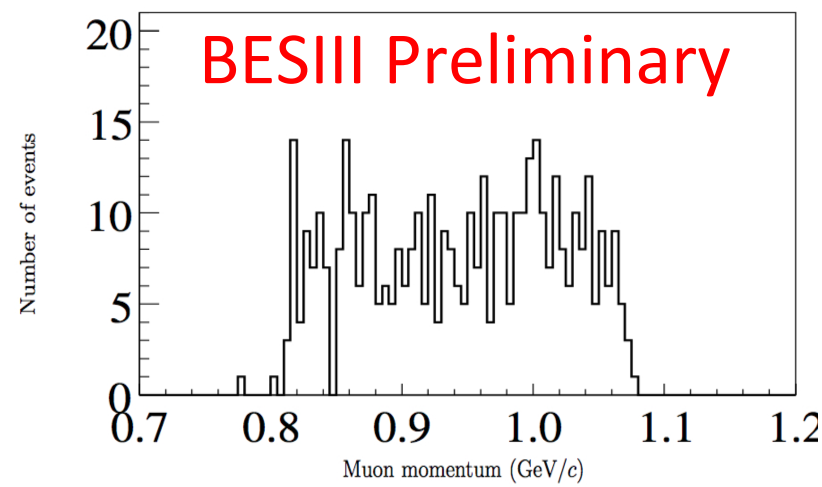
D^+ Leptonic Decays – Signal Selection

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

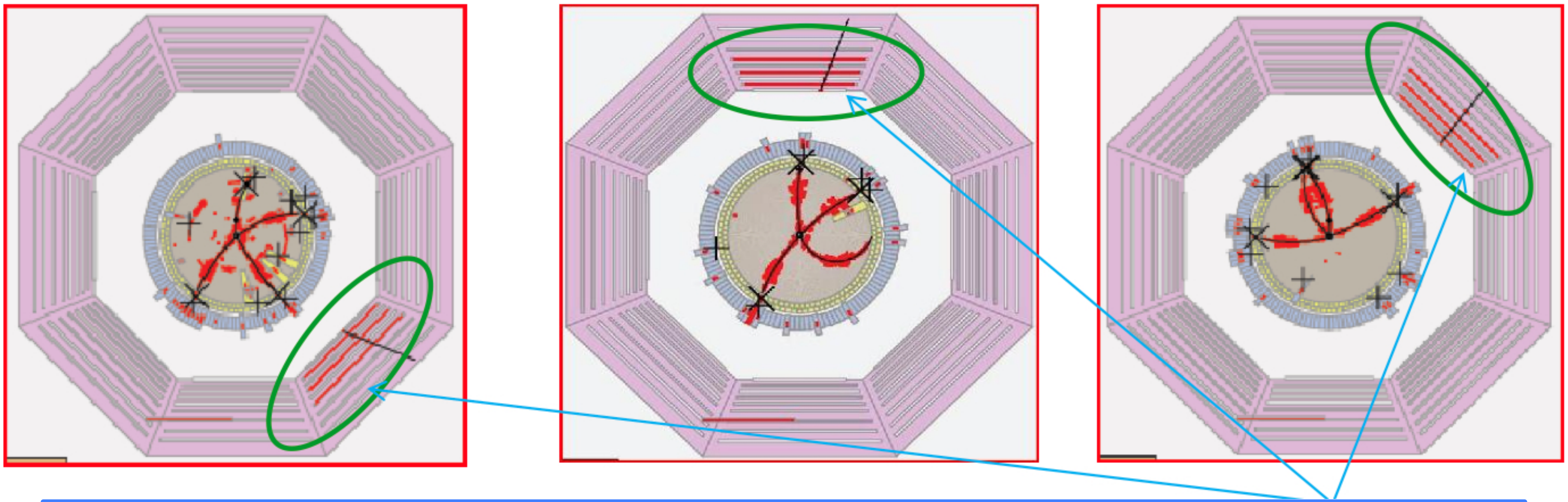
$$M^2_{\text{miss}} = \left(E_{\text{Beam}} - E_\mu\right)^2 - \left(-\vec{p}_{\text{tag}} - \vec{p}_\mu\right)^2 \approx 0$$

425 signal candidates:
small BG, mom. dist.
consistent with $D^+ \to \mu^+ \nu$



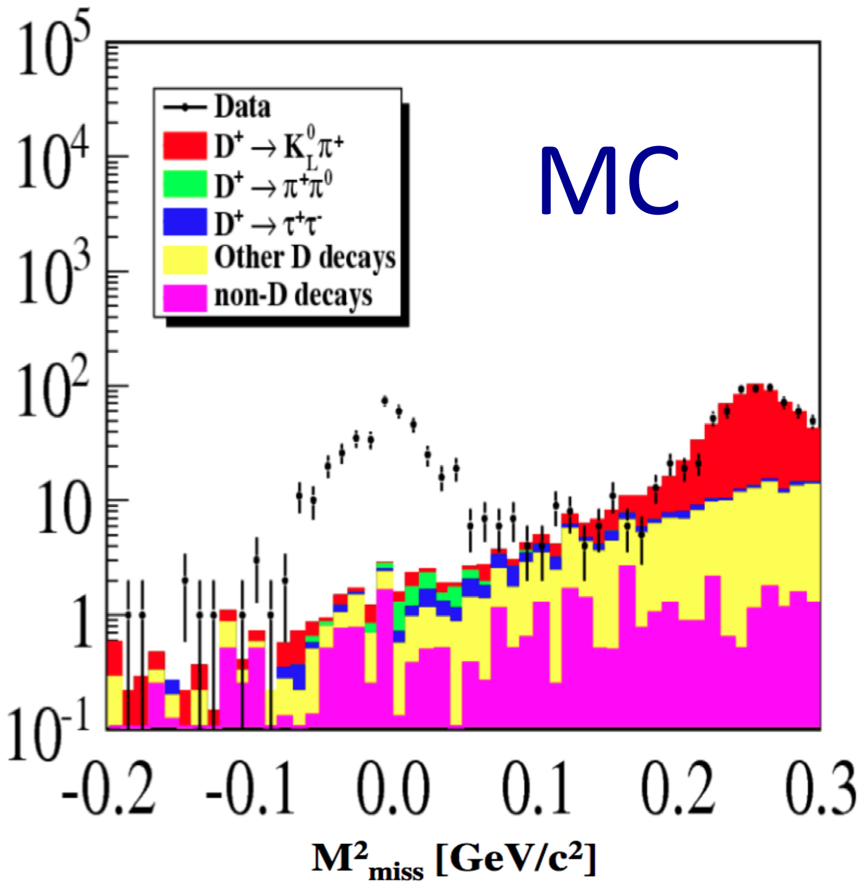


D^+ Leptonic Decays – Sample Events



- Positive muon ID requirement reduces background at the expense of slightly reduced efficiency

D^+ Leptonic Decays – Backgrounds



BESIII Preliminary

Source	N_{bkg}^{MC}	Scale factor f	$N_{bkg}^{data} = \frac{N_{bkg}^{MC}}{f} \times \frac{\eta^{data}}{\eta^{MC}}$
Numbers of background events from $D\bar{D}$ decays			
$D^+ \to K_L^0\pi^+$	111	10.8	$7.9 \pm 0.8 \pm 0.3$
$D^+ \to \pi^+\pi^0$	53	10.8	$3.8 \pm 0.5 \pm 0.3$
$D^+ \to \tau^+\nu_\tau$	96	10.8	$6.9 \pm 0.7 \pm 0.3$
Other D decays	250	10.8	$17.9 \pm 1.1 \pm 0.5$
Sum	510	10.8	$36.4 \pm 1.6 \pm 0.7$
Numbers of background events from $non - D\bar{D}$ decays			
Source	N_{bkg}^{MC}	Scale factor f	$N_{bkg}^{data} = \frac{N_{bkg}^{MC}}{f} \times \frac{\eta^{data}}{\eta^{MC}}$
$e^+e^- \to (\gamma)\psi(3686)$	2	6.3	$0.2 \pm 0.2 \pm 0.0$
$e^+e^- \to (\gamma)J/\psi$	0	5.7	$0.0 \pm 0.0 \pm 0.0$
$e^+e^- \to Light\ Hadron$	33	3.1	$8.2 \pm 1.4 \pm 0.3$
$e^+e^- \to \tau^+\tau^-$	15	6.0	$1.9 \pm 0.5 \pm 0.4$
$\psi(3770) \to non - D\bar{D}$	7	5.8	$0.9 \pm 0.4 \pm 0.9$
Sum			$11.3 \pm 1.6 \pm 1.0$
Total (D decay and non − D decay)			$47.7 \pm 2.3 \pm 1.3$

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

MC BG est.: 47.7 ± 2.6

Indep. data est.: 48.9 ± 4.8

D^+ Leptonic Decays – Results

BESIII Preliminary

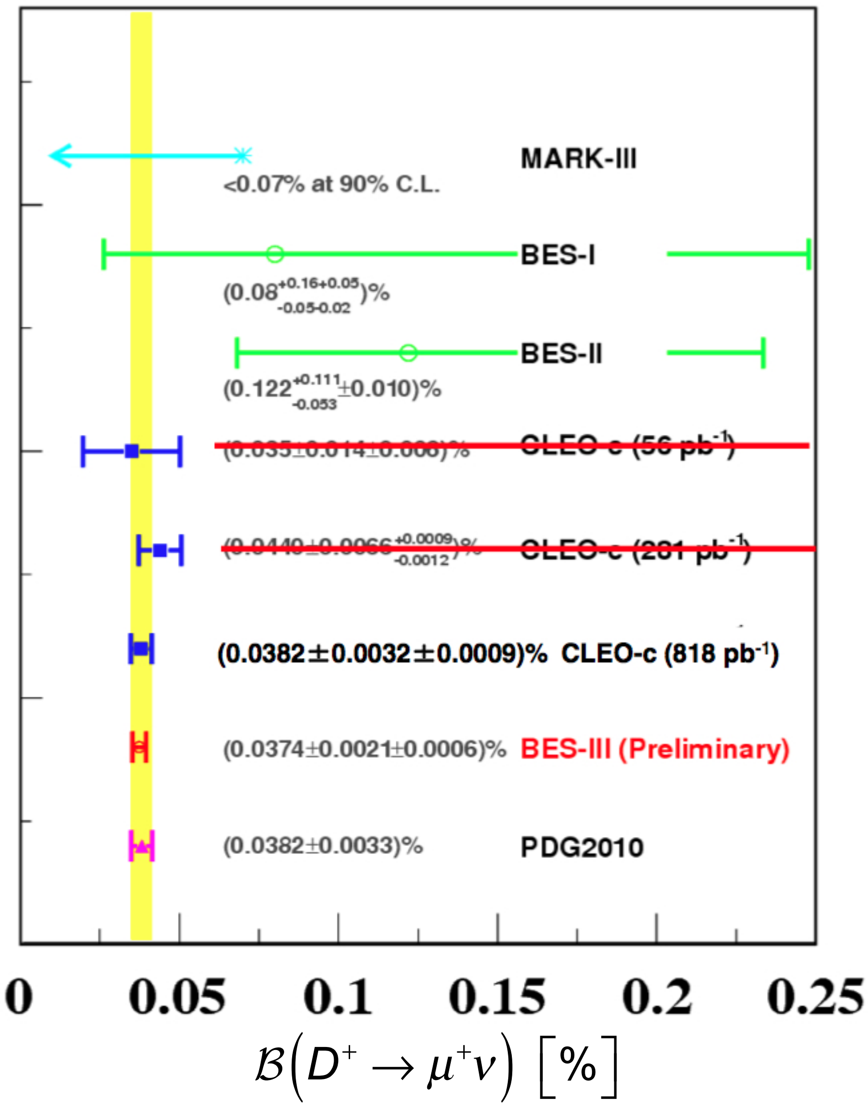
$$N\left(D^+ \to \mu^+ \nu\right) = 377.3 \pm 20.6$$

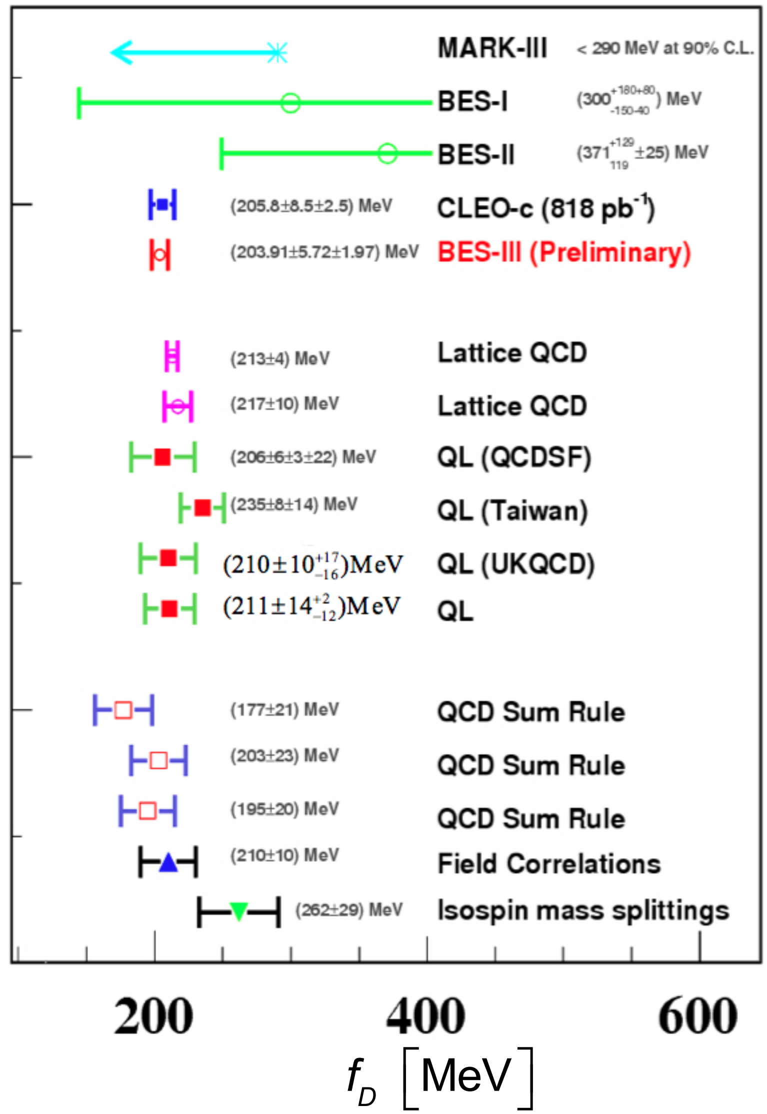
$$\mathcal{B}\left(D^+ \to \mu^+ \nu\right) = \left(3.74 \pm 0.21 \pm 0.06\right) \times 10^{-4}$$

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

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

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

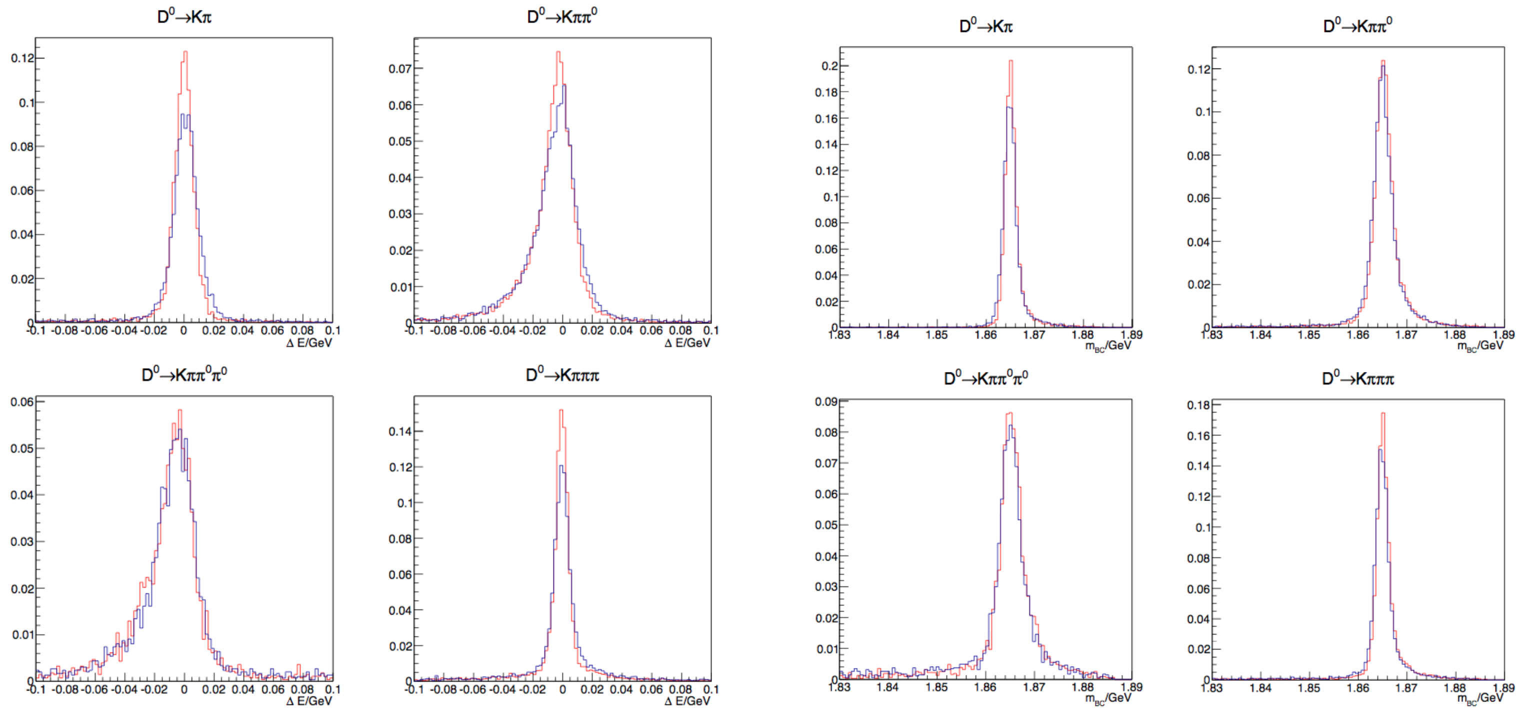




D^0 Semileptonic Decays – Tag Selection

- Four D^0 tag modes

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



$\Delta E\ [\mathrm{GeV}]$ $\quad M_{BC}\ [\mathrm{GeV}]$

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

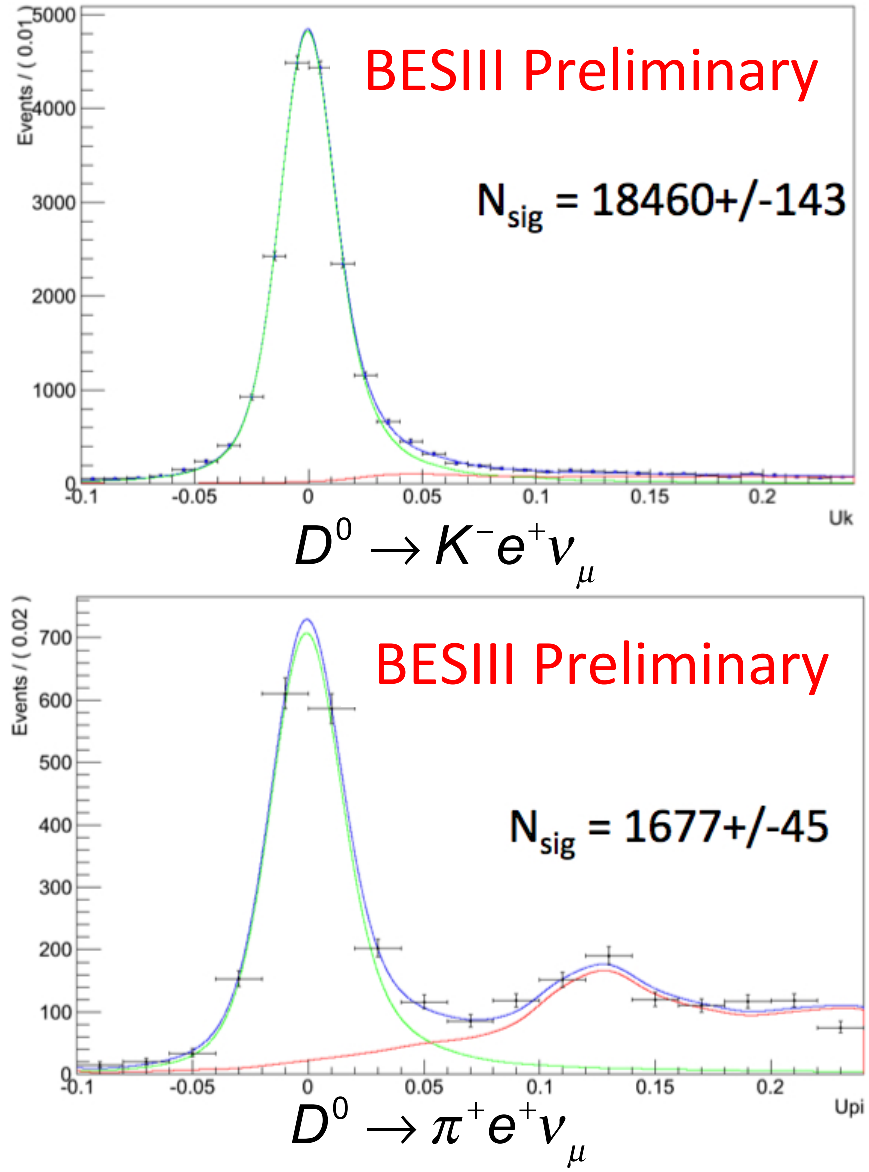
BESIII Preliminary

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 Semileptonic Decays – Branching Fraction

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

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

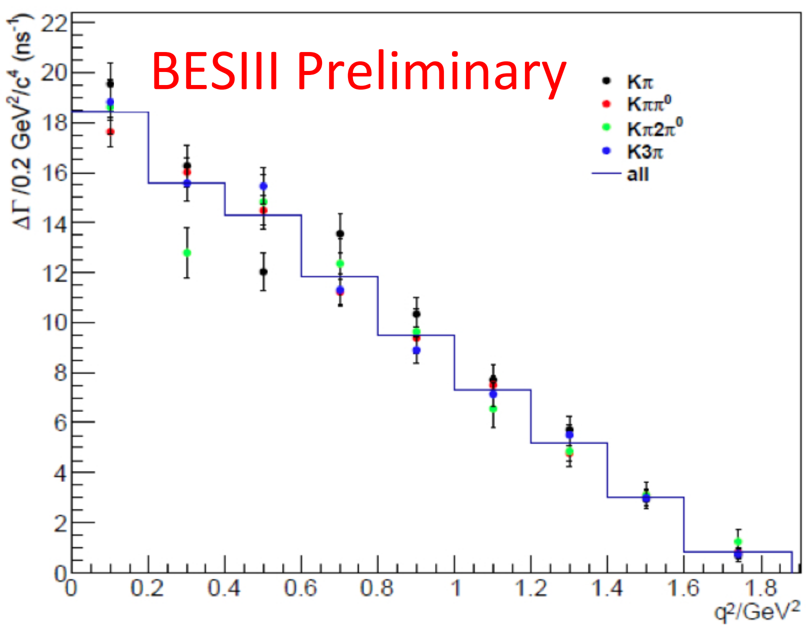
- Systematic uncertainties are preliminary
- Good consistency with CLEO-c, statistical precision is comparable with only 1/3 data analyzed

D^0 Semileptonic Decays – q^2 Distribution

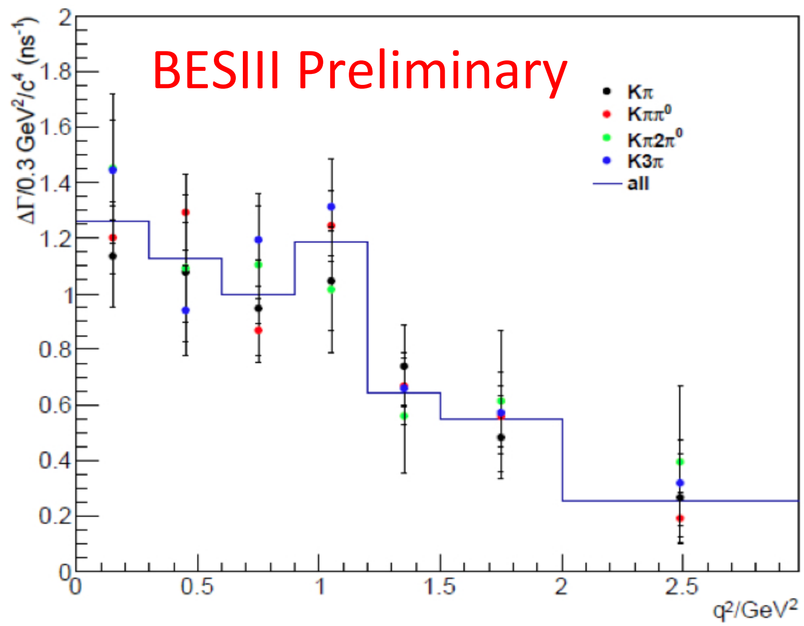
- Partition D^+ semileptonic candidates in bins of

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

- Fit U distribution in each q^2 bin



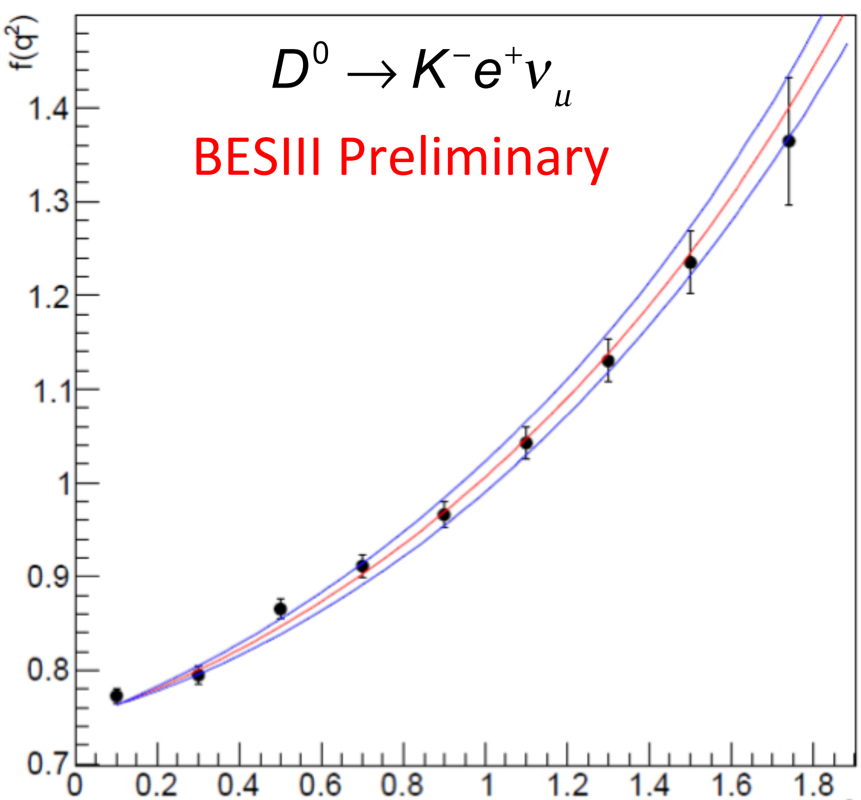
$D^0 \to K^- e^+ \nu_\mu$

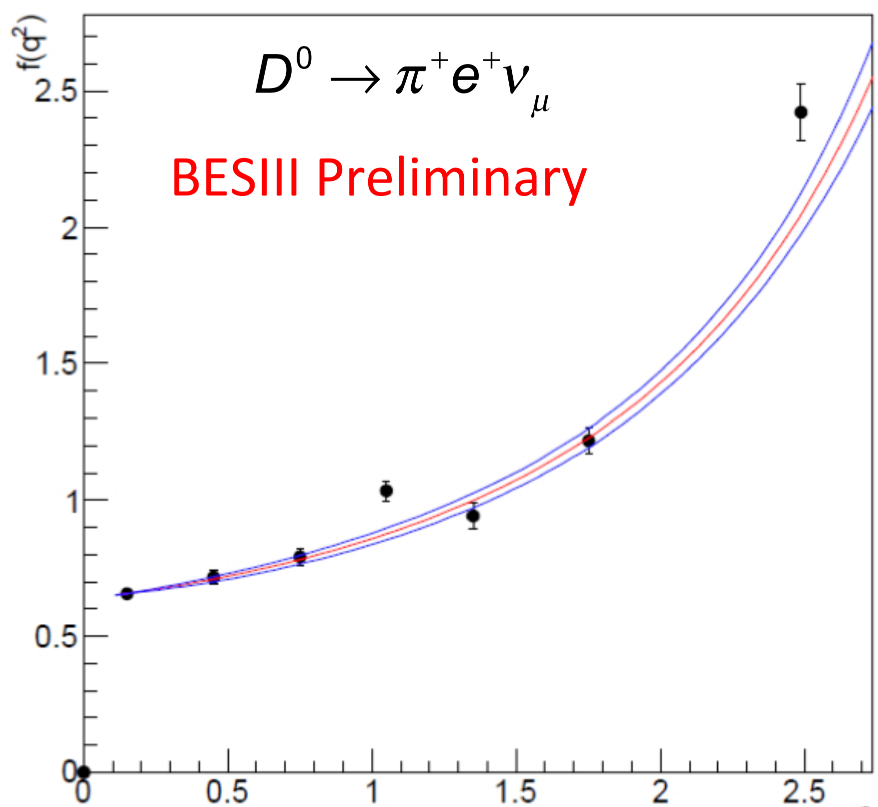


$D^0 \to \pi^+ e^+ \nu_\mu$

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

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





D^0 Semileptonic Decays – Form Factor Parameterizations

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)

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

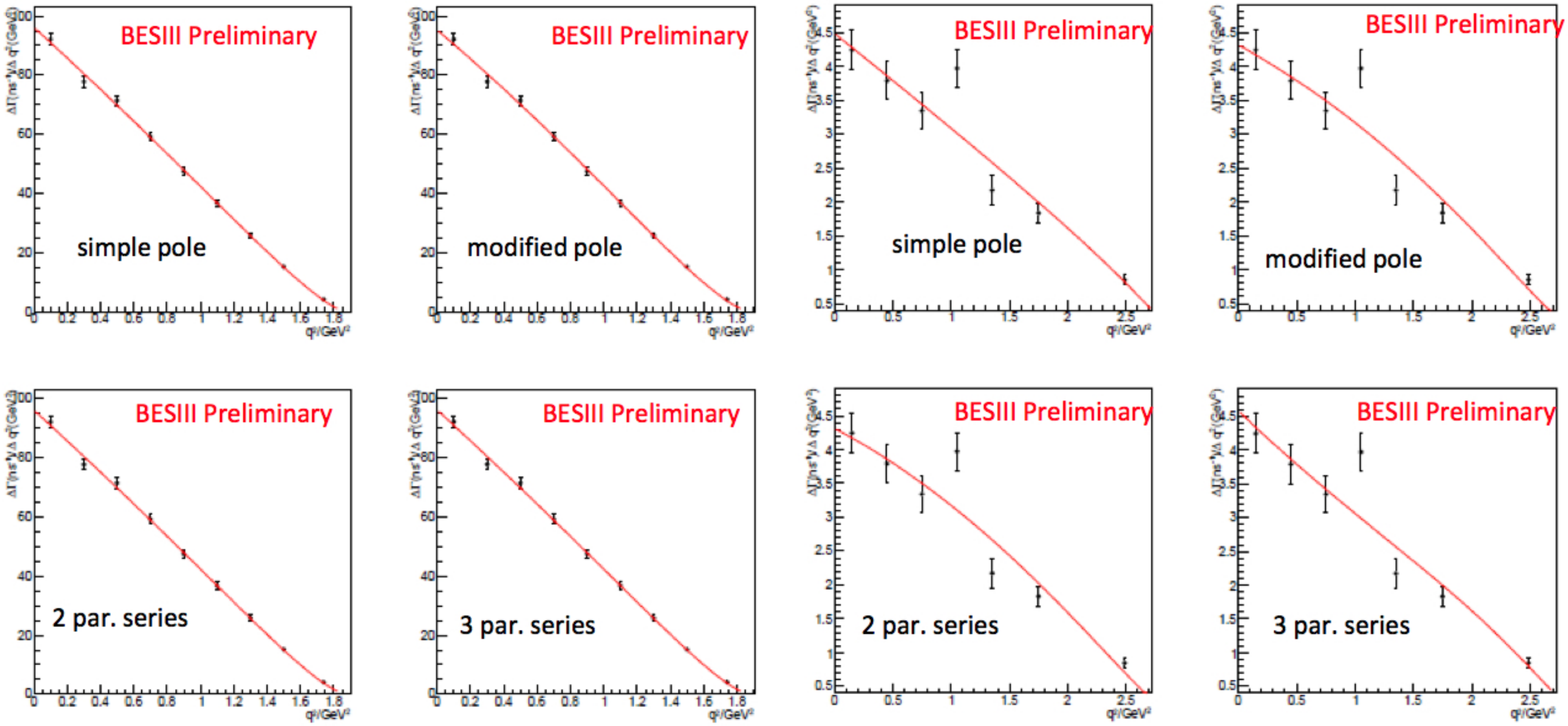
Series Expansion

Becher and Hill
PLB 633, 61 ('06)

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

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

D^0 Semileptonic Decays – $f(q^2)$



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

D^0 Semileptonic Decays – Form Factor Results

Simple Pole	$f_+(0)\|V_{cd(s)}\|$	m_{pole}	
$D^0 \to Ke\nu$	$0.729 \pm 0.005 \pm 0.007$	$1.943 \pm 0.025 \pm 0.003$	
$D^0 \to \pi e\nu$	$0.142 \pm 0.003 \pm 0.001$	$1.876 \pm 0.023 \pm 0.004$	
Modified Pole	$f_+(0)\|V_{cd(s)}\|$	α	
$D^0 \to Ke\nu$	$0.725 \pm 0.006 \pm 0.007$	$0.265 \pm 0.045 \pm 0.006$	
$D^0 \to \pi e\nu$	$0.140 \pm 0.003 \pm 0.002$	$0.315 \pm 0.071 \pm 0.012$	
2 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	
$D^0 \to Ke\nu$	$0.726 \pm 0.006 \pm 0.007$	$-2.034 \pm 0.196 \pm 0.022$	
$D^0 \to \pi e\nu$	$0.140 \pm 0.004 \pm 0.002$	$-2.117 \pm 0.163 \pm 0.027$	
3 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	r_2
$D^0 \to Ke\nu$	$0.729 \pm 0.008 \pm 0.007$	$-2.179 \pm 0.355 \pm 0.053$	$4.539 \pm 8.927 \pm 1.103$
$D^0 \to \pi e\nu$	$0.144 \pm 0.005 \pm 0.002$	$-2.728 \pm 0.482 \pm 0.076$	$4.194 \pm 3.122 \pm 0.448$

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

Future Charm Prospects at BESIII

- Finalize $D^+ \to \mu^+ \nu_\mu$ and $D^0 \to K^- \left(\pi^+\right) e^+ \nu_\mu$ on the 2.9 fb^{-1} $\psi(3770)$ sample
- Extend to $D^+ \to K^0 \left(\pi^0\right) e^+ \nu_\mu$ and other modes
- Highlights of coming data runs:

<u>2012-2013</u>	E_{CM}=4260 and 4360 MeV for "*XYZ*" studies (0.5 fb^{-1} each)
<u>2013-2014</u>	E_{CM}=4170 MeV for D_s (~2.4 fb^{-1})
<u>TBD</u>	Additional $\psi(3770)$ data

Summary and Conclusions

- First results from the BESIII experiment have been presented on
  - D^+ Leptonic Decays

BESIII Preliminary

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

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

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

  - D^0 Semileptonic Decays

BESIII Preliminary

$$\mathcal{B}(D^0 \to K^+ e \nu) = (3.542 \pm 0.030 \pm 0.067)\%$$

$$\mathcal{B}(D^0 \to \pi^+ e \nu) = (0.288 \pm 0.008 \pm 0.005)\%$$

$$\frac{\Delta\Gamma}{\Delta q^2} \text{ distributions } \to \text{ FF fits, parameters}$$

- BESIII has arrived for precision charm physics, with more data and more measurements to come