

Experimental Studies of Charm Meson Production and Decays at BES

荣刚

I will focus my attention on pure and semi-leptonic decays of charmed mesons in experimental point of view !

Institute of High Energy Physics, CAS
(June 23, 2008)

- 1, Brief Introduction
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- 3, Charm Meson Decays at BES-I and BES-II
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Brief Introduction

Why are we interested in Charm Meson decays ?

Charm (粲夸克偶素和粲介子) 的发现使人们真正地相信夸克是组成物质的真实客体，使人们接受**QCD**（量子色动力学）是作为描述强相互作用的基本理论。**Charm** 的发现对粒子物理学的发展起到了巨大（伟大）地推动作用。

伟大的历史作用！

“11月革命”

粲介子的产生和衰变为我们提供了研究相互作用机制的理想实验室：

QCD: 理解和发展描述微扰的和非微扰效应的动力学...。

EW: 精密的检测标准模型理论， ...。

B 衰变的动力学：刻度理论工具、研究**B**衰变...

探索超标准模型的新物理

光辉灿烂的
未来！

Brief Introduction

QCD: 理解和发展描述非微扰效应的动力学...

Charm 夸克是连接轻夸克 (**u, d, s**) 和重夸克 (**b, t**) 的一座桥梁。在描述**Charm** 夸克的产生和衰变中, 有些过程可以用**pQCD**来描述, 有些则不能。这样, 通过实验上精密地研究其产生和衰变过程, 就可以进一步的发展和完善**QCD**理论。对于不能用**pQCD**描述的过程, 其实验结果可以被用于检验非微扰**QCD**的计算 ...

Charm 的衰变为我们提供了在微扰和非微扰边界研究强相互作用的理想实验室。

精密检验标准模型理论

在标准模型中, 弱耦合是由三代夸克决定的, 因此, 粲介子半轻子衰变的实验研究结果, 可以为我们研究和寻找三代夸克和三代轻子存在的物理根源提供重要的实验数据。同时, 从粲介子的弱作用衰变的过程中, 我们还可以测定不同代成员之间的耦合强度、研究衰变动力学机制。

B 介子衰变动力学: 刻度理论工具 (**LQCD**)、研究**B**衰变

$f_D, f_{D_s} \rightarrow f_B, f_{B_s} \rightarrow$ improve accuracy of CKM elements ...

Brief Introduction

探索新物理

$D^0\bar{D}^0$ -bar 混合

CP破坏

稀有衰变



寻找超标准模型的物理（新物理）

这些实验研究工作都可以在**BES-III/BEPC-II** 实验装置上进行。

杨茂志教授 将
系统地讲D物理

从实验出发，与大家一起讨论如下两个问题：

在**BES-I/BEPC** 和 **BES-II/BEPC** 上做过什么？

在**BES-III/BEPC-II** 上能做什么？精度如何？

Experimental Facility

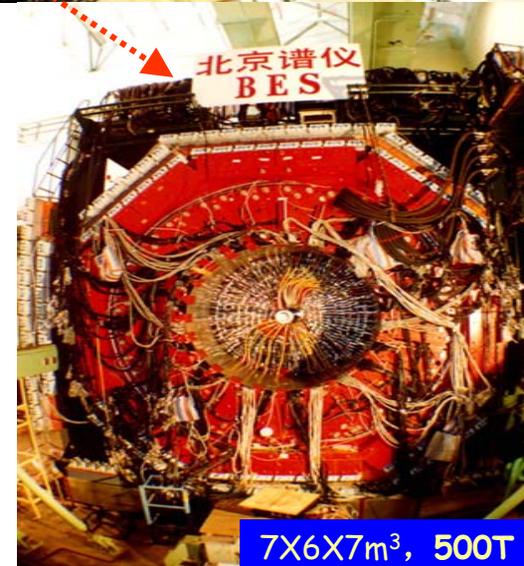
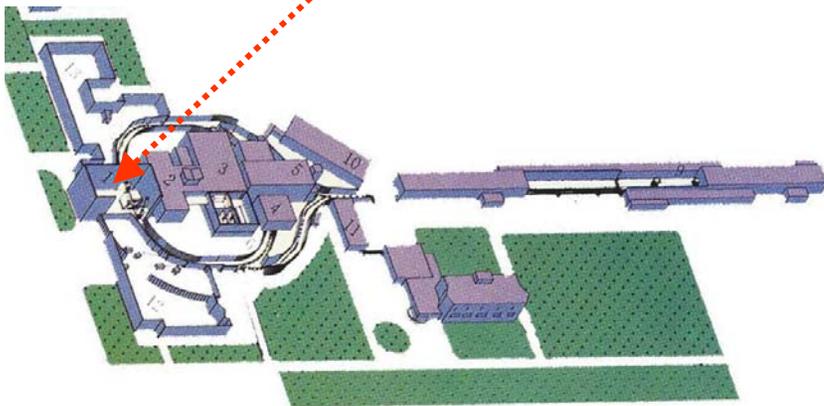
(BES-I & BES-II at BEPC)

The Beijing Electron Positron Collider (BEPC)

BES/BEPC

$L \sim 1 \times 10^{31} / \text{cm}^2 \cdot \text{s}$
at $\psi(3770)$ peak

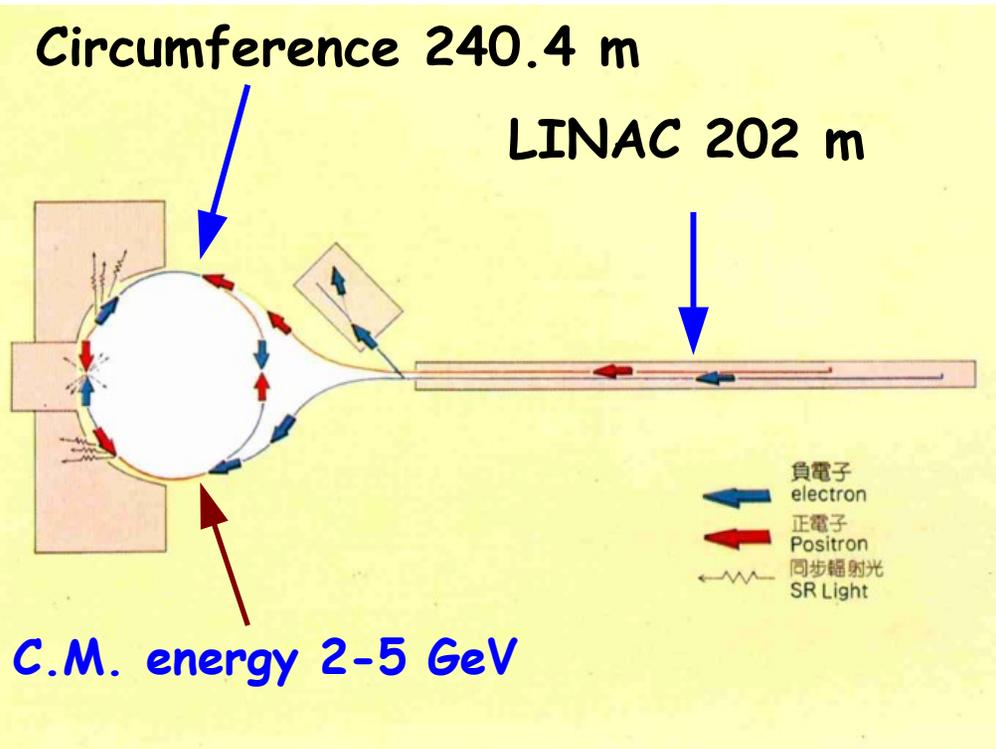
$E_{\text{cm}} \sim 2\text{--}5 \text{ GeV}$



7X6X7m³, 500T

BES/BEPC

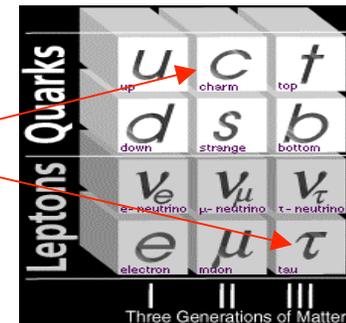
Beijing Electron Positron Collider



BES (Beijing Electron-positron Spectrometer)

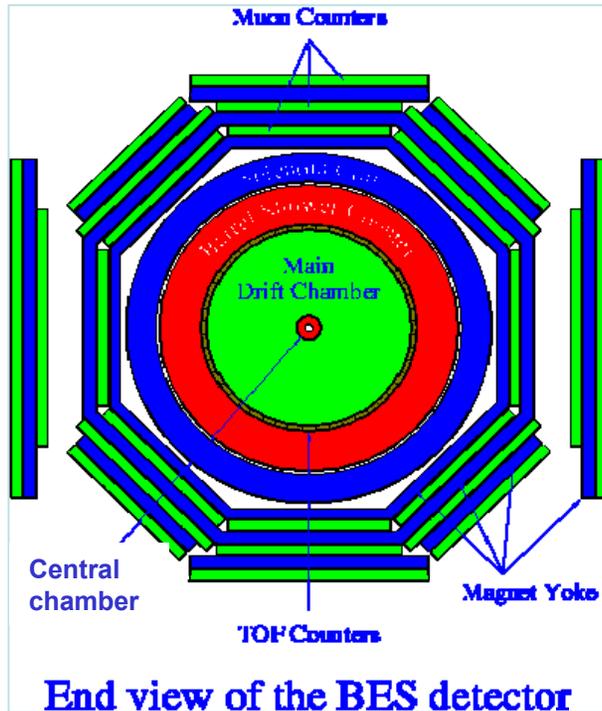
A large general purpose electro-magnetic spectrometer. It measure the **energy**, **momentum** of charged particles, photon and does **particle identification** to reconstruct the decay events fully.

physics goals



Also studies of light hadron (u , d , s quarks) production in e^+e^- annihilation

BES-I Detector



1988 底开始采集数据

Ecm = 3.097 GeV for J/ψ

Ecm ~3.57 GeV for Tau Physics

Ecm = 4.03, 4.14 GeV for Ds

Ecm = 3.686 GeV for ψ(3686)

1994--1996 Upgrade → BES-II

CDC:

MDC: $\sigma_{xy} = 220 \mu\text{m}$

$\sigma_{dE/dx} = 8.5 \%$

$\Delta p/p = 1.7\% \sqrt{(1+p^2)}$

TOF: $\sigma_T \sim 330 \text{ ps}$

BSC: $\Delta E/\sqrt{E} \sim 22 \%$

$\sigma_\phi = 7.9 \text{ mrd}$

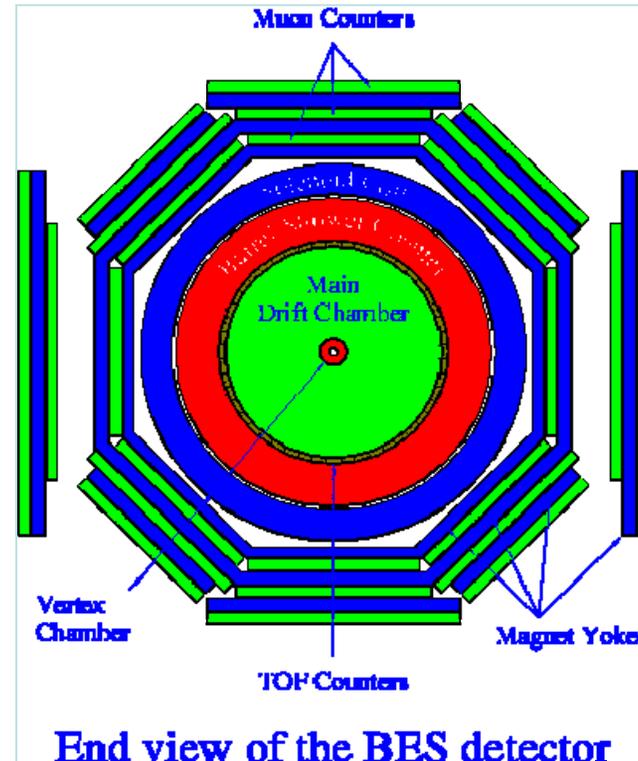
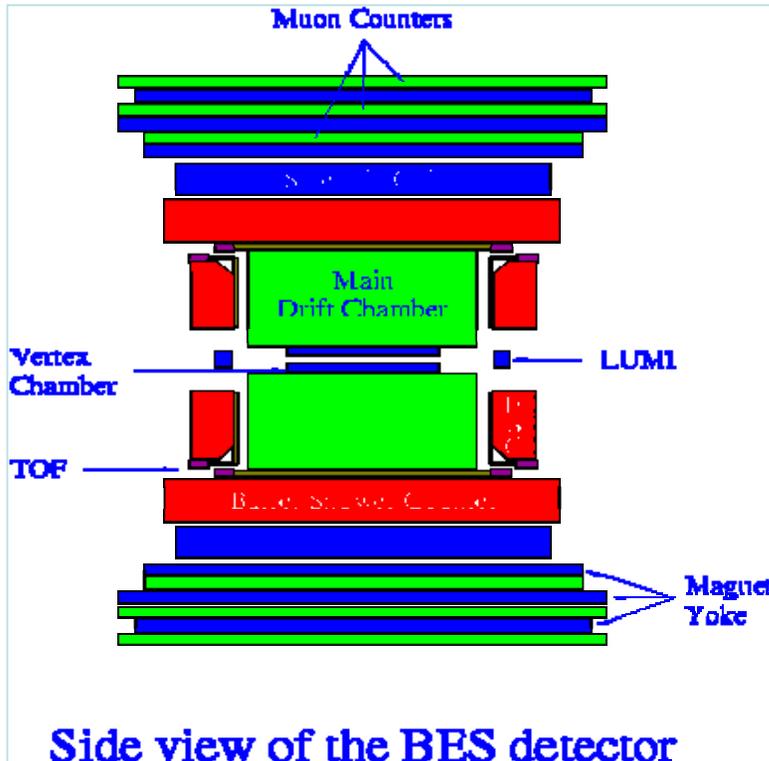
$\sigma_z = 3.1 \text{ cm}$

μ counter: $\sigma_{r\phi} = 3 \text{ cm}$

$\sigma_z = 5.5 \text{ cm}$

B field: 0.4 T

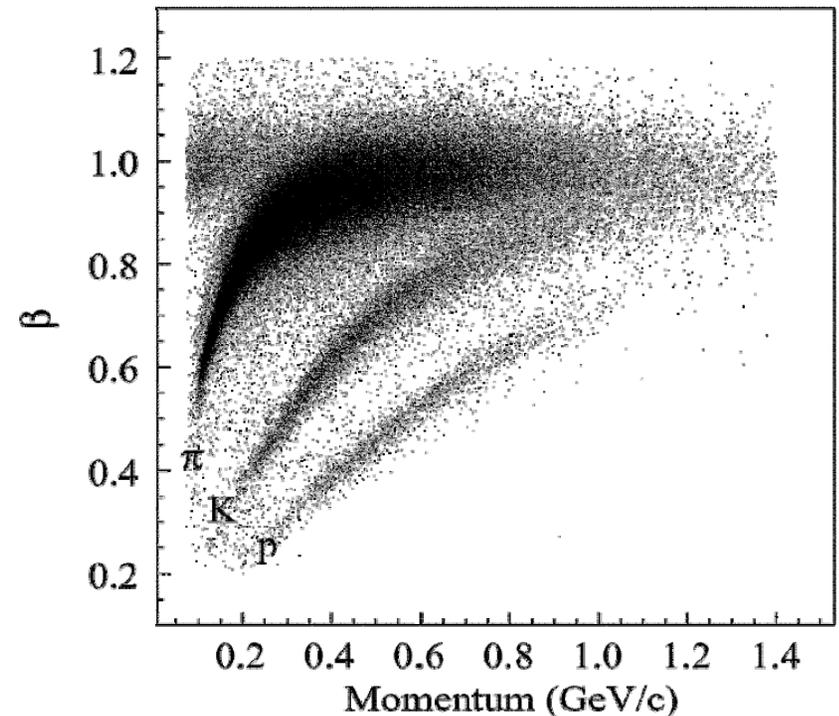
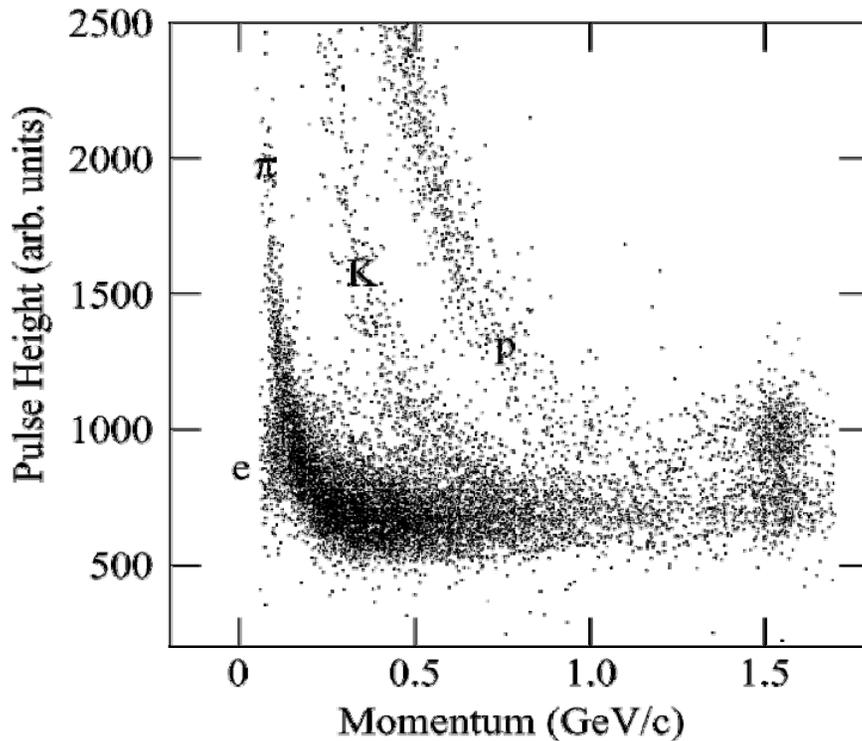
BES-II Detector



VC:	$\sigma_{xy} = 100 \mu\text{m}$	TOF:	$\sigma_T = 180 \text{ ps}$	μ counter:	$\sigma_{r\phi} = 3 \text{ cm}$
MDC:	$\sigma_{xy} = 220 \mu\text{m}$	BSC:	$\Delta E/\sqrt{E} = 22 \%$		$\sigma_z = 5.5 \text{ cm}$
	$\sigma_{dE/dx} = 8.5 \%$		$\sigma_\phi = 7.9 \text{ mrd}$	B field:	0.4 T
	$\Delta p/p = 1.7\% \sqrt{(1+p^2)}$		$\sigma_z = 3.1 \text{ cm}$		

Particle Identification

Muon identification can be done for the charged track with momentum of great than 0.52 GeV/c



Data Samples

$\psi(4030)$ and $\psi(4140)$ data samples

~ 22 pb^{-1} data taken at 4.03 GeV with BES-I

~ 2 pb^{-1} data taken at 4.14 GeV with BES-I

$\psi(3770)$ data sample [at BES-II]

~18 pb^{-1} data taken at 3.773 GeV

~7 pb^{-1} data taken at the region from 3.768 GeV to 3.778 GeV

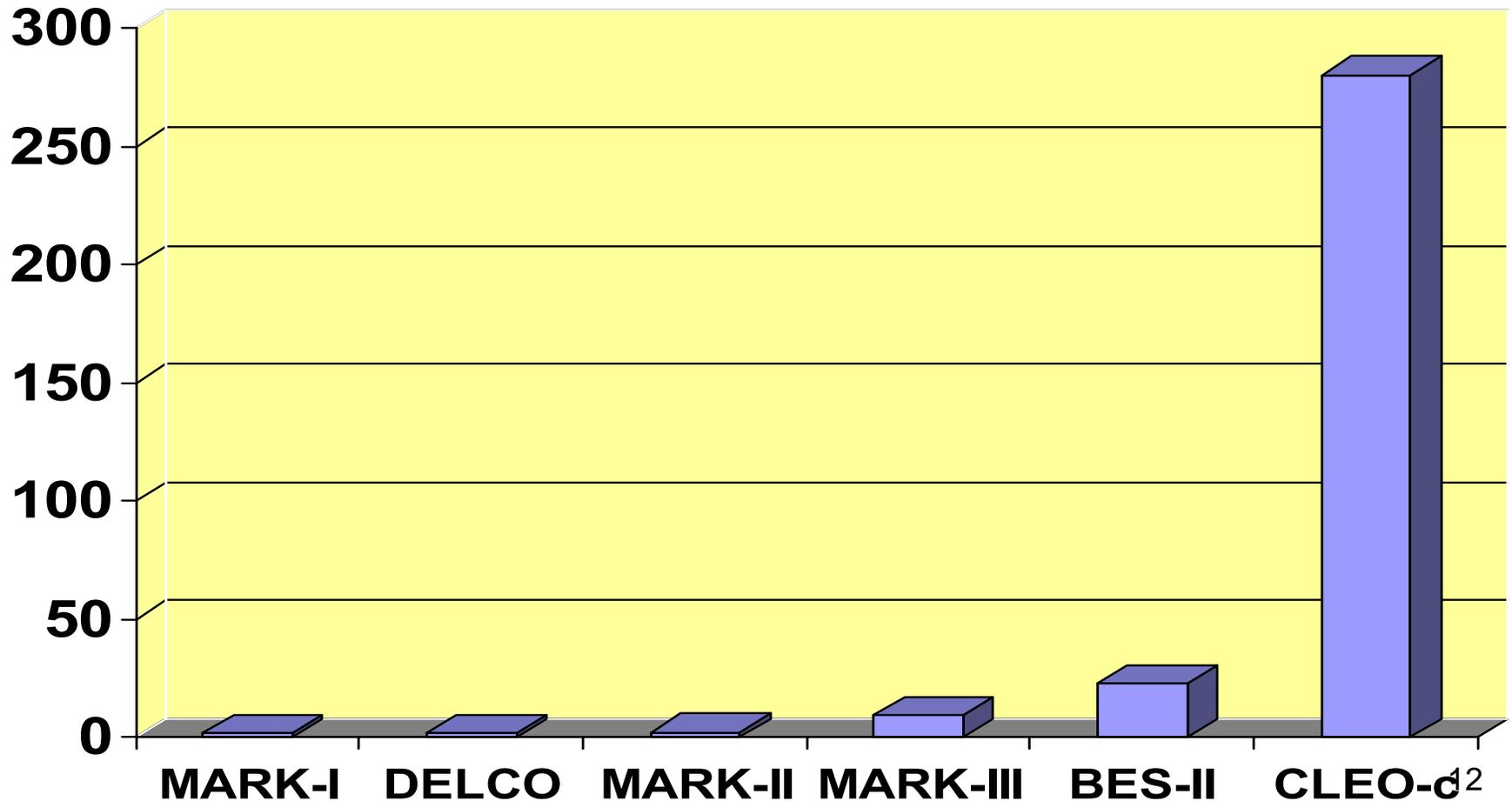
~8 pb^{-1} data taken in the energy region from 3.665 to 3.878 GeV

The total integrated Luminosity is about 33 pb^{-1} .

Data Samples

World $\psi(3770)$ Samples (pb^{-1})

Largest sample from CLEO-c by Summer, 2005

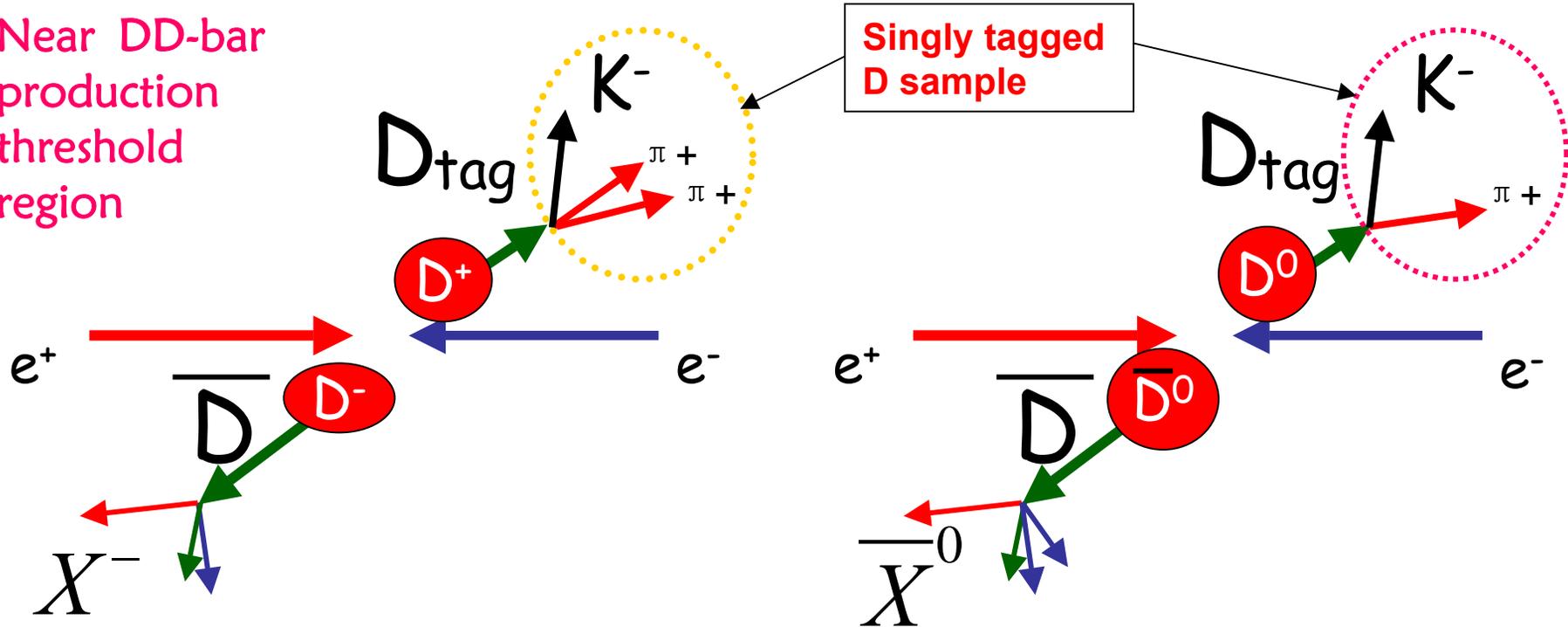


Analysis Methods

Threshold data

特点或优势

Near $D\bar{D}$ -bar production threshold region



Absolute Measurements

With the singly tagged D sample, we can do some absolute measurements and search for some new decay modes of D mesons

**Studies of Charm Meson
Decays with BES-I & BES-II
at BEPC**

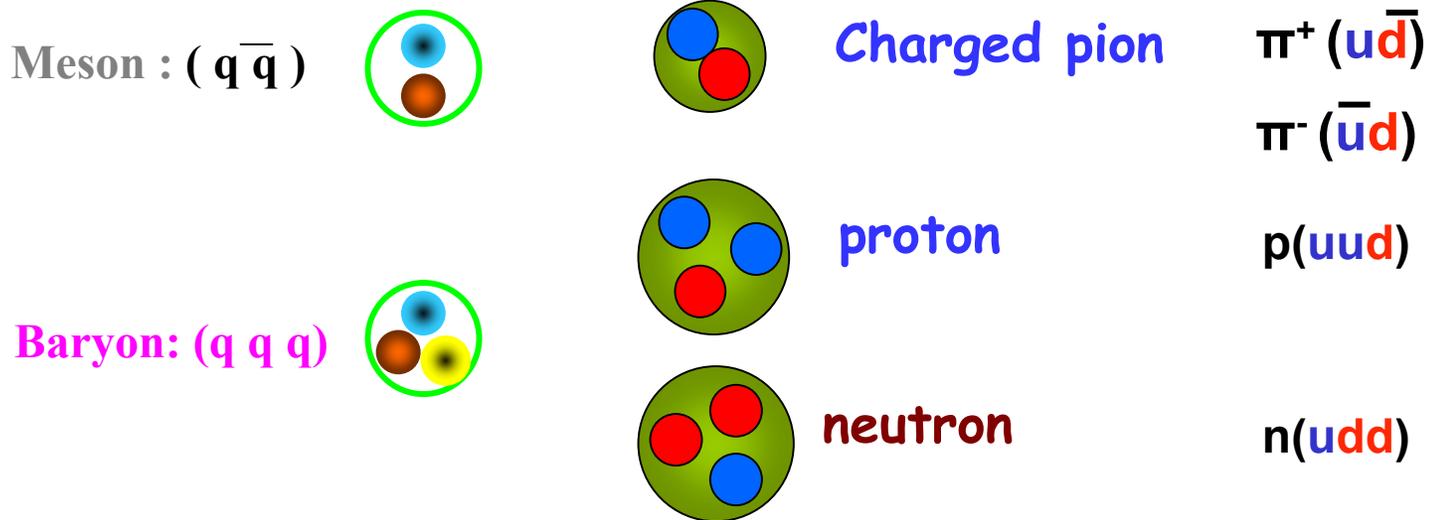
c quark proposed

三夸克模型

1974年前, 人们认识到强子是由两种或三种不同的夸克组成的。

Naive Quark model

- one up quark (charge +2/3) : u
- one down quark (charge -1/3) : d
- one strange quark (charge -1/3): s



三夸克模型于1964年分别由盖尔曼 (Gell-Mann)和兹韦格(Zweig)独立提出 [SU(3) 模型]。该模型理论成功的解释了当时已知的强子谱并成功地描述相互作用的一些特征。

c quark proposed

粲夸克“c”的引入

实验上观测不到奇异数改变($|\Delta S|=1$)的中性流过程, 例如:

$$K^+ \rightarrow \pi^+ \nu \bar{\nu}$$

分支比的上限为:
$$\frac{\Gamma(K^+ \rightarrow \pi^+ \nu \bar{\nu})}{\Gamma(K^+ \rightarrow \pi^0 \mu^+ \nu_\mu)} \leq 10^{-5}$$

为了解释这个实验现象, 1970年 **GIM (Glashow, Iliopoulos & Maiani)** 在理论上引入一个新夸克, 即“c”夸克来解释实验上观测不到弱作用过程中奇异数改变的中性流过程。

根据夸克模型的理论, 如果存在“c”夸克, 就应当存在一系列由“c”和“ \bar{c} ”及“c”和其它夸克($\bar{u}, \bar{d}, \bar{s}$)组成的强子。

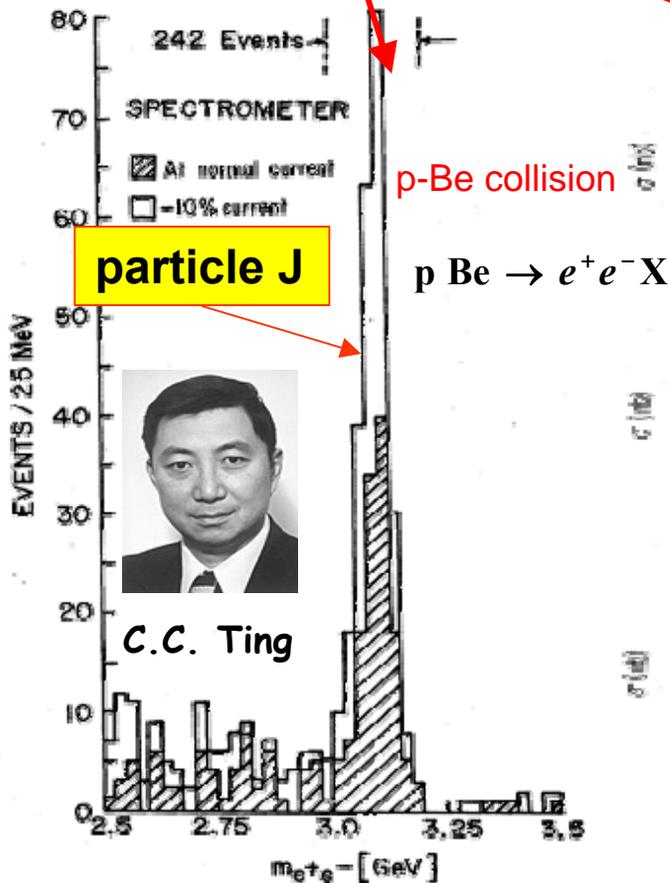
Discovery of c quark

Discovery of J/ ψ

So called "November Revolution of Particle Physics!"

PRL33, 1404 (1974)

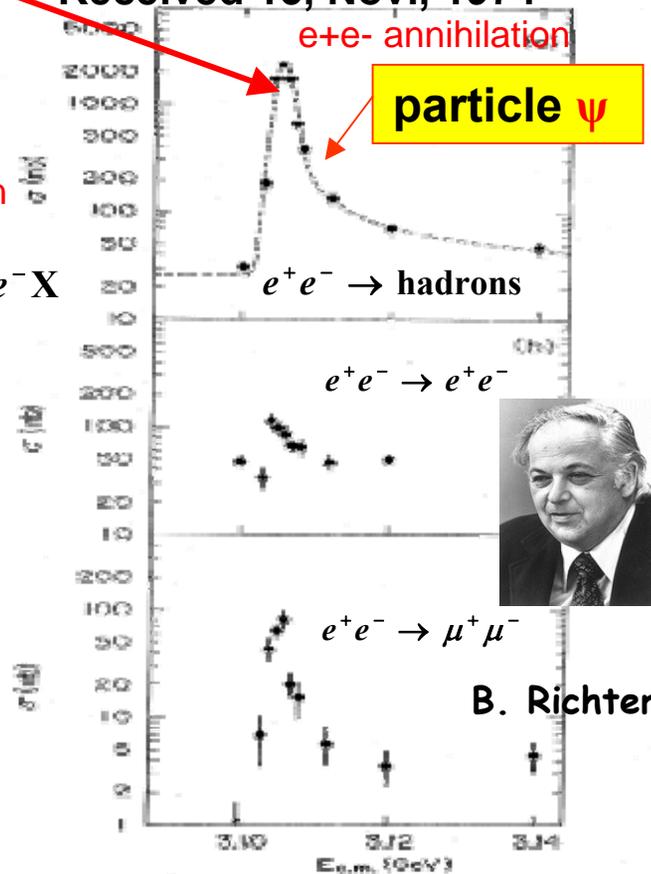
Received 12, Nov., 1974



Charmonium: bound states of $c\bar{c}$

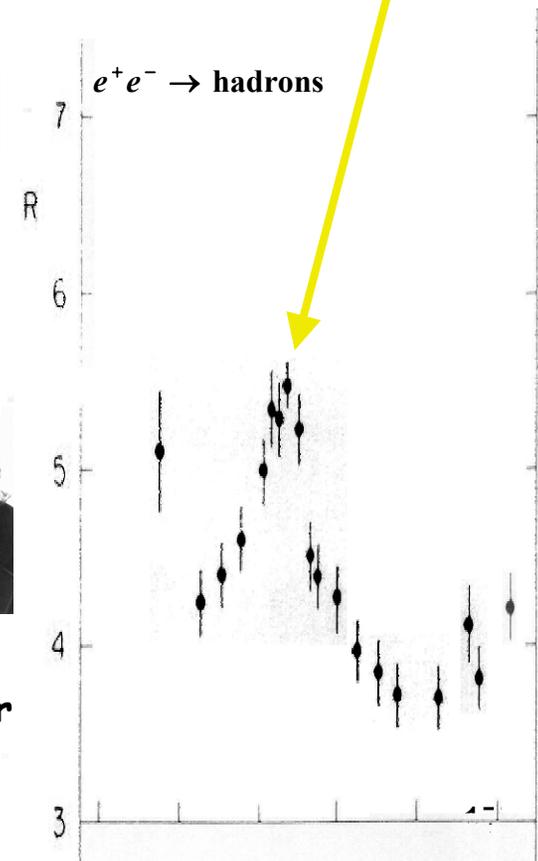
PRL33, 1406 (1974)

Received 13, Nov., 1974



Discovery of ψ (3770)

PRL39, 526 (1977)



Charmonium

粲夸克偶素 (Charmonium)

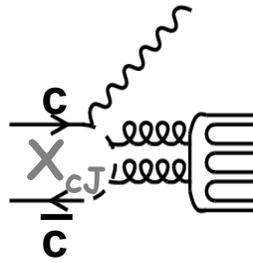
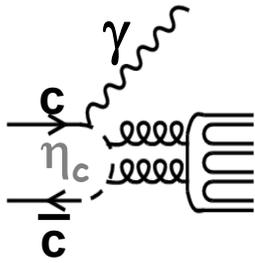
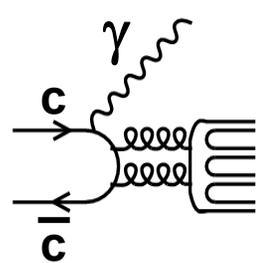
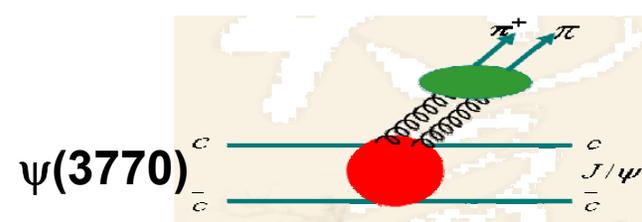
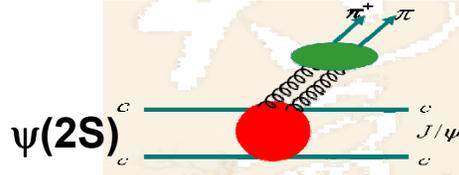
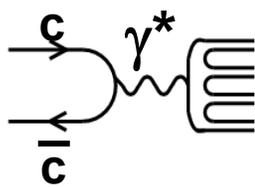
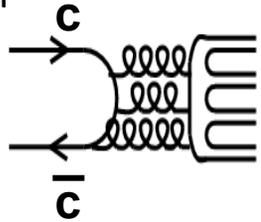
由 $c\bar{c}$ 组成的系统称为粲夸克偶素或粲偶素

J/ ψ

$\psi(2S)$

$\psi(3770)$

J/ ψ



BES discovered the hadronic transition process

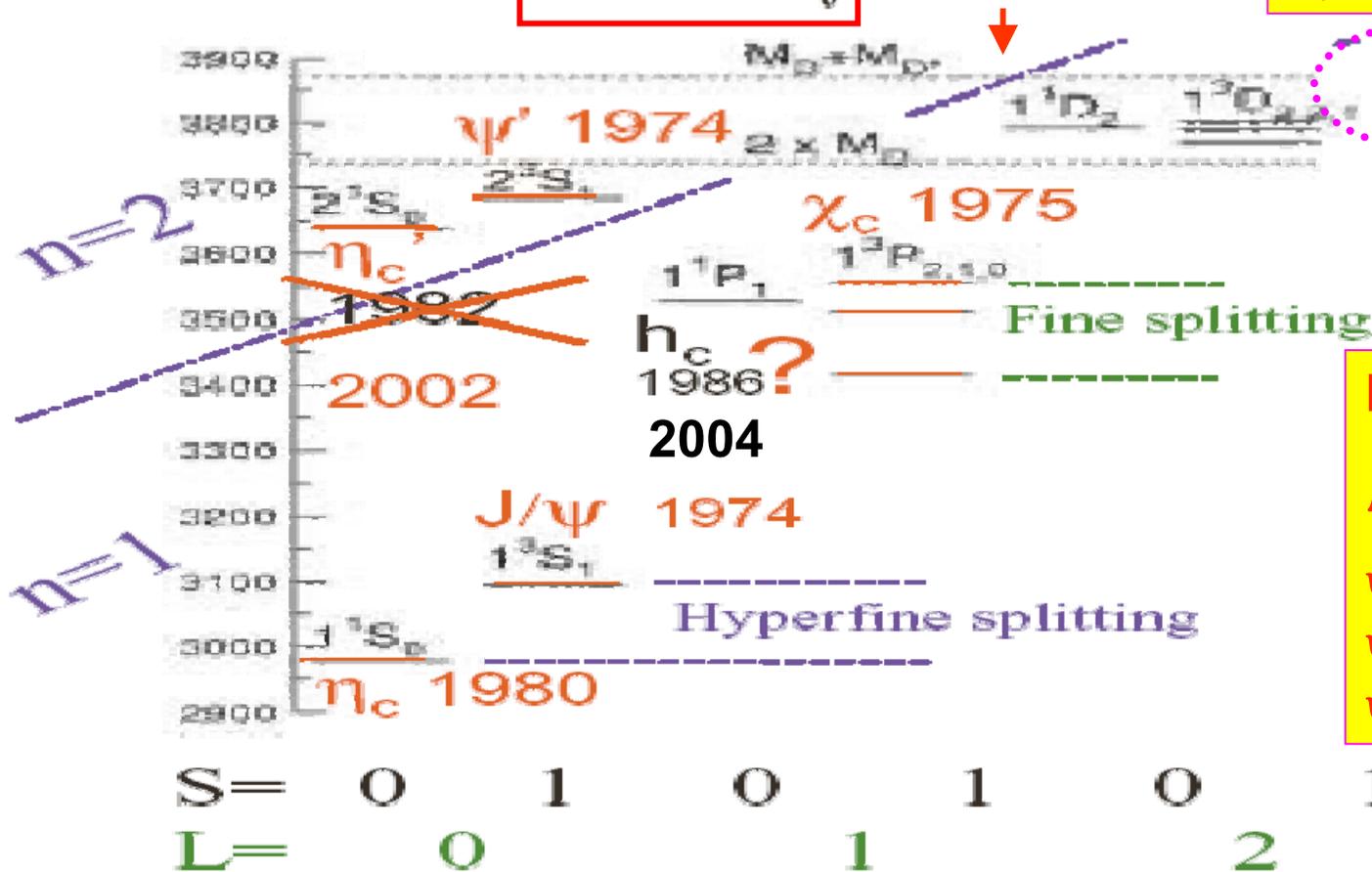
Charmonium

Charmonium is the $c\bar{c}$ bound state. There are 8 states below dissociation energy

$$n \ 2S+1 \ L \ J$$

在DD-bar 阈下，有8个粲偶素态。

Mass [MeV]



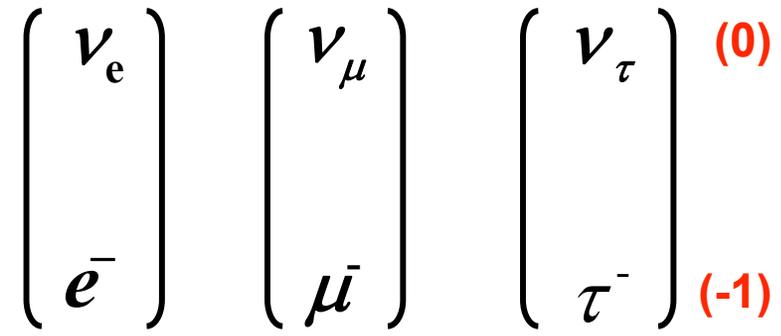
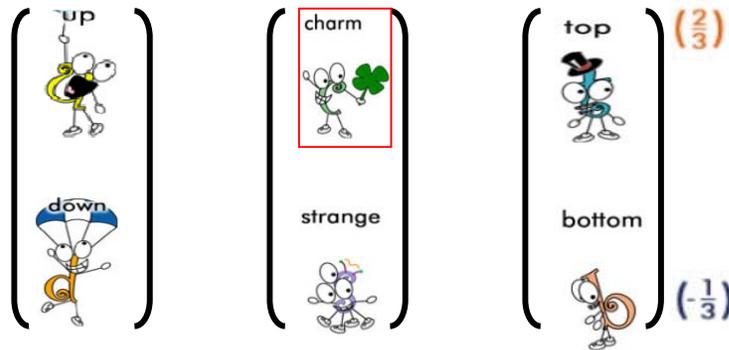
DD-bar 阈以上还有其它态，如：
 $\psi(4040)$ ，
 $\psi(4160)$ ，
 $\psi(4415)$...

3 Generations of Quarks & Leptons

“三代”结构

根据夸克之间跃迁构成的带电强子弱流的情况，每两个夸克可以记为一个两重态，称为一代，六夸克理论中包含三代夸克，它们是：

根据轻子流的情况，轻子也可以记为三个两重态，形成与夸克完全对称的形式，它们是：



“代”： 1 2 3

1 2 3

质量：由轻到重 →

质量：由轻到重 →

在标准模型框架内，带电强子弱流控制三代夸克的上下成员之间相互转变。带电强子弱流的形式为：

$$J_{\mu}^{+} = (\overline{u} \overline{c} \overline{t}) \gamma_{\mu} (1 - \gamma_5) U \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$J_{\mu}^{-} = (\overline{d} \overline{s} \overline{b}) \gamma_{\mu} (1 - \gamma_5) U^{*} \begin{pmatrix} u \\ c \\ t \end{pmatrix}$$

CKM Matrix

U is called Cabbibo Kobayashi & Maskawa mixing matrix,

$$U = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \rightarrow \begin{pmatrix} C_{12}C_{13} & S_{12}C_{13} & S_{13}e^{-i\delta} \\ -S_{12}C_{23} - C_{12}S_{23}S_{13}e^{i\delta} & C_{12}C_{23} - S_{12}S_{23}S_{13}e^{i\delta} & S_{23}C_{13} \\ S_{12}S_{23} - C_{12}C_{23}S_{13}e^{i\delta} & -C_{12}S_{23} - S_{12}C_{23}S_{13}e^{i\delta} & C_{23}S_{13} \end{pmatrix}$$

Where $S_{ij} = \sin \theta_{ij}$ and $C_{ij} = \cos \theta_{ij}$ $ij = 12, 23, 13$

Three angles θ_{ij} and one phase δ are 4 parameters in Standard Model

δ 产生CP破坏效应。

CKM 矩阵的不同表示

四个独立的参量:
 A, λ, ρ, η

$$\begin{pmatrix} 1 - \frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

CKM

Wolfenstein参数化方法

弱作用的本征态是 quarks 的线性组合。

通过重新定义夸克场相位的方法可以吸收掉CKM矩阵元中5个独立参数，只剩下4个独立参数。

CKM Matrix

Wolfenstein 参数化方法 取 $\lambda = S_{12} = \sin\theta_c = 0.22$, 并将其它矩阵元按 λ 展开。实验上有广泛的应用。

特点: 对角元都是 λ 的次方, 近似于1; 而第一代和第二代混合最大, 是 λ 的一次方; 第二代和第三代的混合小一个量级, 是 λ 的二次方; 第一代和第三代混合最小, 是 λ 的三次方。

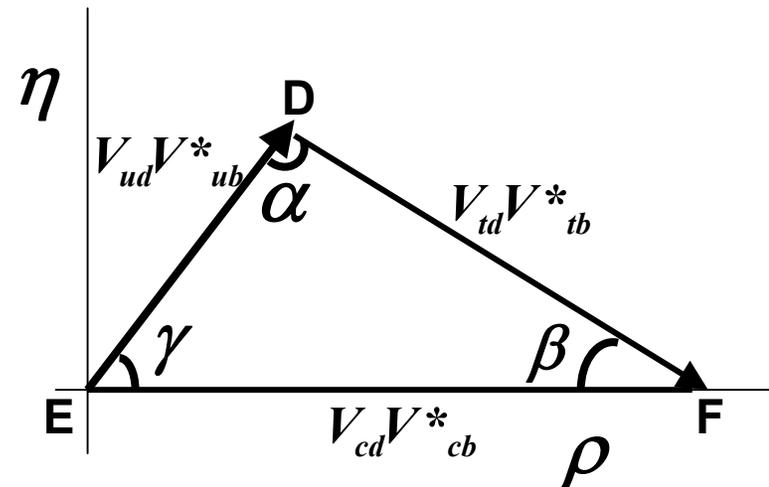
$$\begin{bmatrix} 1 - \frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{bmatrix} + \Theta(\lambda^4)$$

CKM矩阵元的幺正条件 $\mathbf{V}^\dagger \mathbf{V} = \mathbf{1}$ 要求每一列或每一行的元素的平方和为1; 而每两行或每两列的元素的乘积之和为零。

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

(可以有6个类似的等式)

在**Wolfenstein** 表示中, 幺正三角形顶点D的坐标为 (ρ, η) ; $\gamma = \delta$



$$\alpha + \gamma + \beta = 180^\circ \text{ } ^{.22}$$

CKM Matrix

Big Questions to be answered

- 为什么夸克和轻子形成“三代”结构？
- 为什么三代夸克的质量有层次？
- 为什么三代夸克混合有层次？

夸克质量

m_u	m_d	m_s	m_c	m_b	m_t
1.5~3.0 MeV	3~7 MeV	95+~25 MeV	1.25+0.09 GeV	4.20+0.07 GeV	174.2+3.3 GeV

重味物理研究的主要目标之一就是要阐明不同“代”成员之间的关系，寻找“三代”夸克和“三代”轻子存在的物理根源。

在标准模型理论中，CKM矩阵元 (A, λ, ρ, η) 描述夸克与 $W^{+,-}$ 玻色子的耦合强度，它们同费米子的质量一样，都是待定的参数，需要由实验来确定。

实验测定CKM矩阵元，是检测标准模型理论的重要任务之一；是重味物理研究的重要目标之一。

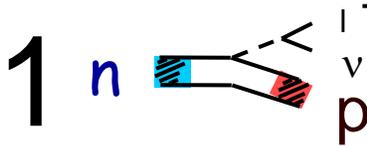
很多测量结果都可以画在上述么正三角形上，并做比较。

CKM Matrix Elements

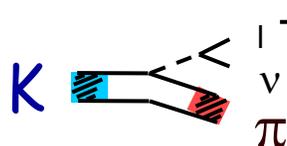
CKM Matrix Status (2001)

BES-III will improve measurements

$$\Delta V_{ud} / V_{ud} = 0.1\%$$



$$\Delta V_{us} / V_{us} = 1\%$$

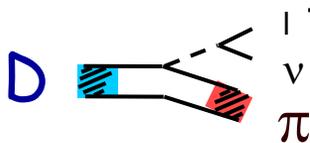


$$\Delta V_{ub} / V_{ub} = 25\%$$



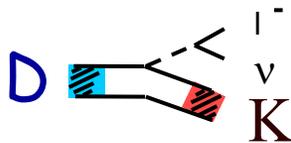
$$\Delta V_{cd} / V_{cd} = 7\%$$

$\nu d \rightarrow c l$

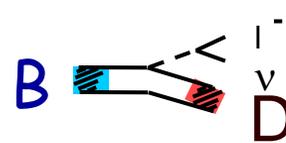


$$\Delta V_{cs} / V_{cs} = 16\%$$

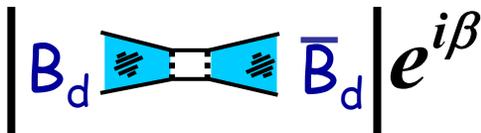
$W \rightarrow c \bar{s}$



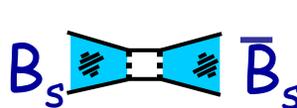
$$\Delta V_{cb} / V_{cb} = 5\%$$



$$\Delta V_{td} / V_{td} = 36\%$$



$$\Delta V_{ts} / V_{ts} = 39\%$$



$$\Delta V_{tb} / V_{tb} = 29\%$$

1

I. Shipsey

V_{ud} , V_{us} and V_{cb} are the best determined due to flavor symmetries: I, SU(3), HQS. Charm (V_{cd} & V_{cs}) and rest of the beauty sector (V_{ub} , V_{td} , V_{ts}) are poorly determined. Theoretical errors on hadronic matrix element dominate.

CKM Matrix Elements

实验测量结果(2006)

~5%误差

~10%误差

根据各种不同的反应或衰变过程测定结果，**PDG06** 的平均值

$ V_{ud} $	$ V_{us} $	$ V_{ub} $	$ V_{cd} $	$ V_{cs} $	$ V_{cb} $	$ V_{td} $	$ V_{ts} $	$ V_{tb} $
0.97377 +- 0.00027	0.2257 +- 0.0021	0.00431 +- 0.00030	0.230 +- 0.011	0.957 +- 0.017 +-0.093	0.0416 +- 0.0006	0.0074 +- 0.0008		>0.78

BES-III将直接
地改进测量精度

BES-III将间接
地改进测量精度

$$\alpha = (99_{-8}^{+13})^\circ$$

$$\sin 2\beta = 0.687 \pm 0.032$$

$$\gamma = (63_{-12}^{+15})^\circ$$

$$|V_{td}/V_{ts}| = 0.208 \pm 0.007$$

CKM Matrix Elements

Global fit in the Standard Model (2006)

PDG (Particle Data Group) 根据各实验的测量结果，根据**CKM**矩阵元要满足的各种约束，全局拟合的结果为

V_{ud}	V_{us}	V_{ub}	V_{cd}	V_{cs}	V_{cb}	V_{td}	V_{ts}	V_{tb}
0.97383	0.2272	0.00396	0.2271	0.9730	0.0422	0.0081	0.0416	0.9991
+-	+-	+-	+-	+-	+-	+-	+-	+-
0.00024	0.0010	0.00009	0.0011	0.0024	0.0005	0.0005	0.0005	0.00003

$$\lambda = 0.2272 \pm 0.0010$$

$$\bar{\rho} = 0.221^{+0.064}_{-0.028}$$

$$\alpha + \beta + \gamma = (184^{+20}_{-15})^\circ$$

$$A = 0.818^{+0.007}_{-0.017}$$

$$\bar{\eta} = 0.340^{+0.017}_{-0.045}$$

BES-III粲介子物理研究结果将会改进这些量的测量精度!

比较**BES-III**将要进行和完成的直接精密测定的 V_{cs} 与 V_{cd} 和 **Global fit** 间接给出的 V_{cs} 与 V_{cd} ，在新物理寻找方面，可以得到一些重要的实验信息。26

Standard Model

标准模型

三代夸克；三代轻子。

自然界中有**4**种基本的相互作用：强相互作用；电磁相互作用；弱相互作用和引力相互作用。对应传播这**4**种作用的传递者分别是：胶子；光子； $W^{+,-}$, Z^0 和 引力子。

统一描述电弱相互作用的理论[**standard electroweak model (SM)**]--- **Glashow-Weiberg-Salam 弱电统一理论 $SU(2) \times U(1)$**

将弱作用和电磁作用由 **$SU(2) \times U(1)$** 的对称群统一起来。

描述强相互作用的理论----**量子色动力学 (QCD)**

标准模型：{ 弱电统一理论
量子色动力学 (QCD)

Charmed mesons

Charmed meson is the **bound state of c quark and one of the light antiquarks.**

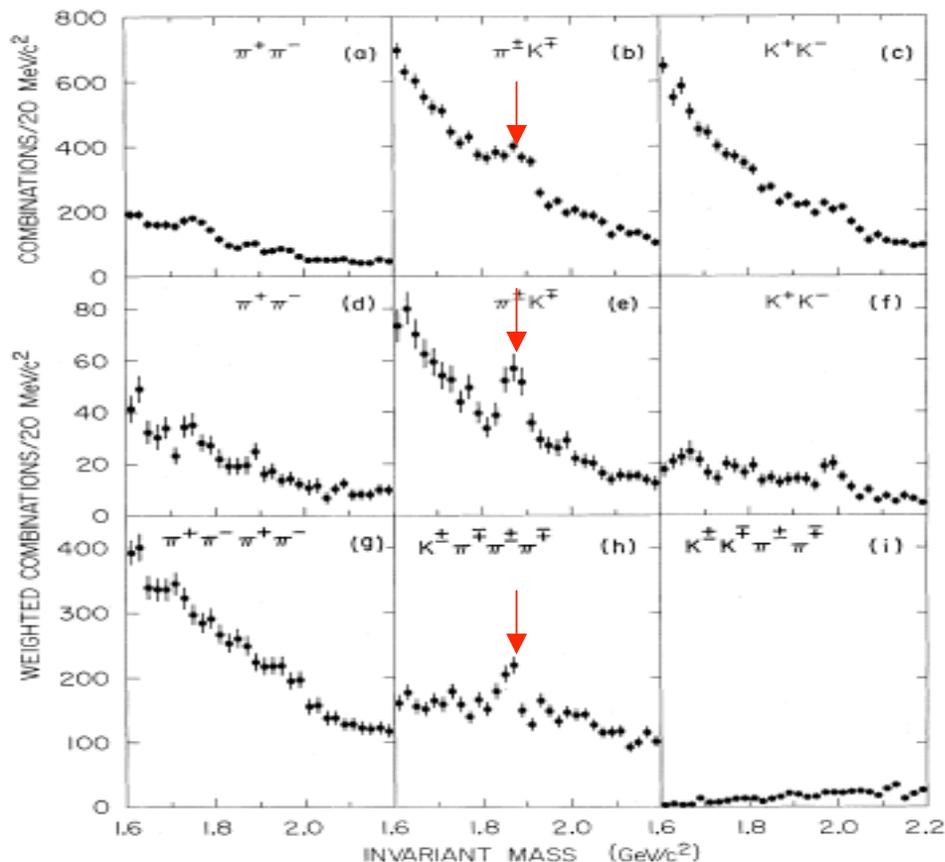
Quark content	$\bar{c}u$	$\bar{c}d$	$\bar{c}s$	$\bar{c}u$	$\bar{c}d$	$\bar{c}s$
Pseudoscalar	D^0	D^+	D_S^+	\bar{D}^0	D^-	D_S^-
Vector	D^{*0}	D^{*+}	D_S^{*+}	\bar{D}^{*0}	D^{*-}	D_S^{*-}

高激发态粲介子 ...

Charm Meson Production

D介子的发现

1976年工作在美国Stanford 直线加速器中心、SPEAR e^+e^- 对撞机上的MARK-I (SLAC-LBL) 实验组，首次观测到 D^0 介子的产生信号。



在3.90—4.60 GeV 区间实验工作，从 $K^+ \pi^+$ 和 $K^+ \pi^+ \pi^+ \pi^-$ 组合中发现了中性D介子。

此后， D^+ 、 D_s^+ 介子和粲重子等一系列粲粒子相继地被发现。

FIG. 1. Invariant-mass spectra for neutral combinations of charged particle. (a) $\pi^+\pi^-$ assigning π mass to all tracks, (b) $K^+\pi^+$ assigning K and π masses to all tracks, (c) K^+K^- assigning K mass to all tracks, (d) $\pi^+\pi^-$ weighted by $\pi\pi$ TOF probability, (e) $K^+\pi^+$ weighted by $K\pi$ TOF probability, (f) K^+K^- weighted by KK TOF probability, (g) $\pi^+\pi^-\pi^+\pi^-$ weighted by 4π TOF probability, (h) $K^+\pi^+\pi^+\pi^-$ weighted by $K3\pi$ TOF probability, (i) $K^+K^-\pi^+\pi^-$ weighted by $KK3\pi$ TOF probability.

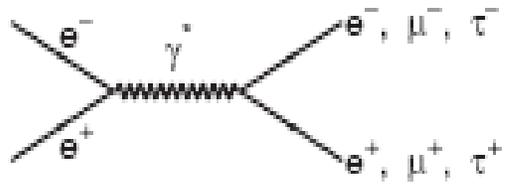
Charm Meson Production

粲介子可以在 e^+e^- 湮灭中直接产生或经过矢量介子衰变而产生。

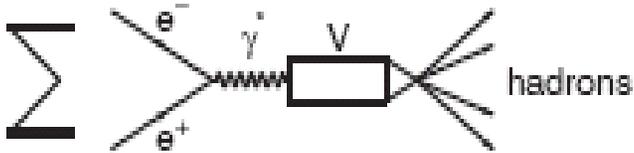
$E_{cm} < 2.0$ GeV: QED过程 + 矢量介子产生

$2.0 < E_{cm} < 3.0$ GeV: QED过程 + 连续强子产生

$3 < E_{cm} < 5.0$ GeV: QED过程 + 矢量介子产生
+ 连续强子产生



(a)



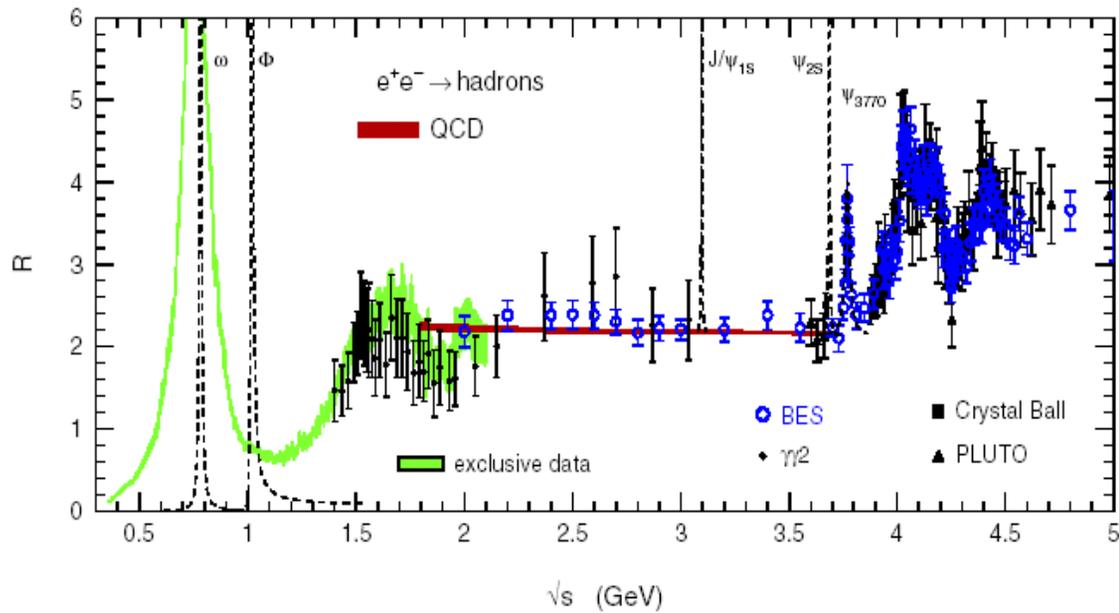
(b)

ϕ, ω, ρ, ψ



(c)

quarks



$\psi(3770)$, $\psi(4040)$, $\psi(4016)$ 等衰变可以产生粲介子对。

Charm Meson Production

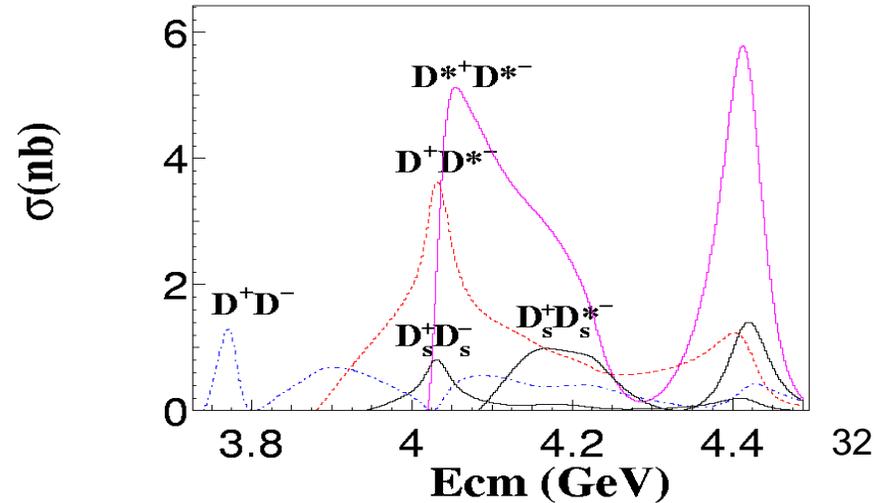
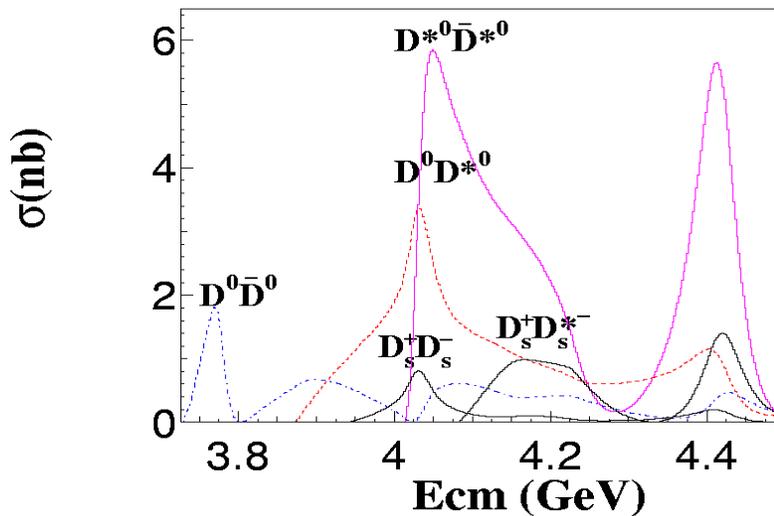
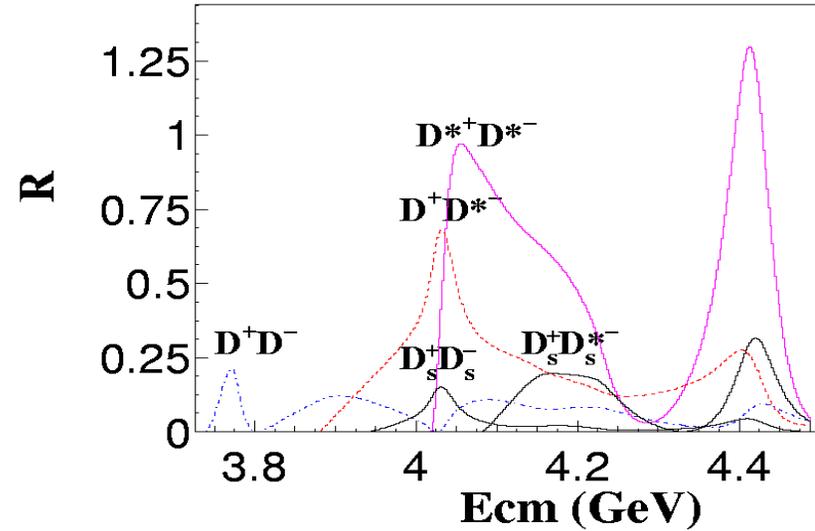
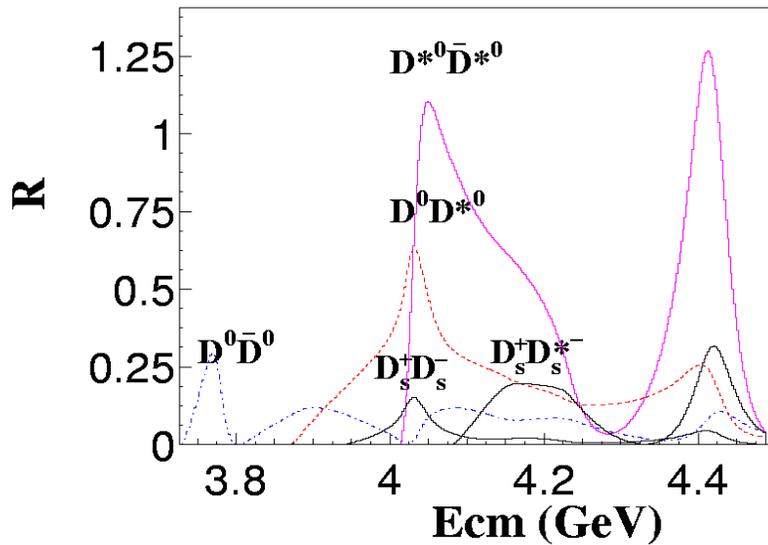
J/ψ 或 $\psi(3686)$ 都不能通过强或电磁作用衰变到 $D\bar{D}$ 。

1D-波为主的 $\psi(3770)$ 质量高于 $D^0\bar{D}^0$ 和 D^+D^- 对产生阈能量， $\psi(3770)$ 是研究D介子衰变的最理想的源。

以3S-波为主的 $\psi(4040)$ 质量高于 $D_s^+D_s^-$ 对产生阈能量，它是研究 D_s^+ 介子衰变的最理想的实验室。

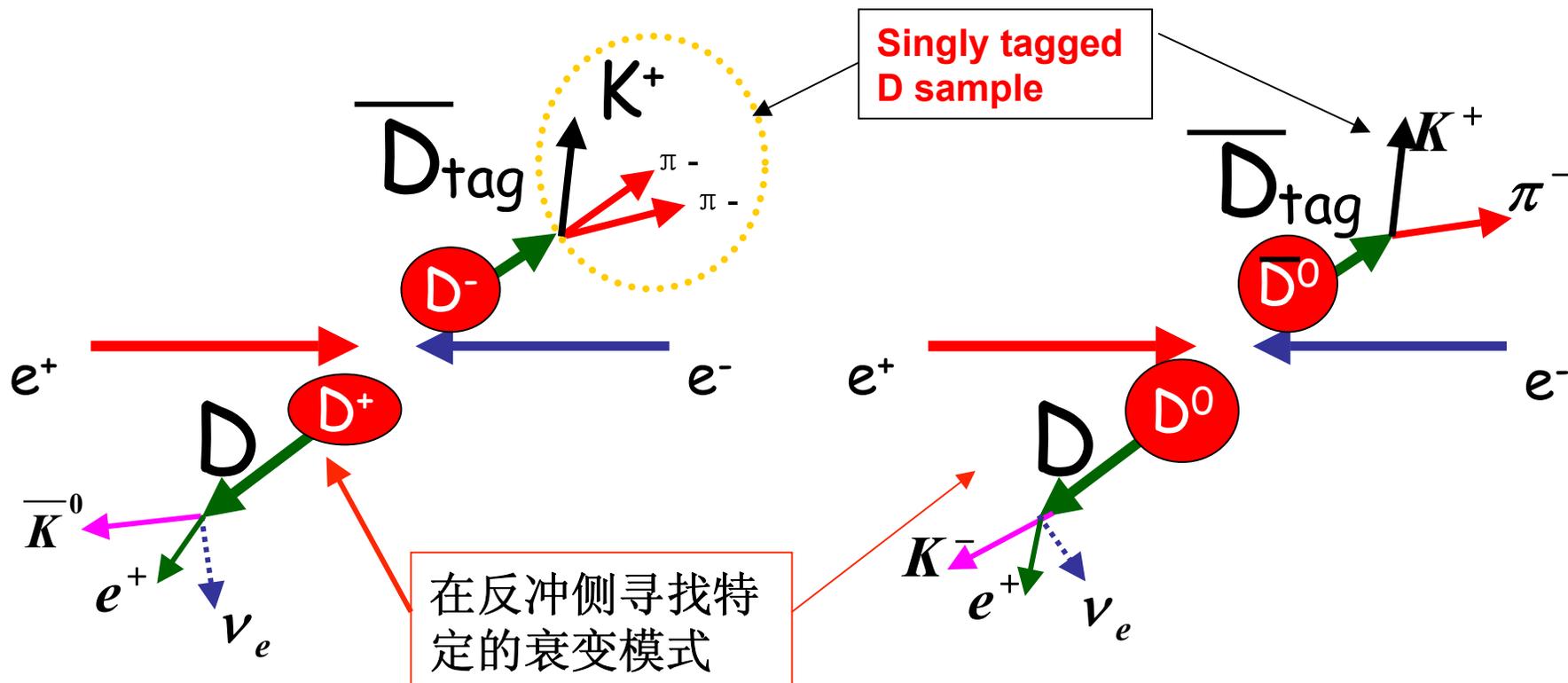
Charm Meson Production

理论(Eichten Model)预期截面



Single & Double Tag Analyses

绝对测量

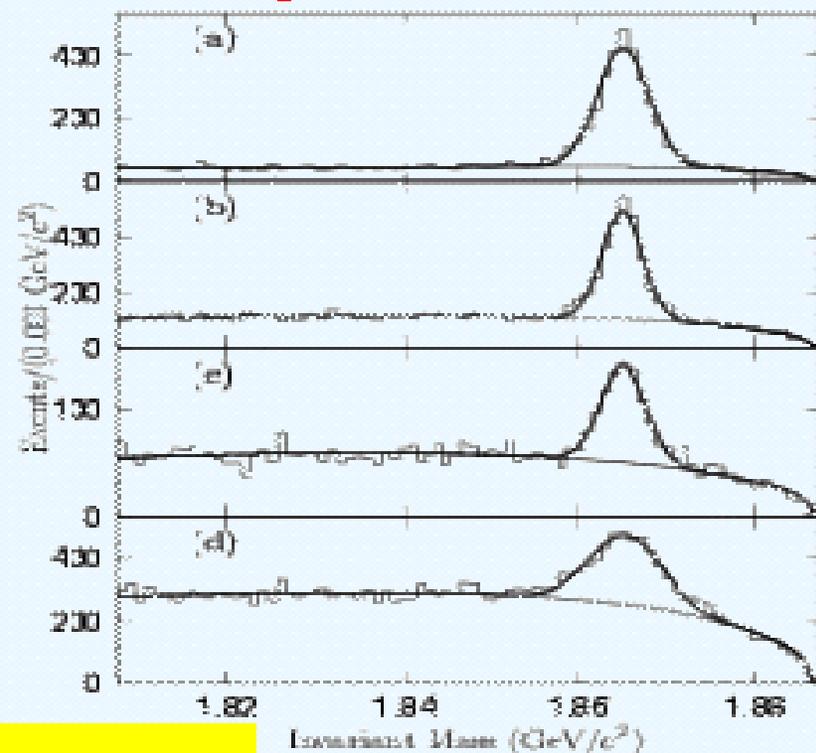
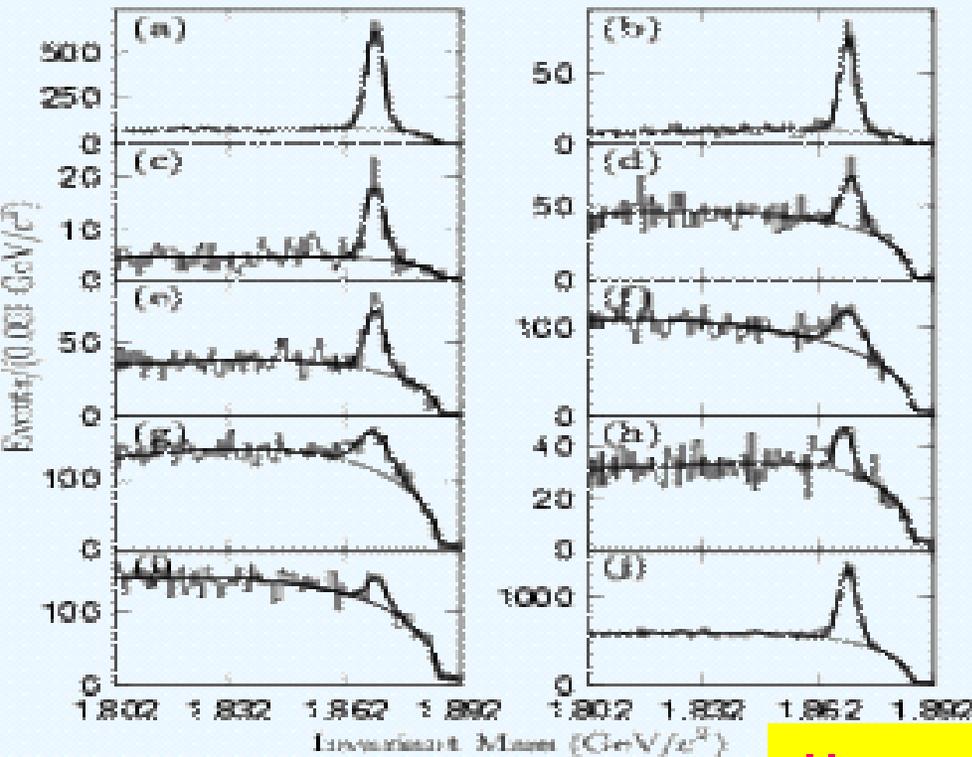


Single & Double Tags

Singly tagged \bar{D} samples

$$N_{D^- \text{ Tag}} = 5321 \pm 125 \pm 160$$

$$N_{D^0 \text{ Tag}} = 7584 \pm 198 \pm 241$$



Mass [m K n π]

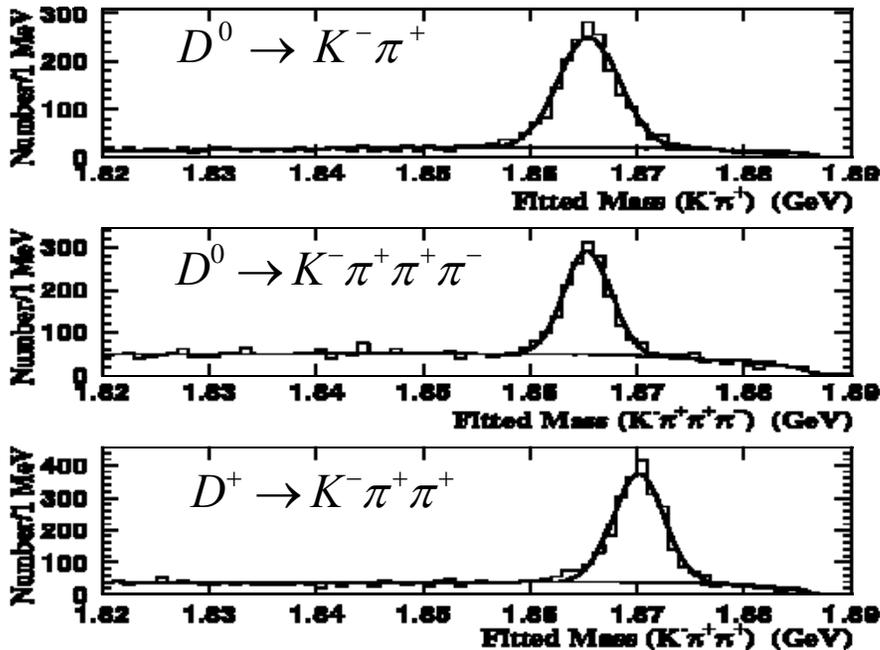
Singly tagged D^- modes: (a) $K^+ \pi^- \pi^-$;
 (b) $K^0 \pi^-$; (c) $K^0 K^-$; (d) $K^+ K^- \pi^-$;
 (e) $K^0 \pi^- \pi^- \pi^+$; (f) $K^+ \pi^- \pi^- \pi^0$; (g) $K^0 \pi^- \pi^0$;
 (h) $K^+ \pi^- \pi^- \pi^+$; (i) $\pi^- \pi^- \pi^+$; (j) Sum

Singly tagged D^0 modes: (a) $K^+ \pi^-$;
 (b) $K^+ \pi^- \pi^- \pi^+$;
 (c) $K^0 \pi^- \pi^+$; (d) $K^+ \pi^- \pi^0$

Charm Meson Production

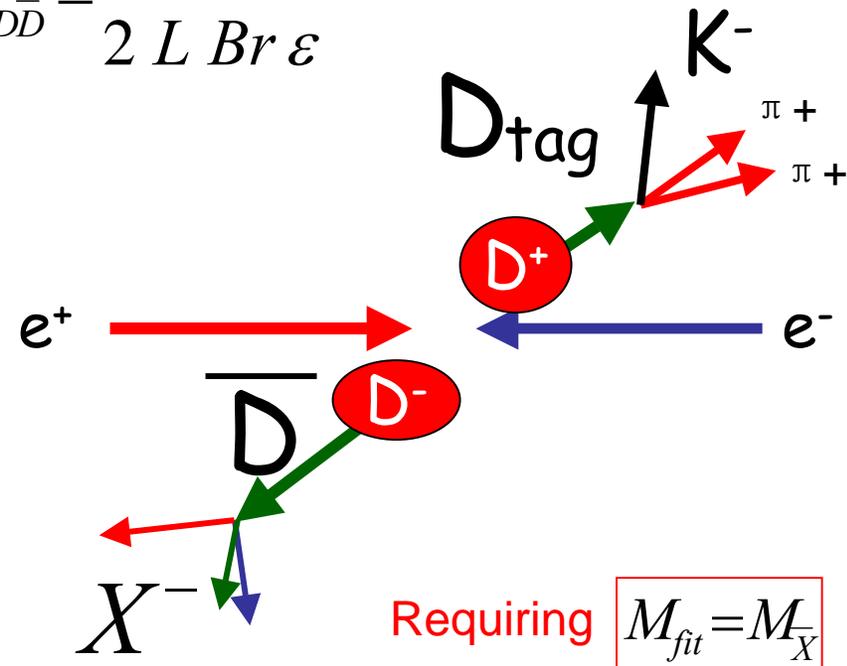
$L = 17.3 \text{ pb}^{-1}$ of data @ 3.773 GeV

Single tag method



Using Kinematic fit method to improve momentum resolution and select the singly tagged D meson

$$\sigma_{D\bar{D}}^{obs} = \frac{N_{D_{tag}}}{2 L Br \varepsilon}$$



Observed cross sections for $D\bar{D}$ -bar production at 3.773 GeV

$$\begin{aligned} \sigma_{D^0 \bar{D}^0}^{obs} &= 3.58 \pm 0.09 \pm 0.31 \text{ nb} \\ \sigma_{D^+ D^-}^{obs} &= 2.56 \pm 0.08 \pm 0.26 \text{ nb} \\ \sigma_{D \bar{D}}^{obs} &= 6.14 \pm 0.12 \pm 0.50 \text{ nb} \end{aligned}$$

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Charm Meson Production

Double tag method

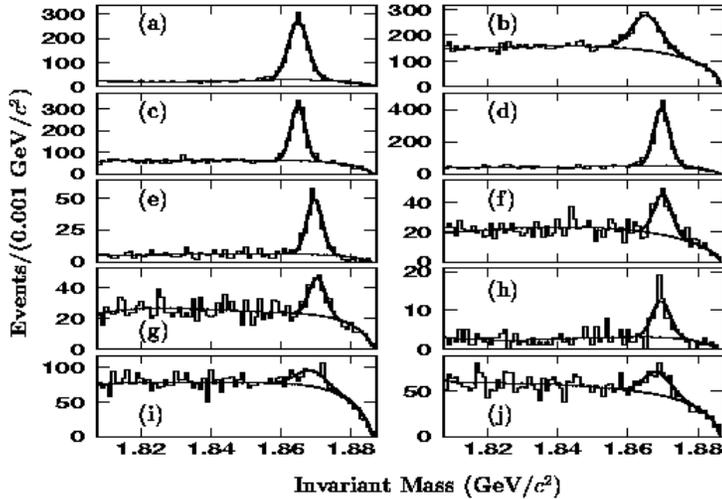


FIG. 1: The distribution of the invariant masses of the $nK\bar{v}n\bar{v}$ ($n=1,2$; $\bar{v}n=1,2,3$) combinations for the single tag modes: (a) $D^0 \rightarrow K^-\pi^+$, (b) $D^0 \rightarrow K^-\pi^+\pi^0$, (c) $D^0 \rightarrow K^-\pi^+\pi^+\pi^-$, (d) $D^+ \rightarrow K^-\pi^+\pi^+$, (e) $D^+ \rightarrow K_S^0\pi^+$, (f) $D^+ \rightarrow K_S^0\pi^+\pi^+$, (g) $D^+ \rightarrow K^-\pi^+\pi^+$, (h) $D^+ \rightarrow K_S^0\pi^+$, (i) $D^+ \rightarrow K^-\pi^+\pi^+\pi^0$, (j) $D^+ \rightarrow K_S^0\pi^+\pi^0$.

$$\chi^2 = \sum_i \left(\frac{N_x(i) - N_x^{\text{net}}(i)}{\sigma_{N_x(i)}^{\text{net}}} \right)^2 + \sum_{ij} \left(\frac{N_d(i,j) - N_d^{\text{net}}(i,j)}{\sigma_{N_d(i,j)}^{\text{net}}} \right)^2$$

$$\sigma_{D^0 D^0}^{\text{obs}} = 3.47 \pm 0.32 \pm 0.21 \text{ nb}$$

$$\sigma_{D^+ D^-}^{\text{obs}} = 2.46 \pm 0.33 \pm 0.20 \text{ nb}$$

$$\sigma_{D\bar{D}}^{\text{obs}} = 5.93 \pm 0.46 \pm 0.35 \text{ nb}$$

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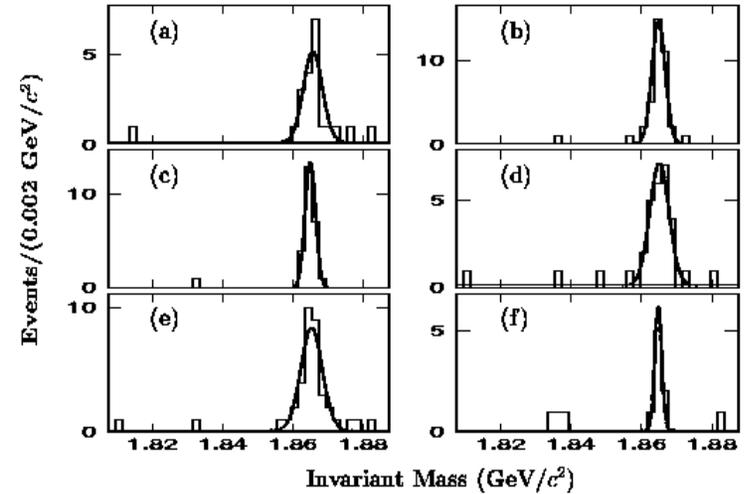


FIG. 2: Distribution of the invariant masses for $K\bar{v}n\bar{v}$ ($n=1, 2, \text{ or } 3$) combinations of six double tag $D^0\bar{D}^0$ modes: (a) $D^0 \rightarrow K^-\pi^+$ vs $\bar{D}^0 \rightarrow K^+\pi^-$, (b) $D^0 \rightarrow K^-\pi^+\pi^0$ vs $\bar{D}^0 \rightarrow K^+\pi^-\pi^0$, (c) $D^0 \rightarrow K^-\pi^+\pi^+\pi^-$ vs $\bar{D}^0 \rightarrow K^+\pi^-\pi^-\pi^+$, (d) $D^0 \rightarrow K^-\pi^+\pi^0$ vs $\bar{D}^0 \rightarrow K^+\pi^-\pi^0$, (e) $D^0 \rightarrow K^-\pi^+\pi^+$ vs $\bar{D}^0 \rightarrow K^+\pi^-\pi^+$, (f) $D^0 \rightarrow K^-\pi^+\pi^+\pi^0$ vs $\bar{D}^0 \rightarrow K^+\pi^-\pi^+\pi^0$.

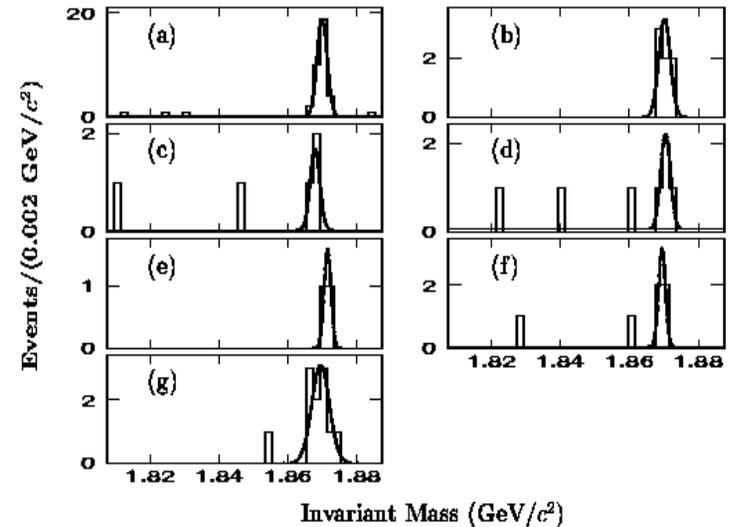
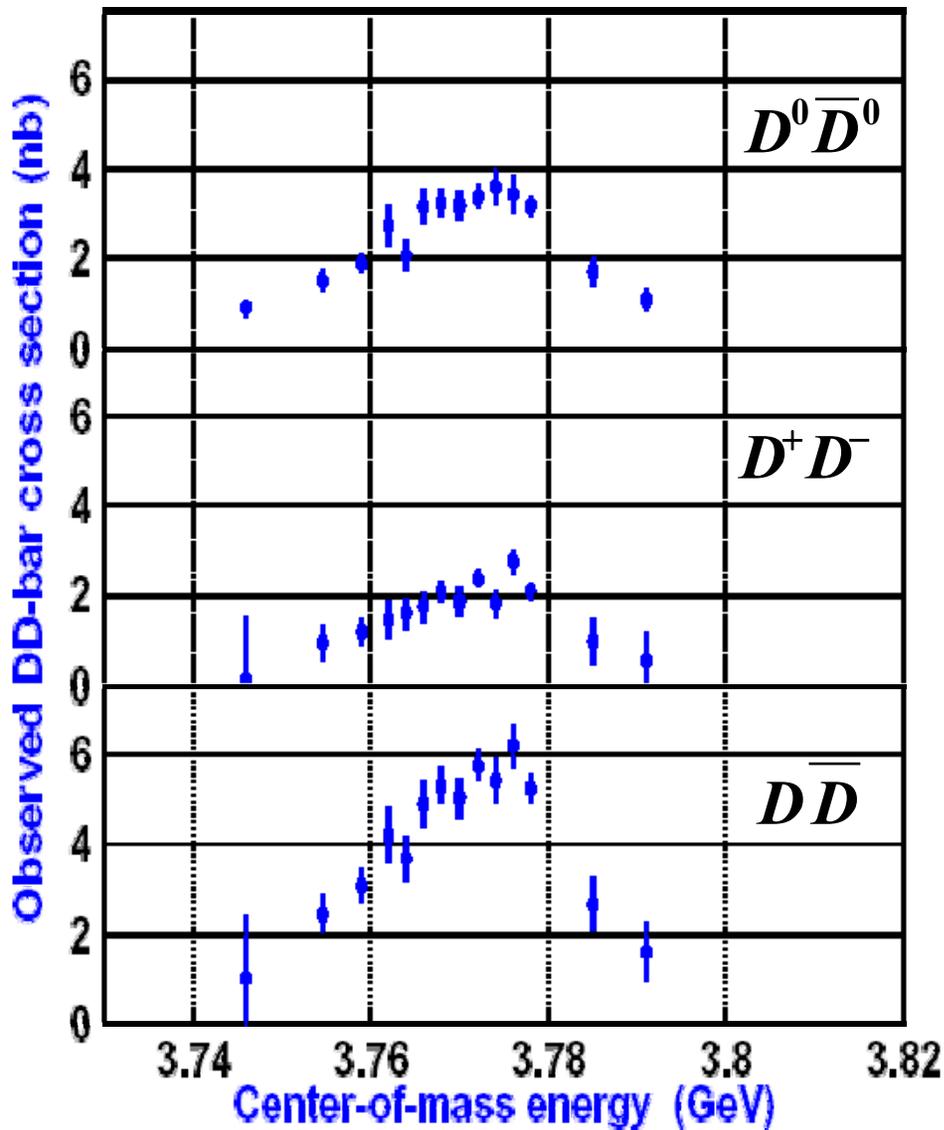


FIG. 3: Distribution of the invariant masses for $K^-\pi^+\pi^+$ combinations of seven double tag D^+D^- modes: (a) $D^+ \rightarrow K^-\pi^+\pi^+$ vs $D^- \rightarrow K^+\pi^-\pi^-$, (b) $D^+ \rightarrow K^-\pi^+\pi^+$ vs $D^- \rightarrow K_S^0\pi^-$, (c) $D^+ \rightarrow K^-\pi^+\pi^+\pi^0$ vs $D^- \rightarrow K_S^0\pi^-\pi^-\pi^+$, (d) $D^+ \rightarrow K^-\pi^+\pi^+$ vs $D^- \rightarrow K^-\pi^+\pi^-$, (e) $D^+ \rightarrow K^-\pi^+\pi^+$ vs $D^- \rightarrow K_S^0K^-$, (f) $D^+ \rightarrow K^-\pi^+\pi^+$ vs $D^- \rightarrow K^+\pi^-\pi^0$, (g) $D^+ \rightarrow K^-\pi^+\pi^+$ vs $D^- \rightarrow \bar{K}^0\pi^-\pi^0$, where the shadow part is background study from Monte Carlo simulation.

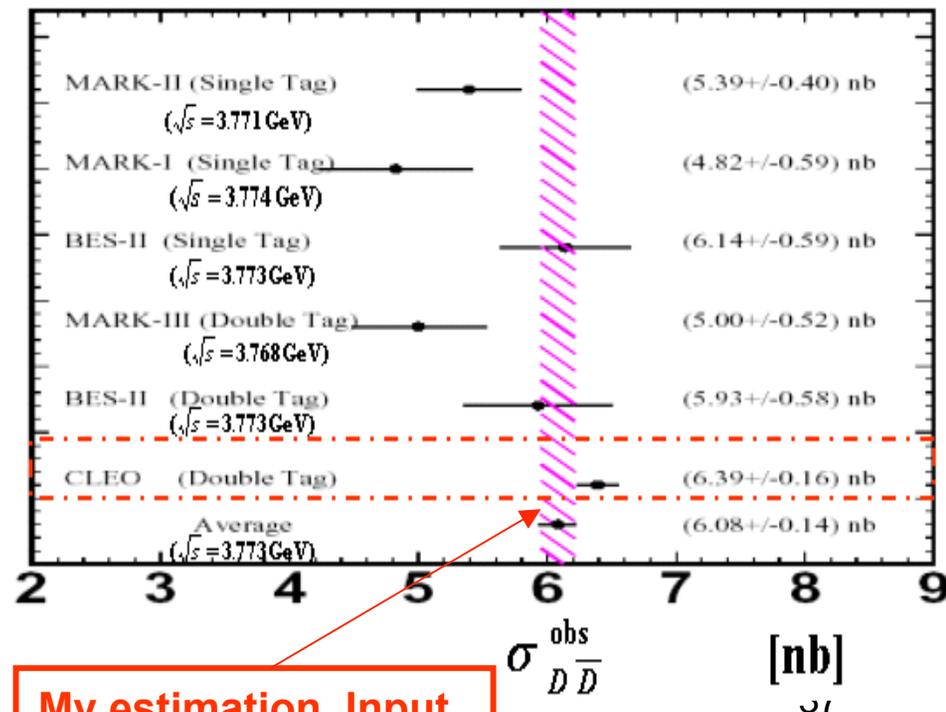
An absolute measurement

Charm Meson Production

BES-II 实验结果



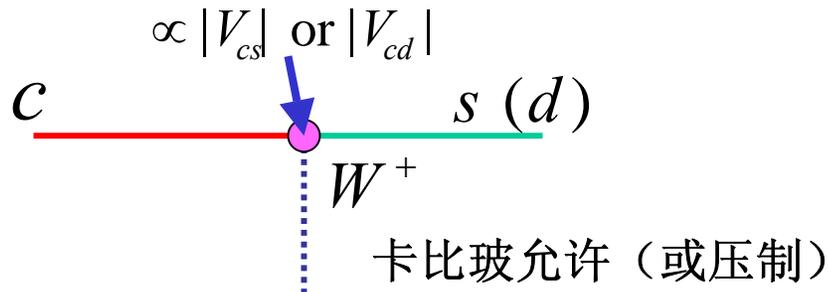
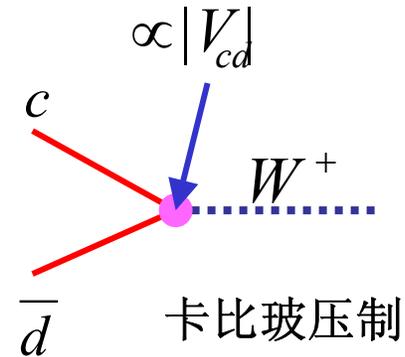
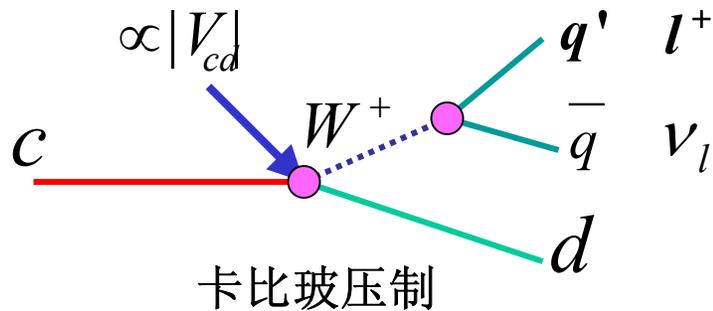
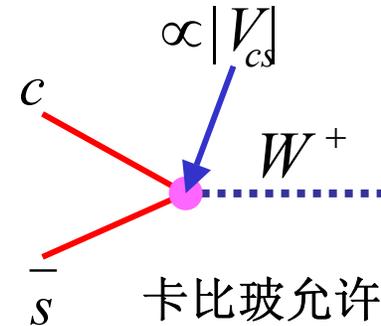
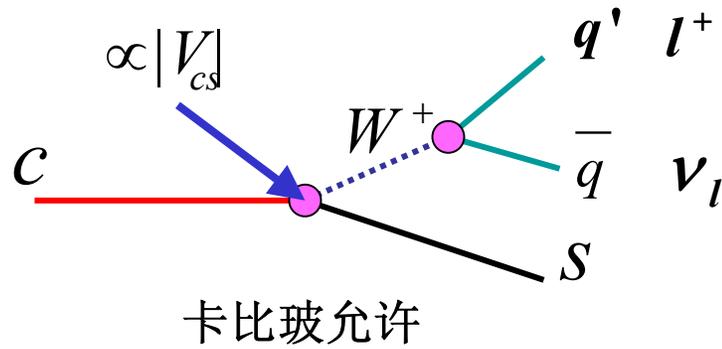
Comparison of measurements of the cross sections for $D\bar{D}$ production



My estimation, Input with PDG04 Br

c Quark Decays

At tree level



Charmed Meson Decays

赝标粲介子只通过弱相互作用发生衰变。根据末态产物不同，其衰变可以分为三种类型：

- 1) 纯轻子衰变 (**Leptonic decays**)
 - 2) 半轻子衰变 (**Semileptonic decays**)
 - 3) 非轻子衰变 (**non-leptonic decays**) 或 强子衰变 (**Hadronic decays**)
- 纯轻子衰变 (**Leptonic decays**)

末态中仅有轻子的衰变过程为纯轻子衰变过程。

$$D^+ \rightarrow \mu^+ \nu, \tau^+ \nu, e^+ \nu,$$

$$D_s^+ \rightarrow \mu^+ \nu, \tau^+ \nu, e^+ \nu,$$

纯轻子衰变过程中，由于末态无强子，因此，理论上最容易处理。理论计算可以给出准确的衰变宽度公式。

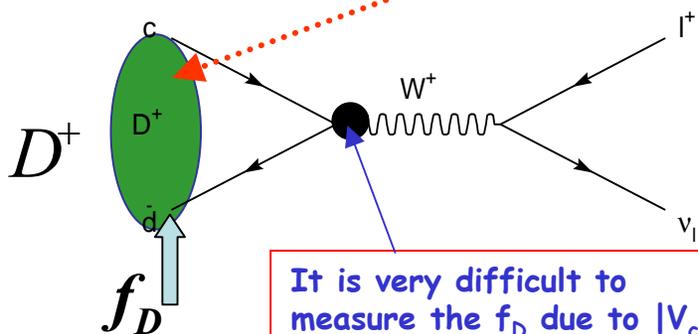
Charmed Meson Decays

Leptonic decays

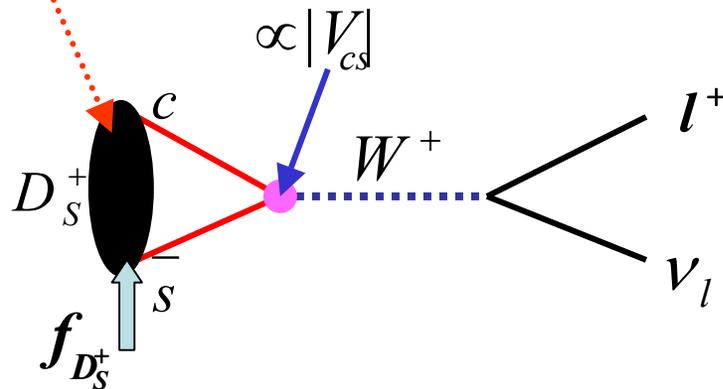
$$D^+ \rightarrow \mu^+ \nu$$

$$D_S^+ \rightarrow \mu^+ \nu$$

在纯轻子衰变的理论处理中，强作用的总体效应可以被参数化到衰变常数 f_{D^+} ($f_{D_S^+}$) 中去。



It is very difficult to measure the f_D due to $|V_{cd}|$



$$\Gamma(D^+ \rightarrow l^+ \nu) = \frac{G_F^2 |V_{cd}|^2}{8\pi} f_{D^+}^2 m_{D^+} m_l \tau_{D^+} \left(1 - \frac{m_l^2}{m_{D^+}^2}\right)^2$$

在粲介子物理中，衰变常数是一个很重要的量，在理论和实验物理中都有很多重要的应用。实验上通过测量衰变分支比，可以确定衰变常数。

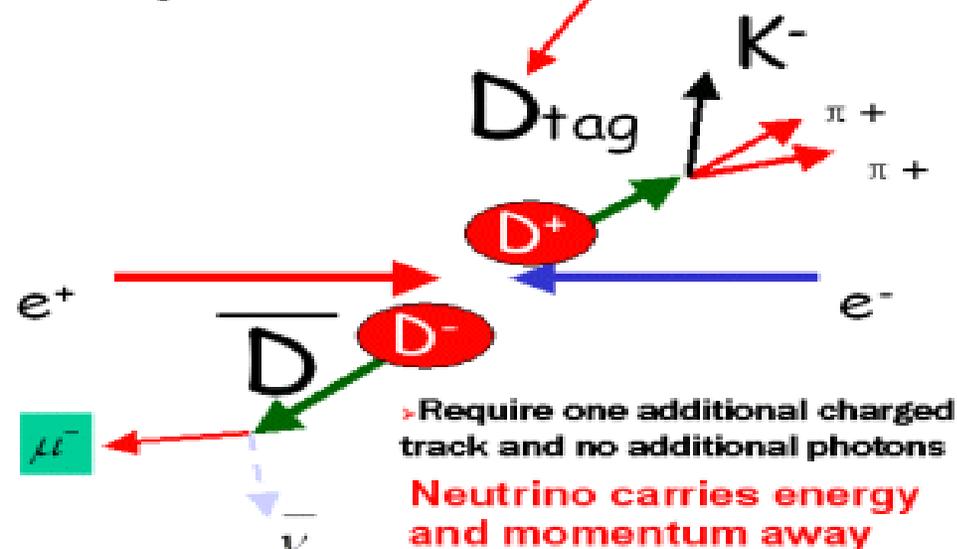
Charmed Meson Decays

实验方法

根据末态丢失中微子的特征，实验上利用测定事例中丢失质量和丢失能量的方法，重建出纯轻子衰变的事例。

Fully reconstruct one D

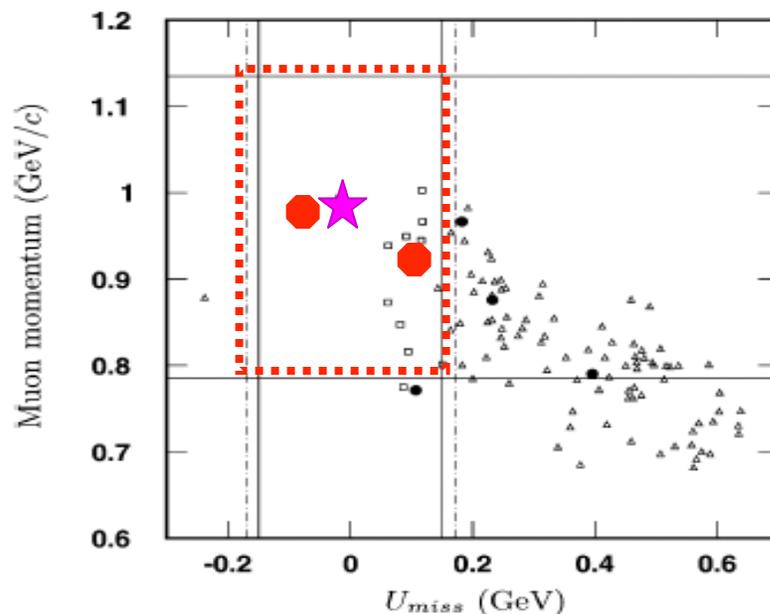
$$N_{D_{\text{tag}}} = 5321 \pm 128$$



3 events found

$$U_{\text{miss}} = E_{\text{miss}} - P_{\text{miss}}$$

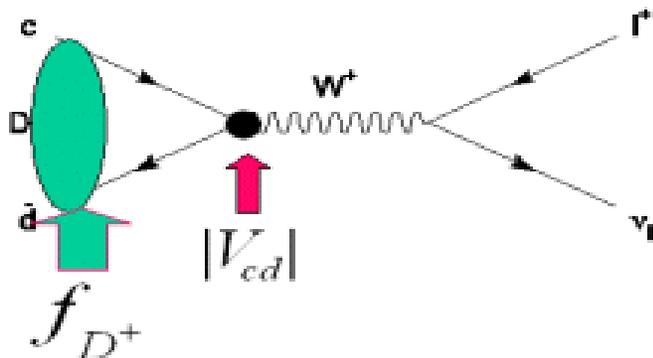
Should be around zero



观测到3个事例

Charmed Meson Decays

Measurement of f_{D^+} at BES-II



$$Br(D^+ \rightarrow l^+ \nu) = \frac{G_F^2 |V_{cd}|^2}{8\pi} f_D^2 m_D m_l \tau_D \left(1 - \frac{m_l^2}{m_D^2}\right)^2$$

$$Br(D^+ \rightarrow \mu^+ \nu) = (0.120_{-0.063-0.009}^{+0.092+0.010})\%$$

$$f_{D^+} = (365_{-113-28}^{+121+32}) \text{ MeV}$$

Measurement of $f_{D_S^+}$ at BES-I

观测到3个 $D_S^+ \rightarrow \mu^+ \nu, \tau^+ \nu$ 事例

$$f_{D_S^+} = (4.3_{-1.3-0.4}^{+1.5+0.4}) \times 10^2 \text{ MeV}$$

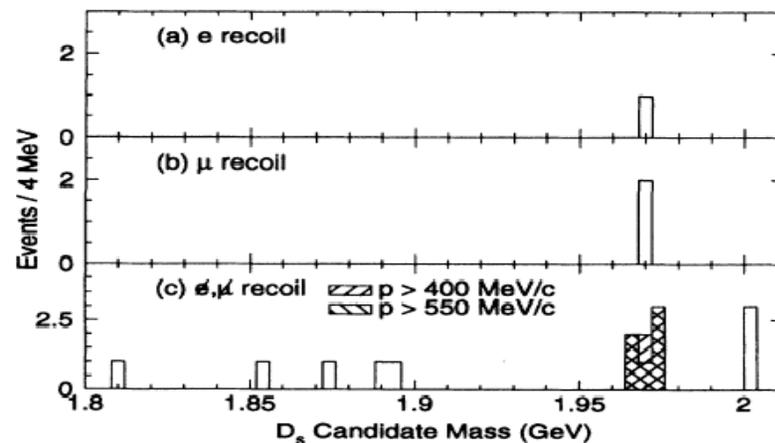
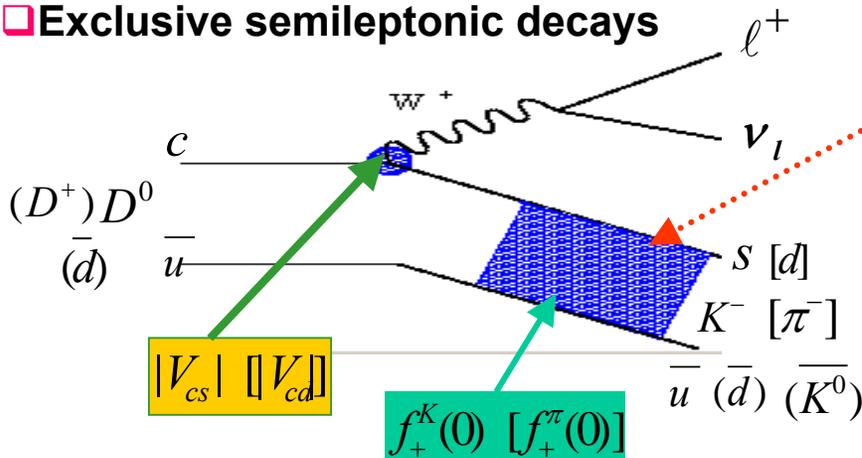


FIG. 2. The distribution of Fig. 1(d) requiring that the recoil system consist of a single charged track identified as (a) an electron; (b) a muon; (c) neither an electron nor a muon. Shading in (c) indicates signal region events which satisfy the lepton kinematic requirements described in the text.

Charmed Meson Decays

•半轻子衰变 (Semileptonic decays)

□ Exclusive semileptonic decays



Strong interaction effects are parameterized by the form factor(s).

CKM 矩阵元, V_{cs}, V_{cd} ,

形状因子 $f_+^K(0)$ $[f_+^\pi(0)]$

很多理论可以计算形状因子。通过对比, 可以检测和发展各种理论模型。

$$A_{SL}(D \rightarrow Kl^+\nu) = \frac{G_F}{\sqrt{2}} V_{cs} L^\mu H_\mu$$

$$H_\mu = (p_D + p_K) f_+^K(q)$$

$$\frac{d\Gamma(D \rightarrow Pl\nu)}{dq^2} = \frac{G_F^2}{24\pi^3} p_P^3 |V_{cq}|^2 |f_+(q^2)|^2$$

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

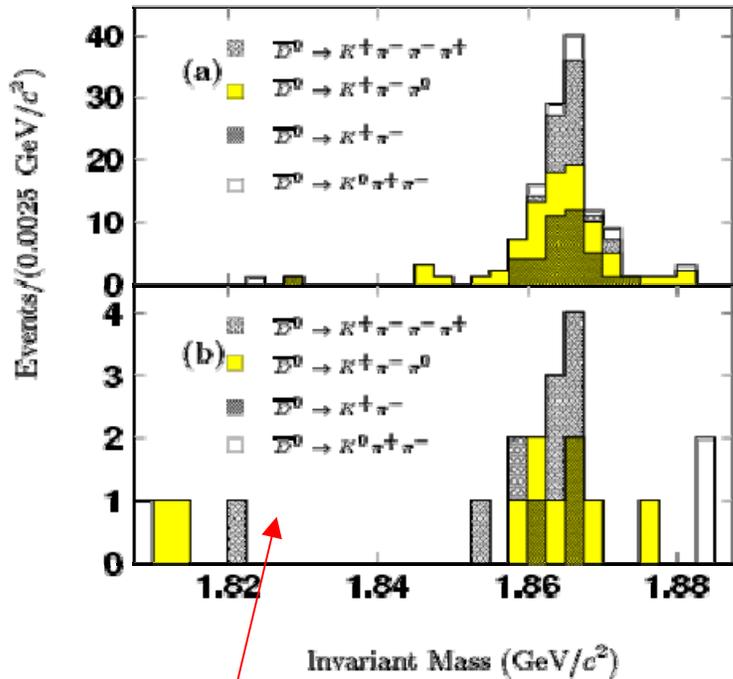
$$\Gamma(D^0 \rightarrow K^- e^+ \nu) = 1.53 |V_{cs}|^2 |f_+^K(0)|^2 \times 10^{11} s^{-1}$$

$$\Gamma(D^0 \rightarrow \pi^- e^+ \nu) = 3.01 |V_{cd}|^2 |f_+^\pi(0)|^2 \times 10^{11} s^{-1}$$

实验上只要我们测出衰变分支比, 就可以测定 $|V_{cs}|^2 |f_+^K(0)|^2$ 和 $|V_{cd}|^2 |f_+^\pi(0)|^2$

Charmed Mesons Decays

$K^- e^+ \nu_e$ (found in REC of \bar{D}^0 tags.)



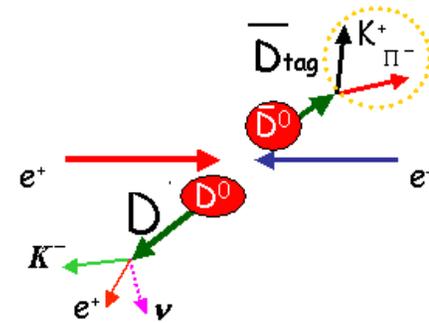
$\pi^- e^+ \nu_e$ (found in REC of \bar{D}^0 tags.)

	BESII(%)	CLEO(%)
$Br(D^0 \rightarrow K^- e^+ \nu_e)$	$3.83 \pm 0.40 \pm 0.27$	$3.44 \pm 0.10 \pm 0.10$
$Br(D^0 \rightarrow \pi^- e^+ \nu_e)$	$0.33 \pm 0.13 \pm 0.03$	$0.262 \pm 0.025 \pm 0.008$

CKM matrix elements

$ V_{cs} $	$ V_{cd} $	$f_+^{K(\pi)}(0)$ input
$0.998 \pm 0.052 \pm 0.145$	$0.251 \pm 0.049 \pm 0.044$	QCDSR [4]
$1.097 \pm 0.057^{+0.061}_{-0.124}$	$0.255 \pm 0.050^{+0.023}_{-0.036}$	LQCD1 [5]
$1.180 \pm 0.062^{+0.085}_{-0.083}$	$0.286 \pm 0.056^{+0.033}_{-0.033}$	LQCD2 [6]
0.996 ± 0.013	0.224 ± 0.016	PDG

	BES	MARKIII [1]
$ V_{cd}/V_{cs} ^2$	$0.043 \pm 0.017 \pm 0.003$	$0.057^{+0.038}_{-0.015} \pm 0.005$



首先重建 \bar{D}^0 , 然后重建 $D^0 \rightarrow K^- e^+ \nu_e$

Form factors

	$ f_+^K(0) $	$ f_+^\pi(0) $
QCDSR [4]	0.78 ± 0.11	0.65 ± 0.11
LQCD1 [5]	$0.71 \pm 0.03^{+0.00}_{-0.07}$	$0.64 \pm 0.05^{+0.00}_{-0.07}$
LQCD2 [6]	$0.66 \pm 0.04^{+0.01}_{-0.00}$	$0.57 \pm 0.06^{+0.01}_{-0.00}$
BES	$0.78 \pm 0.04 \pm 0.03$	$0.73 \pm 0.14 \pm 0.06$

$$\left| \frac{f_+^\pi(0)}{f_+^K(0)} \right| = 0.93 \pm 0.19 \pm 0.07$$

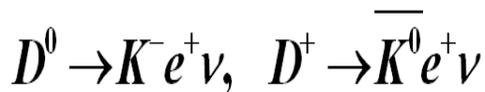
PLB597(2004)39

PRL95(2005)181802

Charm Meson Decays

The 'long-standing puzzle' of whether the Isospin conservation holds in the exclusive semi-leptonic decays of D mesons ?

半轻子衰变的研究

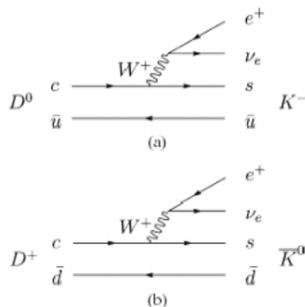


Motivation

Isospin conservation implies

$$\Gamma(D^0 \rightarrow K^- e^+ \nu_e) / \Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e) = 1$$

$$\Gamma(D^0 \rightarrow K^- e^+ \nu_e) / \Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e) = 1.4 \pm 0.2$$



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mu道的测定结果，
联合电子道，得到：

Measurement of the ratio
of the partial widths

	BES	MARK III	PDG02
$\frac{\Gamma(D^0 \rightarrow K^- l^+ \nu_e)}{\Gamma(D^+ \rightarrow \bar{K}^0 l^+ \nu_e)}$	$1.00 \pm 0.17 \pm 0.06$	1.44 ± 0.62	1.4 ± 0.2

Obtained based on the branching
fractions quoted from PDG02

BES-II 实验结果支持“D介子半轻子衰变过程中同位旋守恒”。Solved the long-standing puzzle in D decays !

23

	BES	MARK III	PDG02
$\frac{\Gamma(D^0 \rightarrow K^- e^+ \nu_e)}{\Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e)}$	$1.08 \pm 0.22 \pm 0.07$	1.44 ± 0.62	1.4 ± 0.2

Obtained based on the branching
fractions quoted from PDG02

BES-II 实验结果支持“D介子半轻子衰变过程中同位旋守恒”。解决了粲介子物理领域内过去二十年中存在的一个“Puzzle”。

CLEO-c confirmed the BES-II result

$$\frac{\Gamma(D^0 \rightarrow K^- e^+ \nu_e)}{\Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e)} = 1.00 \pm 0.05 \pm 0.04$$

Moriond EW04 (2004 年 3 月)
ICHEP'04

Paper published in
PLB 608 (2005) 24

Charmed Meson Decays

从粲介子弱衰变的旁观者模型，可以得出两个结论：

- 1) 所有粲介子的寿命或总宽度都相等。
- 2) 粲介子的单举半轻子衰变分支比约为**20%**。

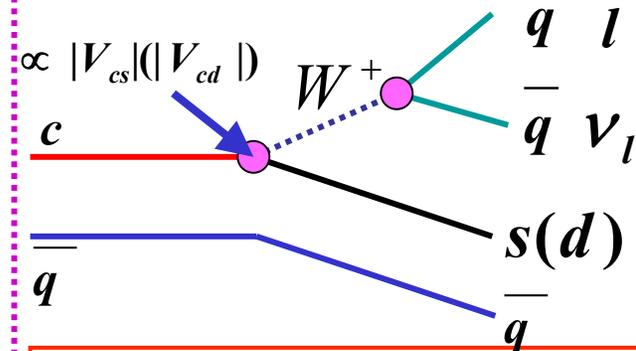
精密的寿命测量实验给出粲介子的寿命

$$\tau_{D^0} = (410.1 \pm 1.5) \times 10^{-15} \text{ s}$$

$$\tau_{D^+} = (1040.1 \pm 7) \times 10^{-15} \text{ s}$$

$$\tau_{D_S^+} = (500 \pm 7) \times 10^{-15} \text{ s}$$

早期的认识— \bar{q} 仅是旁观者



$$B(D \rightarrow X l^+ \nu) = 1/(n_l + n_c) = 20\%$$

$$n_l = 2; \quad n_c = 3$$

$$\frac{\tau_{D^+}}{\tau_{D^0}} = (2.54 \pm 0.02)$$

为什么寿命相差如此之大？究竟是什么因素导致这三个赝标粲介子总宽度不同？它们的巨大差异是来自非强子衰变道还是来自半轻子衰变道？如果旁观者半轻子衰变机制是正确的，则：

$$\Gamma_{SL}(D^+ \rightarrow l^+ X) = \Gamma_{SL}(D^0 \rightarrow l^+ X) = \Gamma_{SL}(D_S^+ \rightarrow l^+ X)$$

Charmed Meson Decays

□ Inclusive semileptonic decays (单举半轻子衰变)

The semileptonic decays of charmed mesons occur primarily through the beta decay of the charmed quark.

旁观者模型

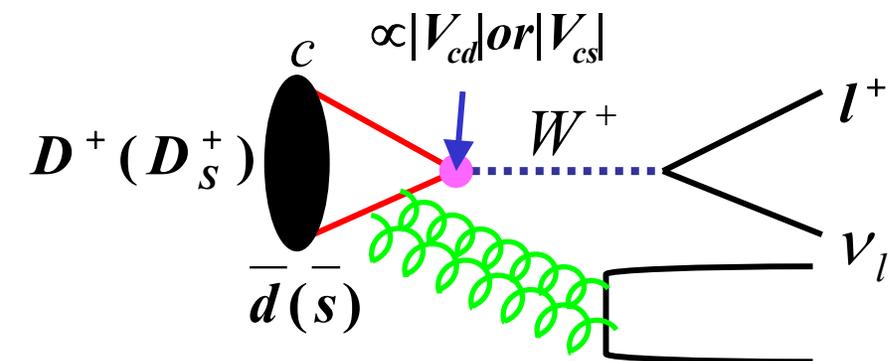
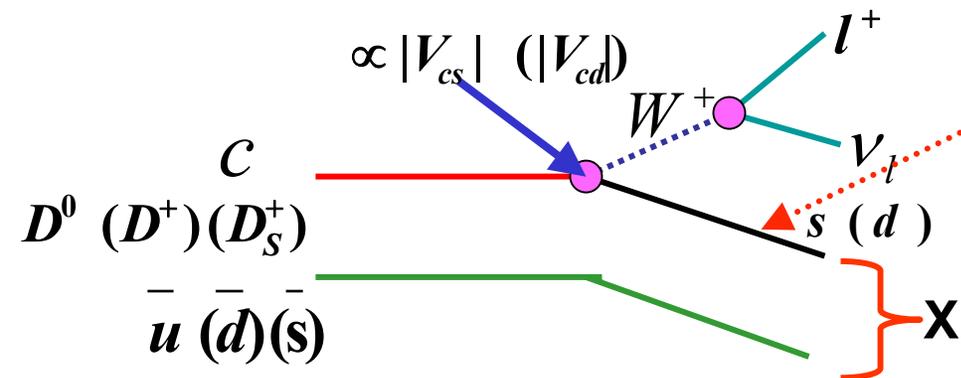
$$\Gamma_{SL}(D \rightarrow X \ell^+ \nu_\ell) = \Gamma_0 \equiv \frac{G_F^2}{192 \pi^2} m_c^5 f\left(\frac{m_s}{m_c}\right)$$

In this picture, the decay rates satisfy:

$$\Gamma_{SL}(D^+) = \Gamma_{SL}(D^0) = \Gamma_{SL}(D_S^+)$$

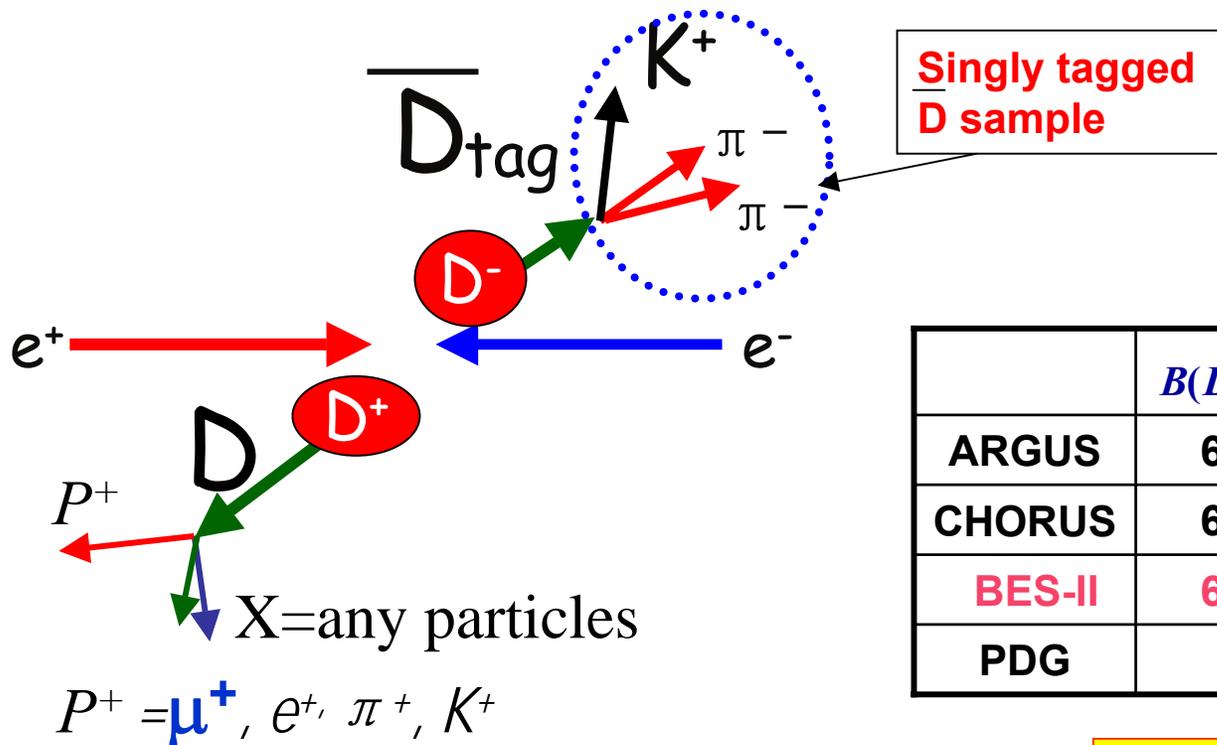
Any differences in the total decay rate are due to the hadronic decays.

比较粲介子的单举半轻子衰变宽度，可以得到有关衰变机制的信息



Charmed Meson Decays

单举半轻子衰变



	$B(D^0 \rightarrow \mu^+ X)(\%)$	$B(D^+ \rightarrow \mu^+ X)(\%)$
ARGUS	$6.0 \pm 0.7 \pm 1.2$	-
CHORUS	$6.5 \pm 1.2 \pm 0.3$	-
BES-II	$6.8 \pm 1.5 \pm 0.6$	$17.6 \pm 0.7 \pm 1.3$
PDG	6.6 ± 0.6	

the first measurement

$$\frac{B(D^+ \rightarrow \mu^+ X)}{B(D^0 \rightarrow \mu^+ X)} = 2.59 \pm 0.70 \pm 0.15$$

$$\frac{\tau_{D^+}}{\tau_{D^0}} = 2.54 \pm 0.02$$

PDG

$$\frac{\Gamma(D^+ \rightarrow e^+ X)}{\Gamma(D^0 \rightarrow e^+ X)} = 0.95 \pm 0.12 \pm 0.07$$

	$B(D^0 \rightarrow e^+ X)(\%)$	$B(D^+ \rightarrow e^+ X)(\%)$
CLEO-c	$6.46 \pm 0.17 \pm 0.13$	$16.13 \pm 0.20 \pm 0.33$
MarkIII	$7.5 \pm 1.1 \pm 0.4$	$17.0 \pm 1.9 \pm 0.7$
BES-II	$6.3 \pm 0.7 \pm 0.4$	$15.2 \pm 0.9 \pm 0.8$
PDG2007	6.55 ± 0.17	16.1 ± 0.4

Charmed Meson Decays - $D_s^+ \rightarrow e + X$

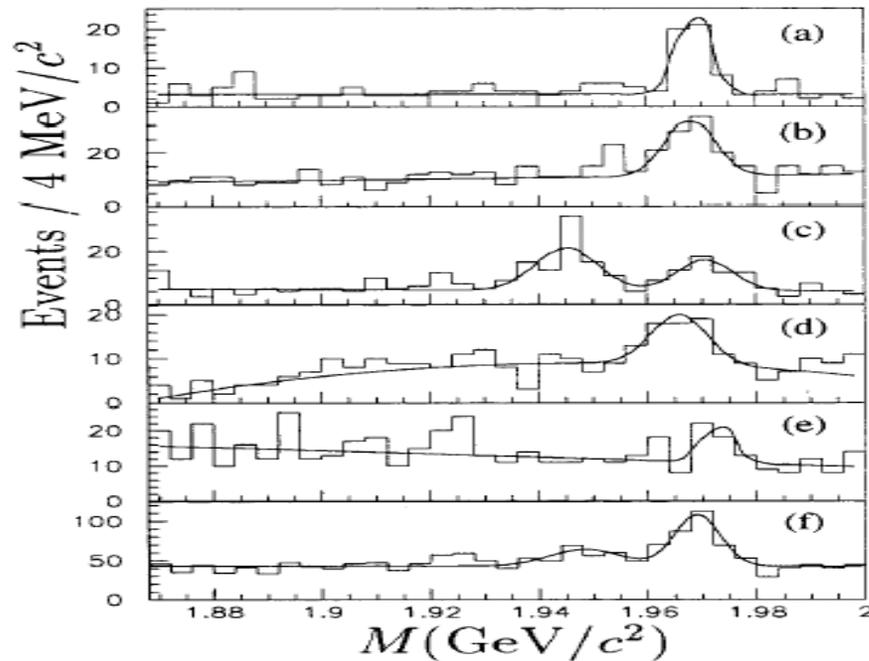


FIG. 1. Mass distribution of D_s single tags. (a) $\phi\pi^+$, (b) $\bar{K}^0 K^+$, (c) $\bar{K}_S^0 K^+$, (d) $K_S^0 K^- \pi^+ \pi^+$, (e) $f_0 \pi^+$, and (f) combined.

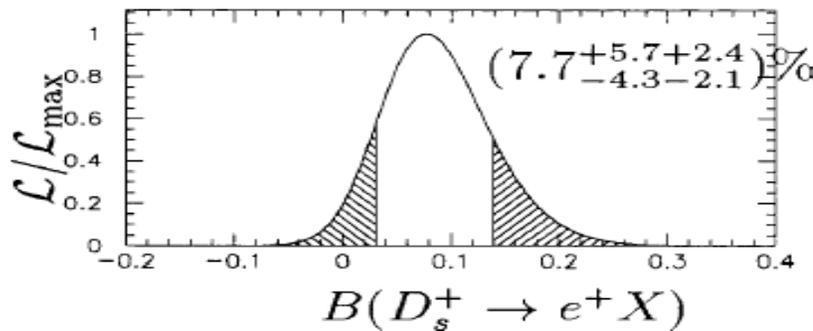


FIG. 3. Normalized likelihood versus branching fraction. The unshaded region, 68.27% of the area to the left (right) of the maximum, defines the error interval. The unphysical region is indicated.

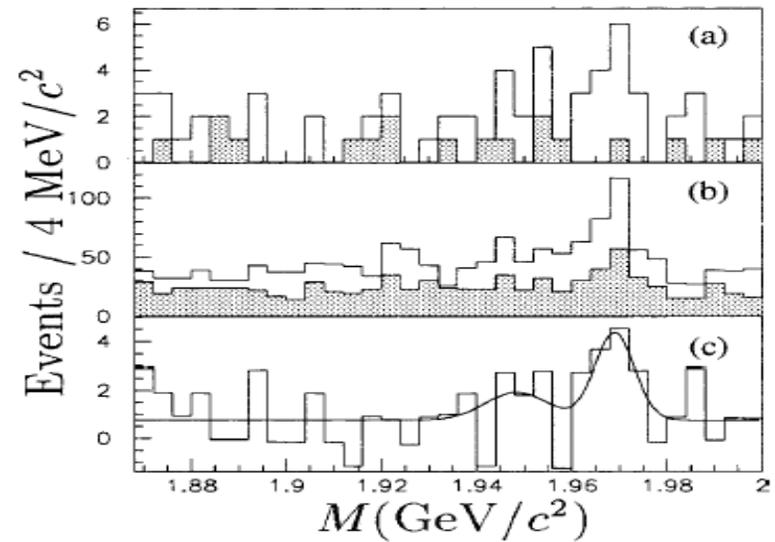


FIG. 2. (a) Single tag mass spectra when a RS (unshaded) and a WS electron (shaded) is detected in the recoil system. (b) Single tag mass spectra when a RS (unshaded) and a WS hadron (shaded) is detected in the recoil system. (c) Single tag mass spectrum of net electrons corrected with charge symmetric background and hadron misidentification.

Our measurement $B(D_s^+ \rightarrow e^+ X) = (7.7_{-4.3-2.1}^{+5.7+2.4})\%$ is consistent with the Mark III [2] upper limit. Our branching fraction corresponds to a D_s semileptonic decay width of $\Gamma(D_s^+ \rightarrow e^+ X) = (1.65_{-0.91-0.45}^{+1.23+0.51}) \times 10^{11} \text{ s}^{-1}$, while D^+ and D^0 measurements [1] lead to $\Gamma(D^+ \rightarrow e^+ X) = (1.63 \pm 0.18) \times 10^{11} \text{ s}^{-1}$ and $\Gamma(D^0 \rightarrow e^+ X) = (1.86 \pm 0.29) \times 10^{11} \text{ s}^{-1}$. The measured semileptonic decays of charmed mesons are consistent with the description of the spectator model, $\Gamma_{\text{SL}}(D^+) \approx \Gamma_{\text{SL}}(D^0) \approx \Gamma_{\text{SL}}(D_s^+)$.

$$\Gamma(D_s^+ \rightarrow e^+ X) = (1.65_{-0.91-0.45}^{+1.23+0.51}) \times 10^{11} \text{ s}^{-1}$$

BES-I

Charmed Meson Decays

结论:

D^0 和 D^+ 的单举半轻子衰变的分宽度相等, 实验结果支持半轻子衰变的旁观者理论模型。

D_S^+ 单举半轻子衰变宽度测定值

$$\Gamma(D_S^+ \rightarrow e^+ X) = (1.65_{-0.91-0.45}^{+1.23+0.51}) \times 10^{11} \text{ s}^{-1}$$

误差太大, 还不能给出很有意义的对比结果, 还须要高精度的实验提高测量精度。这可以在**BES-III/BEPC-II** 实验装置上完成。

在考虑了**QCD**效应之后, 计算给出 $B(c \rightarrow sl^+ \nu) \approx \frac{1}{2c_+^2 + c_-^2 + 2} = 16\%$
($C_+ = 0.74$; $C_- = 1.8$)。

$$B(D^0 \rightarrow e^+ X) = (6.3 \pm 0.7 \pm 0.4)\%$$

$$B(D^0 \rightarrow e^+ X) = (6.7 \pm 0.3)\%$$

$$B(D^+ \rightarrow e^+ X) = (15.2 \pm 0.9 \pm 0.8)\%$$

$$B(D^+ \rightarrow e^+ X) = (17.2 \pm 1.9)\%$$

BES-II

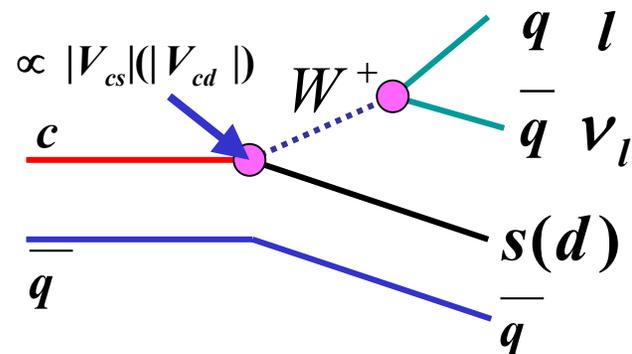
PDG06

Charmed Meson Decays

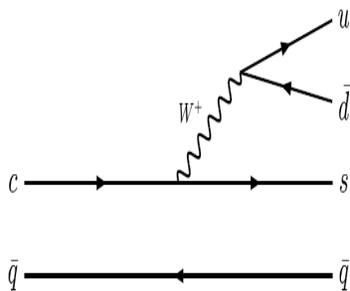
非轻子衰变 (non-leptonic decays)

粲介子寿命的不同和粲介子单举半轻子衰变分支比小于**20%**这些实验事实都说明旁观者模型需要修改。

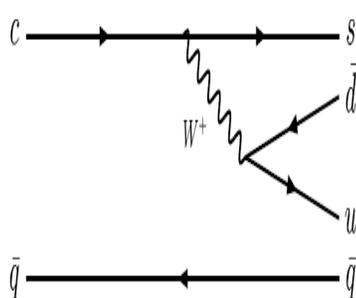
早期的认识— \bar{q} 仅是旁观者



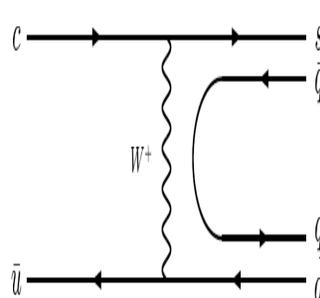
大量实验观测结果和理论研究均表明，总衰变宽度的差异主要来自非轻子衰变道。



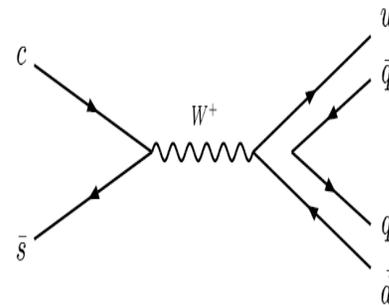
Spectator decays



内W发射



W exchange decay



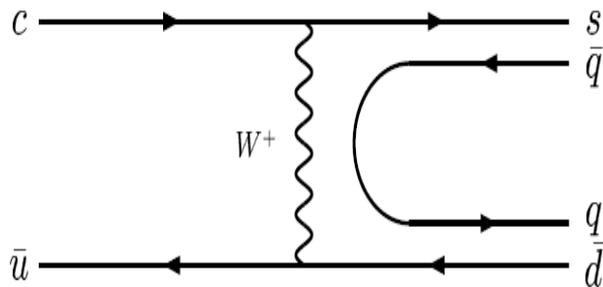
W annihilation decay

Charmed Meson Decays

引起粲介子的寿命差异的主要原因:

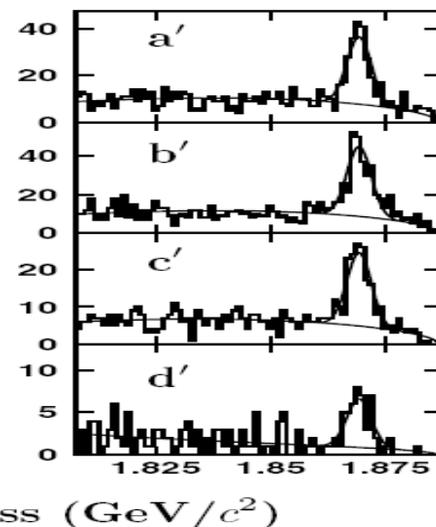
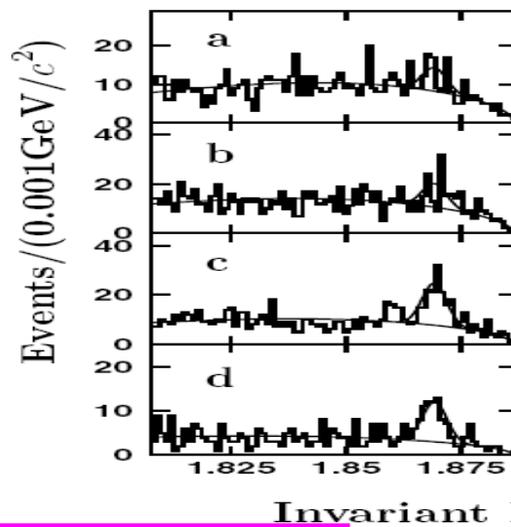
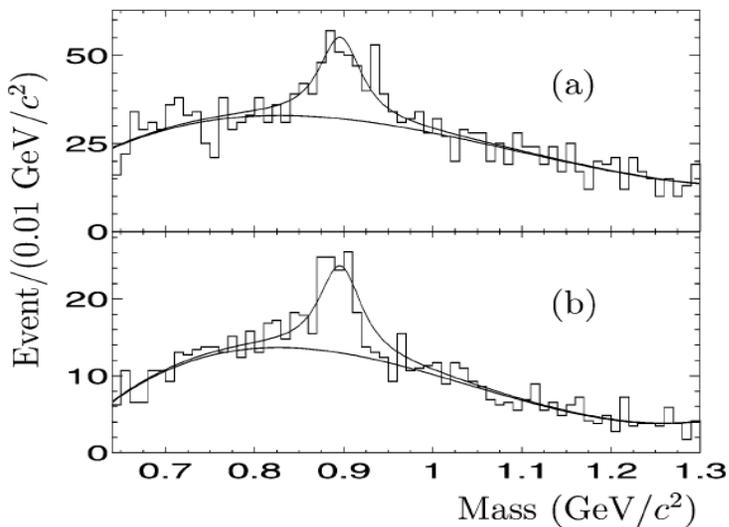
1) D^+ 的衰变被压制 (费米统计认为, 旁观者 \bar{d} 夸克和 c 夸克衰变产生的 \bar{d} 夸克不可区分, 因此, D^+ 衰变的末态较少; 同时, 旁观者 d 夸克和 c 夸克衰变产生的 d 夸克 两个图对应的衰变过程相干涉, 减小了 D^+ 的衰变宽度。)

2) D^0 的衰变被增强了 (W 交换图)。 D^+ 无 W 交换图。



W exchange decay

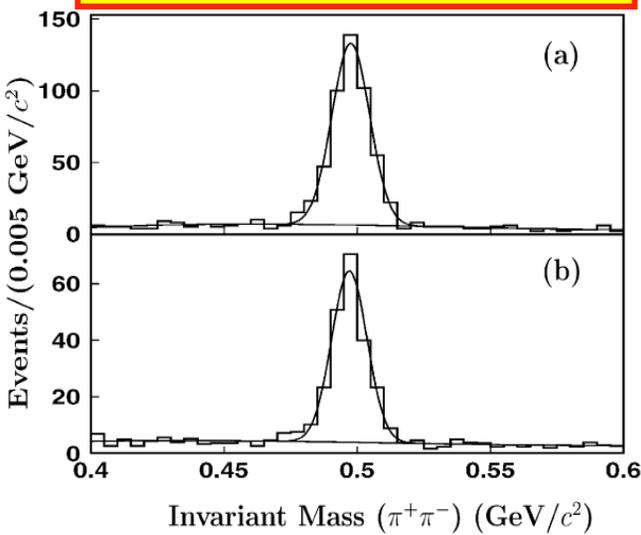
Charm Meson decays -- $D \rightarrow KX$



PLB 625 (2005) 196

Improved & First measurements

PLB 658 (2007) 1

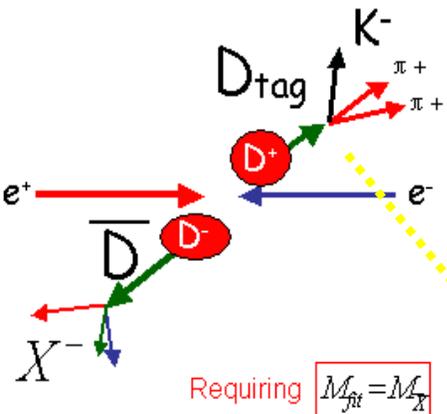


PLB 643 (2006) 246

B[%]	$D^0 \rightarrow KX$	$D^+ \rightarrow KX$
K^+X	$3.5 \pm 0.7 \pm 0.3$	$6.1 \pm 0.9 \pm 0.4$
K^-X	$57.8 \pm 1.6 \pm 3.2$	$24.7 \pm 1.3 \pm 1.2$
$K^0/K^{0\text{bar}}X$	$47.6 \pm 4.8 \pm 3.0$	$60.5 \pm 5.5 \pm 3.3$
$K^{*0}X$	$2.8 \pm 1.2 \pm 0.4$	$1.5^{+2.9}_{-1.0} \pm 0.2 (<6.6 @ 90\%)$
$K^{*0\text{bar}}X$	$8.7 \pm 4.0 \pm 1.2$	$23.2 \pm 4.5 \pm 3.0$
$K^{*-}X$	$<3.6 (@ 90\%)$	$<20.3 (@ 90\%)$
$K^{*-}X$	$15.3 \pm 8.3 \pm 1.9$	$5.7 \pm 5.2 \pm 0.7$

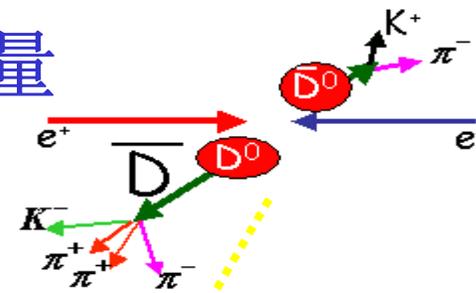
Charmed Meson Decays

$D^0 \rightarrow K^- \pi^+$, $D^+ \rightarrow K^- \pi^+ \pi^+$ 绝对分支比的测量



单标记

双标记



$$N_s(i) = 2N_{D\bar{D}} Br(i) \epsilon(i) - \sum_{j=i}^N (2N_{D\bar{D}} \epsilon(i) \epsilon(i, j) Br(i) Br(j))$$

$$N_d(i, j) = N_{D\bar{D}} Br(i) Br(j) \epsilon(i, j) \quad (i = j)$$

$$N_d(i, j) = 2N_{D\bar{D}} Br(i) Br(j) \epsilon(i, j) \quad (i \neq j)$$

$$\chi^2 = \sum_{i=1}^N \left(\frac{N_s(i) - N_s^{\text{exp}}(i)}{\sigma_{N_s(i)}} \right)^2 + \sum_{i=1, j=i}^{N, N} \left(\frac{N_d(i, j) - N_d^{\text{exp}}(i, j)}{\sigma_{N_d(i, j)}} \right)^2$$

yields ↓

Branching fractions for the D hadronic decays

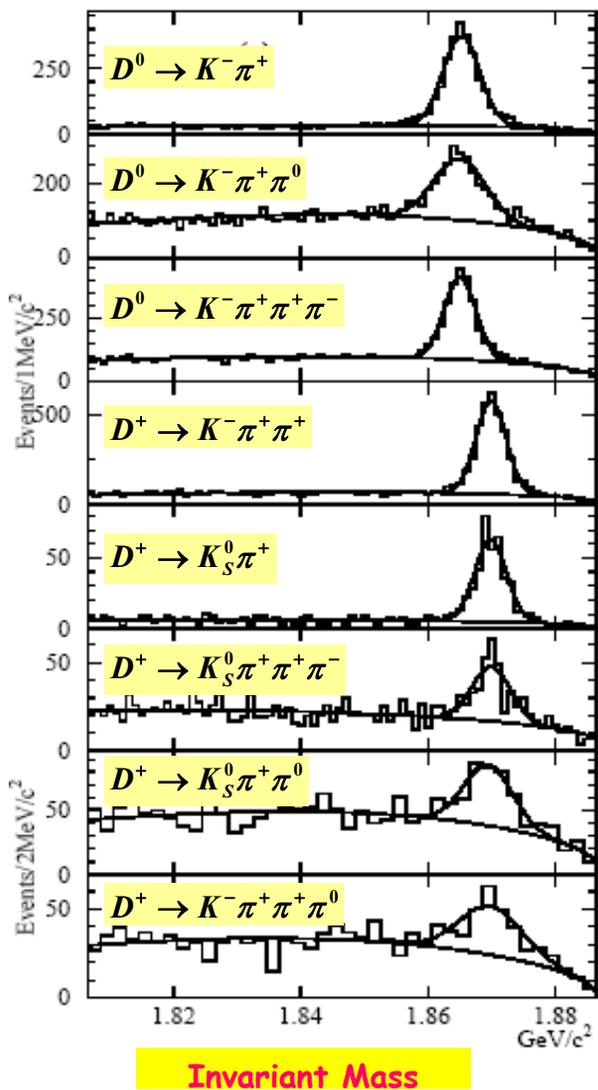
$$\sigma_{D^0 \bar{D}^0} = \frac{N_{D^0 \bar{D}^0}}{L} \quad \text{and} \quad \sigma_{D^+ D^-} = \frac{N_{D^+ D^-}}{L}$$

$$\sigma_{D\bar{D}} = \sigma_{D^0 \bar{D}^0} + \sigma_{D^+ D^-}$$

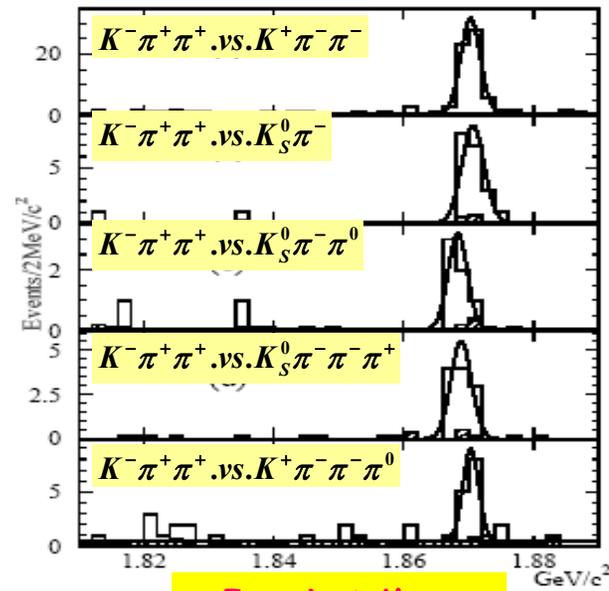
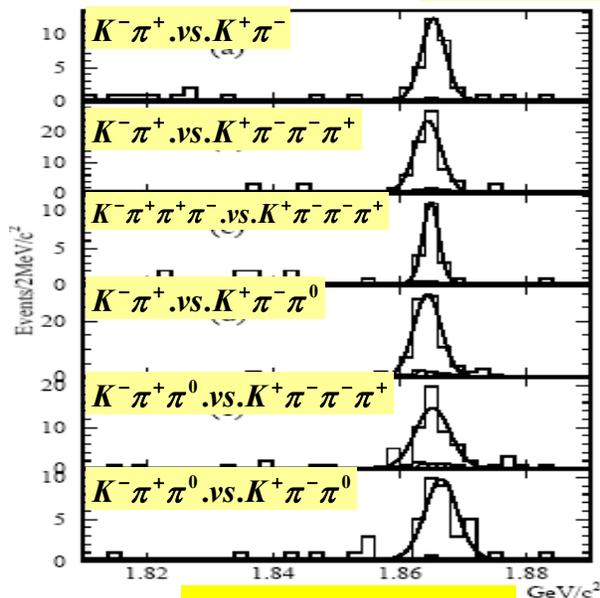
归一化的常数!

Charmed Meson Decays

单标记样本



双标记样本



Invariant Mass

Invariant Mass

$$\chi^2 = \sum_{i=1}^N \left(\frac{N_s(i) - N_s^{\text{exp}}(i)}{\sigma_{N_s(i)}} \right)^2 + \sum_{i=1, j=i}^{N, N} \left(\frac{N_d(i, j) - N_d^{\text{exp}}(i, j)}{\sigma_{N_d(i, j)}} \right)^2$$

Fitted branching fractions

Mode	BES II (%)	PDG04 (%)
$D^0 \rightarrow K^- \pi^+$	$3.92 \pm 0.32 \pm 0.26$	3.80 ± 0.09
$D^0 \rightarrow K^- \pi^+ \pi^0$	$13.2 \pm 1.2 \pm 1.0$	13.0 ± 0.8
$D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$	$8.33 \pm 0.73 \pm 0.80$	7.46 ± 0.31
$D^+ \rightarrow K^- \pi^+ \pi^+$	$10.2 \pm 1.2 \pm 0.8$	9.2 ± 0.6
$D^+ \rightarrow \bar{K}^0 \pi^+$	$3.5 \pm 0.5 \pm 0.3$	2.82 ± 0.19
$D^+ \rightarrow \bar{K}^0 \pi^+ \pi^+ \pi^-$	$7.9 \pm 1.3 \pm 1.0$	7.1 ± 1.0
$D^+ \rightarrow \bar{K}^0 \pi^+ \pi^0$	$15.6 \pm 2.5 \pm 1.4$	9.7 ± 3.0
$D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0$	$6.6 \pm 1.3 \pm 0.6$	6.5 ± 1.1

Charmed Meson Decays

$D_s^+ \rightarrow \Phi \pi^+$ 绝对分支比的测量

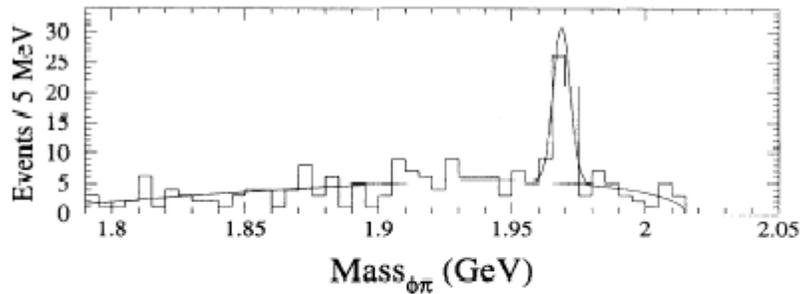


FIG. 1. The distribution in $\phi\pi$ invariant mass, calculated using fitted momentum vectors, for candidates satisfying the 1C fit described in the text at a confidence level greater than 1%; the selection criteria on $M_{K^+K^-}$ and the helicity of the K^+ in the ϕ rest frame have also been applied.

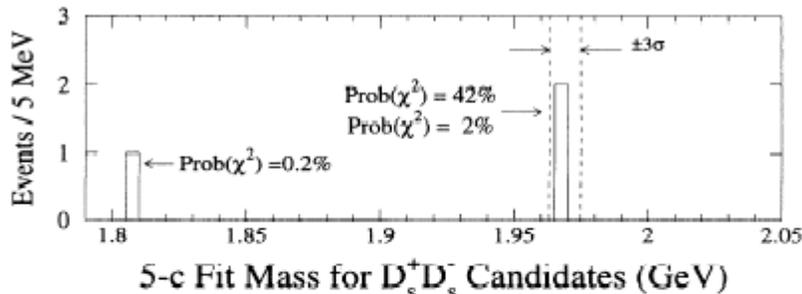


FIG. 2. The distribution in candidate D_s invariant mass, calculated using fitted momentum vectors, for the events which satisfy the 5C fit described in the text at a confidence level greater than 0.1%; the 1C fit masses corresponding to the events in the D_s signal region are given in Table I.

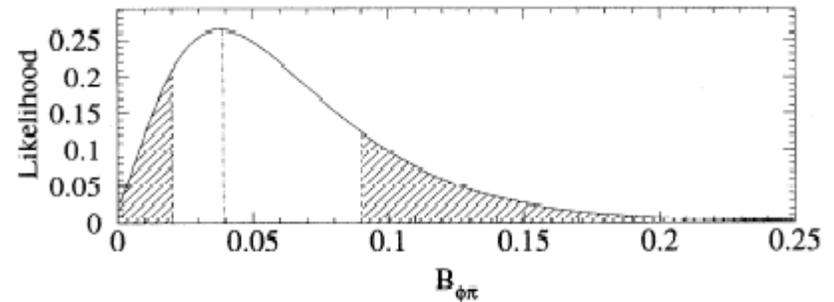


FIG. 3. The variation of the marginalized likelihood function described in the text with $B_{\phi\pi}$; the dashed lines correspond to the $\pm 1\sigma$ statistical error estimates.

$$B_{\phi\pi} = [3.9 \quad +5.1(\text{stat}) \quad +1.8(\text{syst}) \quad -1.9 \quad -1.1(\text{syst})]\%$$

归一化的常数!

Charmed meson Decays

Charmed meson decays

Probes for New Physics

$D^0\bar{D}^0$ Mixing

CP violation

Rare Decays

BES-II 数据样本太小，不能给出有意义的实验结果。

At BES-III we can study these well !

Charm meson production and decays at BES-III

(The Near Future)

Charm Physics Topics at BES-III

Precise test of the Standard Model

- 1、 Purely leptonic decays
 - 2、 Semi-leptonic decays
 - 3、 Non-leptonic decays
-

Probes for New Physics

- 1、 Search for $D^0\bar{D}^0$ mixing
 - 2、 CP Violation
 - 3、 Rare pure or semi-leptonic decays
of charmed mesons
-

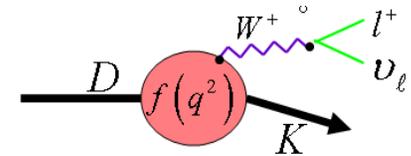
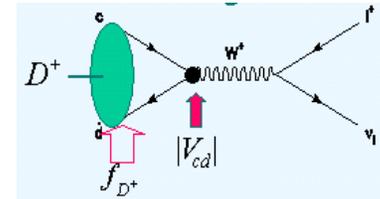
Prof. Y.H. Zheng will
talk about these topics

Topics related to charm production

Why is Charm important ?

Charm plays an important role in understanding the SM (standard model) dynamics in two respects:

Precision measurements of decay constants f_D, f_{D_s} , form-factors of semileptonic decays of Charm mesons provide the calibration of Lattice QCD calculation. In turn, the very precise calculation of the ratios of these decay constants $f_D/f_B, f_{D_s}/f_{B_s}$ and form-factors from LQCD support measurements for B physics.



Precision measurements

The parameters of Standard Model are: $\alpha, G_F, \sin^2 \theta_w, M_H$, fermion mass and mixings

The 4 quark mixing parameters (λ, A, ρ, η) reside in CKM matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

Weak eigenstates

CKM

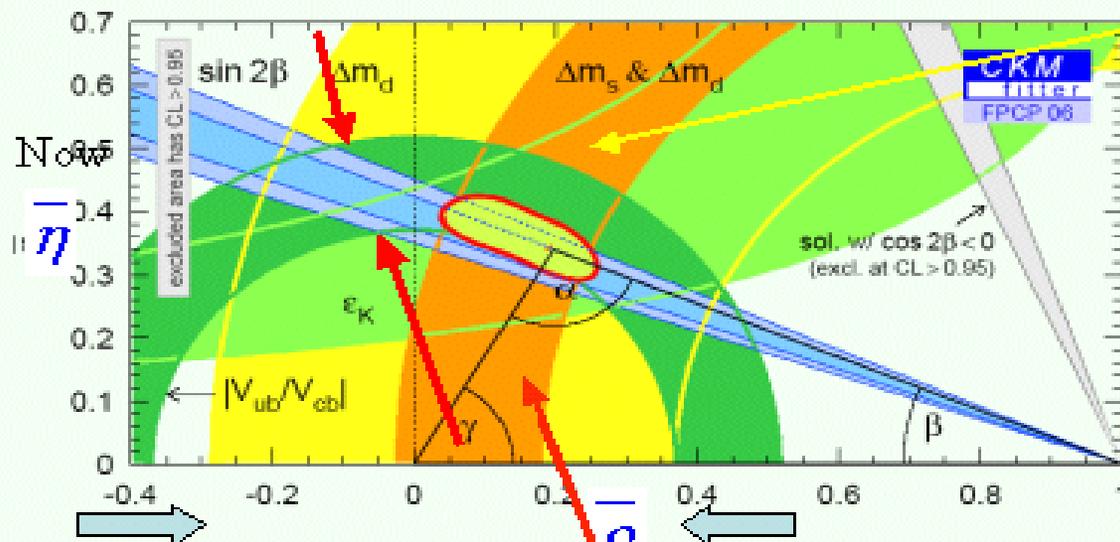
Mass eigenstates

CKM

To understand the quark mixing and CP violation in SM, and detect New Physics in flavor change sector, one must determine the CKM elements as precisely as possible !

Why is Charm important ?

The constraints in (ρ, η) plane arising from some measurements ...



The width of band is mainly dominated by theoretical (LQCD) errors on f_B , f_{B_s} , and B semileptonic form factors .

With Charm data one can calibrate the QCD calculations. If the QCD pass the test with the charm data, the theory errors of a few % on B system decay constants & semileptonic form factor are achieved, and the CKM elements achieved to

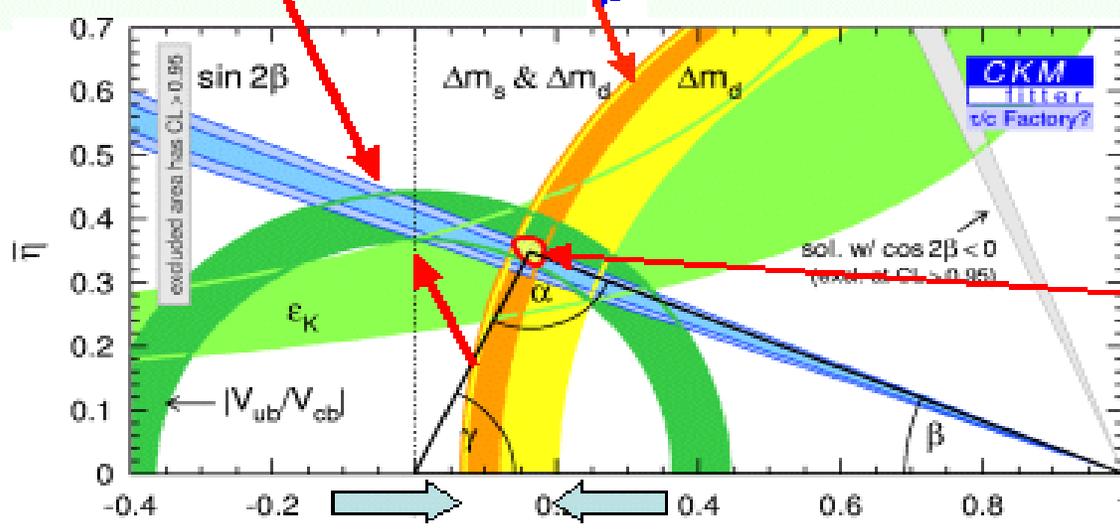


Table 8. LQCD impact (in per cent) on the precision of CKM matrix elements.

	V_{cd}	V_{cs}	V_{cb}	V_{ub}	V_{td}	V_{ts}
2004	7	11	4	15	36	39
LQCD	1.7	1.6	3	5	5	5

Then the uncertainties will be reduced

在BES-III上, 我们可以直接精密测定 V_{cd} 和 V_{cs} , 间接地提高 V_{cb} , V_{ub} , V_{td} , V_{ts} 的测量精度。

Why is Charm important ?

D mesons Unitary Triangle (DUT)

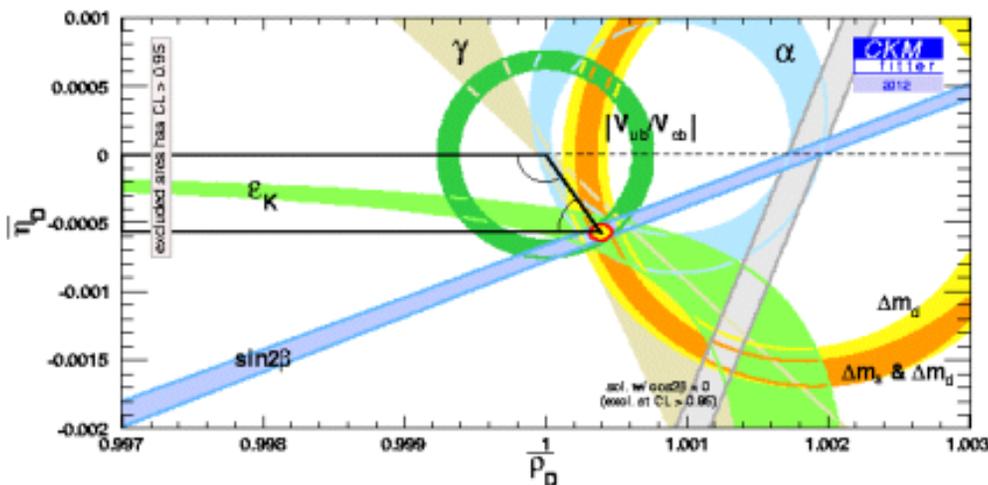


Figure 23.15: Individual constraints and the global CKM fit on the $(\bar{\rho}_D, \bar{\eta}_D)$ plane (as of our prospective in 2012). The shaded areas have 95% CL. Only a part of the D Unitarity Triangle is visible (in black solid lines): the two apices associated with large angles are shown, whereas the missing apex is situated at the origin, far away on the left.

预期到2012年时, Global fit 给出的精度为:

$$\sigma(|V_{cd}|)/|V_{cd}| = 0.4\%$$

$$\sigma(|V_{cs}|)/|V_{cs}| = 0.02\%$$

$$\frac{\sigma(|V_{cd}|/|V_{cs}|)}{|V_{cd}|/|V_{cs}|} = 0.4\%$$

(assuming that the CKM mechanism is the only source for CP violation)

精密测量的 $|V_{cd}|$, $|V_{cs}|$ 和 $|V_{cd}|/|V_{cs}|$ 值可以和 Global fit 值做对比。其比较结果可以为寻找新物理提供重要信息。

这些精密的测量可以在 BES-III/BEPC-II 实验装置上完成。

Why is Charm important ?

Probes for New Physics

Measurements of some transition rates of Charm provide probes for New Physics.

In the SM, the $D^0\bar{D}^0$ mixing, CP violation and rare decays of charm are all small.

$$D^0\bar{D}^0 \text{ mixing } x \approx y \approx 10^{-3} \Rightarrow r_D = [x^2 + y^2]/2 \approx 10^{-6}$$

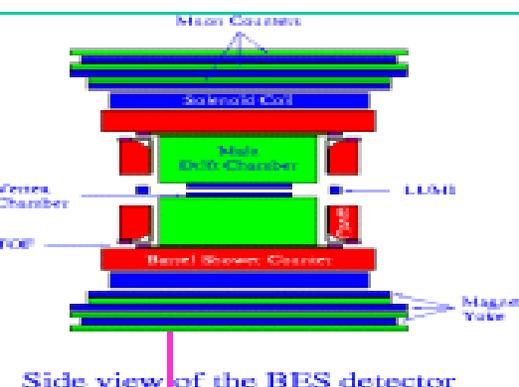
$$CP \text{ violation } \sim 10^{-3}$$

$$\text{Rare decays } \leq 10^{-6}$$

However, some New Physics effects beyond the SM can enhance the mixing, the CP violation and the rare decays. So search for the mixing, the CP violation and the rare decays provide the unique opportunities to search for New Physics beyond the SM indirectly.

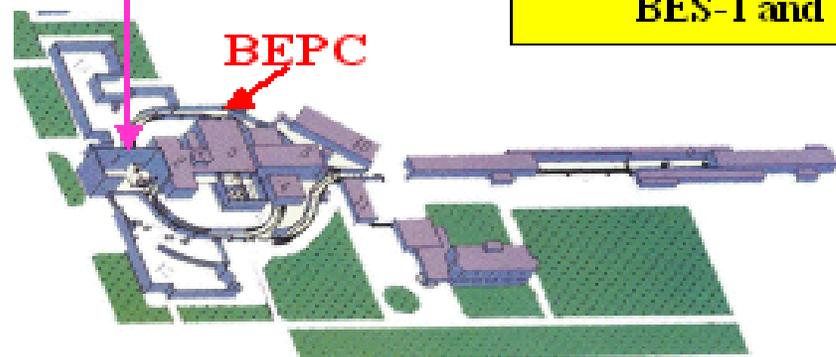
BES-III/BEPC-II

Charm Physics at BES-III

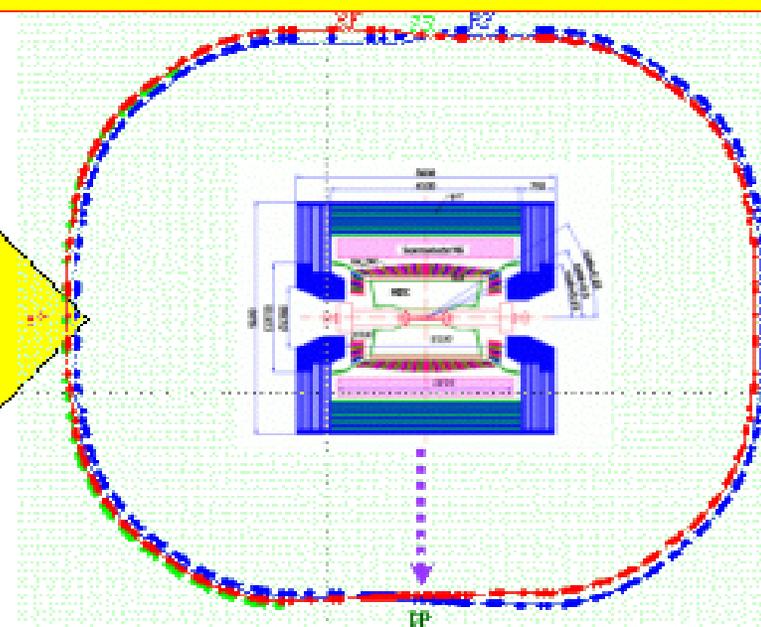


With the BES-II at BEPC we measured many physics quantities about charm and $\psi(3770)$ resonance.

BES-III will be the successor of the previous successful BES-I and BES-II



With the BES-III at the BEPC-II we will more precisely measure these physics quantities and will do some measurements for probes for NEW Physics ! ...



Luminosity reach to 10^{33} at $E_{\text{cm}} = 3.78$ GeV (compare to 10^{31} for BEPC).

Large angle coverage, good charged PID & momentum resolution, good photon energy resolution.

Charm yields at BES-III/BEPC-II

Precision Measurements at BES-III

Charm Production at BES-III

Assuming 6 month running for Physics/year & average efficiency of collecting data is 70%.

Average Lum: $\mathcal{L} = 0.5 \times \text{Peak Lum.}$
One year data taking time: $T = 10^7 \text{s}$

$$N_{\text{event}} / \text{year} = \sigma_{\text{exp}} \times L \times T \times \epsilon_{\text{data taking}}$$

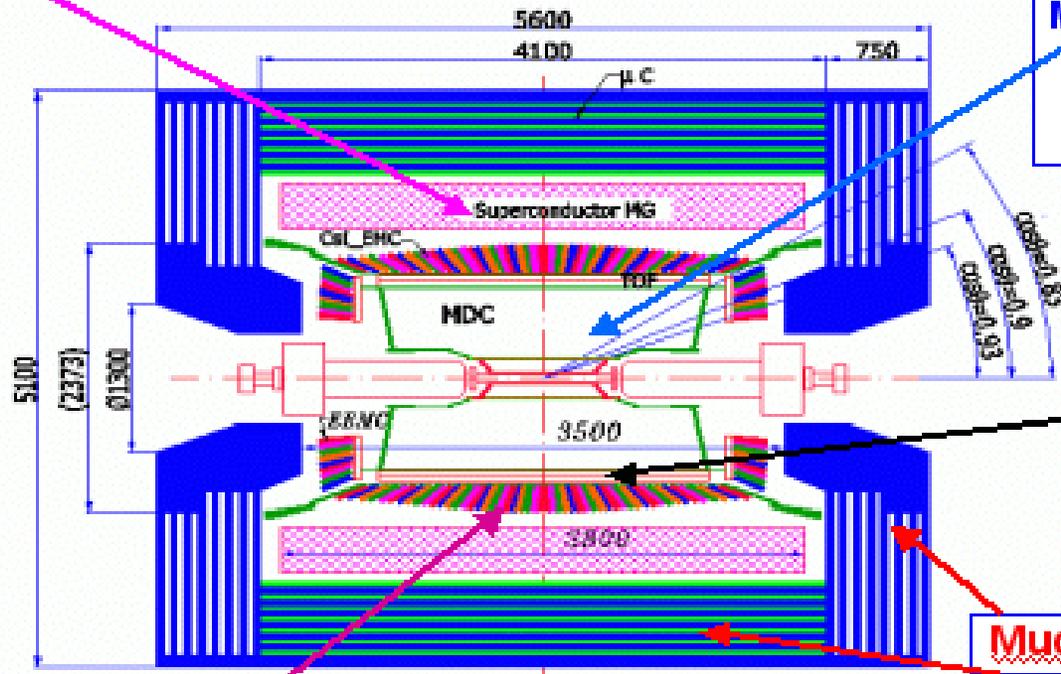
Resonance	Mass(GeV) <i>CMS</i>	Peak Lum. ($10^{33} \text{cm}^{-2} \text{s}^{-1}$)	Physics Cross Section (nb)	$N_{\text{events/yr}}$
J/ ψ	3.097	0.6	3400	6×10^9
τ	3.670	1.0	2.4	7.3×10^6
$\psi(2S)$	3.686	1.0	640	2.0×10^9
$D^0 \bar{D}^0$	3.770	1.0	3.6	11×10^6
$D^+ D^-$	3.770	1.0	2.6	7.9×10^6
$D_s D_s$	4.030	0.6	0.32	0.6×10^6
$D_s \bar{D}_s$	4.140	0.6	0.67	1.2×10^6

BES-III Detector

BESIII Detector

Magnet: 1 T Super conducting

Two rings, 93 bunches:
• Luminosity
 $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ @ 3.78 GeV
 $6 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ @ 3.10 GeV
 $6 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ @ 4.20 GeV



MDC: small cell & He gas
 $\sigma_{\text{p}} = 130 \mu\text{m}$
 $\sigma_{\text{p}} = 0.5\%$ @ 1 GeV
 $dE/dx = 6\%$

TOF:
 $\sigma\tau = 100 \text{ ps}$ Barrel
 110 ps Endcap

Muon ID: 9 layer RPC

EMCAL: CsI crystal
 $\Delta E/E = 2.5\%$ @ 1 GeV
 $\alpha z = 0.6 \text{ cm}/\sqrt{E}$

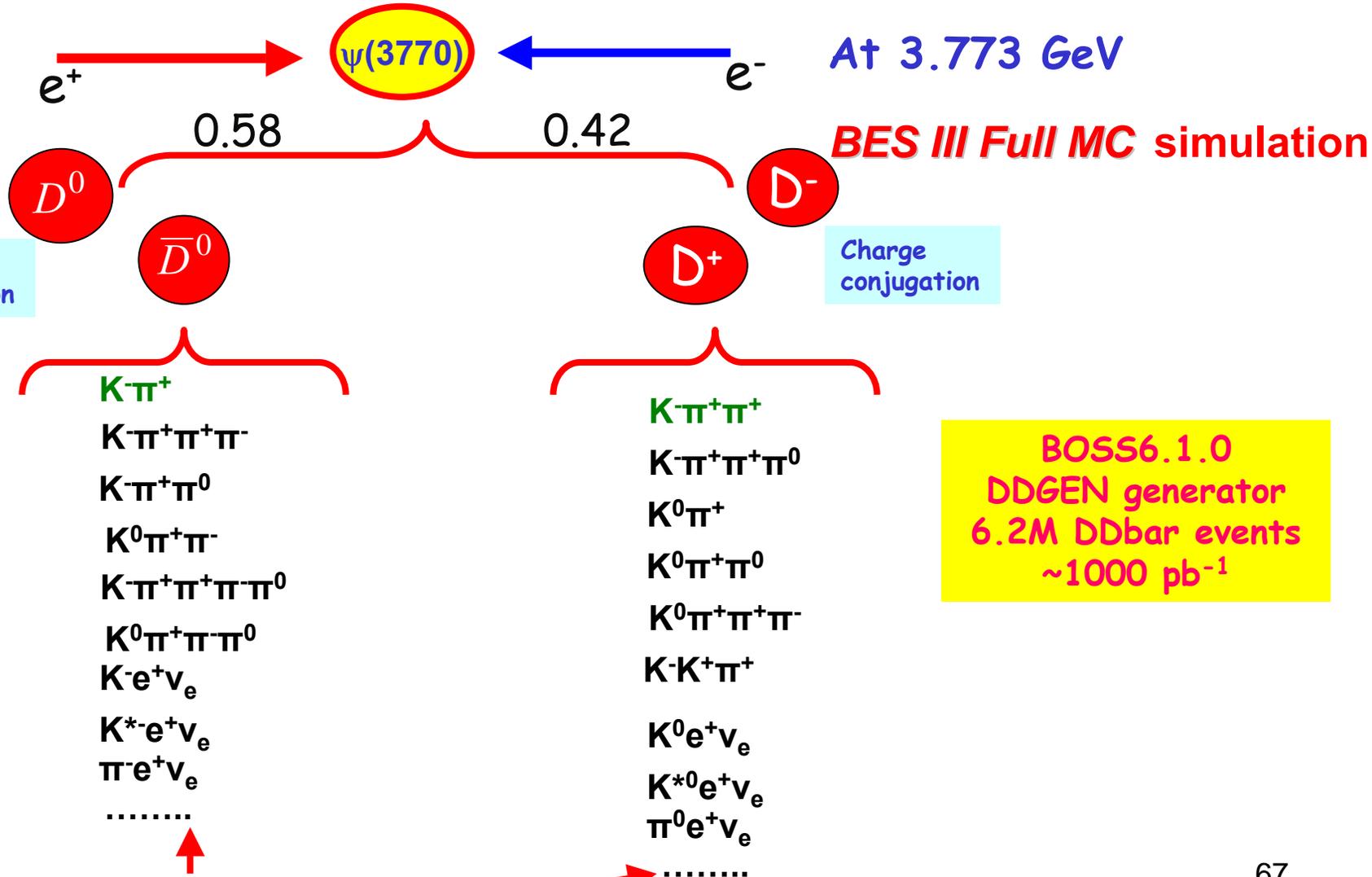
Data Acquisition:
Event rate = 3 kHz
Thruput ~ 50 MB/s

Trigger: Tracks & Showers
Pipelined; Latency = 6.4 μs

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

Monte Carlo Simulation

With BESIII Offline Software System (BOSS)

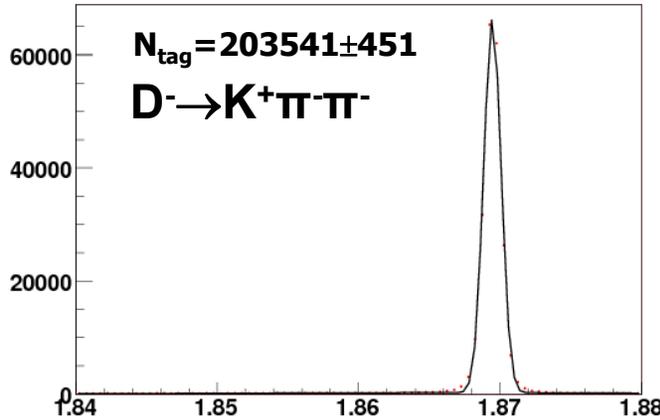


All possible modes with branching fractions from PDG

D Leptonic decays

BES III Full MC simulation

对应 1fb^{-1} 数据



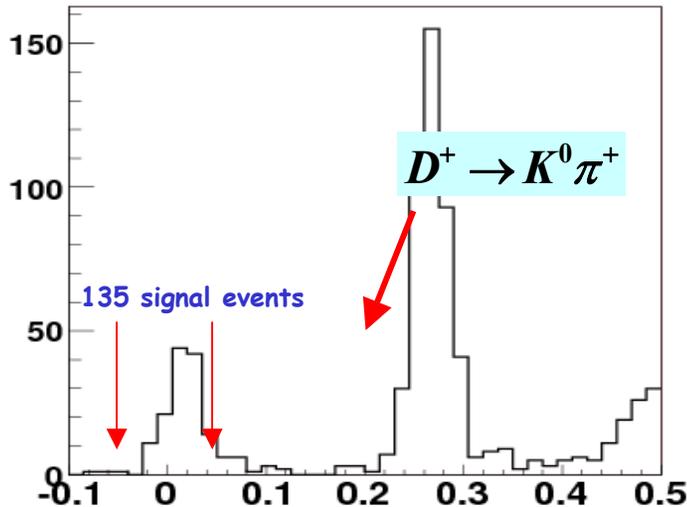
Beam Constraint Mass

$$M_{bc} = \sqrt{E_{\text{beam}}^2 - p_{mK\pi}^2}$$

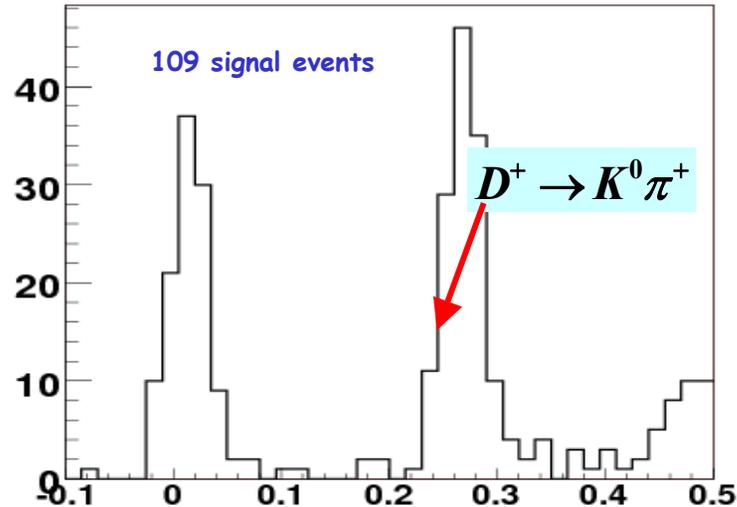
$$B(D^+ \rightarrow \mu^+ \nu_\mu) = \frac{N(D^+ \rightarrow \mu^+ \nu_\mu)}{N_{\text{tag}} \times \epsilon_{D^+ \rightarrow \mu^+ \nu_\mu}}$$

M_{bc}

Not use μ Information



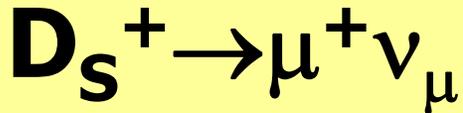
Use μ Information



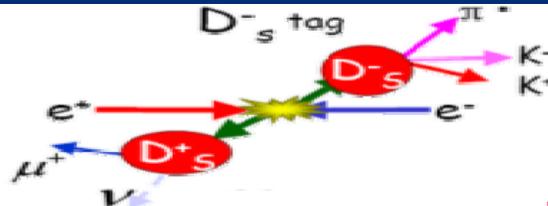
$U_{\text{miss}} = E_{\text{miss}} - P_{\text{miss}}$

$U_{\text{miss}} = E_{\text{miss}} - P_{\text{miss}}$

Ds Leptonic decays



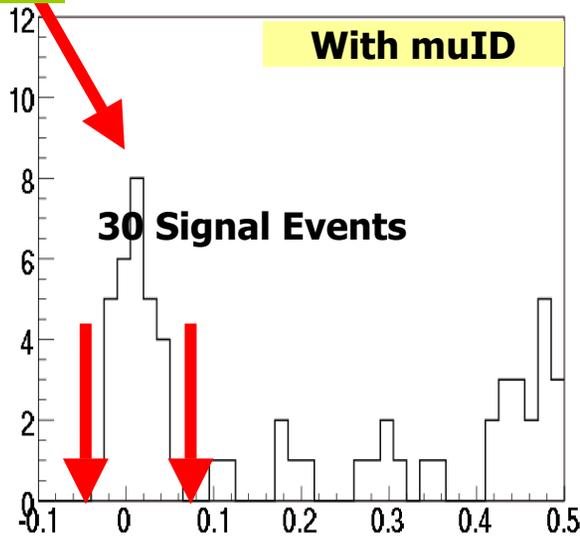
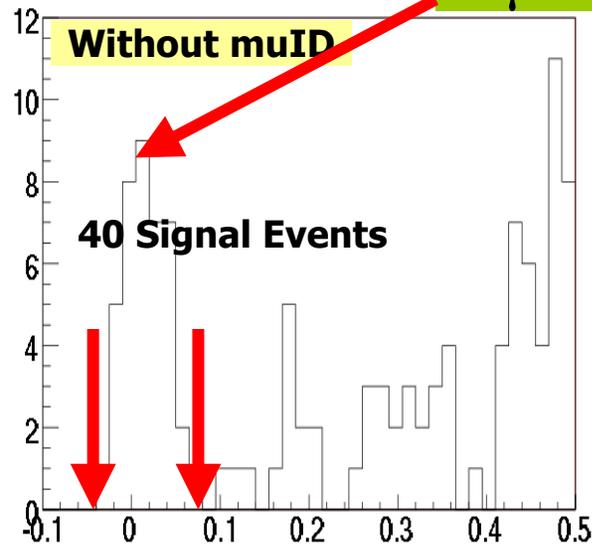
BOSS 6.1.0



For 1 Tag Mode:

$N^{\text{Tag}}(\Phi\pi)$	11456 ± 107
ϵ	59.9%
N^{Sig}	30.0 ± 5.5
B	$(0.44 \pm 0.08)\%$
Input	0.4%
$\Delta Br / Br$	~18%
$\Delta f_{D_s} / f_{D_s}$	~9%

$\mu^+ \nu$



$$U_{\text{miss}} = E_{\text{miss}} - P_{\text{miss}}$$

$$U_{\text{miss}} = E_{\text{miss}} - P_{\text{miss}}$$

$\Gamma(D_s^+ \rightarrow \mu^+ \nu_\mu) / \Gamma(D_s^+ \rightarrow \phi \pi^+)$
with 5M $e^+e^- \rightarrow c\bar{c}$ events

8 Tag Mode : $K^+ K^- \pi^-, K_s^0 K^-, \eta \pi^-, \eta' \pi^-,$
 $(314 \text{ pb}^{-1}) \quad \phi \rho^-, \pi^+ \pi^- \pi^-, K^{*-} K^{*0}, \eta \rho^-$

8 Tag Modes

$E_{\text{CM}} = 4.17 \text{ GeV}$

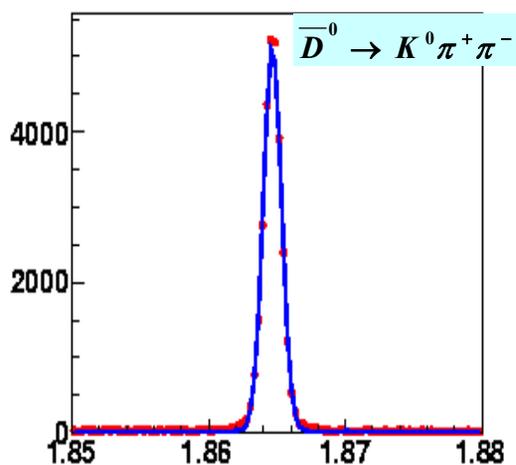
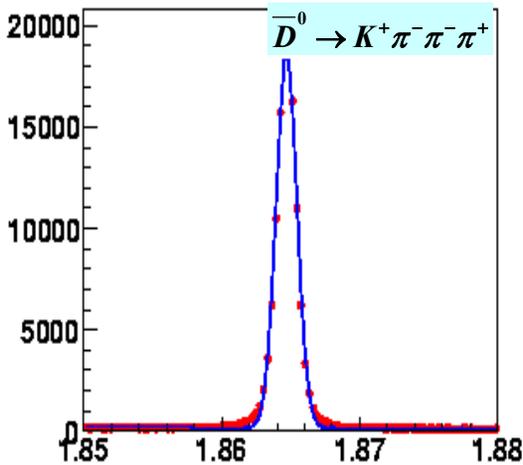
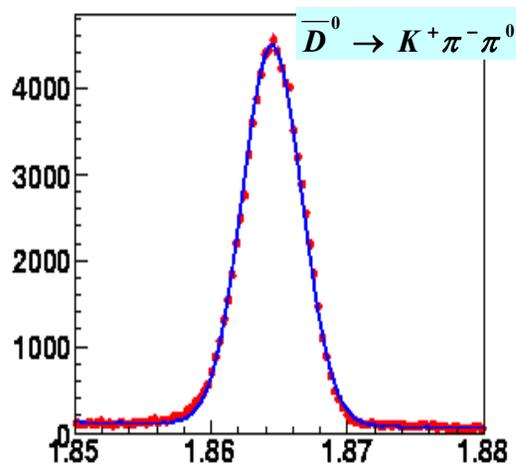
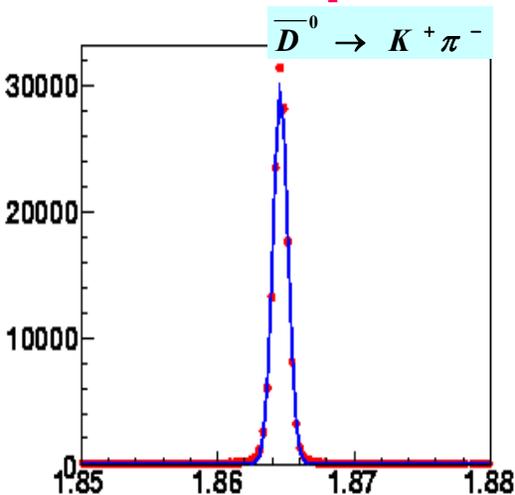
$E_{\text{CM}} = 4.03 \text{ GeV}$

	CLEOII	CLEO-c Pre.	BESIII [4fb⁻¹]
$\Delta f_{D_s} / f_{D_s}$	7%	~5%	~2.8%

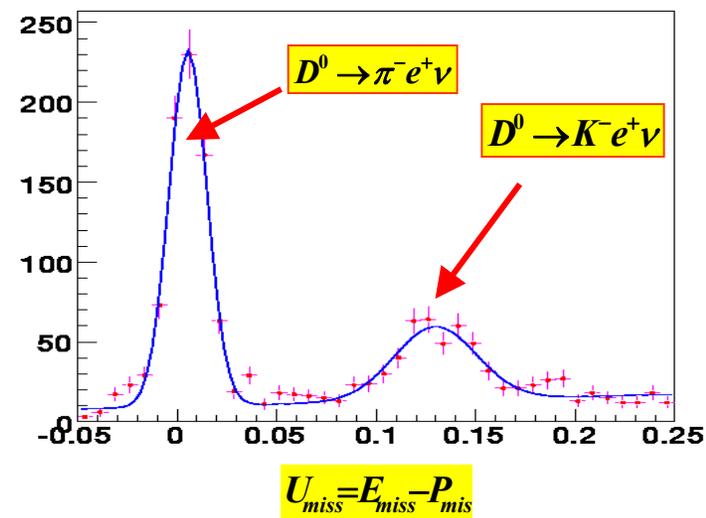
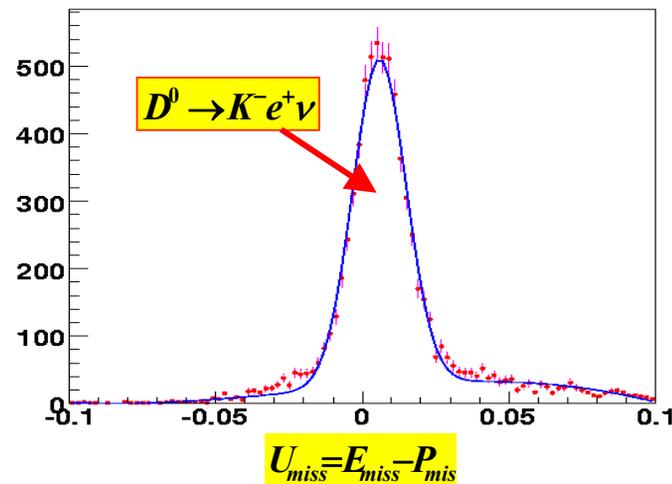
D Exclusive semileptonic decays

800pb⁻¹

BES III Full MC simulation



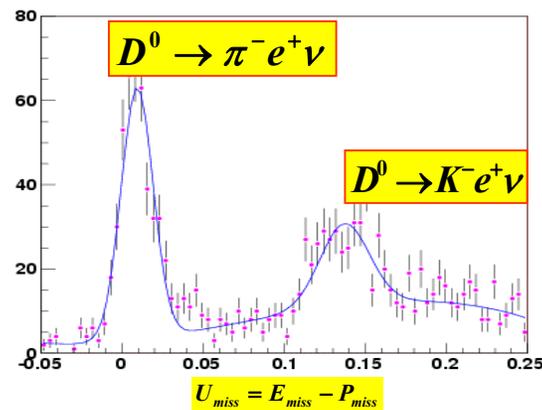
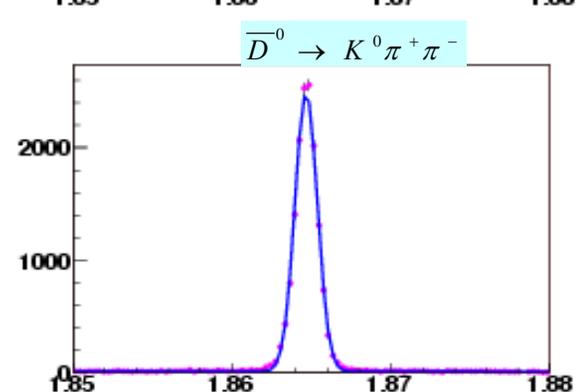
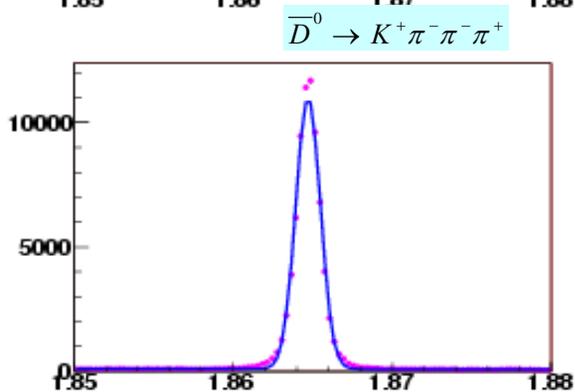
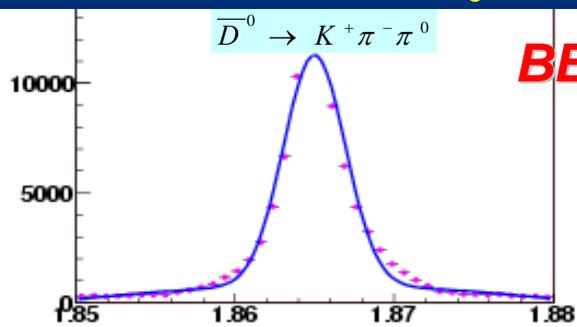
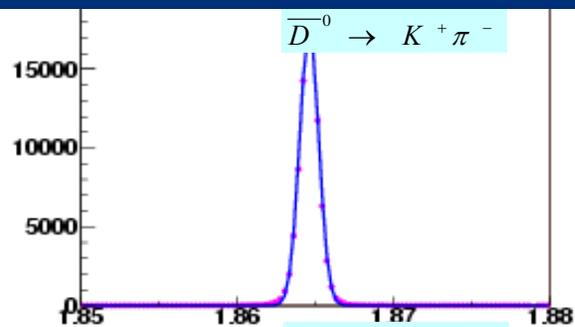
M_{BC}



D Exclusive semileptonic decays

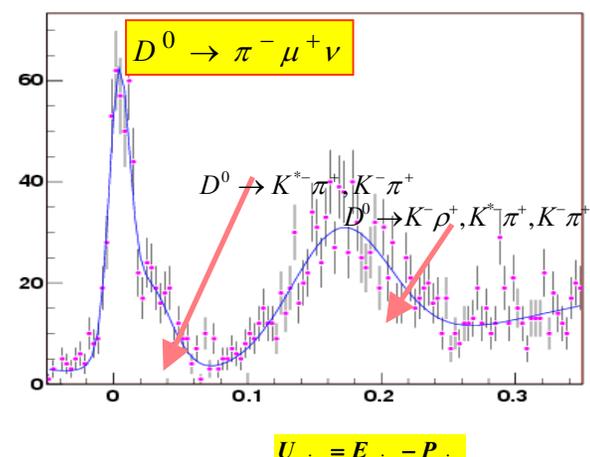
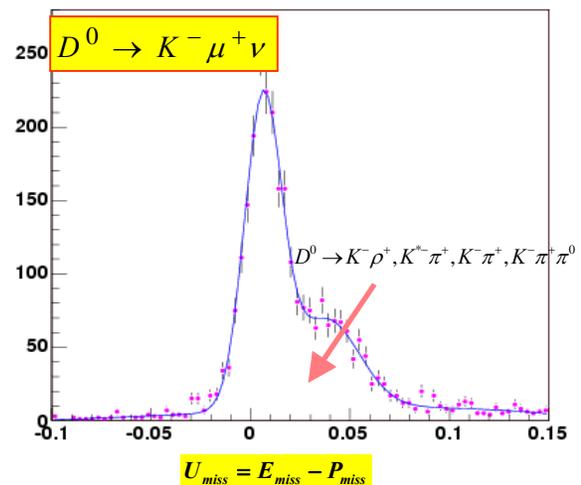
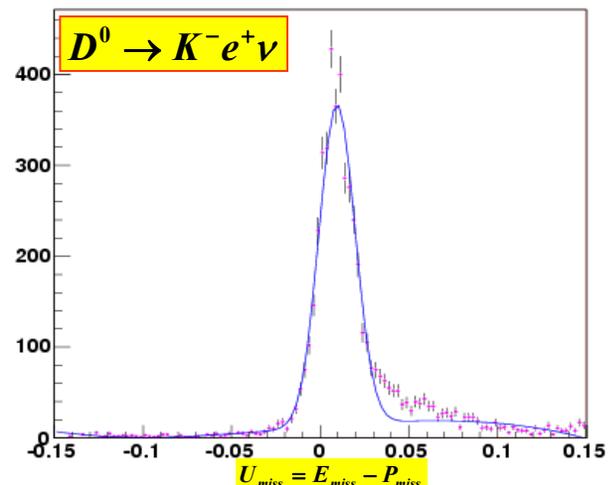
BES III Full MC simulation

$\sim 500 \text{ pb}^{-1}$

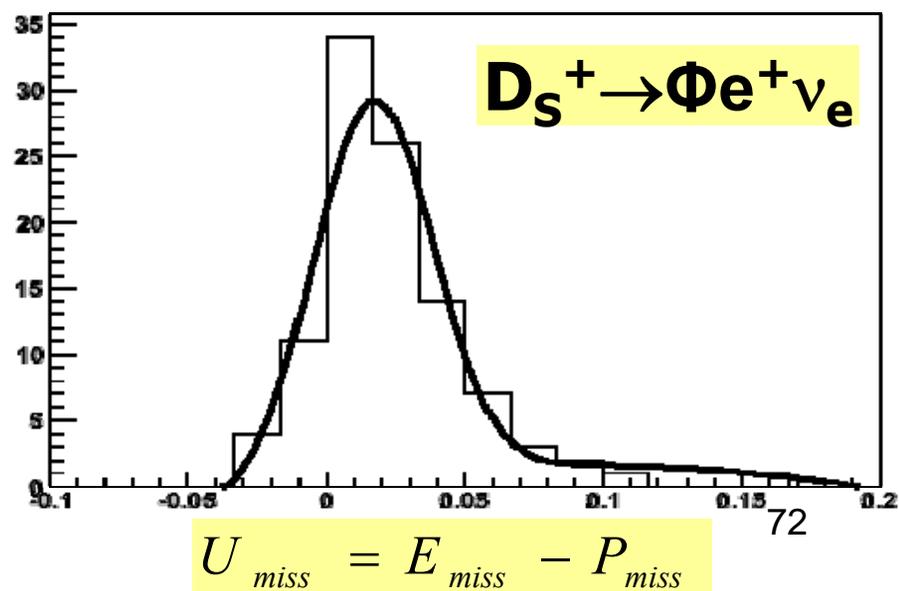
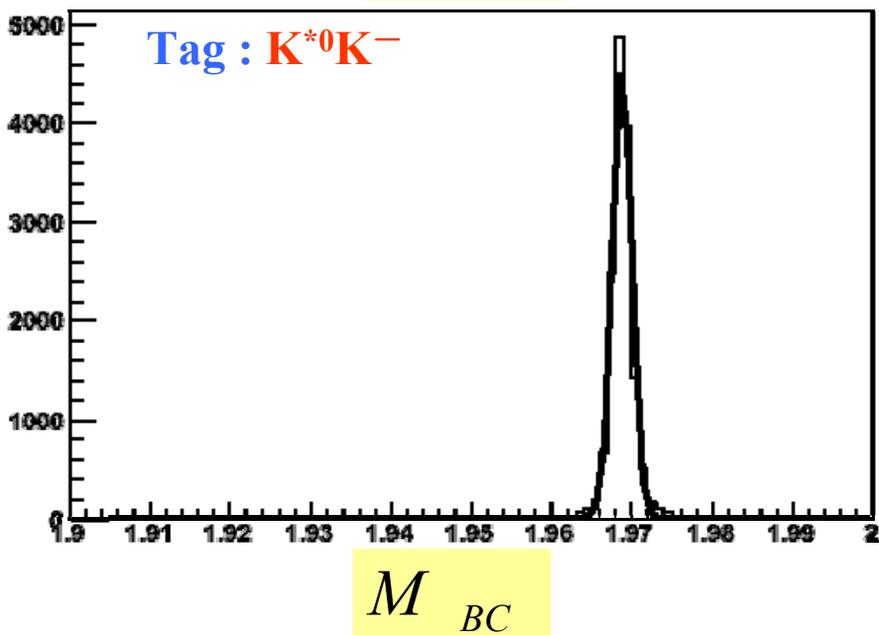
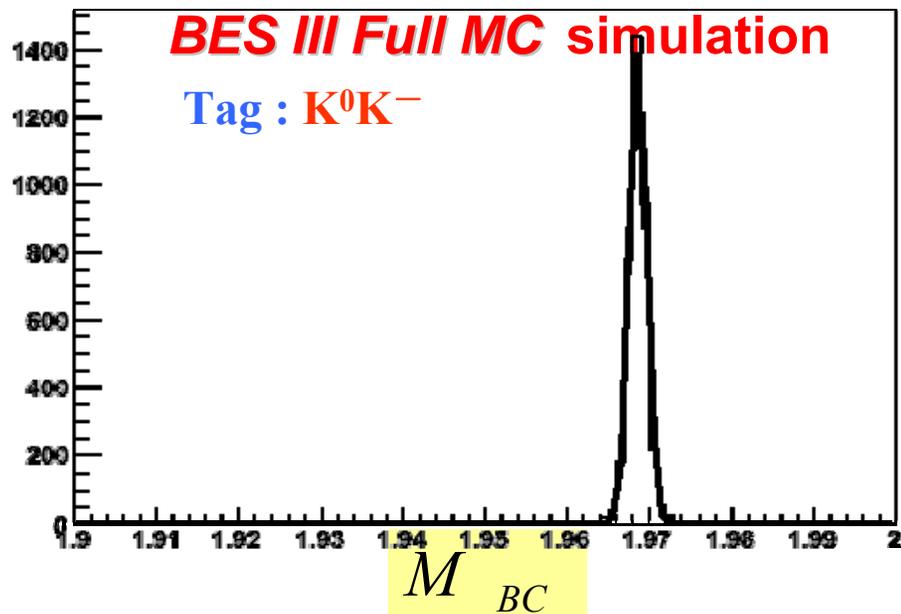
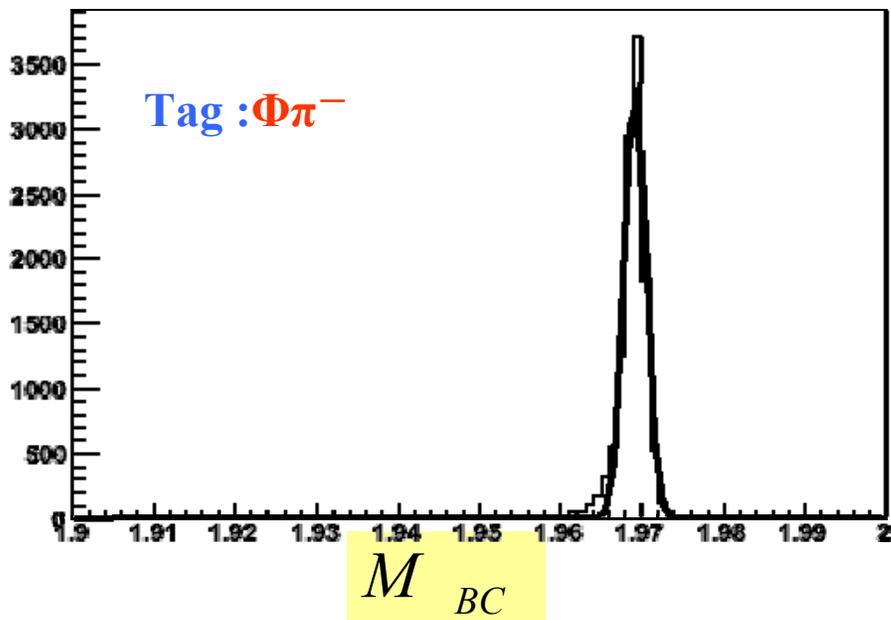


M_{BC}

M_{BC}



Ds Exclusive semileptonic decays

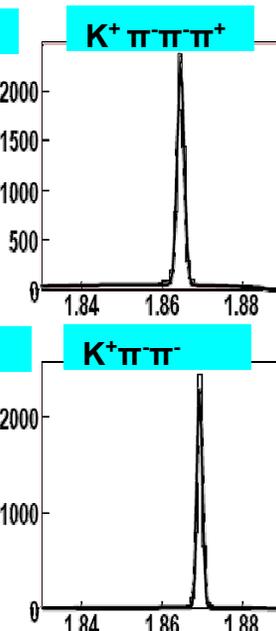
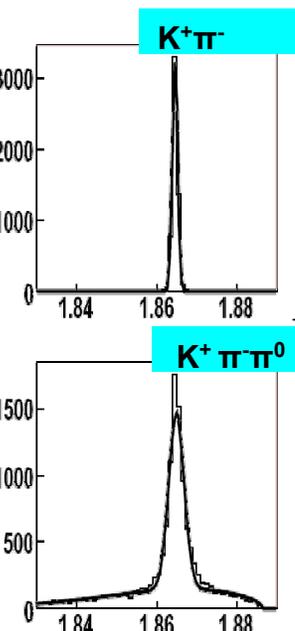
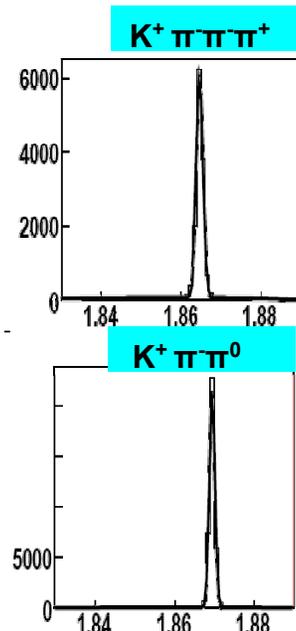
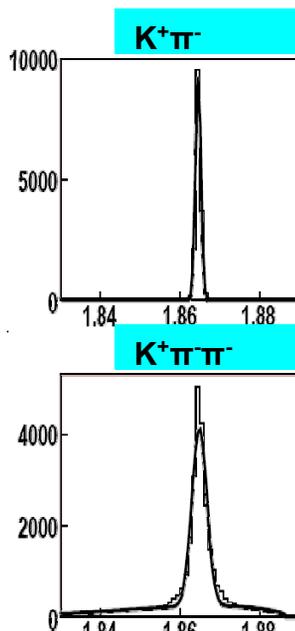
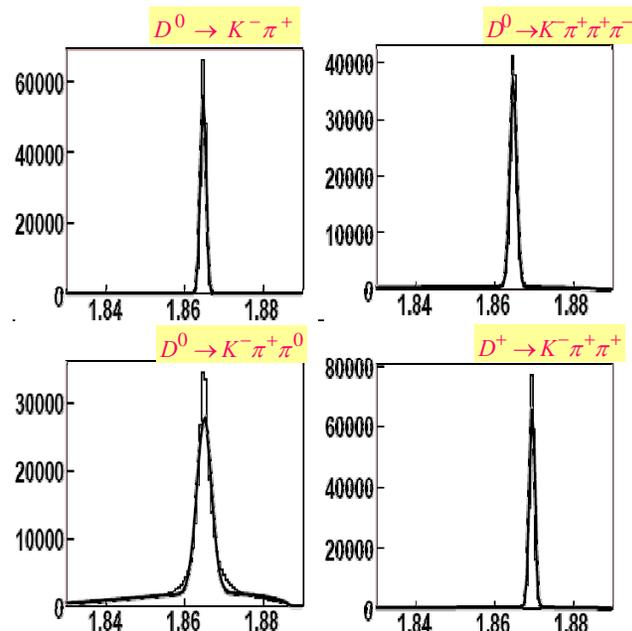


Inclusive semileptonic decays

Single tags

1000 pb⁻¹

Electron yields



Beam Constraint Mass [mK_{ns}]

Beam Constraint Mass [mK_{ns}]

Beam Constraint Mass [mK_{ns}]

right-sign electrons

wrong-sign electrons

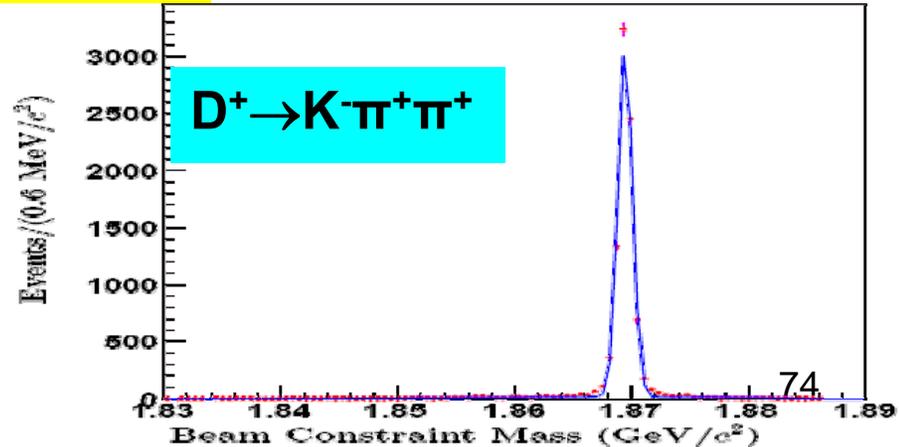
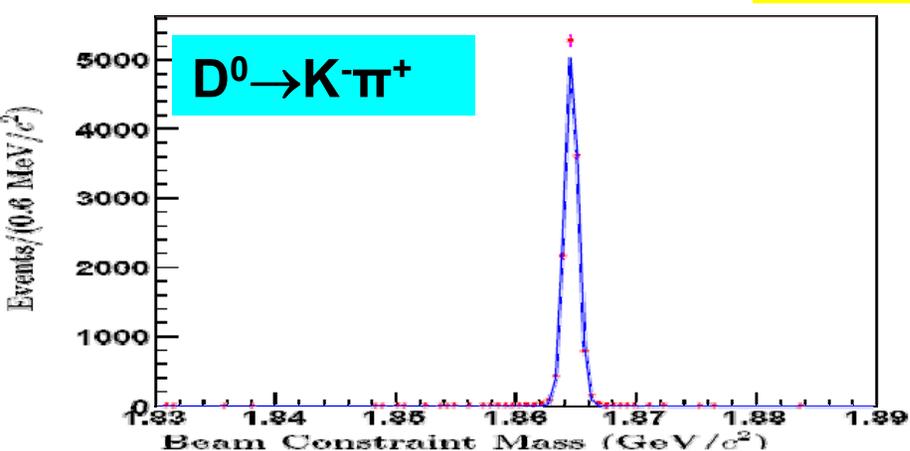
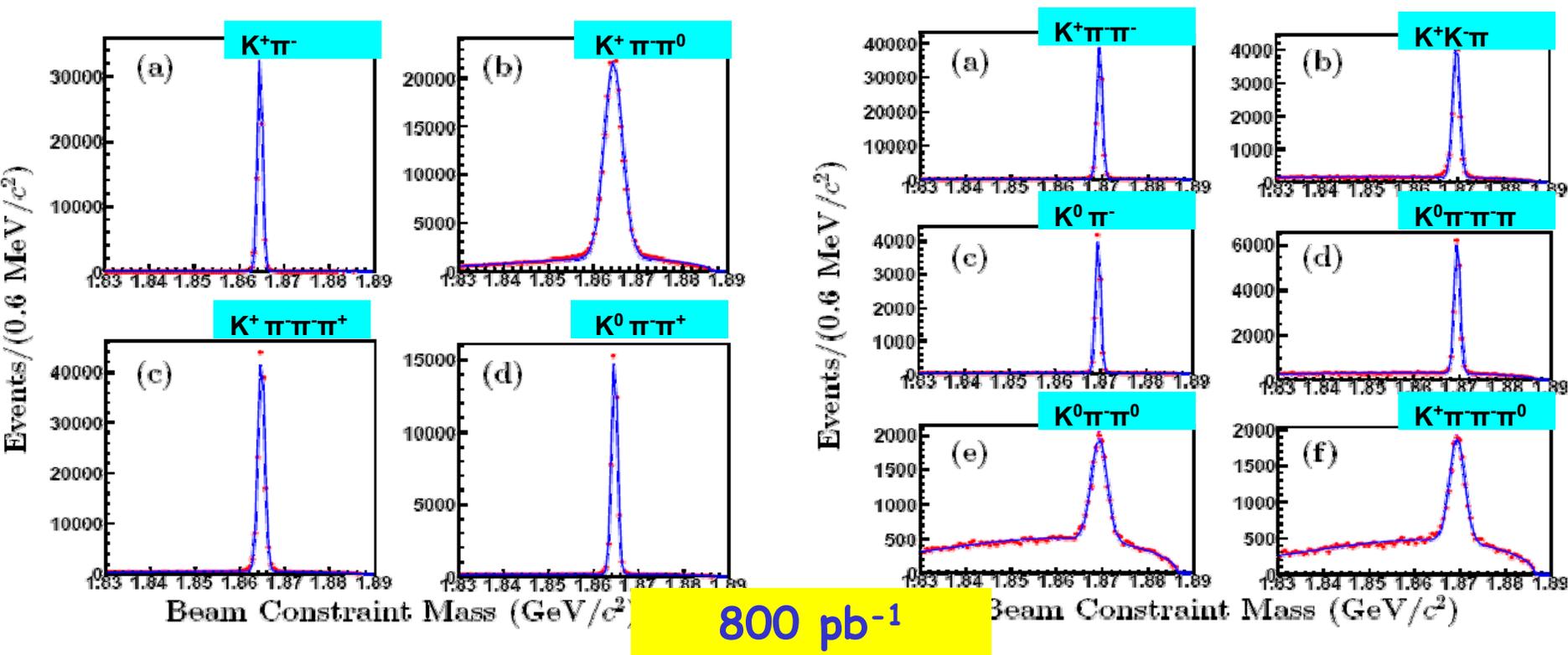
$$N_{D^- \text{ Tag}} = 195500$$

$$N_{D^0 \text{ Tag}} = 502500$$

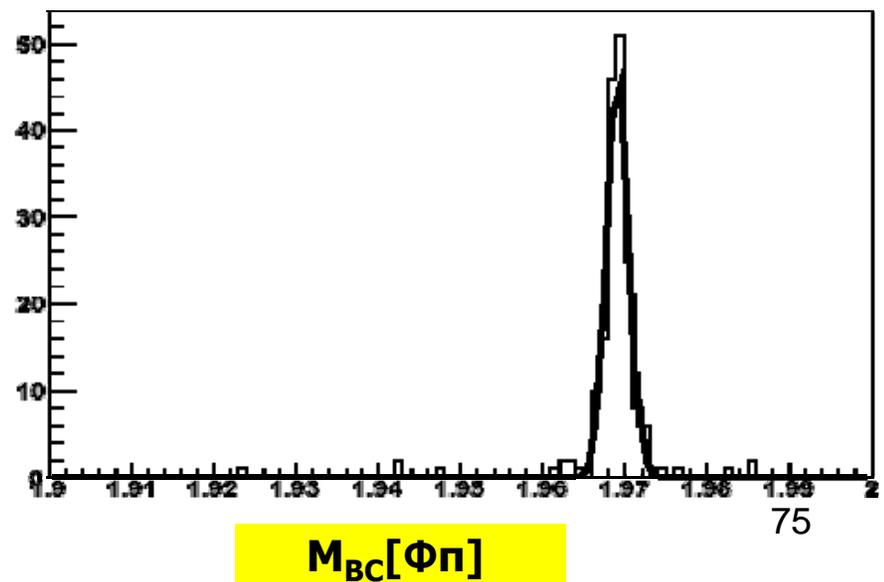
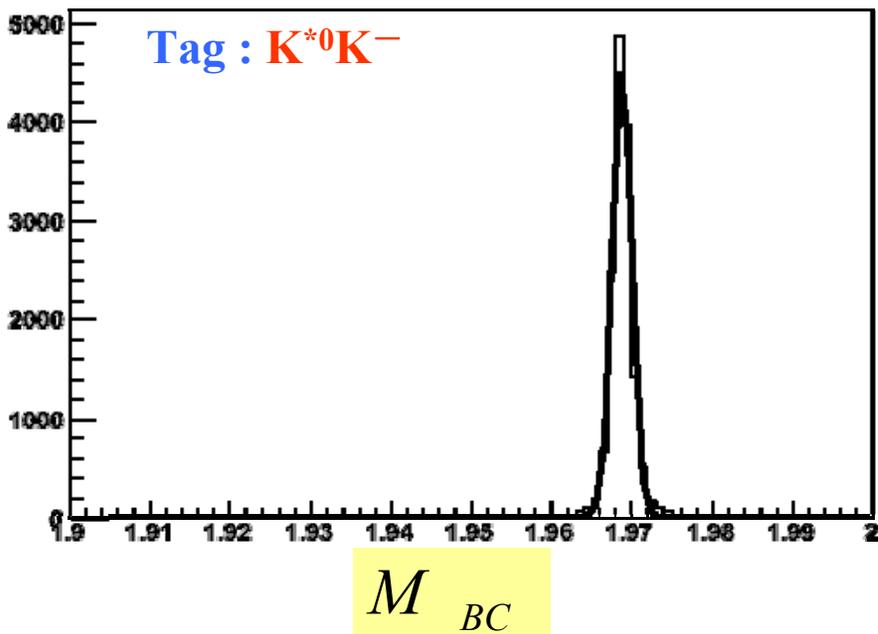
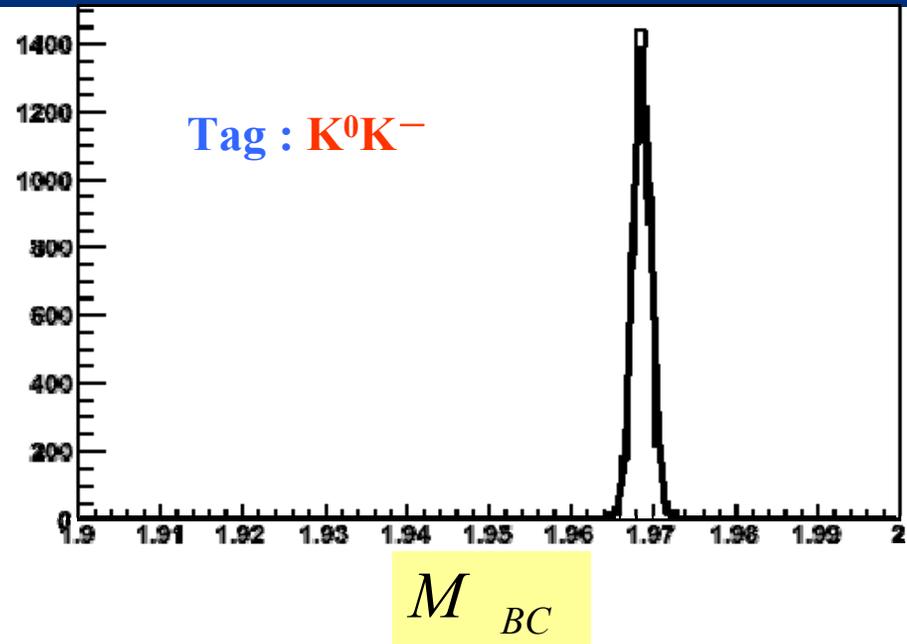
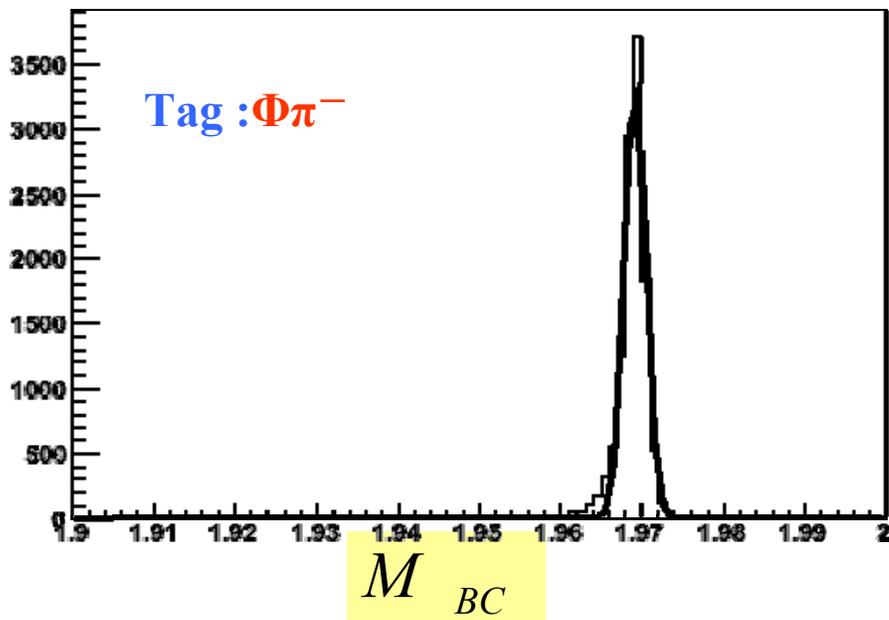
$$\begin{pmatrix} N_e^{\text{obs},i} \\ N_K^{\text{obs},i} \\ N_\pi^{\text{obs},i} \end{pmatrix} = \begin{pmatrix} \epsilon_e^i & f_{\pi \rightarrow e}^i & f_{K \rightarrow e}^i \\ f_{e \rightarrow K}^i & \epsilon_K^i & f_{\pi \rightarrow K}^i \\ f_{e \rightarrow \pi}^i & f_{K \rightarrow \pi}^i & \epsilon_\pi^i \end{pmatrix} \begin{pmatrix} N_e^{\text{real},i} \\ N_K^{\text{real},i} \\ N_\pi^{\text{real},i} \end{pmatrix}$$

wrong-sign electrons are used to estimate the charge symmetric background, e.g. $\pi \rightarrow \gamma e + e^-$, γ conversions etc.

D non-leptonic decays



Ds non-leptonic decays



Expected Results on Charm Decays

Statistical error only

Relative error (%) on the measurements

281 pb⁻¹

Mode	$\delta B / B$ (4 fb ⁻¹)	$\delta B / B$ (20 fb ⁻¹)	$\delta B / B$ (PDG 04)	CLEO-c
$D^0 \rightarrow K^- \pi^+$	0.5	0.2	2.3	
$D^+ \rightarrow K^- \pi^+ \pi^+$	0.5	0.2	6.5	
$D^0 \rightarrow K^- e^+ \nu$	0.7	0.3	5.0	
$D^0 \rightarrow \pi^- e^+ \nu$	1.8	0.8	16.6	
$D^0 \rightarrow K^- \mu^+ \nu$	0.9	0.4		
$D^0 \rightarrow \pi^- \mu^+ \nu$	2.1	1.0		
$D^+ \rightarrow \mu^+ \nu$	4.0	2.0	~100	15.0
f_{D^+}	2.0	0.9		7.5

314 pb⁻¹

Mode	$\delta B / B$ (4.015 GeV)	$\delta B / B$ (4.16 GeV)	$\delta B / B$ (PDG 06)	CLEO-c
$D_s^+ \rightarrow \phi \pi^+$	4.0		14	
$D_s^+ \rightarrow \phi e^+ \nu$	5		17	
$D_s^+ \rightarrow \mu^+ \nu$	5.7		18	
$D_s^+ \rightarrow \tau^+ \nu$				
$f_{D_s^+}$	~2.8	1.3	9	4.7 76

About one year data taking \rightarrow 4fb⁻¹ for designed luminosity

Leptonic decays

$f_{D(s)}$ at BESIII

3 generation unitarity global fit:

hep-ph/0406184 CKM fitter group

$$\frac{\Delta |V_{cd}|}{|V_{cd}|} \approx 1.1\% \quad \frac{\Delta |V_{cs}|}{|V_{cs}|} \approx 0.06\%$$

$$\frac{\Delta \tau_D}{\tau_D} \approx 0.6\% \quad \frac{\Delta \tau_{D_s}}{\tau_{D_s}} \approx 1.0\%$$

With 20fb^{-1}
at BESIII

$$\frac{\Delta B}{B} \approx (2 \sim 4)\%$$

$$\frac{\Delta f_{D(s)}}{f_{D(s)}} = \sqrt{\left(\frac{1}{2} \frac{\Delta \tau_{D(s)}}{\tau_{D(s)}}\right)^2 + \left(\frac{1}{2} \frac{\Delta B}{B}\right)^2 + \left(\frac{\Delta |V_{cd(s)}|}{|V_{cd(s)}|}\right)^2}$$

$$\frac{\Delta f_D}{f_D} \approx 1.2\% \quad \text{BESIII} \quad E_{\text{cm}} = 3.773 \text{ GeV}$$

$$\frac{\Delta f_{D_s}}{f_{D_s}} \approx 2.1\% \quad \text{BESIII} \quad E_{\text{cm}} = 4.03 \text{ GeV}$$

Challenge LQCD Prediction

Exclusive Semileptonic decays

Decay rates relates to CKM Matrix elements and form factor

$$\frac{d\Gamma(D \rightarrow Pl\nu)}{dq^2} = \frac{G_F^2}{24\pi^3} p_P^3 |V_{cq}|^2 |f_+(q^2)|^2 \quad \left. \begin{array}{l} \Gamma(D \rightarrow Kev_e) = \frac{B(D \rightarrow Kev_e)}{\tau_D} = 1.53 |V_{cs}|^2 |f_+^K(0)|^2 \times 10^{11} s^{-1} \\ \Gamma(D \rightarrow \pi e\nu_e) = \frac{B(D \rightarrow \pi e\nu_e)}{\tau_D} = 3.01 |V_{cd}|^2 |f_+^\pi(0)|^2 \times 10^{11} s^{-1} \end{array} \right\}$$

$$f_+(q^2) = \frac{f_+(0)}{1 - q^2 / m_{\text{pole}}^2}$$

To extract V_{cs} & V_{cd} need form factor from theory at one fixed q^2 point.

$$\frac{\Delta |V_{cq}|}{|V_{cq}|} = \sqrt{\left(\frac{\Delta B}{2B}\right)^2 + \left(\frac{\Delta \tau_D}{2\tau_D}\right)^2 + \left(\frac{\Delta f}{f}\right)^2}$$

1. Well measured life times of D mesons from PDG06

$$\frac{\Delta \tau_{D^0}}{\tau_{D^0}} = 0.4\%$$

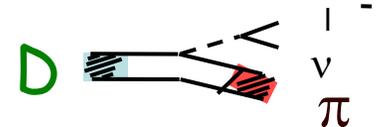
2. With 4 fb^{-1} $\Psi(3770)$ data at BESIII

$$\left(\frac{\Delta B}{B}\right)_{\text{stat.}} \sim 0.7\%, 1.8\%$$

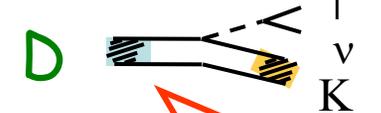
3. Form factor from theory (Lattice QCD).

Assuming $\Delta f/f \sim 1.5\%$.

$\Delta V_{cd}/V_{cd} \sim 1.8\%$



$\Delta V_{cs}/V_{cs} \sim 1.6\%$



BESIII: $L=4 \text{ fb}^{-1}$

$\psi(3770)$ MC

simulation

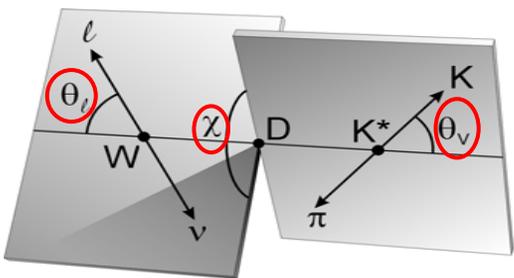
Quark models, HQET, Lattice & other methods have all been invoked to calculate form factor absolute normalizations. These calculations have been done mostly at $q^2 = 0$ or $q^2 = q_{\text{max}}^2$. (i.e. $w=1$, just like F in V_{cb} in $B \rightarrow D^* l\nu$)

Great contribution to CKM Unitarity

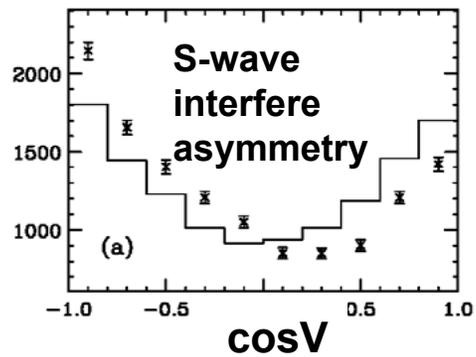
Exclusive Semileptonic decays



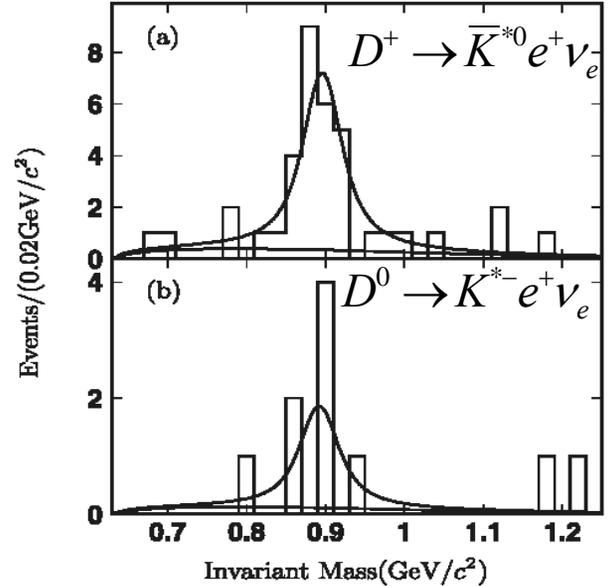
Focus FPCP 2006



$0.8 < M(K\pi) < 0.9 \text{ GeV}/c^2$



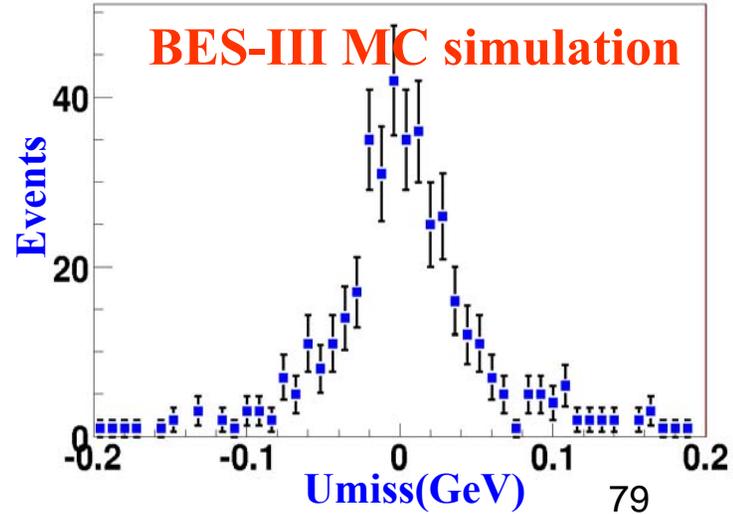
BES-II



$$\int |A|^2 d\chi = \frac{1}{8} q^2 \left\{ \begin{aligned} &((1 + \cos\theta_l) \sin\theta_v)^2 |H_+(q^2)|^2 |BW|^2 \\ &+ ((1 - \cos\theta_l) \sin\theta_v)^2 |H_-(q^2)|^2 |BW|^2 \\ &+ (2 \sin\theta_l \cos\theta_v)^2 |H_0(q^2)|^2 |BW|^2 \\ &+ 8 (\sin^2\theta_l \cos\theta_v) H_0(q^2) h_0(q^2) \text{Re}\{Ae^{-i\delta} BW\} \\ &+ O(A^2) \end{aligned} \right\}$$

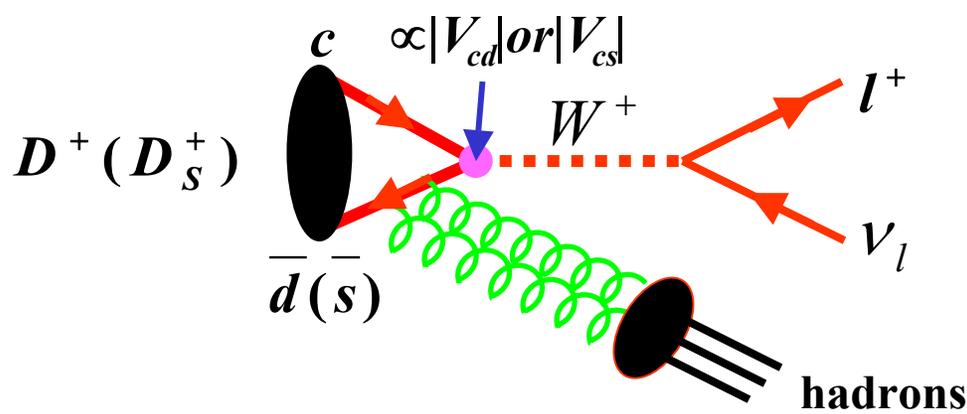
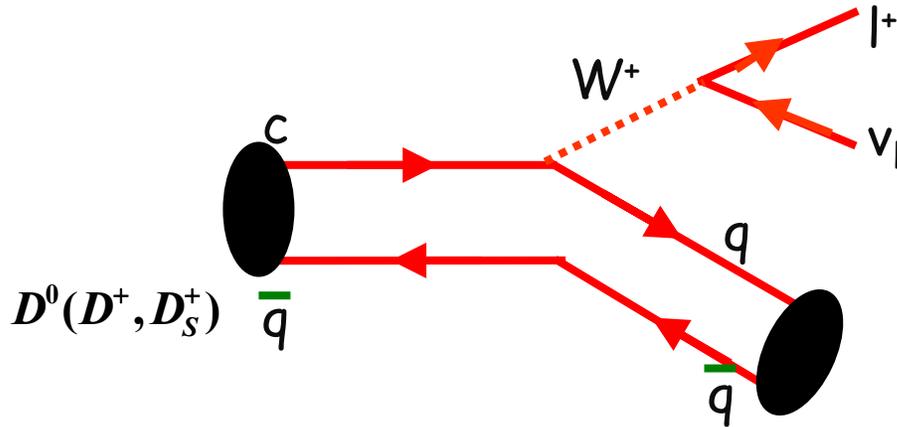
$H_0(q^2)$, $H_+(q^2)$, $H_-(q^2)$ are helicity-basis form factors which are computable by LQCD. A new factor $h_0(q^2)$ is needed to describe s-wave interference piece.

BES-III MC simulation



Inclusive Semileptonic decays

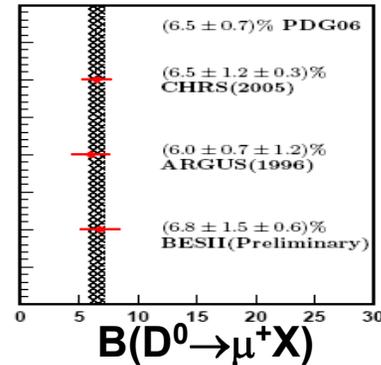
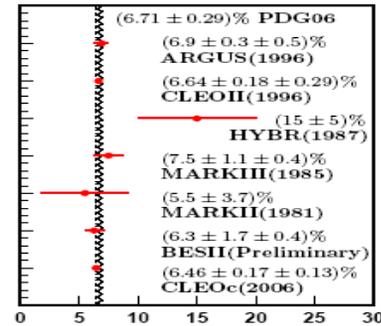
Measurements of $B(D \rightarrow \ell^+ X) (\ell = e, \mu)$



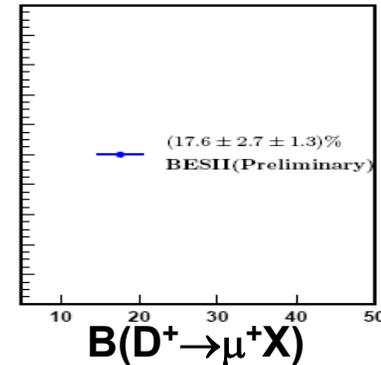
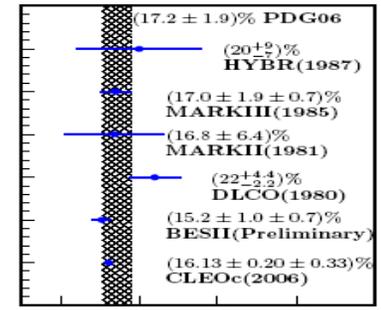
with the BES-III detector, we may have the opportunity to study these decays, to check:

$$\Gamma_{SL}(D^0 \rightarrow X \ell^+ \nu_\ell) \stackrel{?}{=} \Gamma_{SL}(D^+ \rightarrow X \ell^+ \nu_\ell) \stackrel{?}{=} \Gamma_{SL}(D_S^+ \rightarrow X \ell^+ \nu_\ell)$$

$B(D^0 \rightarrow e^+ X)$



$B(D^+ \rightarrow e^+ X)$



CLEOc's results are not used in PDG06 average

$\Delta B/B[\%]$	Current Exp.	BESIII [4 fb ⁻¹]
$D^0 \rightarrow e^+ X$	2.6%	~0.3%
$D^+ \rightarrow e^+ X$	1.3%	~0.3%
$D^0 \rightarrow \mu^+ X$	22%	~1.0%
$D^+ \rightarrow \mu^+ X$	15%	~1.0%

Non-leptonic decays

Precise measurements of absolute branching fractions of charmed meson decays

Measurements of the interference effects between different decay amplitudes

Dalitz plot analysis

Study of the single and double Cabibbo suppressed decays

...

Precise Measurements at BES-III

A short summary
on the Absolute
Measurement

After CLEO-c, the accuracy on the absolute measurements still needs to be improved.

Why is it so important ?

1) Form factors in D semi-leptonic decays & decay constants f_{D^+} and $f_{D_s^+}$ can be used to calibrate Lattice QCD calculations.

$$[f_{D^+} = 235 \pm 8 \pm 14 \text{ MeV LQCD}]$$

$$[\Delta f_{D^+} / f_{D^+} = 7\% \text{ LQCD}]$$

2) Precise measurements of inclusive semileptonic branching fractions \leftrightarrow lifetimes of D mesons \rightarrow to understand decay mechanism.

3) Engineering measurements

a) Determine production rate of charm in B decays.

b) Realism of MC generator & BCK subtraction when looking for New Physics in general.

CLEO-c
expects to
improve f_{D^+}
measurement
at $\sim 5\%$ with
 $\sim 800 \text{ pb}^{-1}$ of
 $\psi(3770)$ data

BES-III can
improve f_{D^+}
measurement at
 $\sim 2\%$ accuracy
level with 4 fb^{-1} of
 $\psi(3770)$ data;
and improve
 f_{D_s} measurement
at 1.3% accuracy
level with 4 fb^{-1} of
 $\psi(4170)$ data

Probes for NP -- Rare Pure or Semi-leptonic Decays

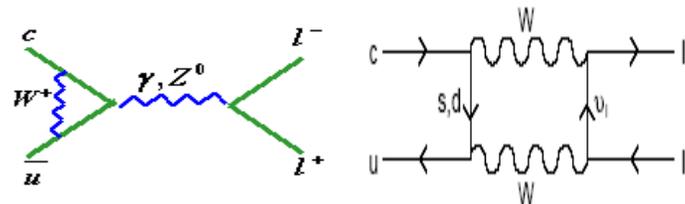
在标准模型理论中，短距离的**Charm** 味道改变中性流是高度的**GIM**机制压低的。

标准模型理论预期:

SM

$$B(D^0 \rightarrow e^+ e^-) \sim 10^{-23}$$

$$B(D^0 \rightarrow \mu^+ \mu^-) \sim 3 \times 10^{-13}$$



但是，一些超标准模型的新物理（如：**R-parity violating SUSY**）可增大这些衰变过程的几率，给出较大的分支比：

$$B(D^0 \rightarrow e^+ e^-) \text{ up to } 10^{-10}$$

$$B(D^0 \rightarrow \mu^+ \mu^-) \text{ up to } 10^{-6}$$

$$B(D^0 \rightarrow e^\pm \mu^\mp) \text{ up to } 10^{-6}$$

Best limits are from BABAR

(Burdman et al., Phys. Rev. D66, 014009).

在标准模型理论中衰变过程 $D^0 \rightarrow e^\pm \mu^\mp$ 是禁戒的。

.....

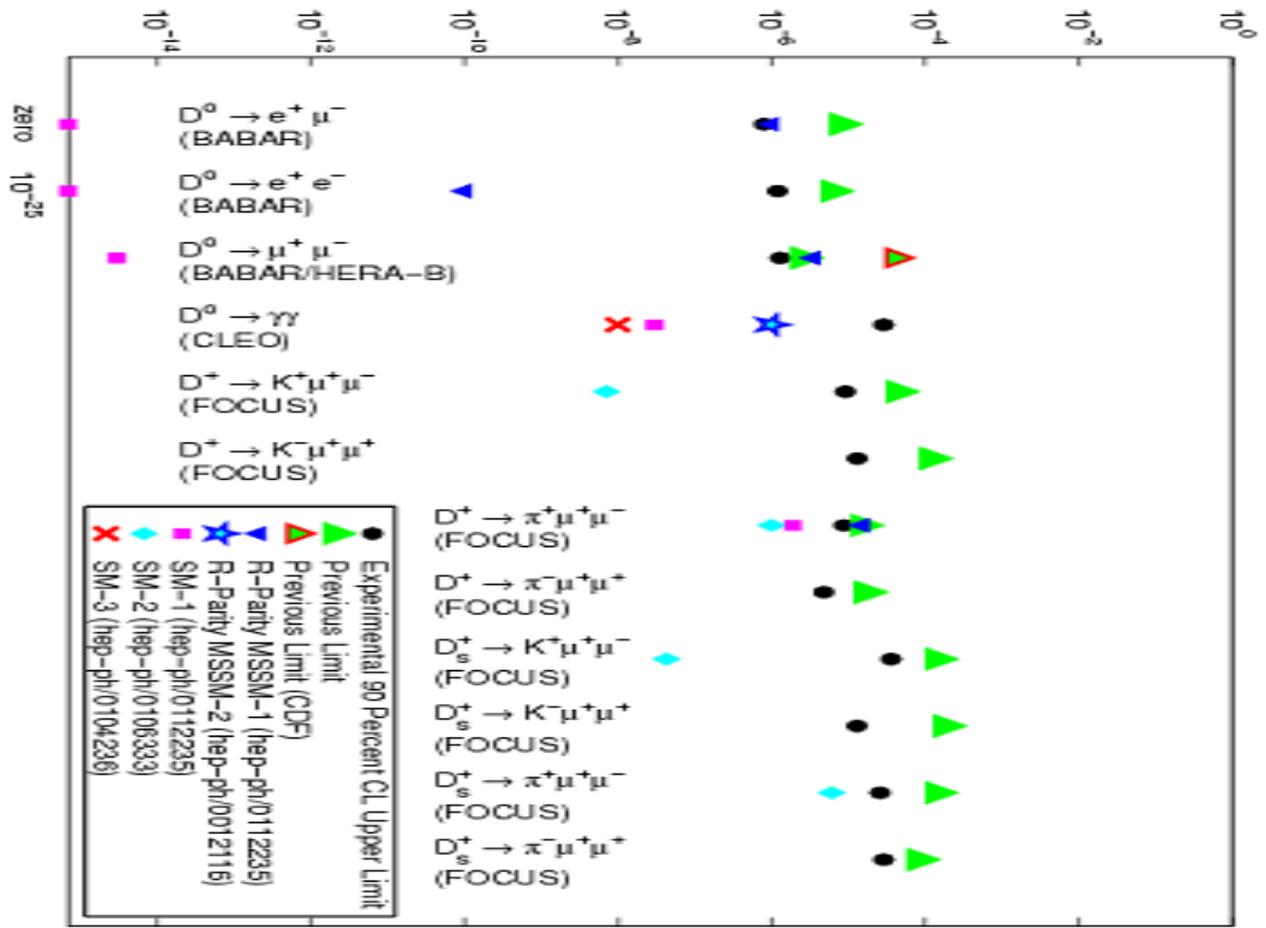
Search for these kinds of rare decays can probe New Physics

Probes for NP-- Rare Pure or Semi-leptonic Decays

Current status

Experimental upper limits are about $10^{-5} \sim 10^{-6}$

Branching Fraction



Talk from Ian Shipsey

Expt. sensitivity $10^{-5} - 10^{-6}$
 Just beginning to confront models of New Physics in an interesting way.

Still plenty of room for New Physics.

Outlook: promising CDF/D0, B factories, CLEO_c/BES III superflavour

Probes for NP-- Rare Pure or Semi-leptonic Decays

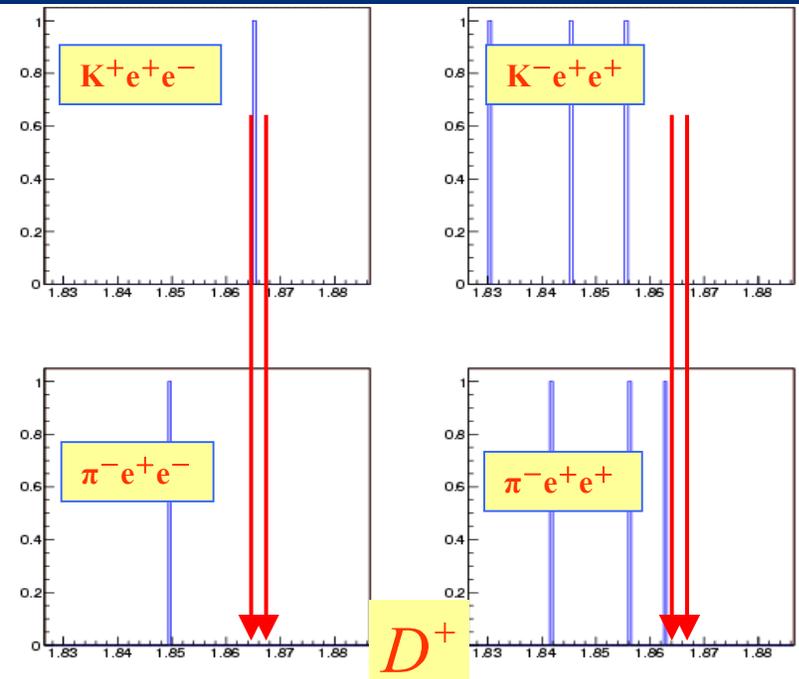
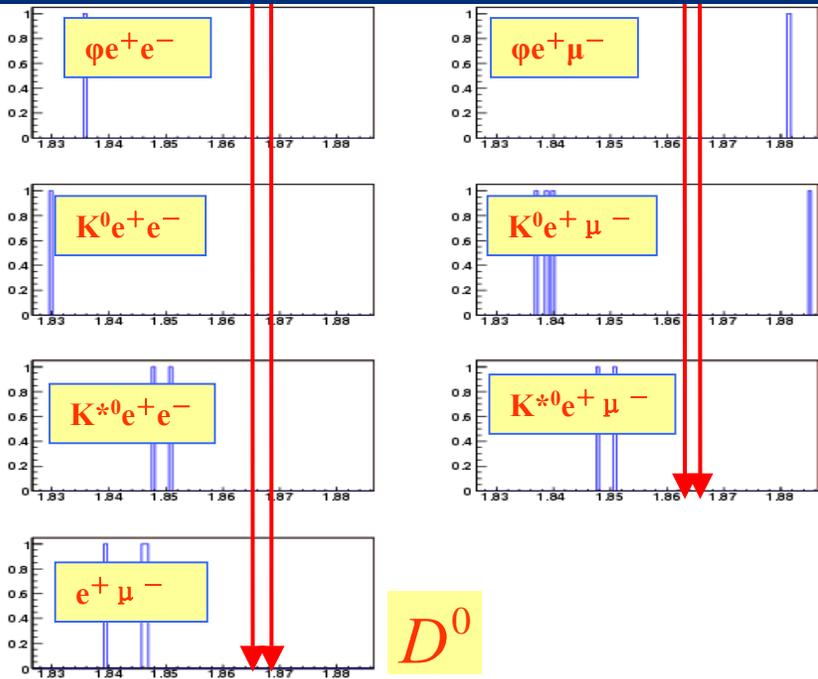
Current status



Main Experiments Cited by PDG ($10^{-4} \sim 10^{-5}$)

Decay Mode	E653 (10^{-4})	E791 (10^{-4})	FOCUS (10^{-5})
$D_S^+ \rightarrow K^+ e^\pm \mu^\mp$	—	6.3	—
$D_S^+ \rightarrow K^- e^+ \mu^+$	—	6.8	—
$D_S^+ \rightarrow \pi^+ e^\pm \mu^\mp$	—	6.1	—
$D_S^+ \rightarrow \pi^- e^+ \mu^+$	—	7.3	—
$D_S^+ \rightarrow K^+ \mu^+ \mu^-$	5.9	1.4	3.6
$D_S^+ \rightarrow K^- \mu^+ \mu^+$	5.9	1.8	1.3
$D_S^+ \rightarrow \pi^+ \mu^+ \mu^-$	4.3	1.4	2.6
$D_S^+ \rightarrow \pi^- \mu^+ \mu^+$	4.3	1.6	2.9
$D_S^+ \rightarrow K^+ e^+ e^-$	—	16	—
$D_S^+ \rightarrow K^- e^+ e^+$	—	6.3	—
$D_S^+ \rightarrow \pi^+ e^+ e^-$	—	2.7	—
$D_S^+ \rightarrow \pi^- e^+ e^+$	—	6.9	—

Probes for NP--Rare decays



Decay Mode	N^{obs}	N^{up}	$\epsilon(\%)$	U.L. (10^{-6})
$D^0 \rightarrow e^\mp \mu^\pm$	0	2.30	40.9	1.58
$D^0 \rightarrow \phi e^+ e^-$	0	2.30	8.2	7.88
$D^0 \rightarrow \phi e^\mp \mu^\pm$	0	2.30	8.2	7.88
$D^0 \rightarrow K^0 e^+ e^-$	0	2.30	11.6	5.57
$D^0 \rightarrow \bar{K}^0 e^\mp \mu^\pm$	0	2.30	11.6	5.57
$D^0 \rightarrow K^{*0} e^+ e^-$	0	2.30	11.7	5.52
$D^0 \rightarrow K^{*0} e^\mp \mu^\pm$	0	2.3	11.7	5.52

Decay Mode	N^{obs}	N^{up}	$\epsilon(\%)$	U.L. (10^{-6})
$D^+ \rightarrow \pi^+ e^+ e^-$	0	2.30	26.2	3.40
$D^+ \rightarrow \pi^- e^+ e^+$	0	2.30	25.3	3.53
$D^+ \rightarrow K^+ e^+ e^-$	1	3.89	22.8	6.62
$D^+ \rightarrow K^- e^+ e^+$	0	2.30	23.9	3.73

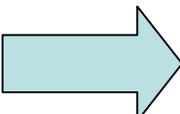
With 0.5 fb^{-1} $\Psi(3770)$ data, the sensitivity can up to 10^{-6} .

Probes for NP--Rare decays

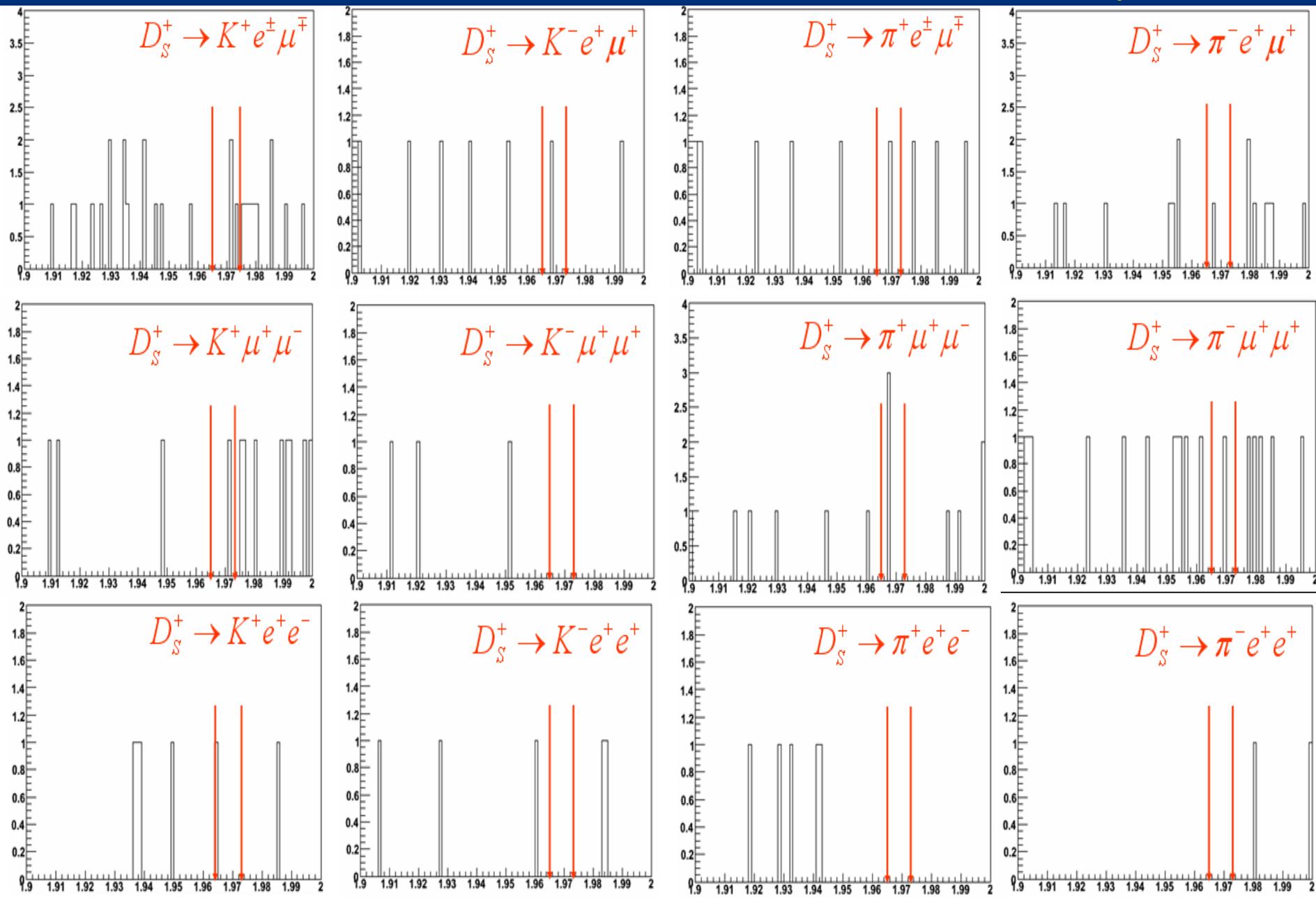
D^0 Decay Mode	U.L. $\times 10^{-6} (0.5 \text{ fb}^{-1})$
$*D^0 \rightarrow e^+e^-$	1.58
$*D^0 \rightarrow \mu^+\mu^-$	1.58
$D^0 \rightarrow e^\mp\mu^\pm$	1.58
$D^0 \rightarrow \phi e^+e^-$	7.88
$*D^0 \rightarrow \phi\mu^+\mu^-$	7.88
$D^0 \rightarrow \phi e^\mp\mu^\pm$	7.88
$D^0 \rightarrow \bar{K}^0 e^+e^-$	5.57
$*D^0 \rightarrow \bar{K}^0 \mu^+\mu^-$	5.57
$D^0 \rightarrow \bar{K}^0 e^\mp\mu^\pm$	5.57
$D^0 \rightarrow K^{*0} e^+e^-$	5.52
$*D^0 \rightarrow K^{*0} \mu^+\mu^-$	5.52
$D^0 \rightarrow K^{*0} e^\mp\mu^\pm$	5.52
$*D^0 \rightarrow \rho^0 e^+e^-$	3.45
$*D^0 \rightarrow \rho^0 \mu^+\mu^-$	3.45
$*D^0 \rightarrow \rho^0 e^\mp\mu^\pm$	3.45

D^+ Decay Mode	U.L. $\times 10^{-6} (0.5 \text{ fb}^{-1})$
$D^+ \rightarrow \pi^+ e^+ e^-$	3.40
$*D^+ \rightarrow \pi^+ \mu^+ \mu^-$	3.40
$*D^+ \rightarrow \pi^+ e^\mp \mu^\pm$	3.40
$D^+ \rightarrow \pi^- e^+ e^+$	3.53
$*D^+ \rightarrow \pi^- \mu^+ \mu^+$	3.53
$*D^+ \rightarrow \pi^- e^+ \mu^+$	3.53
$D^+ \rightarrow K^+ e^+ e^-$	6.62
$*D^+ \rightarrow K^+ \mu^+ \mu^-$	6.62
$*D^+ \rightarrow K^+ e^\mp \mu^\pm$	6.62
$D^+ \rightarrow K^- e^+ e^+$	3.73
$*D^+ \rightarrow K^- \mu^+ \mu^+$	3.73
$*D^+ \rightarrow K^- e^+ \mu^+$	3.73
$*D^+ \rightarrow K^{*+} e^+ e^-$	24.87
$*D^+ \rightarrow K^{*+} \mu^+ \mu^-$	24.87
$*D^+ \rightarrow K^{*+} e^\mp \mu^\pm$	24.87
$*D^+ \rightarrow K^{*-} e^+ e^+$	24.87
$*D^+ \rightarrow K^{*-} \mu^+ \mu^+$	24.87
$*D^+ \rightarrow K^{*-} e^+ \mu^+$	24.87

Note: the * means that the upper limit is estimated.

 If with 20 fb^{-1} $\Psi(3770)$ data, the sensitivity can go down to $10^{-7} \sim 10^{-8}$.

Probes for NP--Rare decays



Probes for NP--Rare decays

BES-III M.C. Simulation 4 fb⁻¹

Decay Mode	Obs. Number	UP. Number	Efficiency	U.L. (10 ⁻⁶)
$D_S^+ \rightarrow K^+ e^\pm \mu^\mp$	3	6.68	31.2%	12.2
$D_S^+ \rightarrow K^- e^+ \mu^+$	1	3.89	31.2%	7.14
$D_S^+ \rightarrow \pi^+ e^\pm \mu^\mp$	1	3.89	31.2%	7.14
$D_S^+ \rightarrow \pi^- e^+ \mu^+$	1	3.89	31.2%	7.14
$D_S^+ \rightarrow K^+ \mu^+ \mu^-$	1	3.89	28.8%	7.71
$D_S^+ \rightarrow K^- \mu^+ \mu^+$	0	2.30	28.8%	4.53
$D_S^+ \rightarrow \pi^+ \mu^+ \mu^-$	3	6.68	28.8%	13.2
$D_S^+ \rightarrow \pi^- \mu^+ \mu^+$	1	3.89	28.8%	7.71
$D_S^+ \rightarrow K^+ e^+ e^-$	1	3.89	33.8%	6.58
$D_S^+ \rightarrow K^- e^+ e^+$	0	2.30	33.8%	3.89
$D_S^+ \rightarrow \pi^+ e^+ e^-$	0	2.30	33.8%	3.89
$D_S^+ \rightarrow \pi^- e^+ e^+$	0	2.30	33.8%	3.89



If with 20 fb⁻¹ $\Psi(4030)$ data, the sensitivity can go down to about 10⁻⁷.

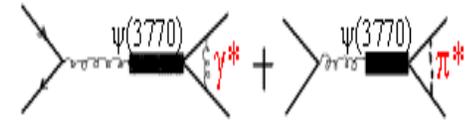
Ratio of charged/neutral $D\bar{D}$ production

Why are we interested in ?

Fraction of D^+ and D^0 yields

$$f = \left[\frac{p_{+-}}{p_{00}} \right]^3 = 0.69 \quad \text{pure phase space}$$

$$f = F \left[\frac{p_{+-}}{p_{00}} \right]^3 \quad F \text{ accounts for}$$



$$f = \frac{\sigma(e^+e^- \rightarrow D^+D^-)}{\sigma(e^+e^- \rightarrow D^0\bar{D}^0)} = 0.787 \pm 0.074 \pm 0.05$$

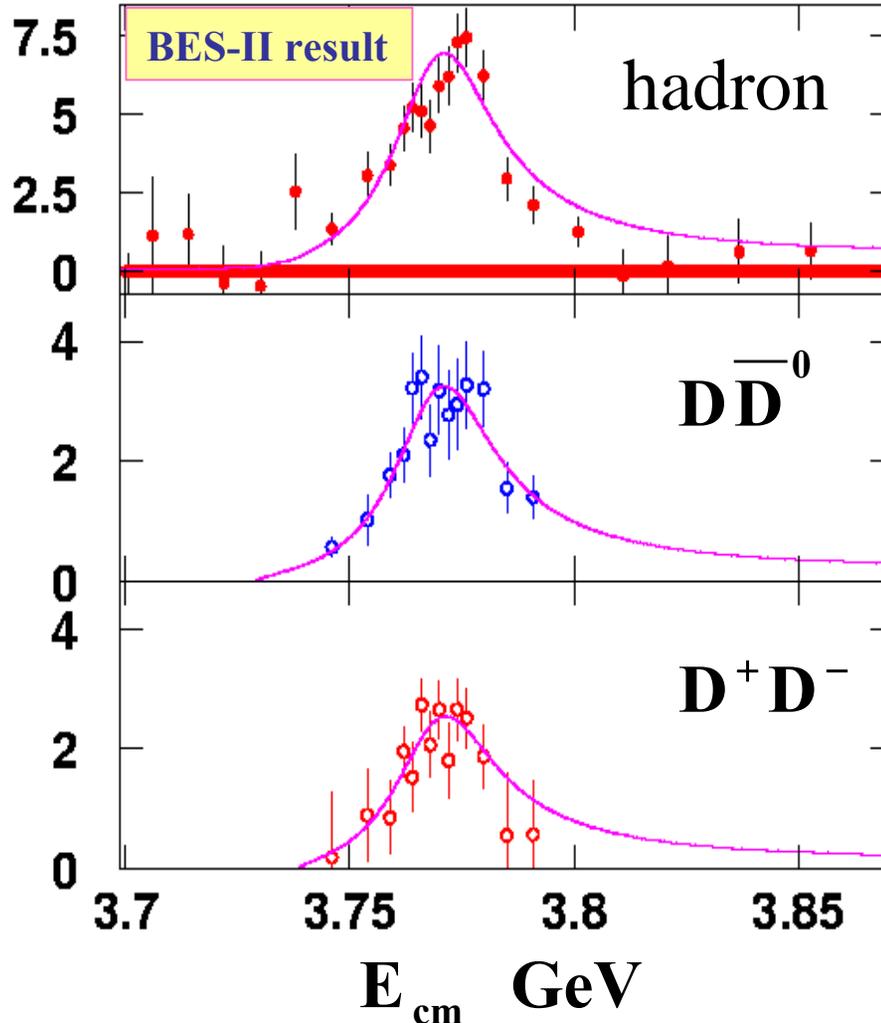
$$E_{cm} = 3.773 \text{ GeV}$$

BES

$$f = \frac{\sigma(e^+e^- \rightarrow D^+D^-)}{\sigma(e^+e^- \rightarrow D^0\bar{D}^0)} = 0.715 \pm 0.026 \pm \Delta_{\text{sys}}$$

CLEO-c

$$f = \frac{\sigma(e^+e^- \rightarrow D^+D^-)}{\sigma(e^+e^- \rightarrow D^0\bar{D}^0)} = 0.776 \pm 0.024^{+0.014}_{-0.006}$$

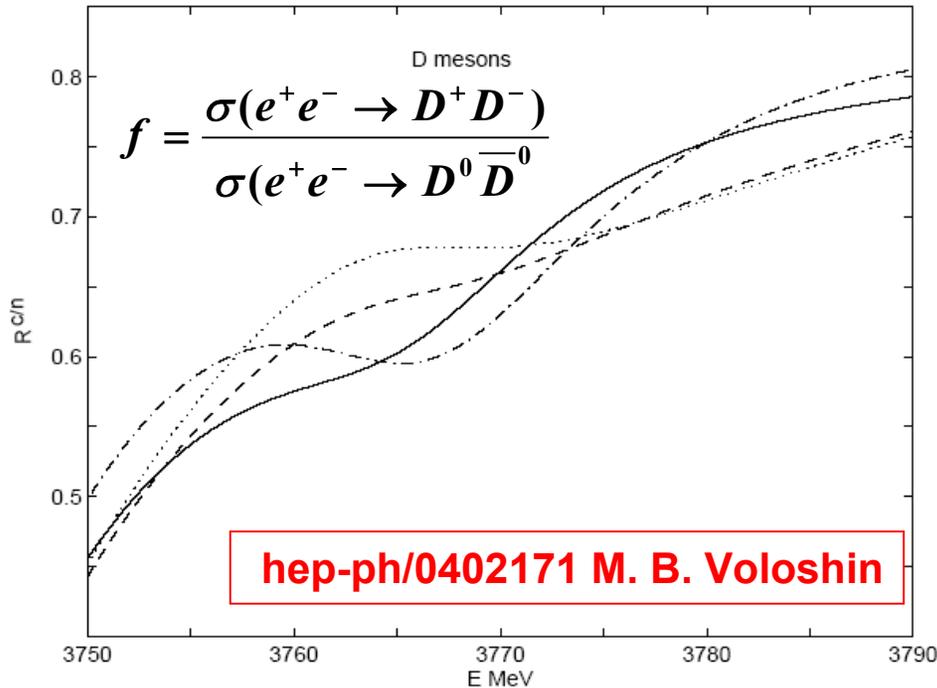


The ratio would vary with changing the c.m. energy.

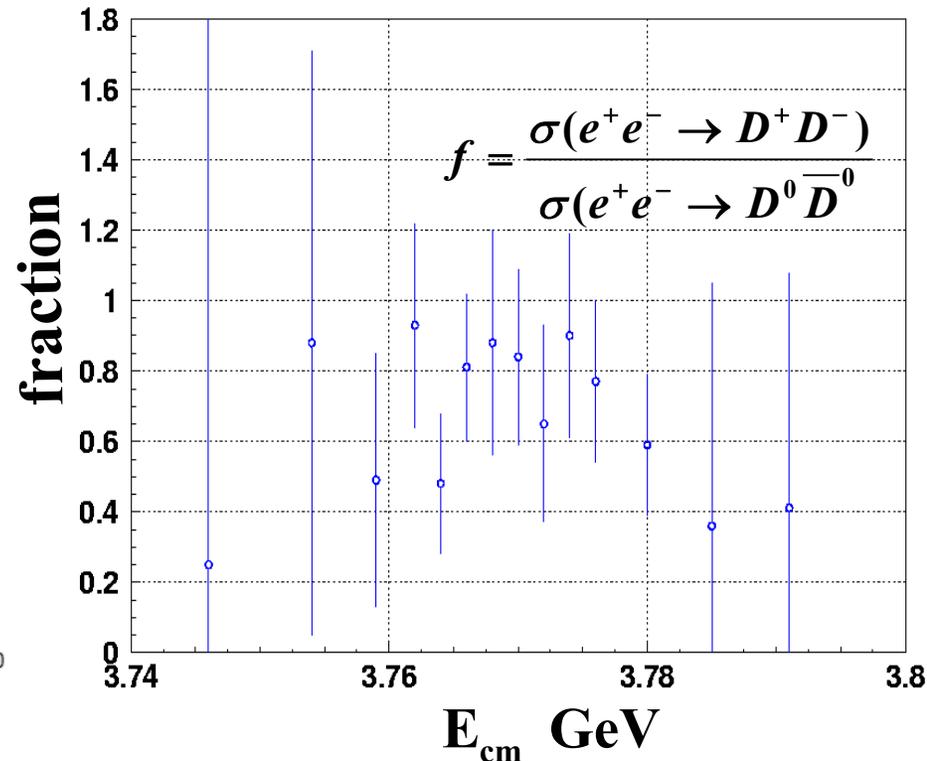
Ratio of charged/neutral $D\bar{D}$ production

Fraction of charged and neutral yields

Theoretical prediction

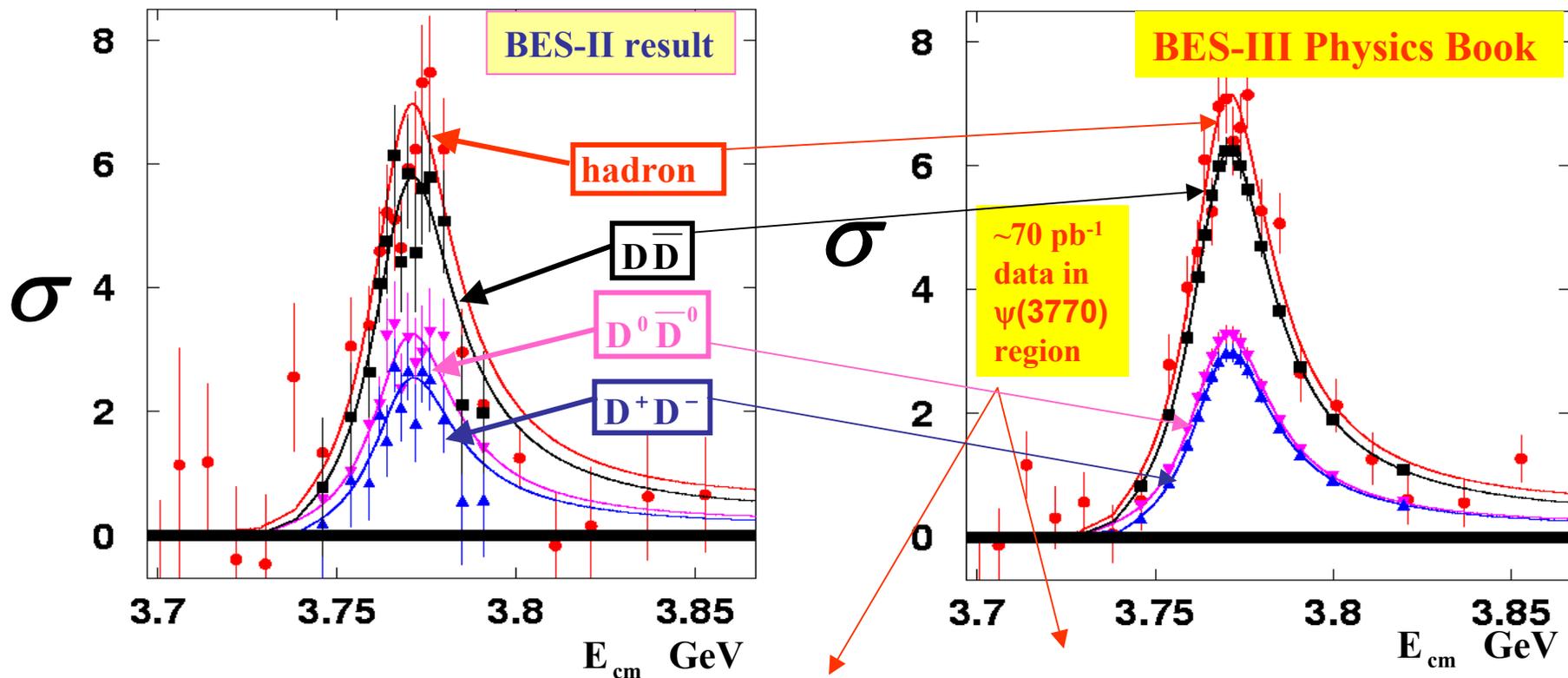


My calculations based on the two observed cross sections only! It is not official !!



We can measure the fraction f vs E_{cm} . A finer cross section scan over the $\psi(3770)$ resonance with the BES-III at the BEPC-II will give results on these measurements

Measurement of DD-bar Line-shape



$\Gamma_{\psi(3770)}^{\text{tot}}$	26.8 ± 0.5 MeV	26.9 MeV
$\Gamma_{\psi(3770)}^{ee}$	256 ± 9 eV	251 eV
	Measured value	Input value

$B[\psi(3770) \rightarrow D\bar{D}]$	$(88.2 \pm 2.4 \pm \sim 2.0) \%$	Measured value
	89 %	Input value

With $\sim 70 \text{ pb}^{-1}$ of data collected from 3.65 to 3.875 GeV with the BES-III Detector at BEPC-II, we can precisely measure the DD-bar line-shape and the ratio of the rates of the charged and neutral yields at different center-of-mass energies.

Summary

BES-I & BES-II/BEPC

首测定 f_D ，绝对测定 f_{D_s}

首次测定 $\text{Br}(D_s^+ \rightarrow eX)$, etc.....

首次测定 $\text{Br}(D^+ \rightarrow \mu^+X)$, etc.....

改进测定 V_{cd} , V_{cs} 和形状因子

精密测定 $\frac{\Gamma(D^0 \rightarrow K^- e^+ \nu_e)}{\Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e)} = 1.00 \pm 0.17 \pm 0.06$, 判定在D介子遍举半轻子衰变中同位旋仍然守恒; 解决了长期存在的“同位旋不守恒之疑难”!

首次测定 DD-bar 产生的形状。

**BES-I和
BES-II 先
前的实验
研究成果**

Summary

BES-III
的粲介子
物理专题

Precise test of the Standard Model

1、Purely leptonic decays

测定 f_{D^+} , $f_{D_s^+}$ → 刻度 LQCD → f_B , f_{B_s} → 高精度的CKM 矩阵元。

2、Semileptonic decays

直接测定 V_{cs} , V_{cd} or $f_{K^+}(0)$, $f_{\pi^+}(0)$, $f_{K^+}(q^2)$, $f_{\pi^+}(q^2)$, 及矢量衰变过程 $D \rightarrow V l^+ \nu$ 的形状因子。

3、non-leptonic decays

Absolute branching fractions of D decays

Dalitz plot analysis

研究不同衰变振幅之间的干涉效应等 ...。

Summary

**BES-III的粲
介子物理专题**

Probes for New Physics

1、 Search for $D^0\bar{D}^0$ mixing

2、 CP Violation

3、 Rare Decays of D mesons

Rare semi-leptonic decays

Rare purely leptonic decays



Professor Zheng
will give a lecture.



寻找新物理

Topics Related to Charm Meson Production

DD-bar line-shape

Ratio of charged and neutral D yields

...

Summary

BES-III粲介子物
理研究的预期精度

BES-III/BEPC-II

Precision test SM (with 4 fb⁻¹ data)

- Pure leptonic decays $f_{D^+} \sim 2.0\%$; $f_{D_s^+} \sim 1.3\%$
- Semileptonic decays $V_{cs} \sim 1.6\%$; $V_{cd} \sim 1.8\%$
- Absolute Hadronic Branching fractions $B(D^0 \rightarrow K^- \pi^+) \sim 0.5\%$
 $B(D^+ \rightarrow K^- \pi^+ \pi^+) \sim 0.5\%$
- Something more.....

Search for New Physics (with 4 fb⁻¹ data)

- $D^0 \bar{D}^0$ Mixing Sensitivity : 7.5×10^{-4}
- CP Violation Sensitivity : $A_{CP} < 2.5 \times 10^{-2}$ @ 90% C.L.

(See Professor Zheng's Talk)

- Rare Decays Sensitivity : 10^{-7} for D mesons @ 90% C.L.
Sensitivity : $10^{-5} \sim 10^{-6}$ for D_s mesons @ 90% C.L.

The END

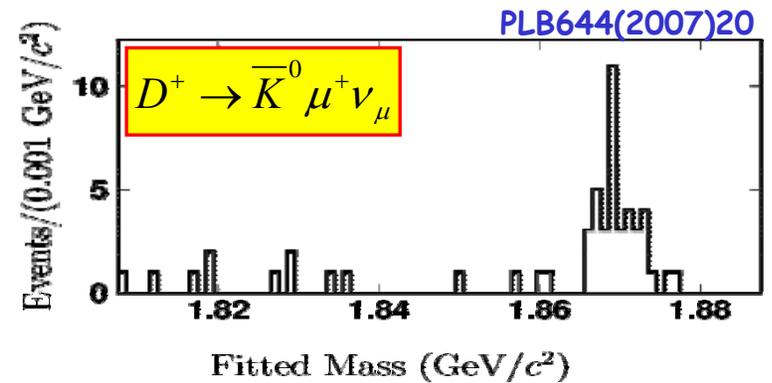
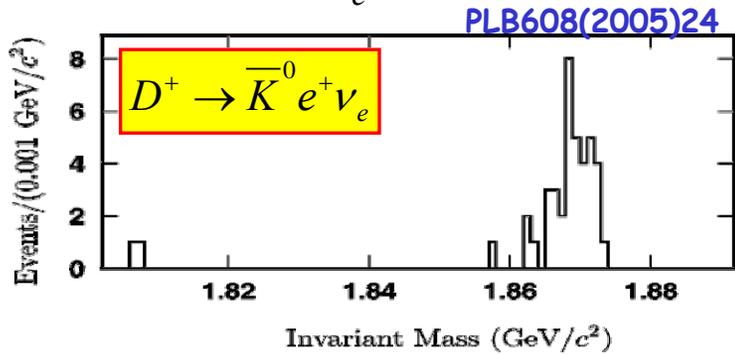
Backup slides

Charm Physics-Isospin Invariance ?

'long-standing puzzle' of whether Isospin conservation holds in the semi-leptonic decays of D mesons ?

Isospin conservation implies $\Gamma(D^0 \rightarrow K^- e^+ \nu_e) / \Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e) = 1$

$\Gamma(D^0 \rightarrow K^- e^+ \nu_e) / \Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e) = 1.4 \pm 0.2$ PDG04



$$\text{BF}(D^+ \rightarrow \bar{K}^0 e^+ \nu_e) = (8.95 \pm 1.59 \pm 0.67)\%$$

$$\text{BF}(D^+ \rightarrow \bar{K}^0 \mu^+ \nu_\mu) = (10.3 \pm 2.3 \pm 0.8)\%$$

$$\frac{\Gamma(D^0 \rightarrow K^- e^+ \nu_e)}{\Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e)} = 1.08 \pm 0.22 \pm 0.07$$

$$\frac{\Gamma(D^0 \rightarrow K^- \mu^+ \nu_\mu)}{\Gamma(D^+ \rightarrow \bar{K}^0 \mu^+ \nu_\mu)} = 0.87 \pm 0.24 \pm 0.15$$

Support isospin conservation holds in the exclusive D semileptonic decays!

CLEO, PRL95(2005)181801

$$\frac{\Gamma(D^0 \rightarrow K^- \ell^+ \nu_\ell)}{\Gamma(D^+ \rightarrow \bar{K}^0 \ell^+ \nu_\ell)} = 1.00 \pm 0.17 \pm 0.06$$

$$\frac{\Gamma(D^0 \rightarrow K^- e^+ \nu_e)}{\Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e)} = 1.00 \pm 0.05 \pm 0.094$$

BEPCII/BESIII Project

Design

- Two ring machine
- 93 bunches each
- Luminosity X 5 CESR-c design

$$10^{33} \text{ cm}^{-2} \text{ s}^{-1} @ 1.89 \text{ GeV}$$

$$6 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} @ 1.55 \text{ GeV}$$

$$6 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} @ 2.1 \text{ GeV}$$

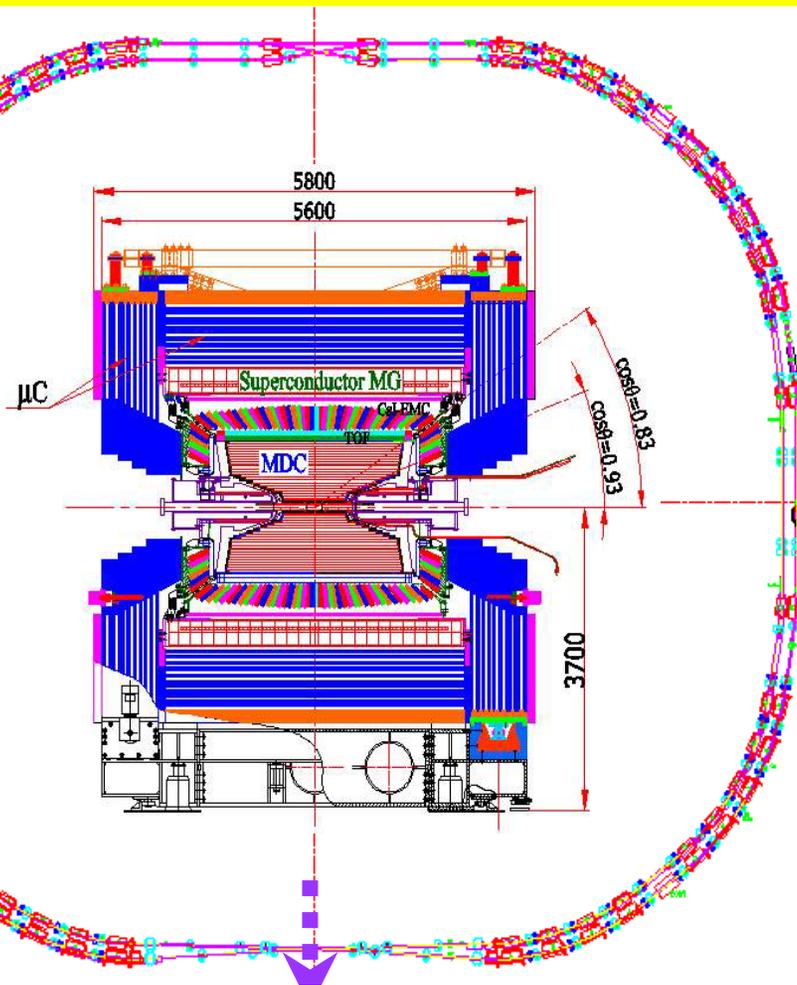
- New BESIII

Status and Schedule

- Most contracts signed
- Linac installed 2005
- Ring to be installed 2006
- BESIII in place
and Commissioning 2007

BEPCII/BESIII

data taking summer of 2008



run plan not decided: example 5/fb/yr 15/fb/3yrs

3 yrs @ 3770 30M DD̄/yr = 90MDD̄ ~ × 20 full CLEO-c

3 yrs @ 4170 2M Ds̄Ds̄/yr = 6MDs̄Ds̄ ~ × 20 full CLEO-c

CKM Matrix Elements

CKM 的测定

$|V_{ud}|$ 由**beta** 衰变或**muon**衰变率来测定。

$|V_{us}|$ 由**K**介子的半轻子衰变率来测定。

$|V_{ub}|$ 由**B**介子衰变到**non-charm** 的半轻子衰变率来测定。

$|V_{cd}|$ 由中微子产生实验确定；由**D**介子半轻子衰变率来测定。

(Single charm particle production in high energy neutrino interaction)

$|V_{cs}|$ 由中微子产生实验确定；由**D**介子半轻子衰变率来测定。

$|V_{cb}|$ 由**B**→**D*****l**⁺**v** 遍举半轻子衰变率来测定。

$|V_{td}|$ 由**B**⁰**B**⁰-**bar** 混合实验确定。

$|V_{ts}|$ 由**B**_s**B**_s-**bar** 混合实验确定。

$|V_{tb}|$ **t**→**b****l**⁺**v** semileptonuc decay。

$$|V_{cd}| = 0.230 \pm 0.011$$

夸克质量

m_u	m_d	m_s	m_c	m_b	m_t
1.5~3.0 MeV	3~7 MeV	95+-25 MeV	1.25+-0.09 GeV	4.20+-0.07 GeV	174.2+3.3 GeV