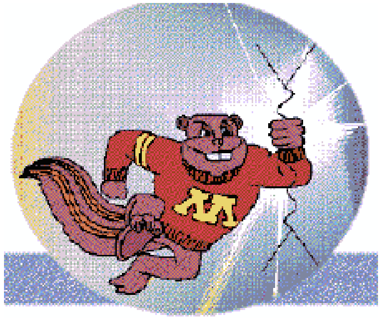
D^+ Leptonic and D^0 Semileptonic Decays First Results from BESIII



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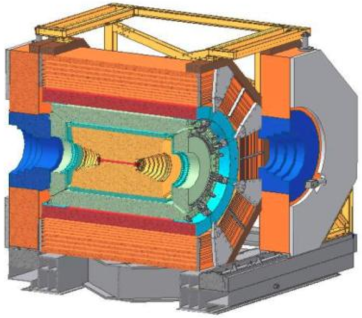

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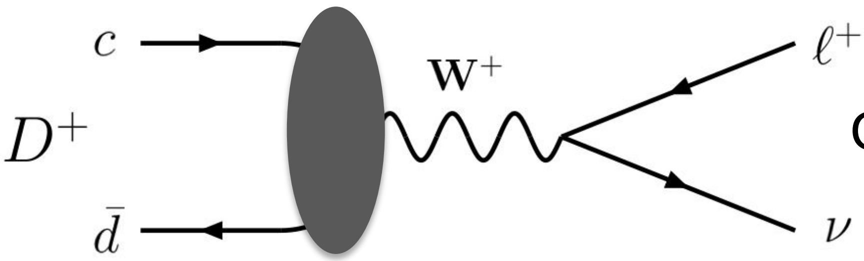
Melbourne

36th International Conference on High Energy Physics

4 – 11 July 2012
Melbourne Convention and Exhibition Centre

Window on Weak and Strong Physics

Leptonic Decay

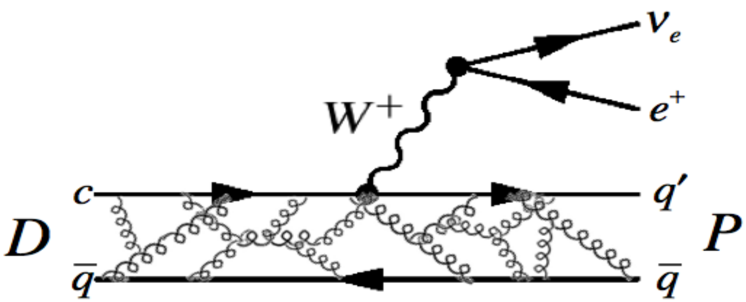


$$\Gamma\left(D^+ \to \ell^+ \nu_\ell\right) = f_D^2 \left|V_{cd}\right|^2 \frac{G_F^2}{8\pi} m_D m_\ell^2 \left(1 - \frac{m_\ell^2}{m_D^2}\right)^2$$

- 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} (esp. ratios)
- Sensitivity to New Physics

Window on Weak and Strong Physics

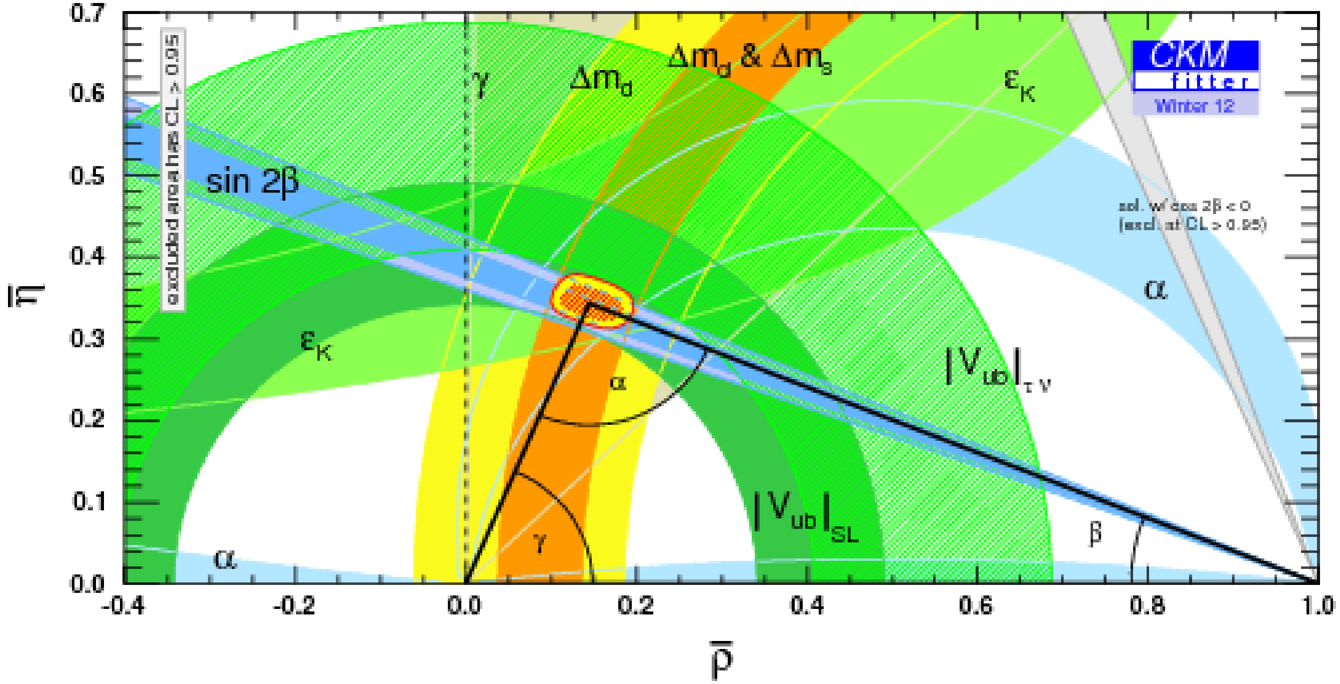
Semileptonic Decay



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

- 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

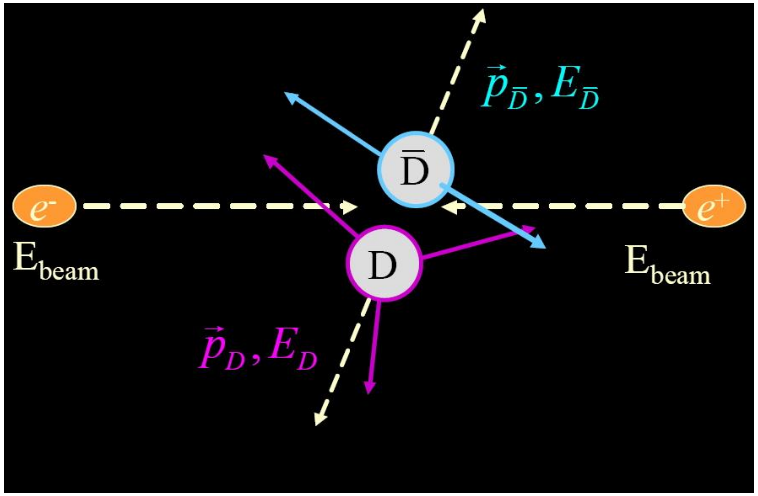
Window on Weak and Strong Physics



- 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

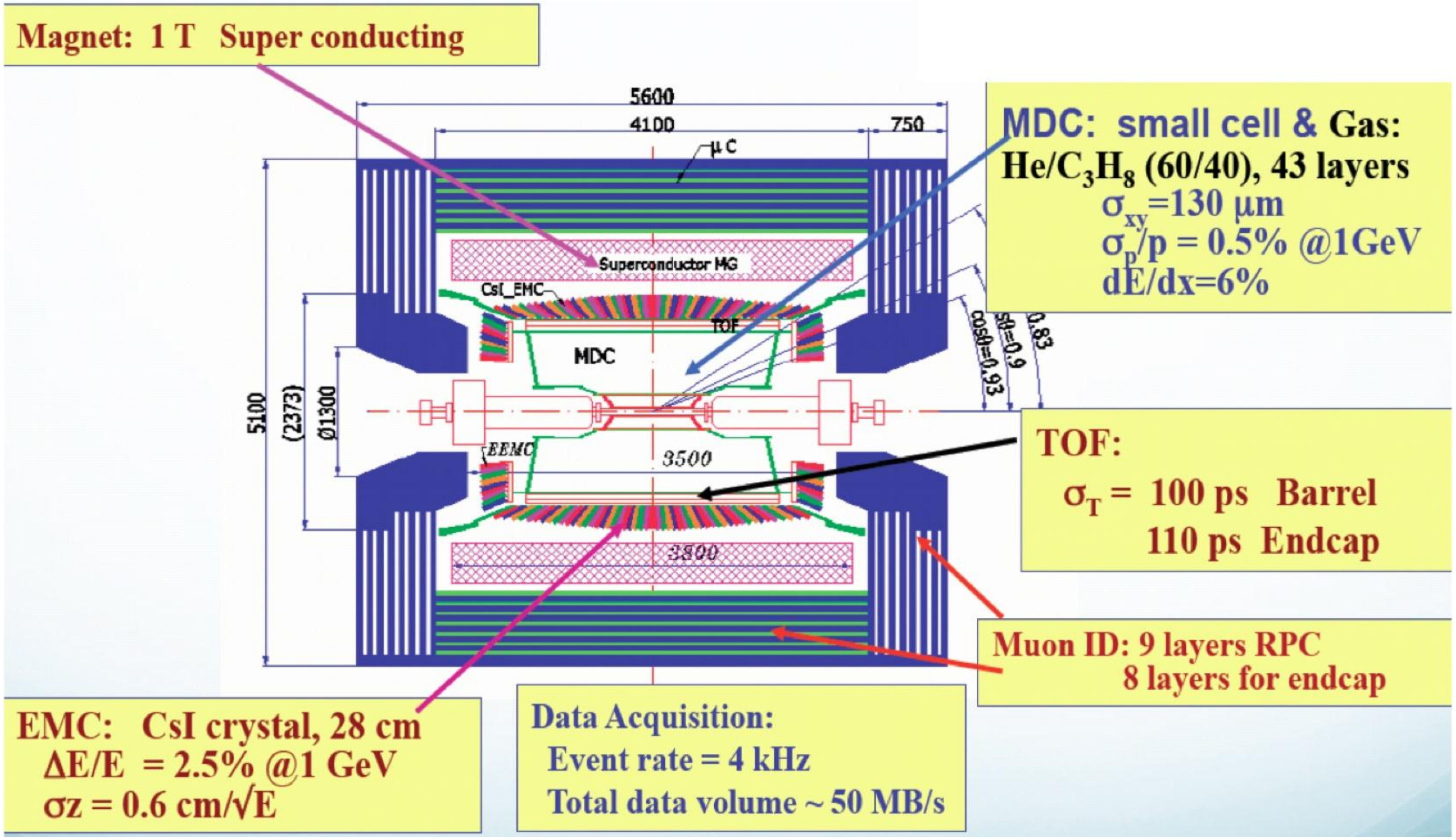


$$\Delta E = E_D - E_{Beam}$$

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

- 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

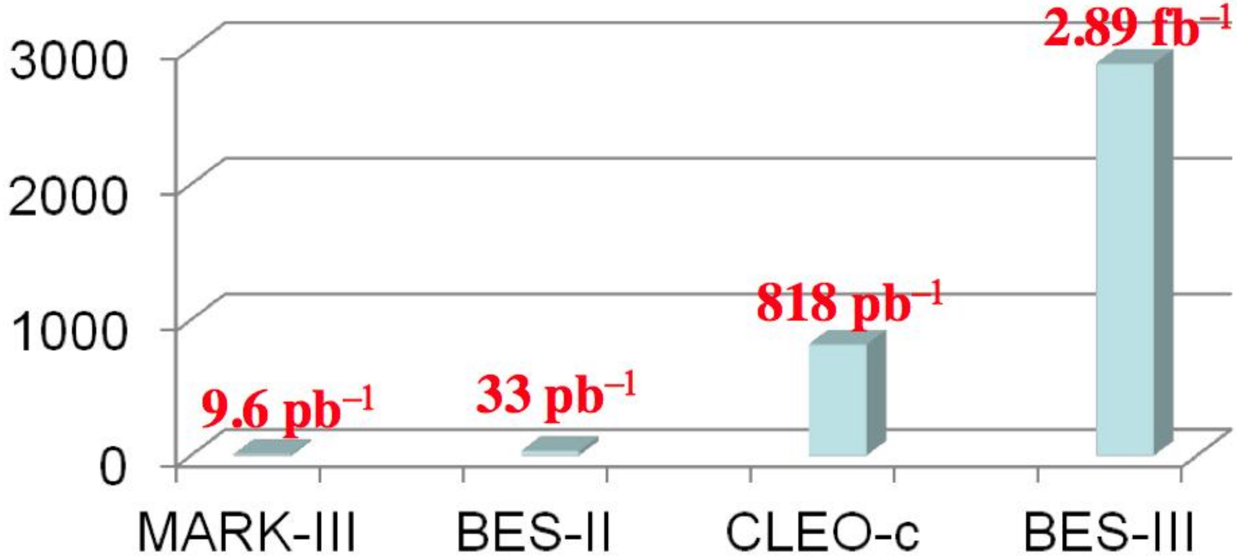
BESIII at BEPCII



- 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

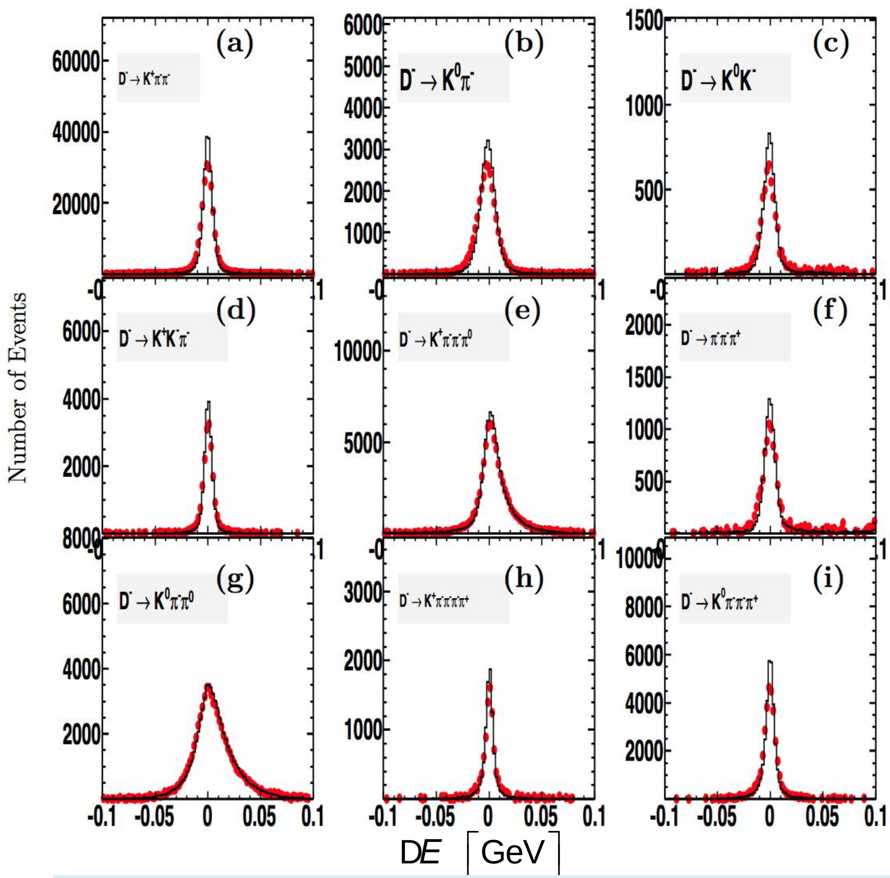


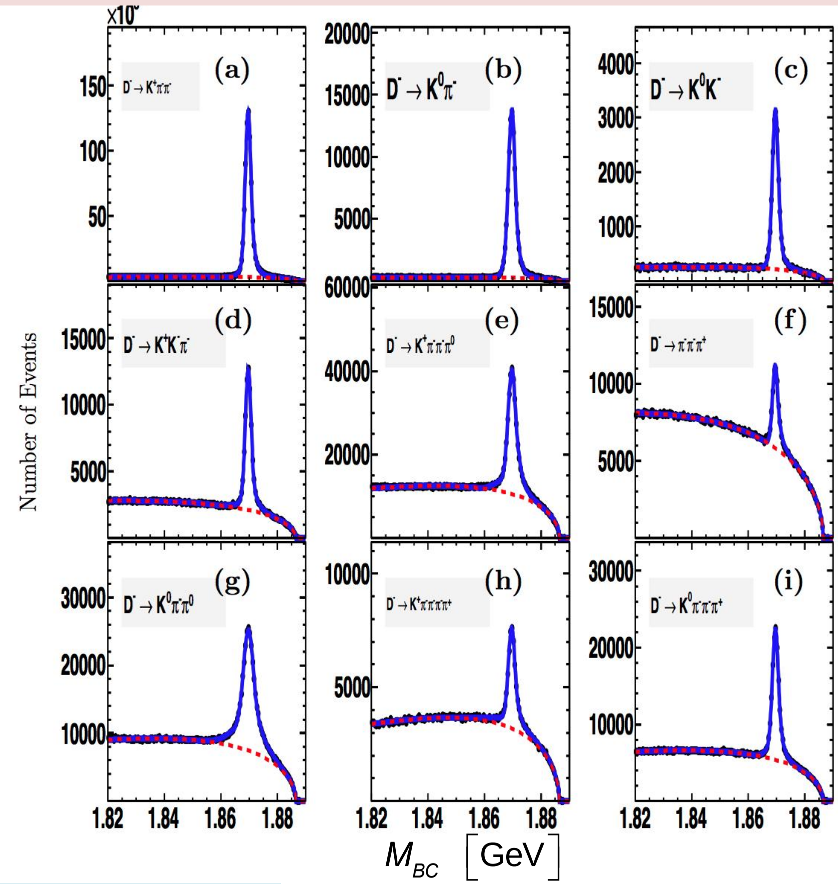
- Tools/techniques for precision charm physics still under development – all results are PRELIMINARY
  - $D^+ \to K^0 \left(\pi^0\right) e^+ \nu_\mu$ analysis is "partially blind" – 0.92 fb^{-1} analyzed so far. Full 2.9 fb^{-1} later for final results

$D^+ \to \mu^+\nu$ - 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

$D^+ \to \mu^+\nu$ - Signal Selection

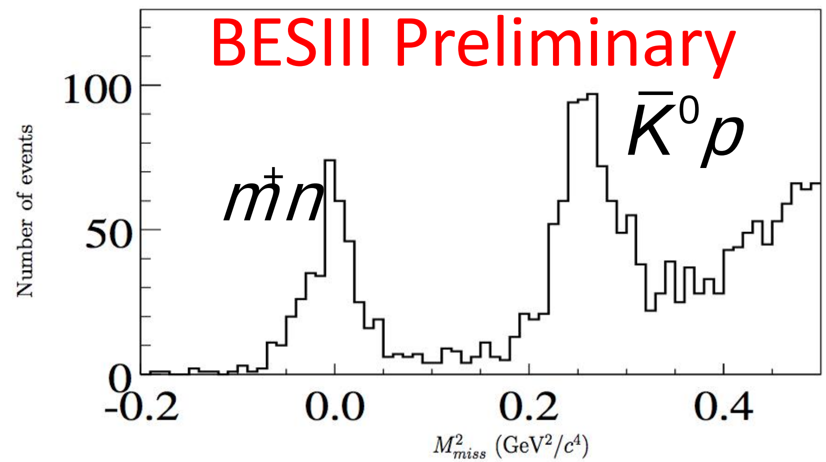
- Exactly one track in addition to tag, with the right charge
- Positive muon identification
- No extra photon
- Select on consistency with leptonic decay:

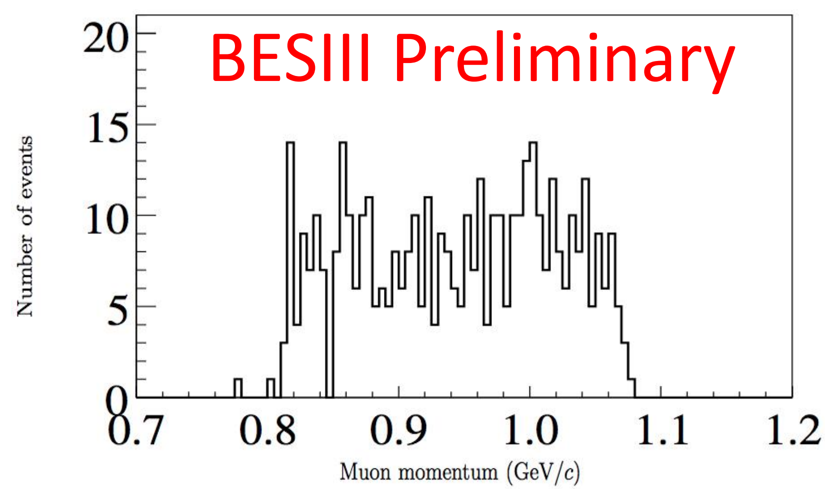
$$M^2_{\text{miss}} = \left(E_{\text{Beam}} - E_{\mu}\right)^2 - \left(-\vec{p}_{\text{tag}} - \vec{p}_{\mu}\right)^2 \approx 0$$

425 signal candidates:

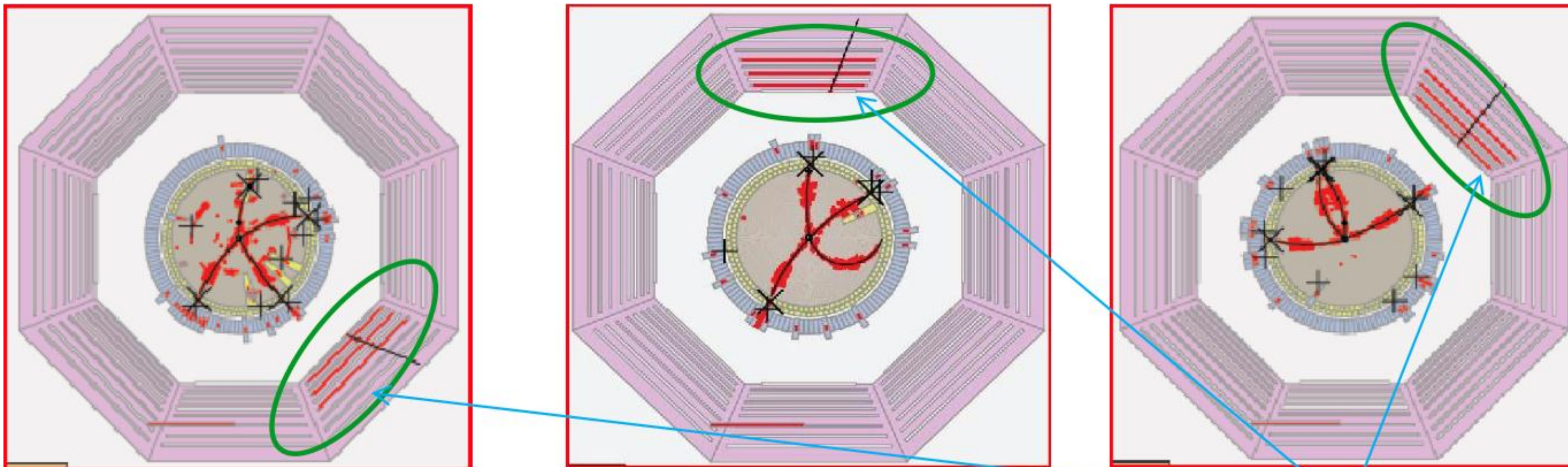
small BG, mom. dist.

consistent with $D^+ \to \mu^+\nu$



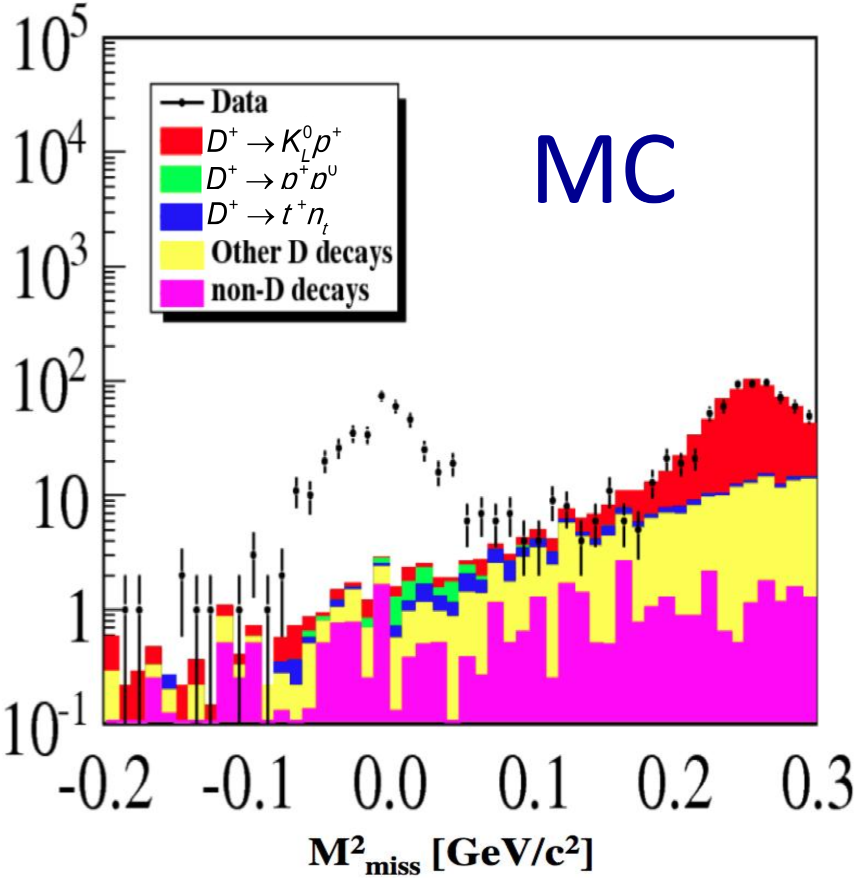


$D^+ \to \mu^+\nu$ - Sample Events



- Positive muon ID requirement reduces background at the expense of a ~20% efficiency loss

$D^{+} \to m^{+} n$ - Backgrounds



MC BG est.: 47.7 ± 2.6

Indep. data est.: 48.9 ± 4.8

BESIII Preliminary

Numbers of background events from $D\bar{D}$ decays			
Source	N_{bkg}^{MC}	Scale factor f	$N_{bkg}^{data} = \frac{N_{bkg}^{MC}}{f} \times \frac{\eta^{data}}{\eta^{MC}}$
$D^+ \to K_L^0 \pi^+$	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	$47.7 \pm 2.3 \pm 1.3$
$N(D^+ \to \mu^+\nu_\mu)$	$377.3 \pm 20.6 \pm 2.6$

$D^+ \to m^+ n$ - Results

BESIII Preliminary

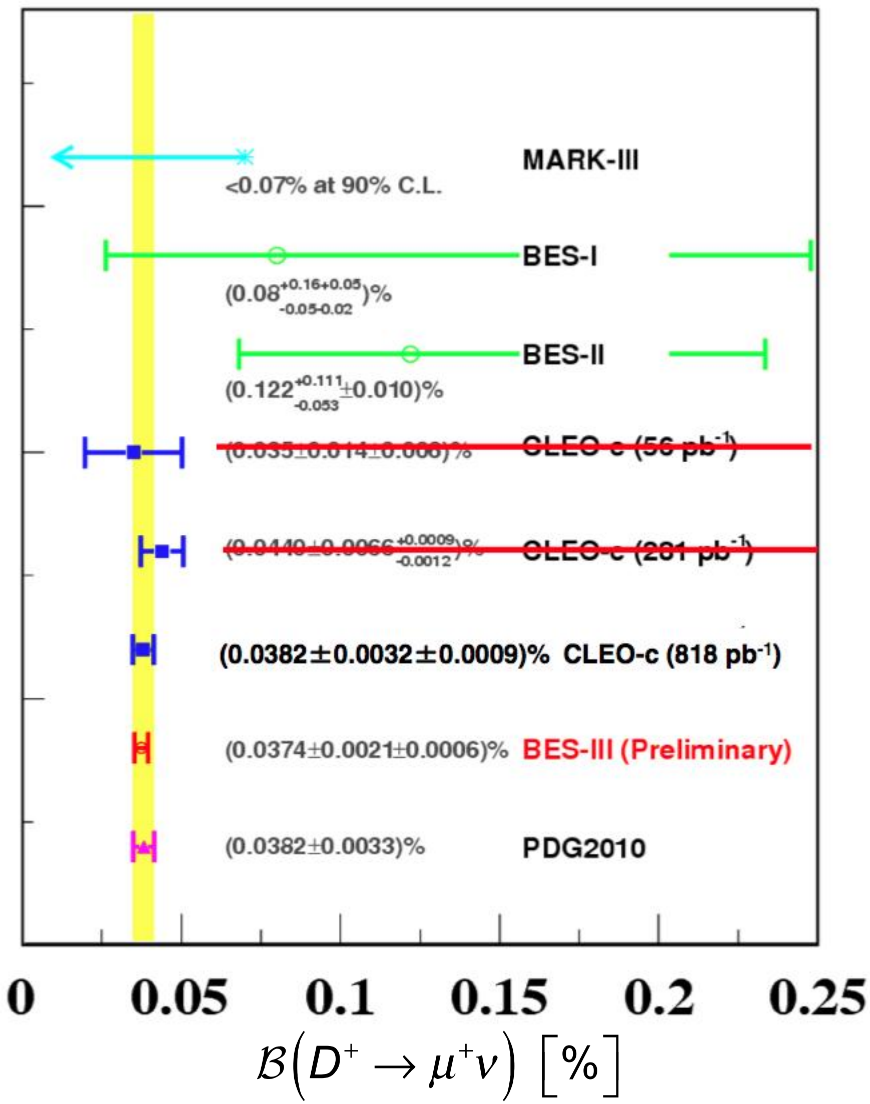
$$N\left(D^+ \to m^+ n\right) = 377.3 \pm 20.6$$

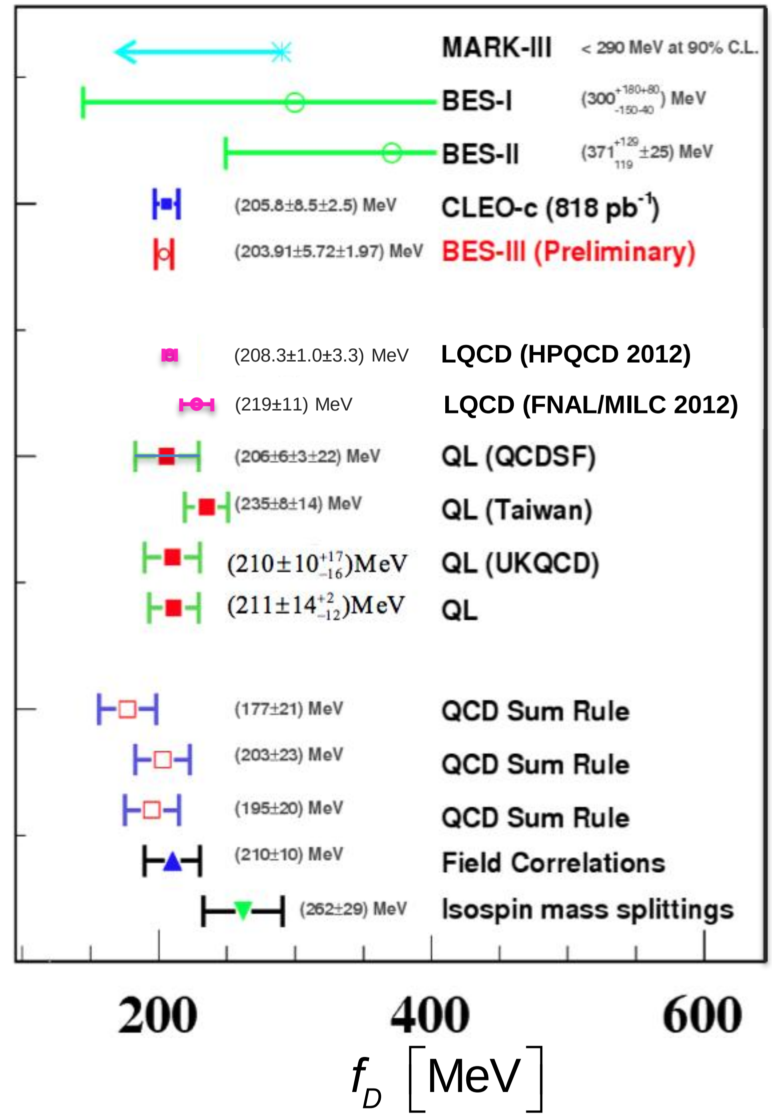
$$\mathcal{B}\left(D^+ \to \mu^+ \nu\right) = \left(0.0374 \pm 0.0021 \pm 0.0006\right)\%$$

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

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

$D^{+} \rightarrow m^{+}n$ - Comparisons (from G. Rong)

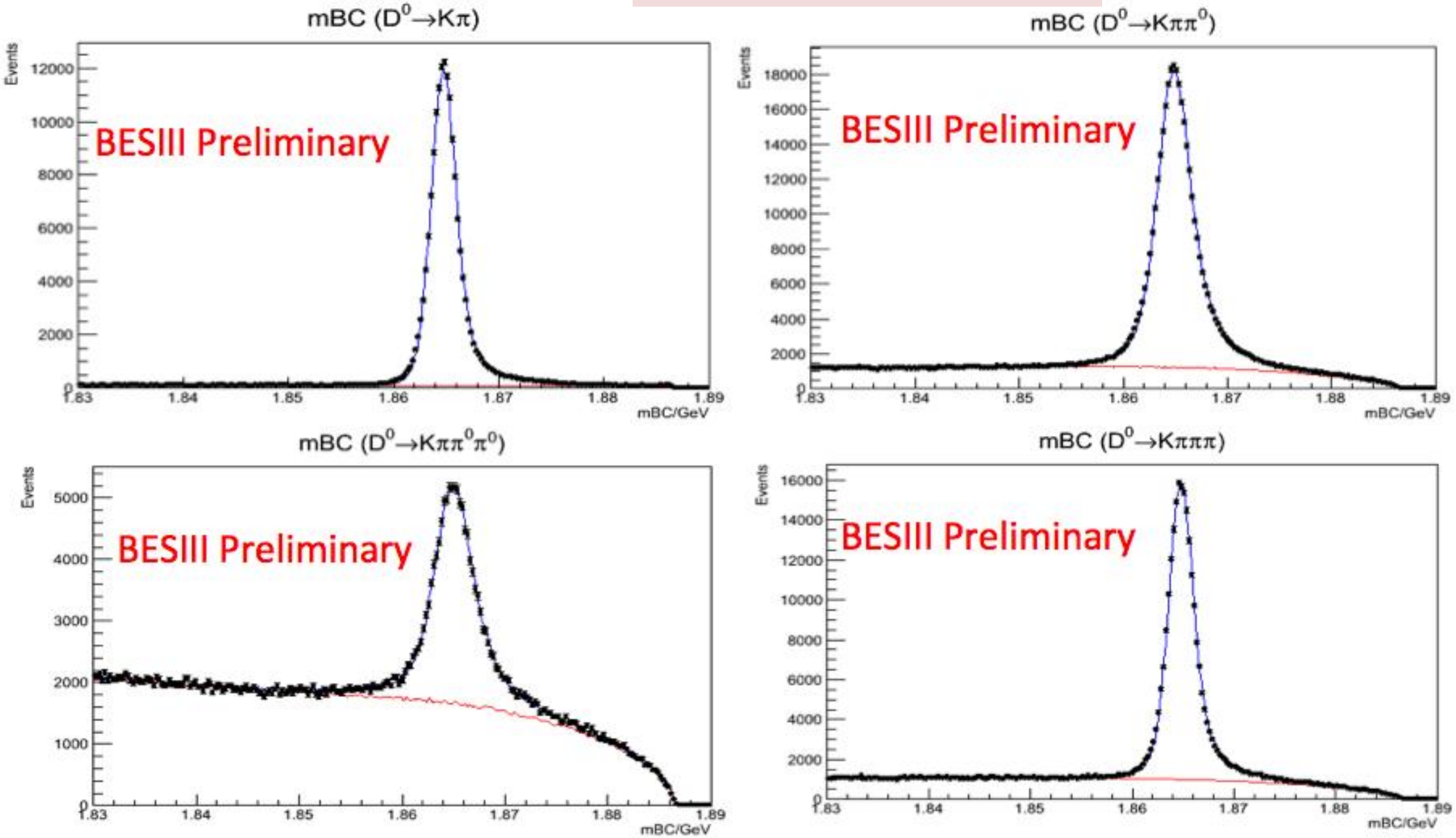




$D^0 \rightarrow K^- \left(p^-\right) e^+ n_e$ - Tag Selection

- Four D^0 tag modes

$K^- p^+$	$K^- p^+ p^0$
$K^- p^+ p^0 p^0$	$K^- p^+ p^+ p^-$



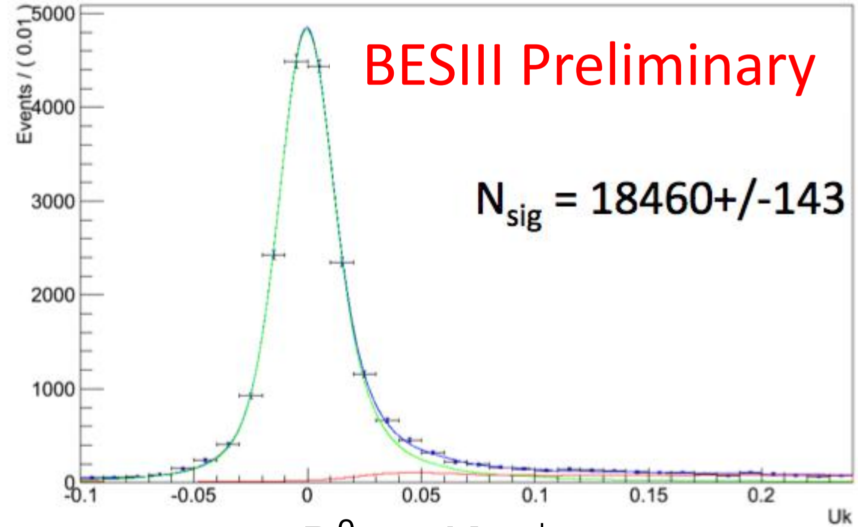
$$N_{D^0}^{tag} = \left(0.774 \pm 0.001\right) ´ \; 10^6 \text{ in } 0.92 \text{ fb}^{-1}$$

$D^0 \rightarrow K^- \left(p^-\right) e^+ n_e$ - Signal Selection

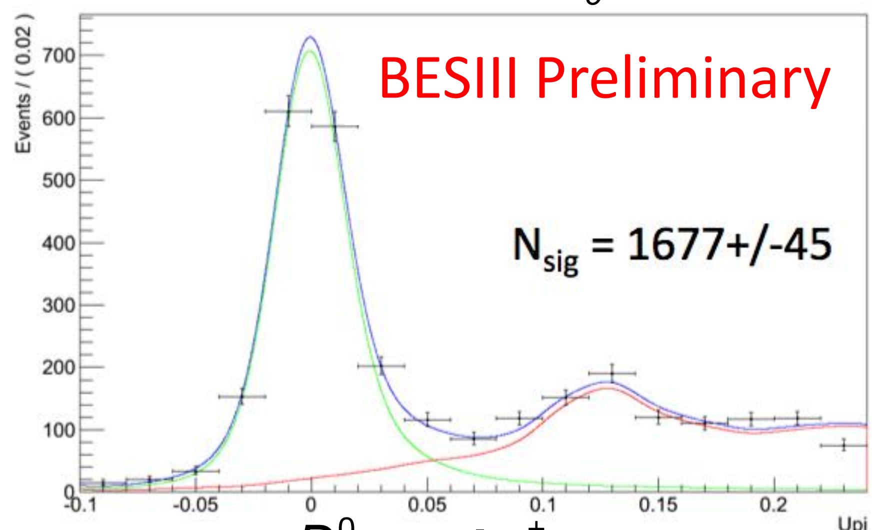
- Tag plus exactly two oppositely-charged tracks
- Kaon/pion/electron ID
- Electron has right charge
- No extra neutral energy
- Select on consistency with semileptonic decay

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

- Fit *U* distribution to extract yield



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



$D^0 \rightarrow p^- e^+ n_e$

$D^0 \to K^- \left(p^-\right) e^+ n_e$ - 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

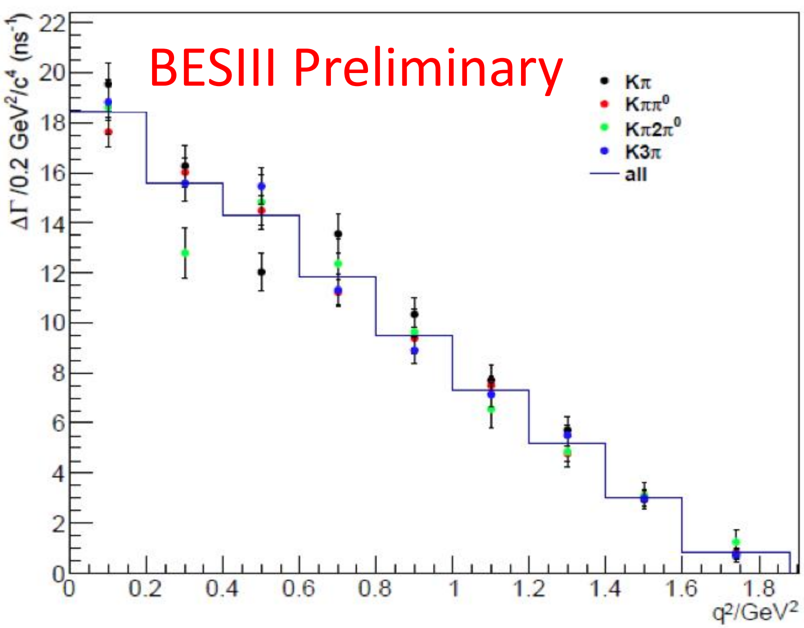
- Systematic uncertainties are preliminary
- Good consistency with CLEO-c, statistical precision is comparable with only 1/3 data analyzed

$D^0 \to K^- \left(p^-\right) e^+ n_e$ - q^2 distribution

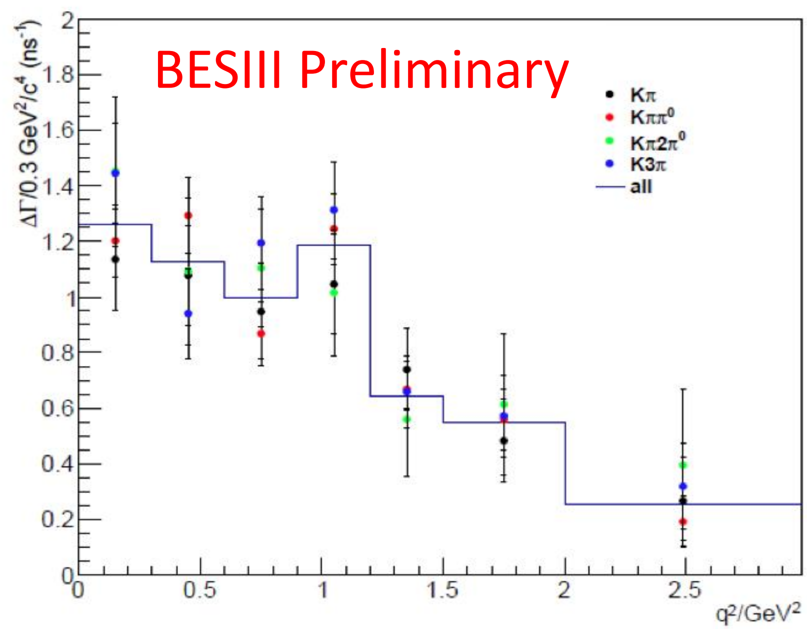
- Partition D^0 semileptonic candidates in bins of

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

- Fit U distribution in each q^2 bin



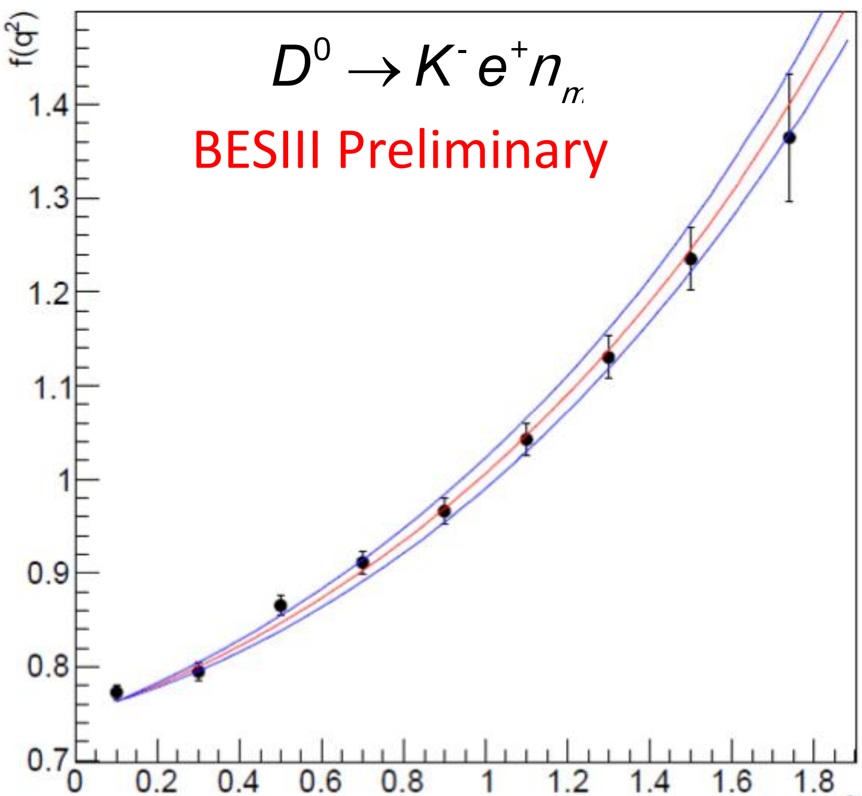
$D^0 \to K^- e^+ n_e$

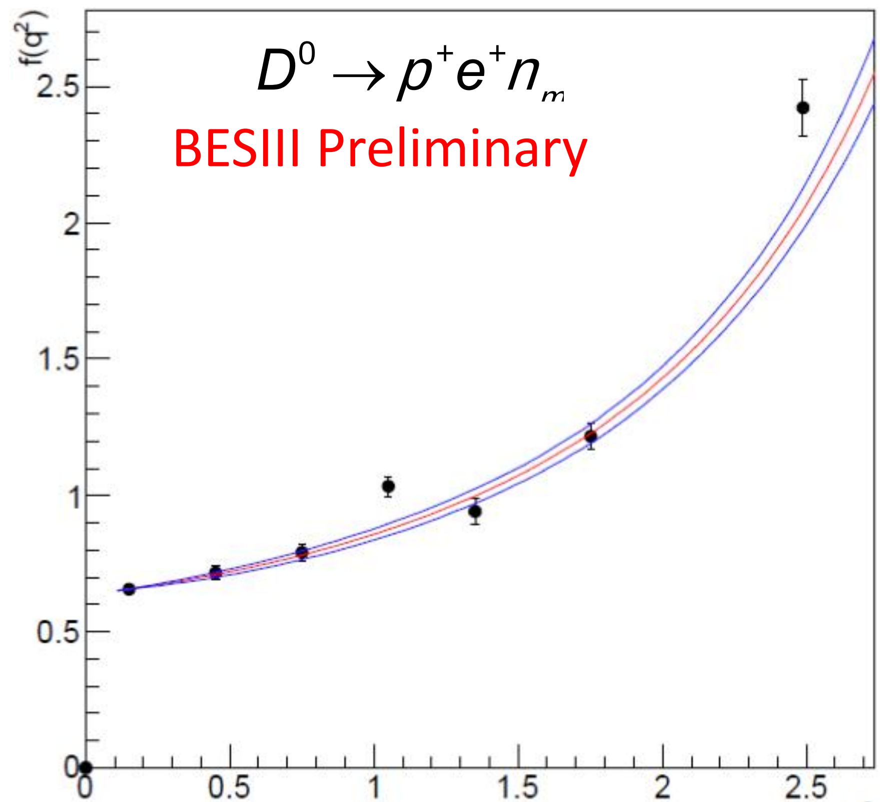


$D^0 \to p^- e^+ n_e$

$D^0 \rightarrow K^- (p^-) e^+ n_e$ - Project $f(q^2)$

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





$D^0 \rightarrow K^- \left(p^-\right) e^+ n_e$ - FF Parameterizations

Simple Pole Model

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

Modified Pole Model

Becirevic and Kaidalov
PLB 478, 417 (‘00)

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

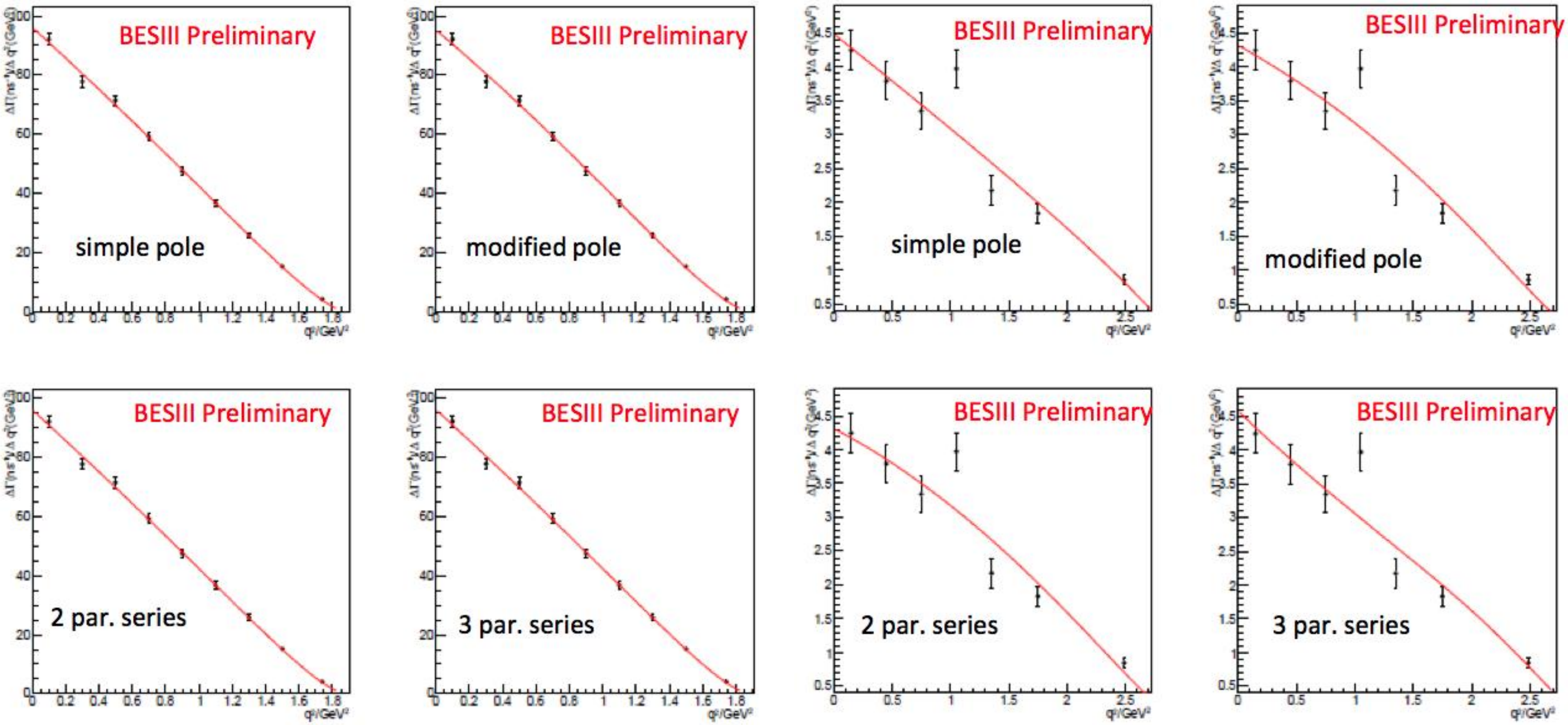
Series Expansion

Becher and Hill
PLB 633, 61 (‘06)

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

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

$D^0 \rightarrow K^- (p^-) e^+ n_e$ - FF Fits



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

$D^0 \rightarrow p^- e^+ n_e$

$D^0 \rightarrow K^- \left(p^-\right) e^+ n_e$ - FF Results

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

BESIII Preliminary

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

Future Charm Prospects at BESIII

- Finalize $D^+ \to m^+ n_m$ and $D^0 \to K^- \left(p^-\right) e^+ n_e$ on the 2.9 fb^{-1} $\psi(3770)$ sample
- Extend to $D^+ \to K^0 \left(p^0\right) e^+ n_e$ 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
  - D^0 Semileptonic Decays

BESIII Preliminary

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

$$\mathcal{B}(D^+ \to \mu^+ \nu) = (0.0374 \pm 0.0021 \pm 0.0006)\%$$

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

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