Semileptonic and Leptonic D Decays from BESIII

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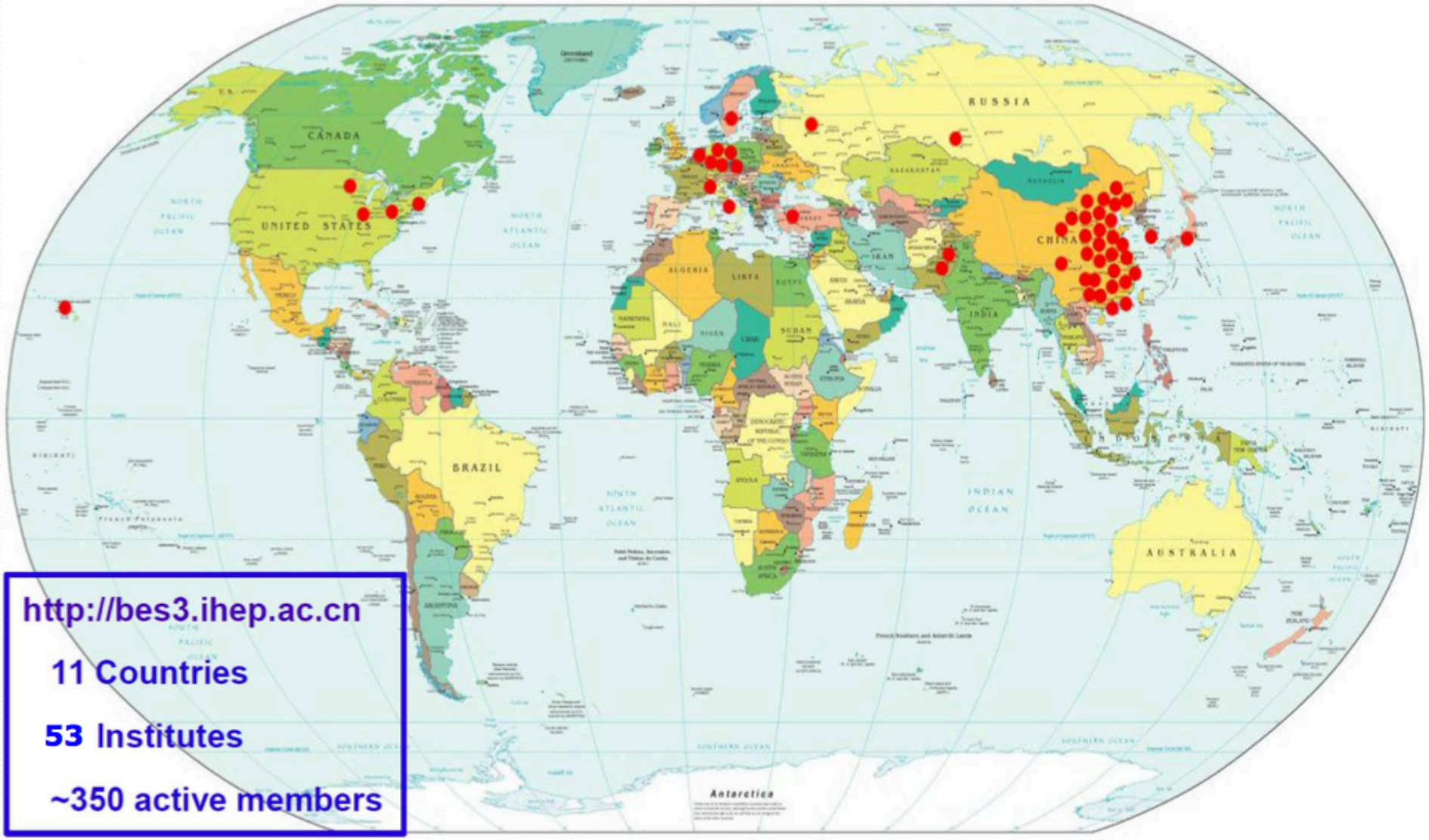
HQL2014

The BES-III Collaboration



http://bes3.ihep.ac.cn

11 Countries

53 Institutes

~350 active members

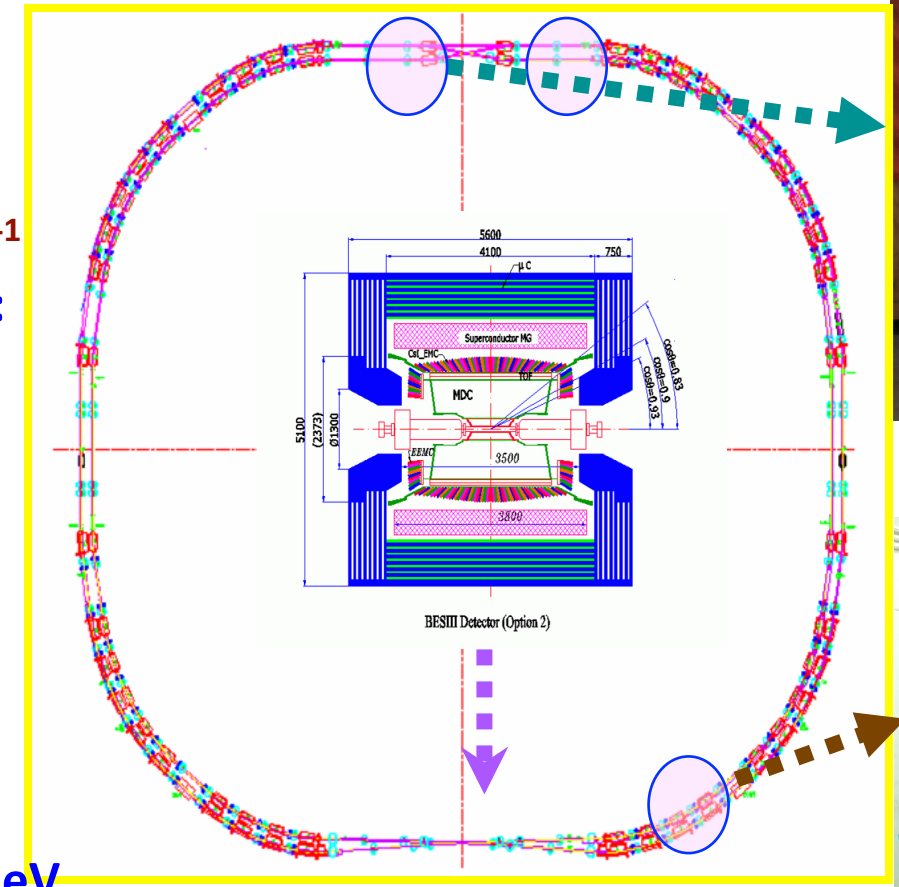
Outline

- Overview of BEPCII/BESIII
- Motivation for (Semi)Leptonic D Decay Physics
- Leptonic Analysis
- Semileptonic Analysis
- Summary

BEPCII: a high luminosity double–ring collider

Beam energy:
1.0-2.3 GeV
Luminosity:
0.7×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

22 mrad crossing angle



SC RF

Beam magnets

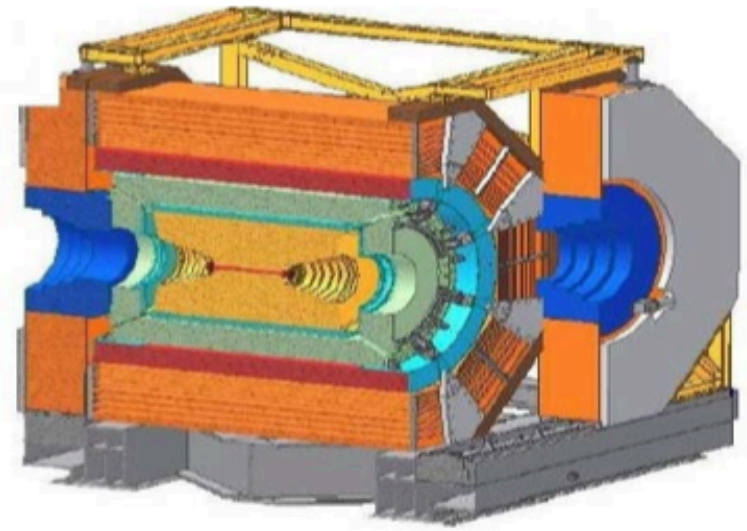
Use many bunches and SC mini-beta.

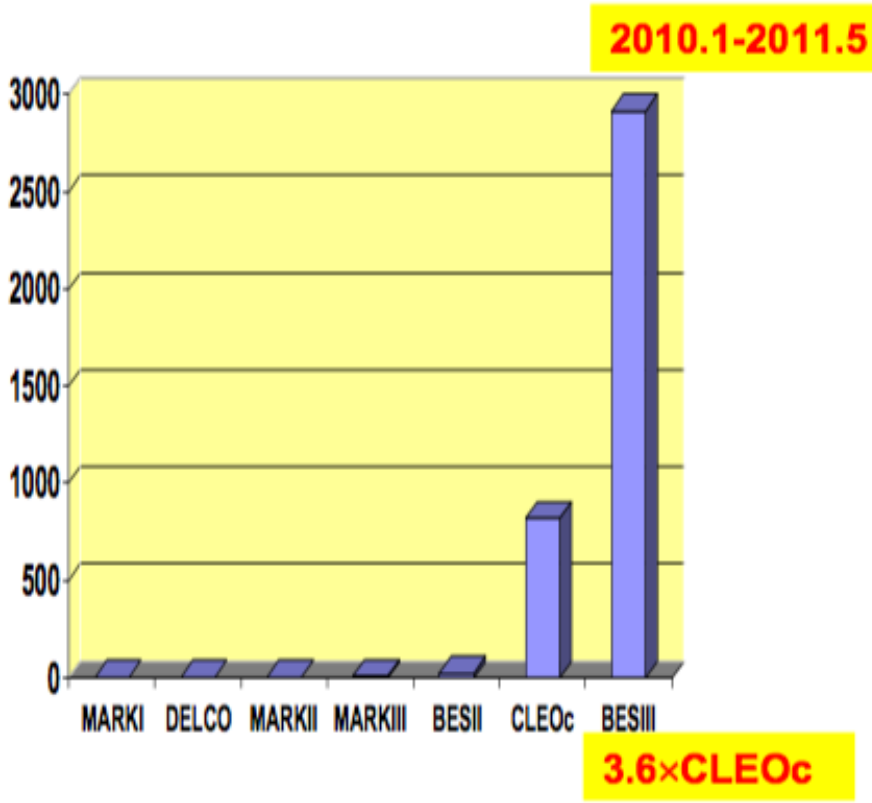
BESIII ψ(3770) Data Sample

2.92 fb^{-1} data were taken around 3.773 GeV

$e^+e^- \rightarrow \psi(3770) \rightarrow D^+D^-$

$e^+e^- \rightarrow \psi(3770) \rightarrow D^0\bar{D}^0$





BES-III

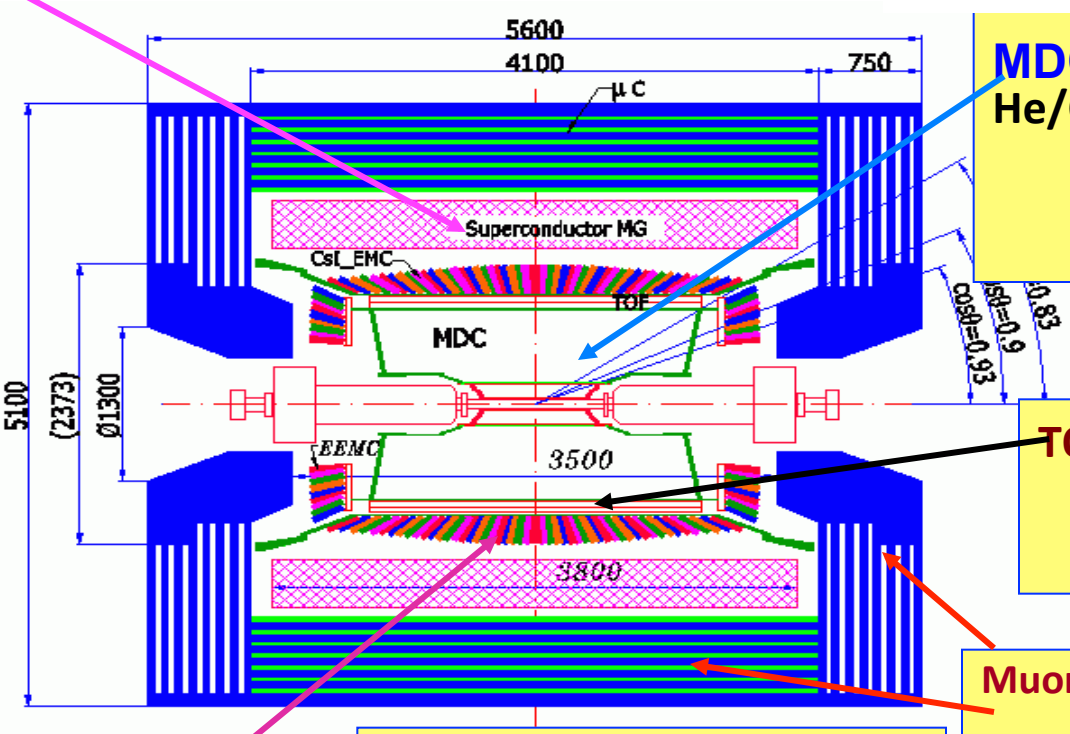
BESIII detector: all new !

CsI calorimeter

Precision tracking

Time-of-flight + dE/dx PID

Magnet: 1 T Super conducting



MDC: small cell & Gas:
He/C3H8 (60/40), 43 layers
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
ΔE/E = 2.5% @1 GeV
σz = 0.6 cm/√E

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

The detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

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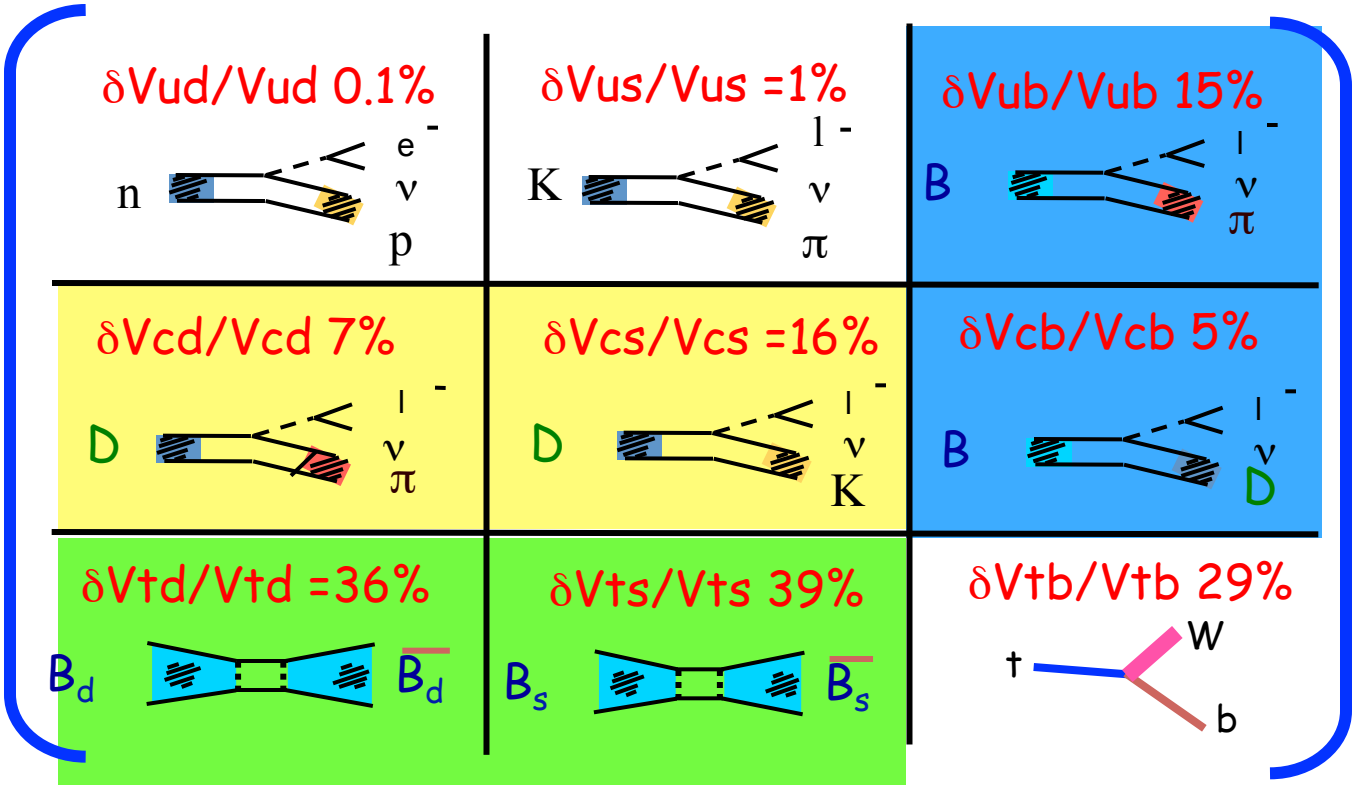
Motivation



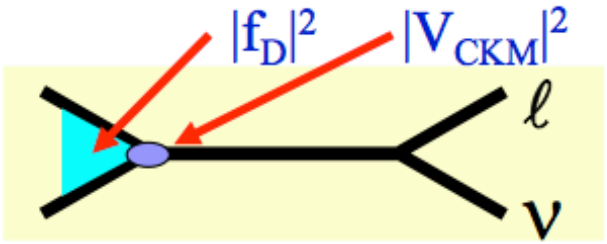
BESIII

BESIII + Lattice QCD +B factories

BESIII + Lattice QCD +B factories + ppbar

Leptonic D Decay

$$\Gamma(D_q^+ \to l\,\upsilon) = \tfrac{1}{8\pi} G_F^2 M_{D_q^+} m_l^2 \left(1 - \frac{m_l^2}{M_{D+}^2}\right) f_{D+}^2 |V_{cq}|^2$$



$$\Delta M_d = 0.50\,ps^{-1}\left[\frac{\sqrt{B_{B_d}}\, f_{B_d}}{200MeV}\right]^2\left[\frac{|V_{td}|}{8.8\times10^{-3}}\right]^2$$

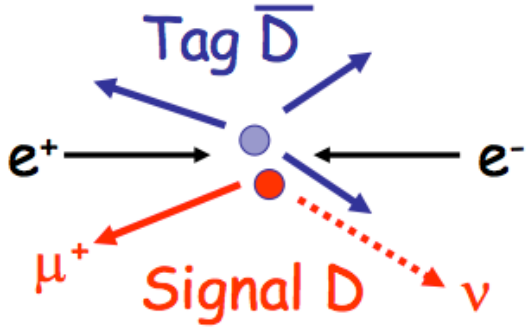
Decay constant ~ $|\psi(0)|^2$ (QCD). Precision f_D allows precise extraction of |Vcq|
In the B sector a similar factor is in the mixing equation.
Alternatively, $|Vcd|^2$ from unitarity constraints allow a test of lattice QCD of f_D.

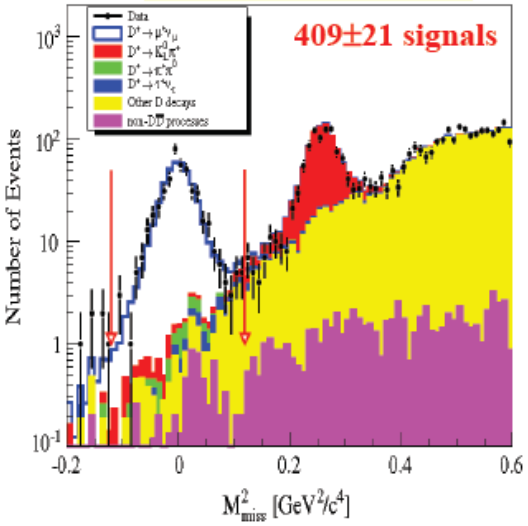
Ratios of the decay constant are particularly strong tests.
Ratios of t and m modes are windows to new physics.

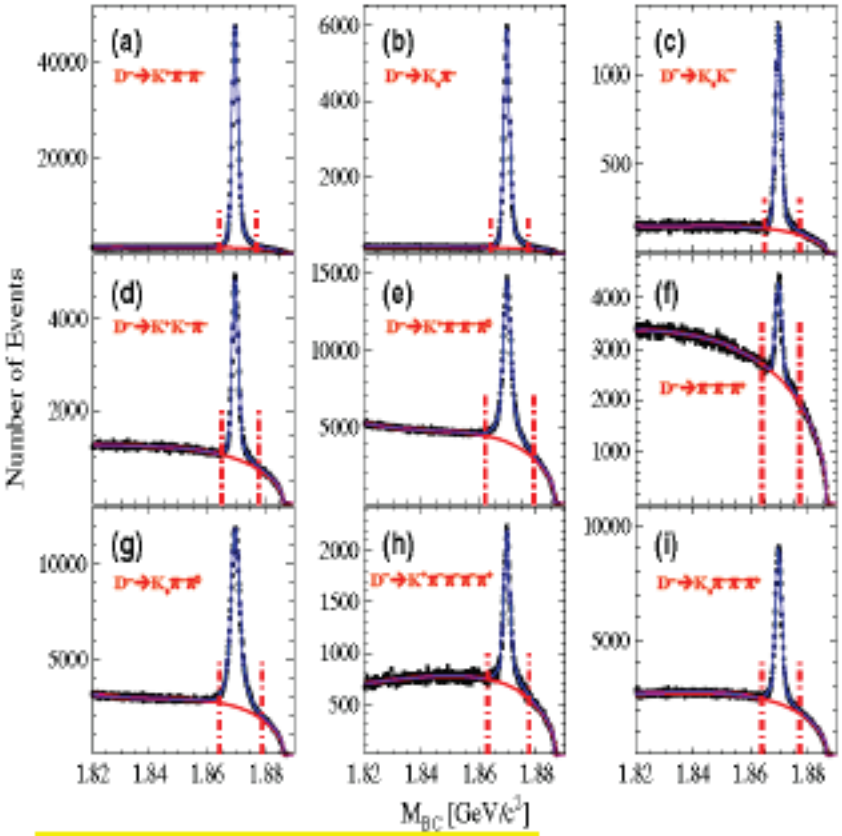
New Physics

$$\frac{\Gamma(D^+ \to \tau^+ \nu)}{\Gamma(D^+ \to \mu^+ \nu)} \neq \frac{m_\tau^2\left(1-m_\tau^2/M_D^2\right)^2}{m_\mu^2\left(1-m_\mu^2/M_D^2\right)^2}$$

DTag Approach





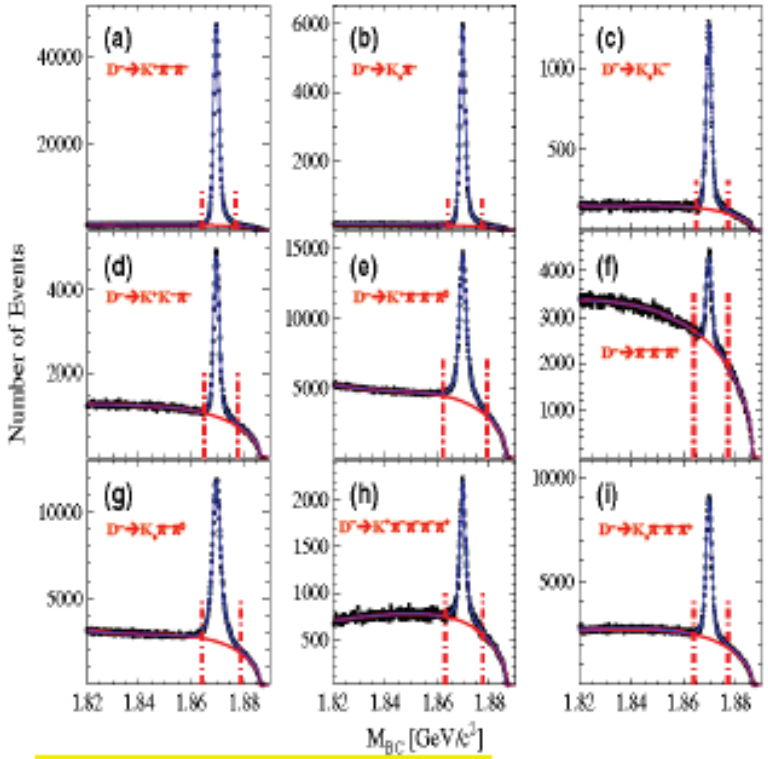


→Require single track on other side: μ

- PID suppresses K
- Calorimeter suppresses π^+
- Require low energy in CC

Use D 4-vector to calculate missing mass (~0 for ν).

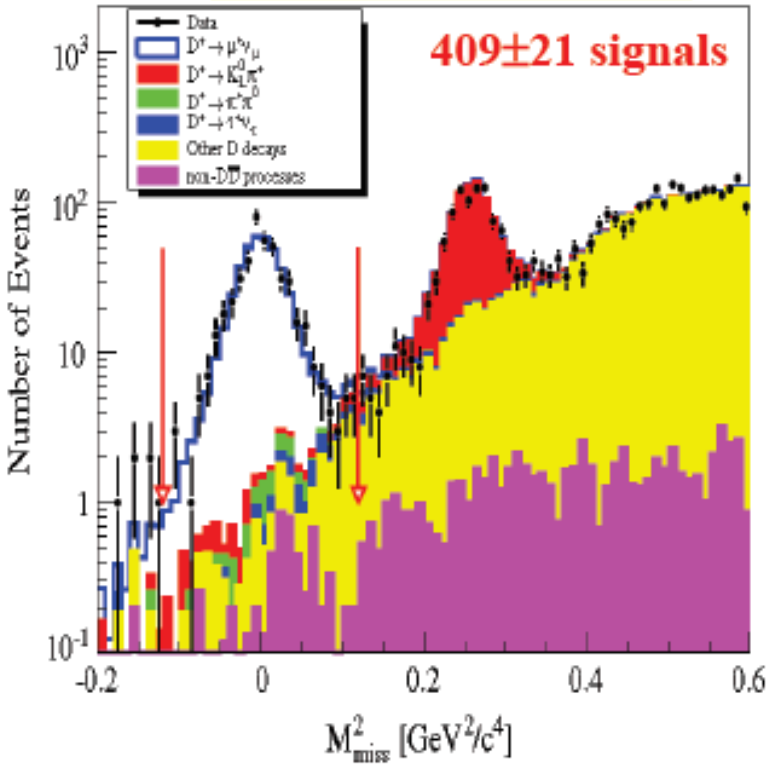
$e^+e^- \rightarrow \psi(3770) \rightarrow D^+D^-$



$N_{D^-_{tag}} = (170.31 \pm 0.34) \times 10^4$

2.92 fb^{-1} data@ 3.773 GeV

PRD89(2014)051104R



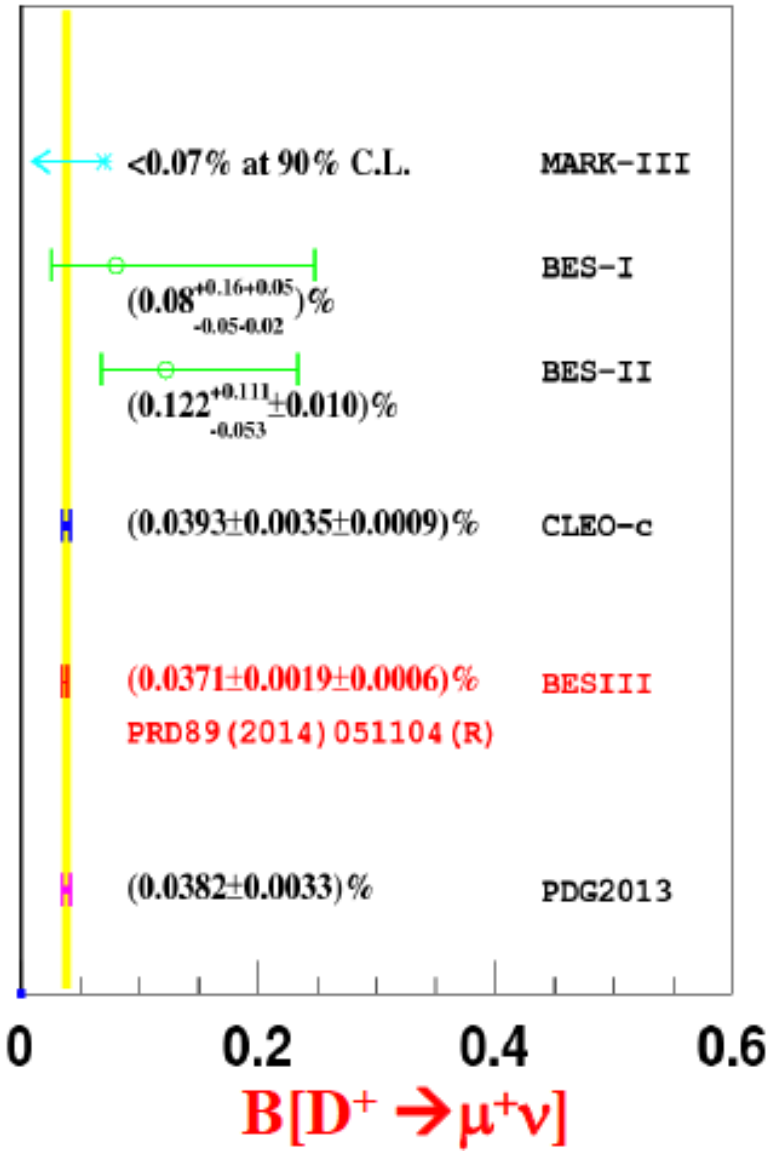
$B[D^+ \to \mu^+\nu] = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$

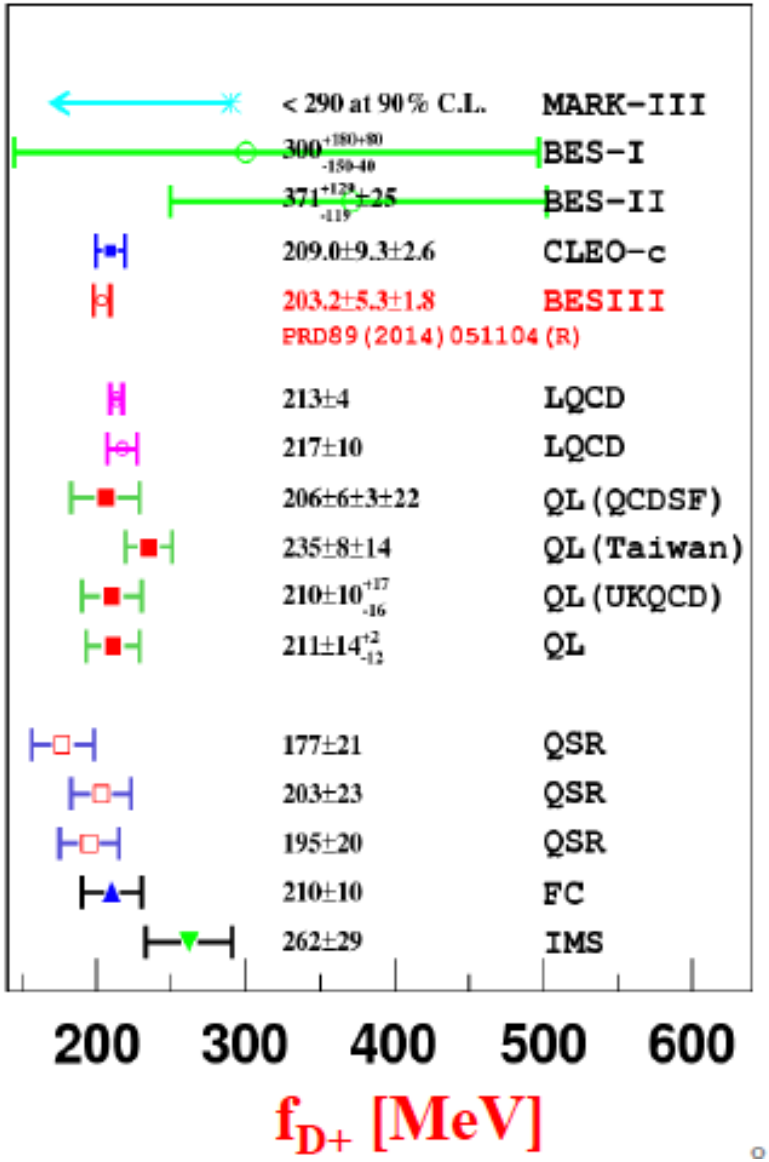
Input t_{D+}, m_{D+}, m_{μ^+} on PDG and $|V_{cd}|$ of CKM-Fitter

$f_{D^+} = (203.2 \pm 5.3 \pm 1.8)$ MeV

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

$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$


<0.07% at 90% C.L.
MARK-III
BES-I
$(0.08^{+0.16+0.05}_{-0.05-0.02})\%$
BES-II
$(0.122^{+0.111}_{-0.053}\pm0.010)\%$
(0.0393±0.0035±0.0009)%
CLEO-c
(0.0371±0.0019±0.0006)%
BESIII
PRD89 (2014) 051104 (R)
(0.0382±0.0033)%
PDG2013
0
0.2
0.4
0.6
$B[D^+ \to \mu^+\nu]$


< 290 at 90% C.L.
MARK-III
$300^{+180+80}_{-150-40}$
BES-I
$371^{+128}_{-119}\pm25$
BES-II
209.0±9.3±2.6
CLEO-c
203.2±5.3±1.8
BESIII
PRD89 (2014) 051104 (R)
213±4
LQCD
217±10
LQCD
206±6±3±22
QL (QCDSF)
235±8±14
QL (Taiwan)
$210\pm10^{+17}_{-16}$
QL (UKQCD)
$211\pm14^{+2}_{-12}$
QL
177±21
QSR
203±23
QSR
195±20
QSR
210±10
FC
262±29
IMS
200
300
400
500
600
f_{D+} [MeV]

Excusive SL Decays

Technique
→D-Tag event
→Identify electron
→Reconstruct the hadronic component
→Check for consistency with neutrino
U=E_{miss}-|P_{miss}|

Signal count is fit from U distribution

Single tag mode

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

Cut on ΔE and fit M_{bc}

From Monte Carlo

Tag Modes:

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

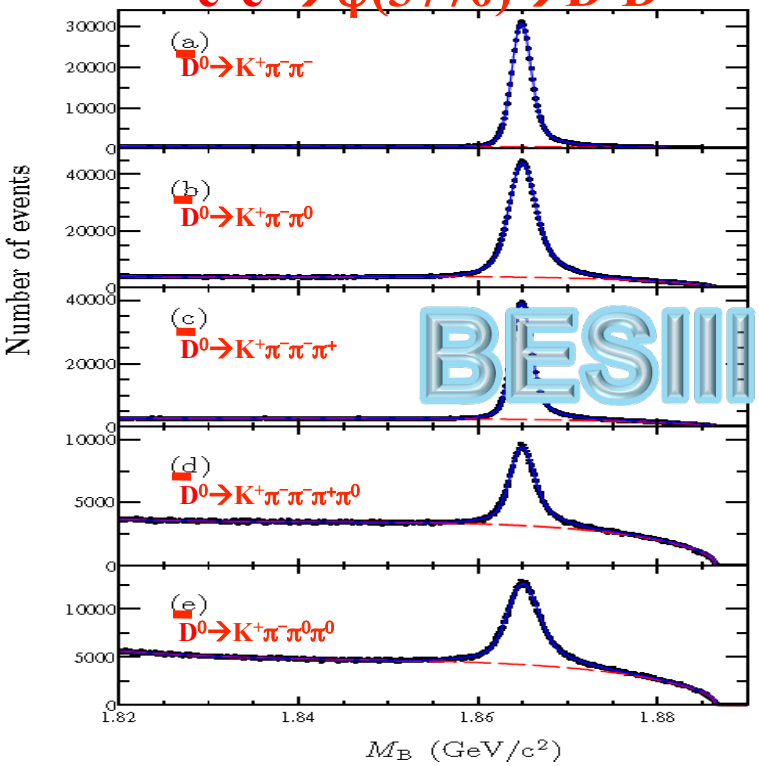
Multiple tag modes

$$B_{sig} = \frac{N_{sig}}{\sum N_{tag}\left(\epsilon_{tag+sig}/\epsilon_{tag}\right)}$$

Studies of $D^0 \to K(\pi)^- e^+ \nu$ at BESIII

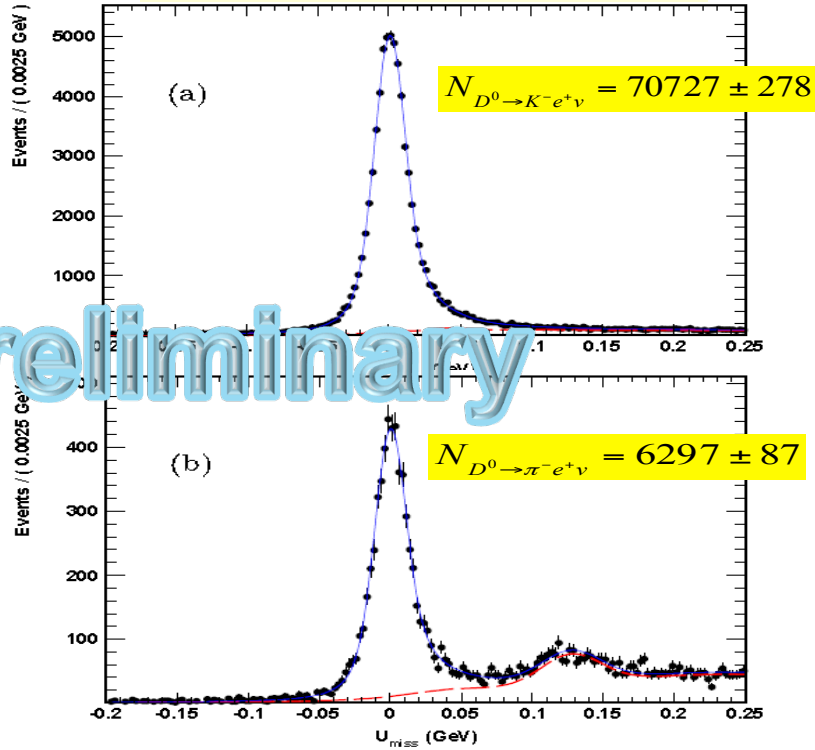
New results based on 2.917 fb^{-1} data supersede those preliminary results presented at CHARM2012 which was based on ~1/3 data.

$e^+e^- \to \psi(3770) \to D^0\bar{D}^0$



$N_{\bar{D}^0_{tag}} = (279.33 \pm 0.37) \times 10^4$

2.917fb^{-1} data@3.773 GeV

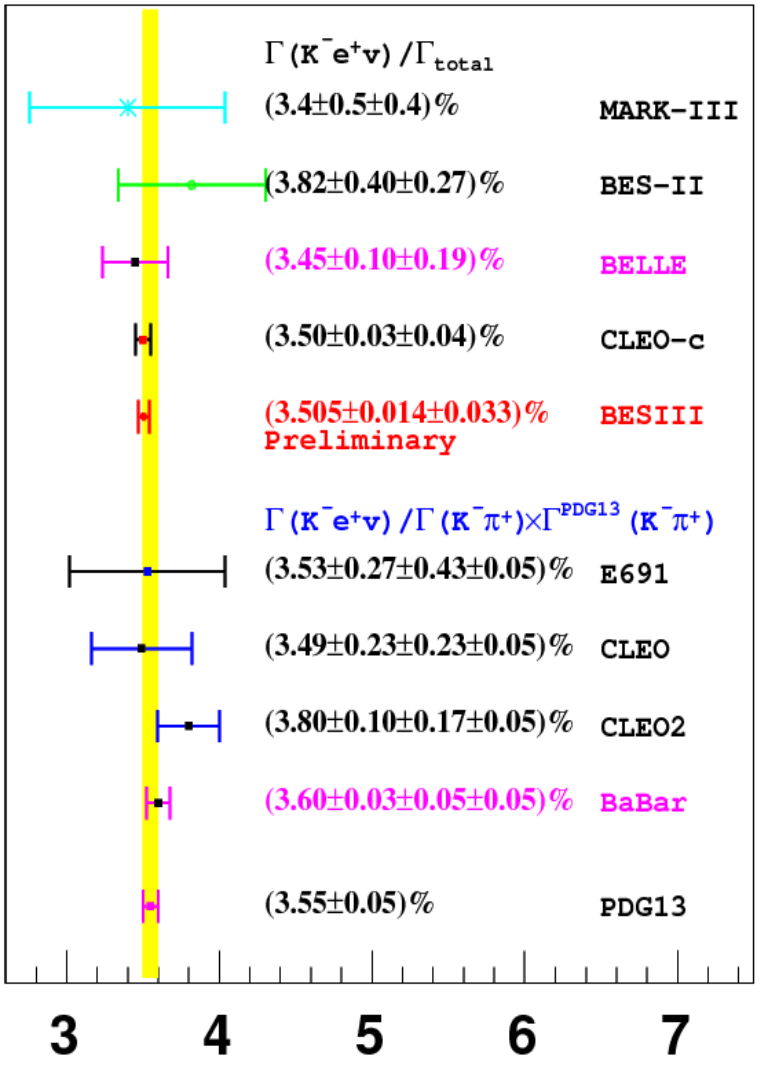


BESIII Preliminary

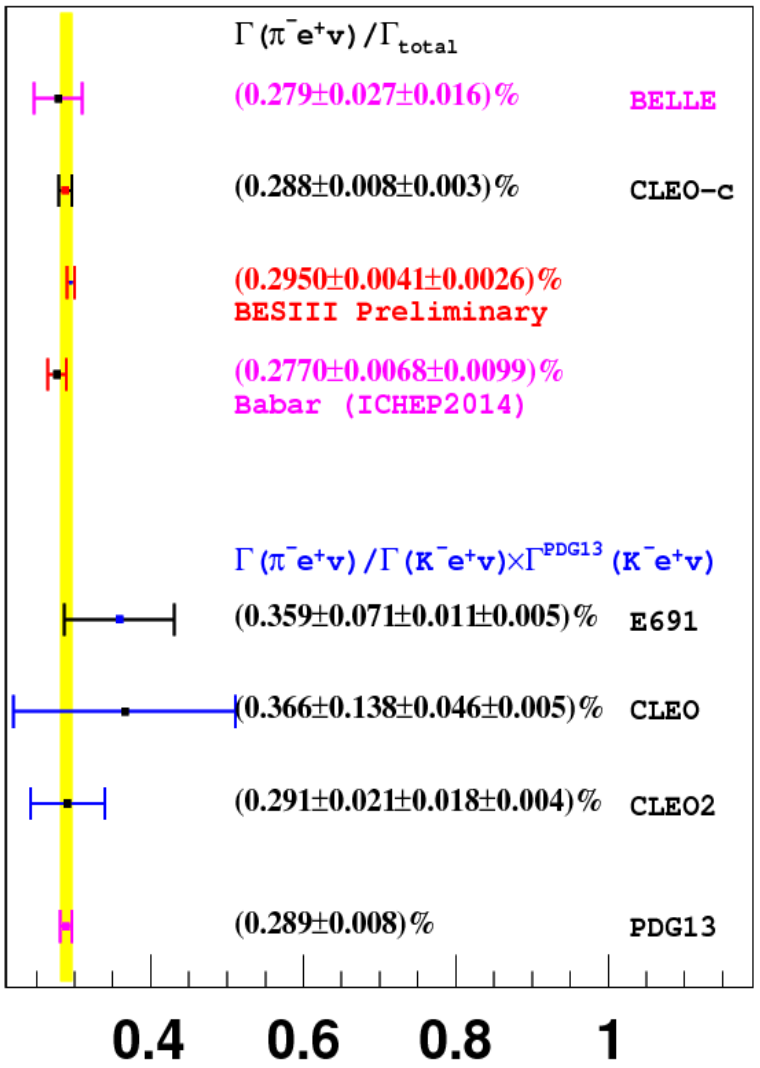
$B_{D^0 \to K^- e^+ \nu} = (3.505 \pm 0.014 \pm 0.033)\%$

$B_{D^0 \to \pi^- e^+ \nu} = (0.2950 \pm 0.0041 \pm 0.0026)\%$

Comparisons of $B[D^0 \to K(\pi)^- e^+ \nu]$

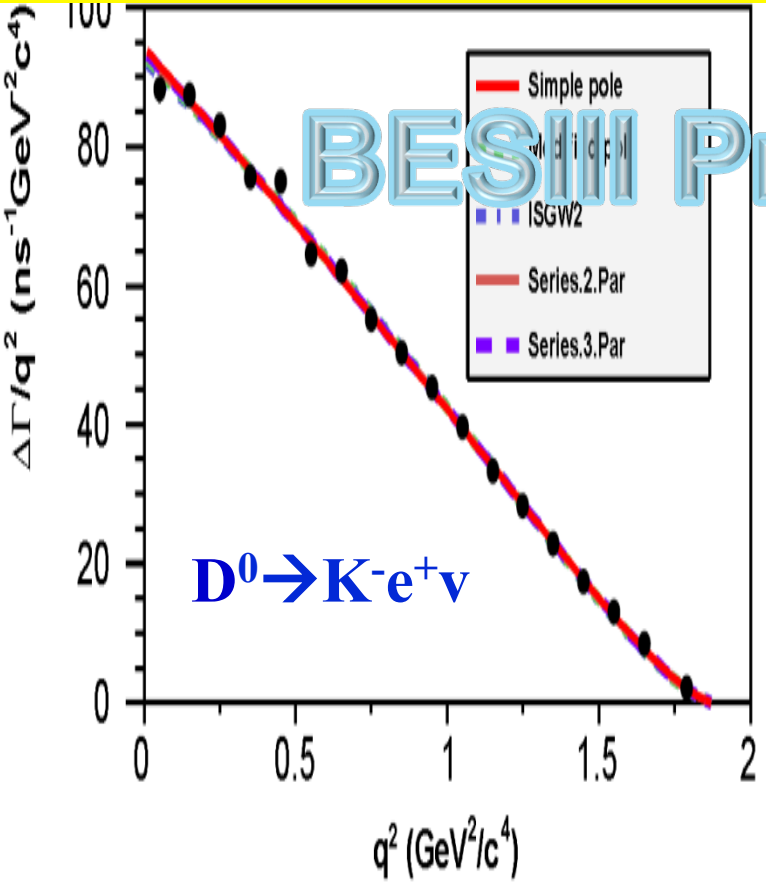


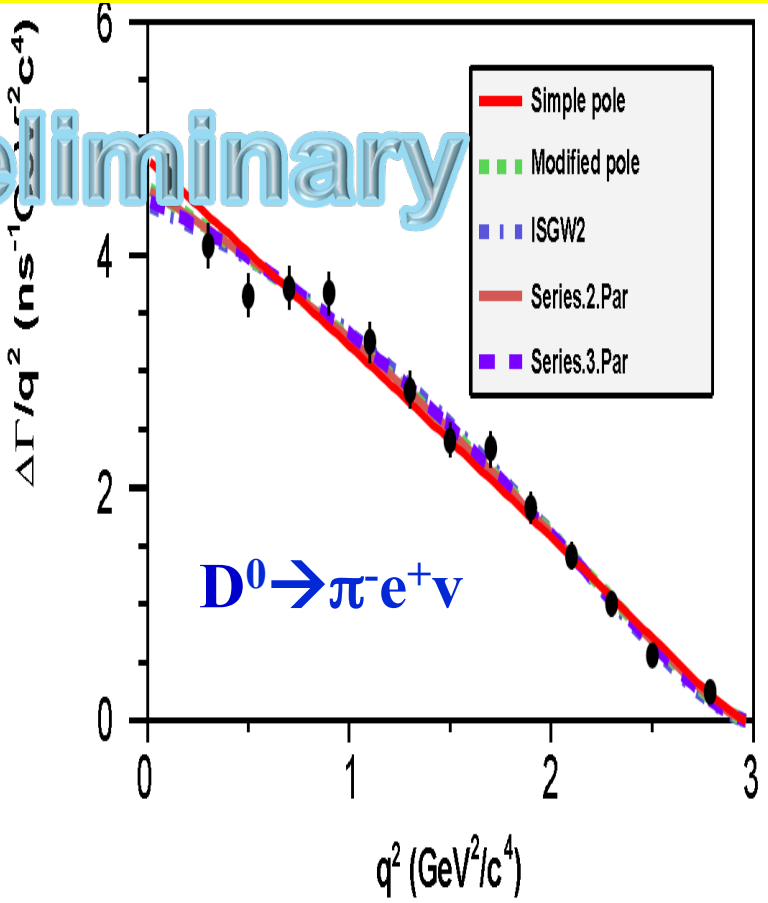
$B[D^0 \to K^- e^+ \nu]$



$B[D^0 \to \pi^- e^+ \nu]$

Fits to $\Delta\Gamma[D^0 \to K(\pi)^- e^+ \nu]$





- **Single pole form**

$$f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{M^2_{\rm pole}}}$$

- **Modified pole model**

$$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{M^2_{\rm pole}})(1 - \alpha\frac{q^2}{M^2_{\rm pole}})}$$

- **ISGW2 model**

$$f_+(q^2) = f_+(q^2_{\rm max})\left(1 + \frac{r^2_{\rm ISGW2}}{12}(q^2_{\rm max} - q^2)\right)^{-2}$$

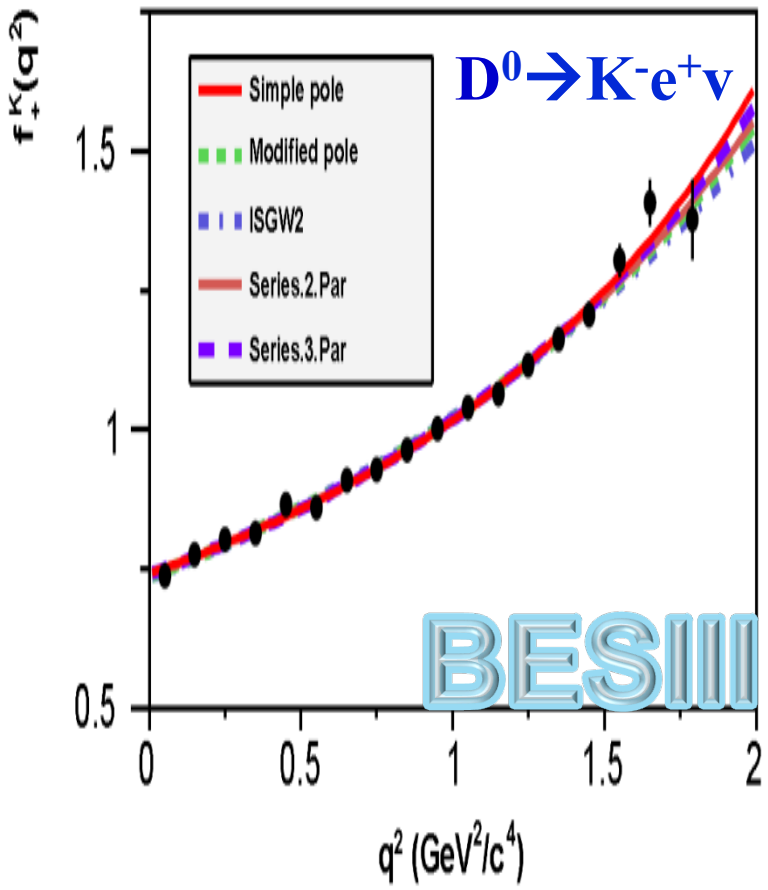
- **Series expansion model**

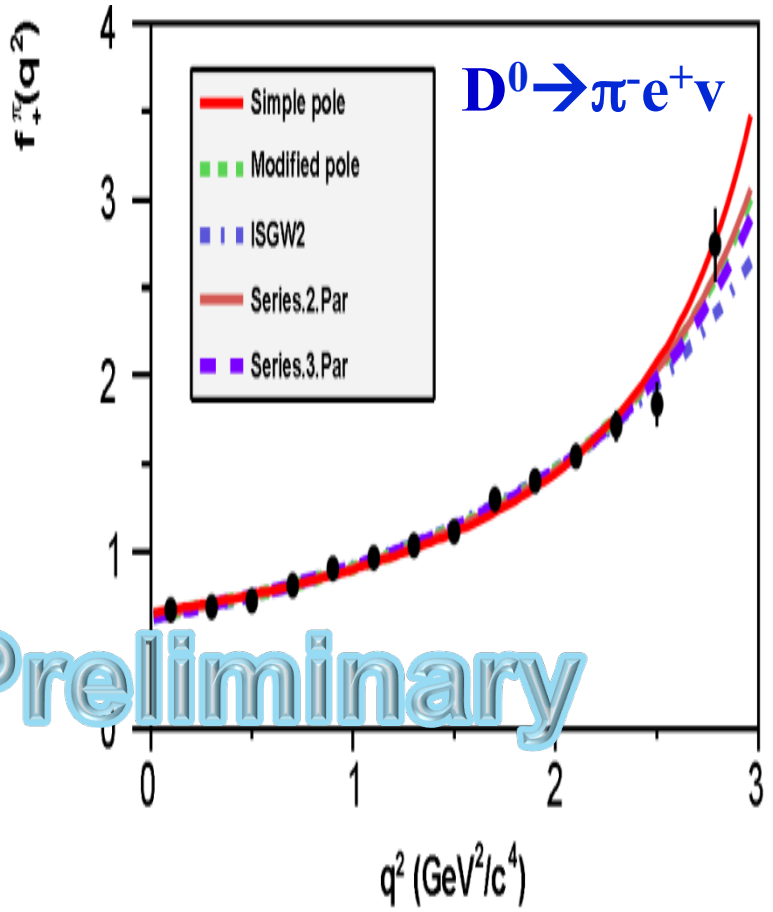
$$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)}a_0(t_0)\left(1 + \sum_{k=1}^{\infty} r_k(t_0)[z(t,t_0)]^k\right)$$

Extracted Parameters of Form Factors

		$D^0 \to K^- e^+ \nu$		$D^0 \to \pi^- e^+ \nu$
Simple Pole	$f_K^+(0)\|V_{cs}\|$	0.7209±0.0022±0.0033	$f_\pi^+(0)\|V_{cd}\|$	0.1475±0.0014±0.0005
	M_{pole}	1.9207±0.0103±0.0069	M_{pole}	1.9114±0.0118±0.0038
Mod. Pole	$f_K^+(0)\|V_{cs}\|$	0.7163±0.0024±0.0034	$f_\pi^+(0)\|V_{cd}\|$	0.1437±0.0017±0.0008
	α	0.3088±0.0195±0.0129	α	0.2794±0.0345±0.0113
ISGW2	$f_K^+(0)\|V_{cs}\|$	0.7139±0.0023±0.0034	$f_\pi^+(0)\|V_{cd}\|$	0.1415±0.0016±0.0006
	r_{ISGW2}	1.6000±0.0141±0.0091	r_{ISGW2}	2.0688±0.0394±0.0124
Series.2.Par	$f_K^+(0)\|V_{cs}\|$	0.7172±0.0025±0.0035	$f_\pi^+(0)\|V_{cd}\|$	0.1435±0.0018±0.0009
	r_1	-2.3241±0.0864±0.0575	r_1	-2.0365±0.0807±0.0260
Series.3.Par	$f_K^+(0)\|V_{cs}\|$	0.7196±0.0035±0.0041	$f_\pi^+(0)\|V_{cd}\|$	0.1420±0.0024±0.0010
	r_1	-2.3331±0.1587±0.0804	r_1	-1.8434±0.2212±0.0690
	r_2	3.4223±3.9090±2.4092	r_2	-1.3871±1.4615±0.4677

Projections on Form Factors $f^{K(\pi)}_{+}(q^2)$



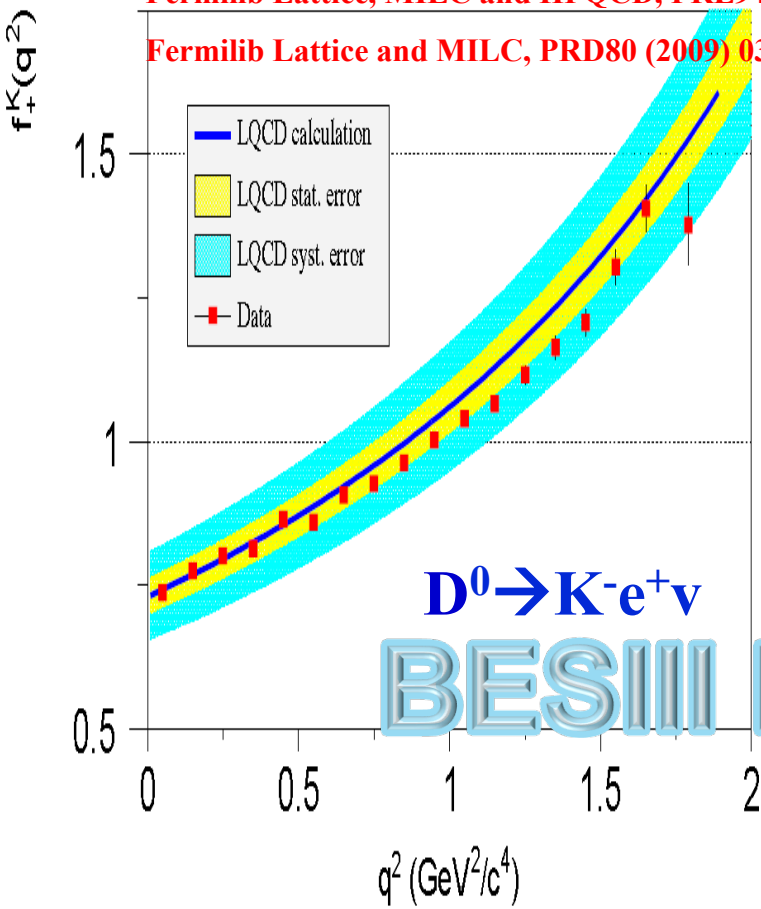


Comparisons of Form Factors

Experimental data calibrate LQCD calculation

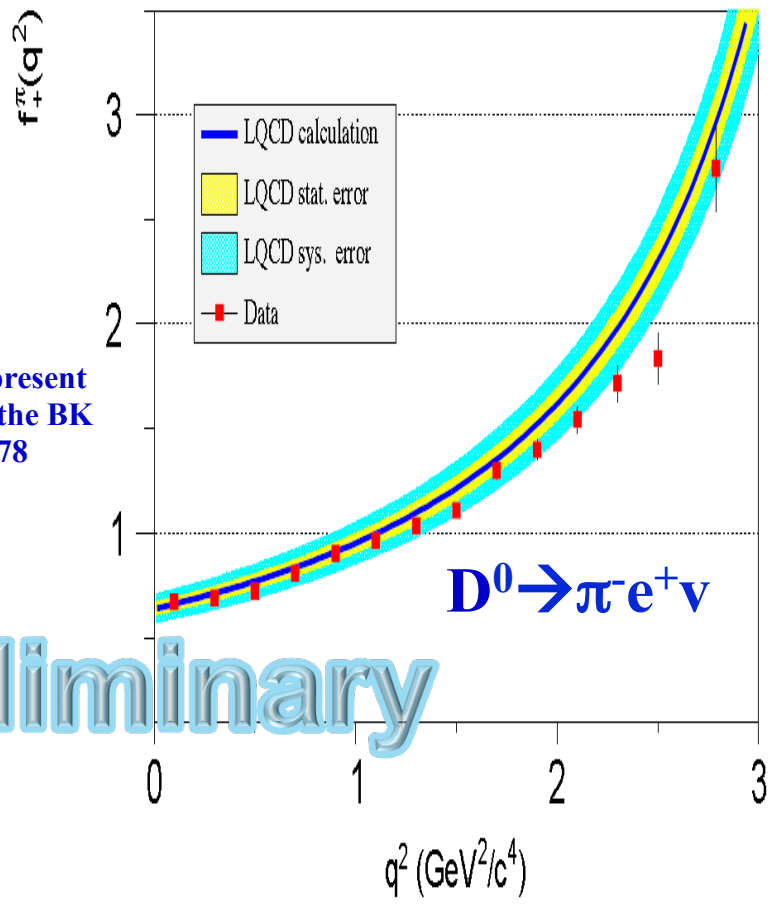
Fermilib Lattice, MILC and HPQCD, PRL94 (2005) 011601

Fermilib Lattice and MILC, PRD80 (2009) 034026



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

Solid lines represent LQCD fits to the BK model, PLB478 (2000)417



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

BESIII Preliminary

Summary

- The BESIII (semi)leptonic analyses are based on 2.92 fb^{-1} collected at $\psi(3770)$.
- The leptonic results for the branching fraction, decay constant and V_{cd} are a significant improvement over previous analyses.
- Similarly, the new semileptonic results, $D^0 \rightarrow K/\pi\ e\ \nu$, are the world's highest precision measurements.
- Say something about D+ coming soon.
- Lattice results are consistent with the data.