Recent results on charm physics at BESIII

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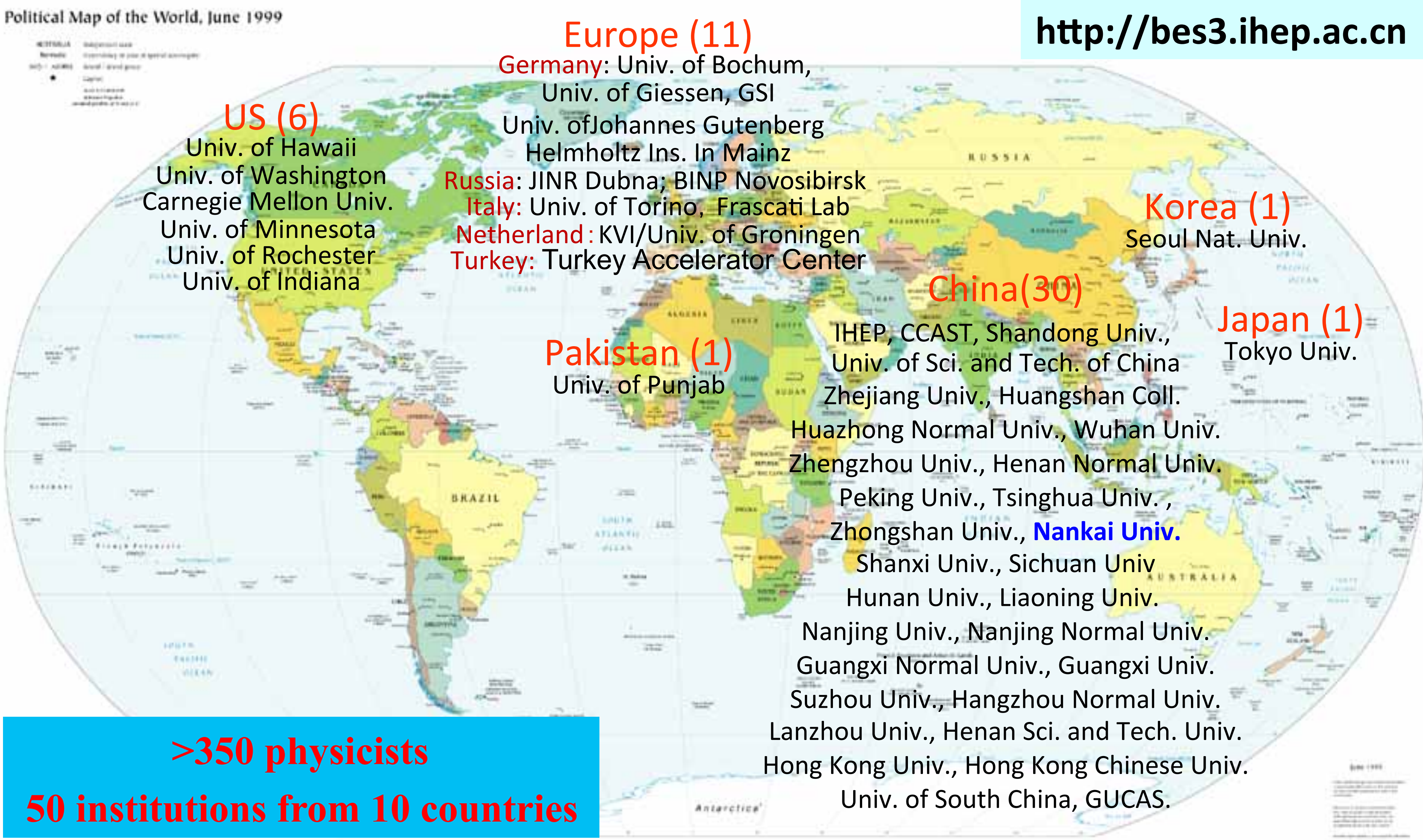
Outline

- Introduction to BEPCII/BESIII
- Selected charm results at BESIII
  - Leptonic decay and f_D
  - Semi-leptonic decay and V_{cs}/V_{cd}
  - Rare decay of $D^0 \rightarrow \gamma\ \gamma$
- Summary

The BESIII Collaboration



http://bes3.ihep.ac.cn

US (6)
Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (11)
Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. ofJohannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Frascati Lab
Netherland : KVI/Univ. of Groningen
Turkey: Turkey Accelerator Center

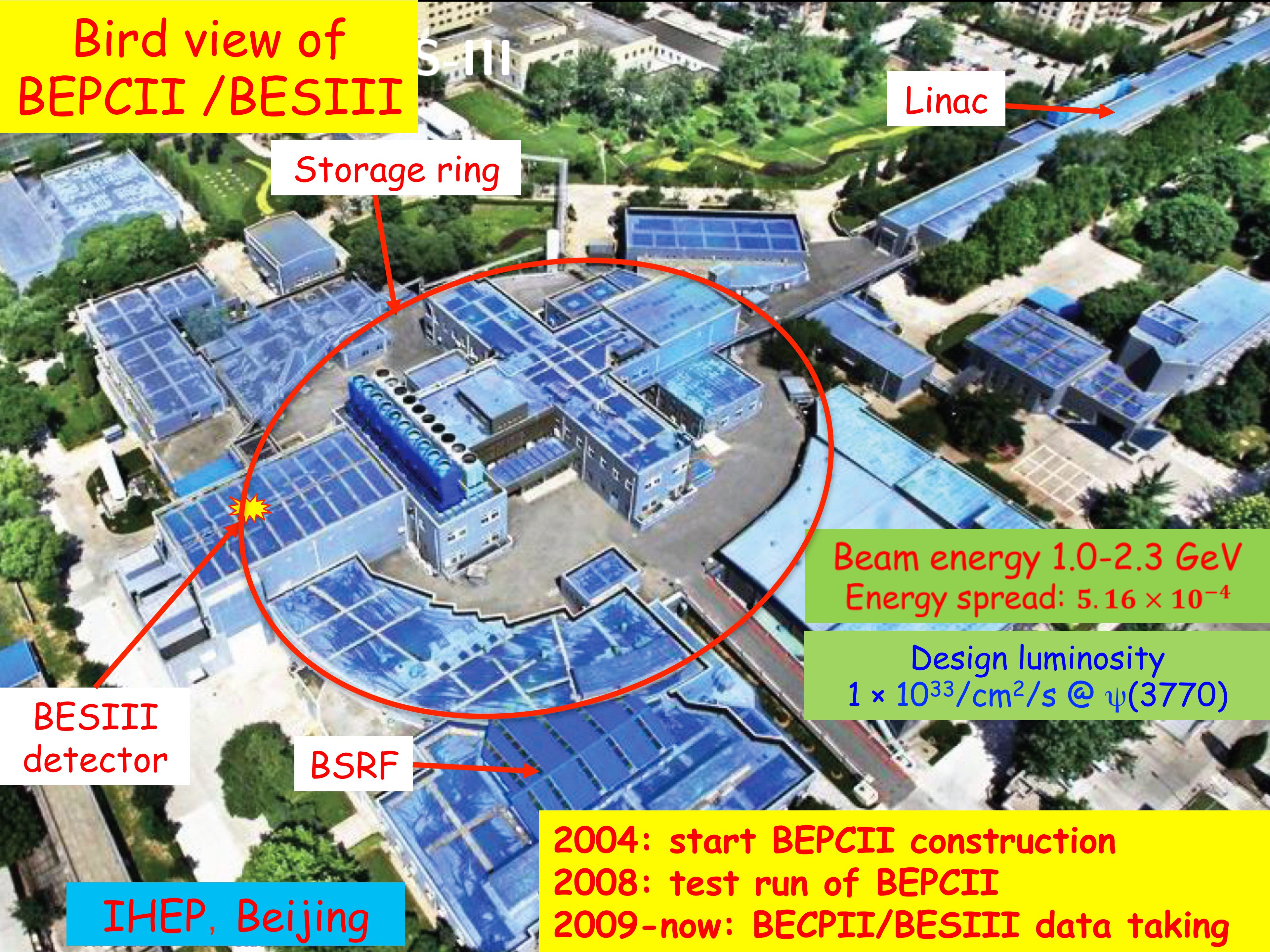
Korea (1)
Seoul Nat. Univ.

Pakistan (1)
Univ. of Punjab

China(30)
IHEP, CCAST, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ., **Nankai Univ.**
Shanxi Univ., Sichuan Univ
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese Univ.
Univ. of South China, GUCAS.

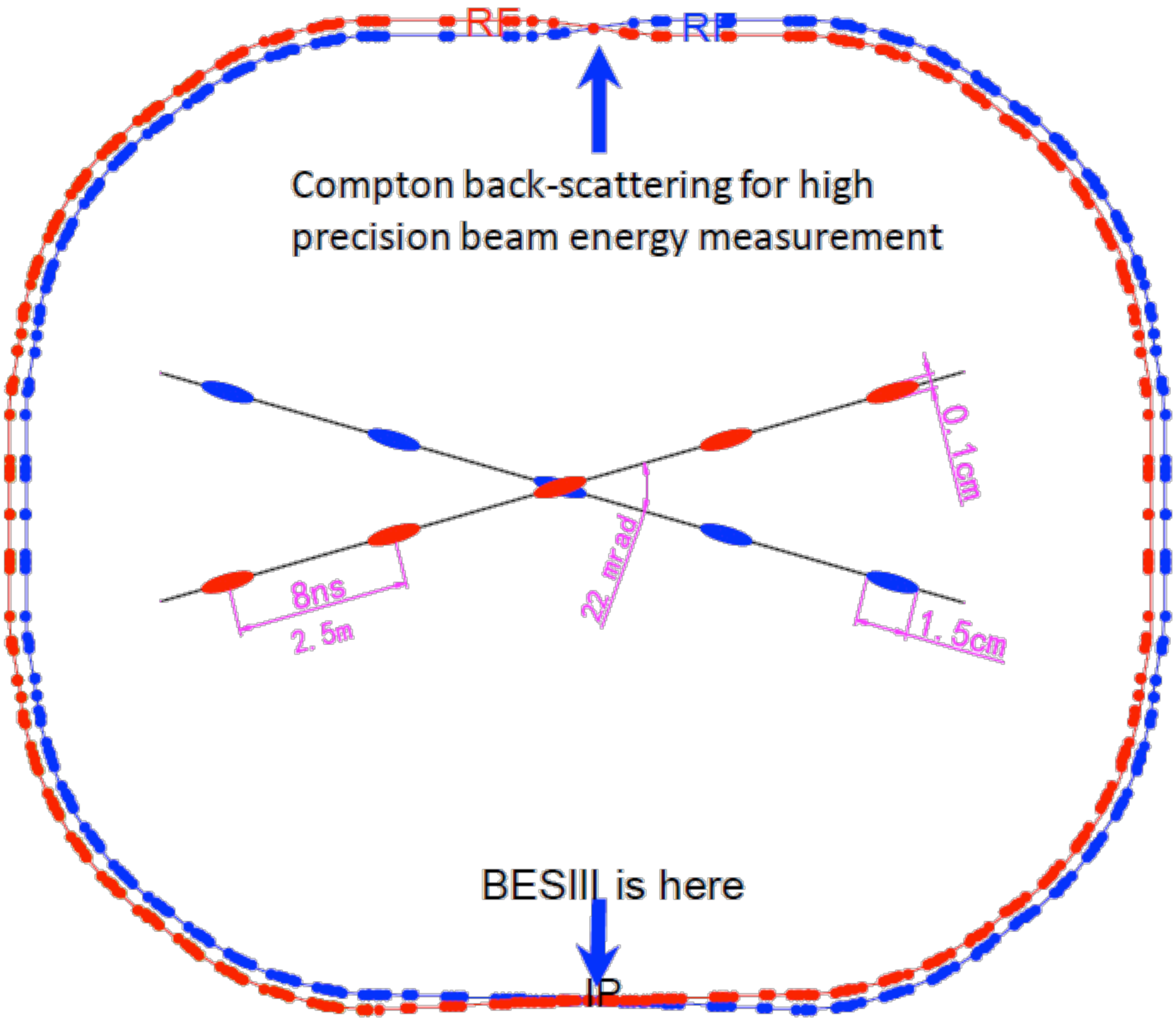
Japan (1)
Tokyo Univ.

>350 physicists
50 institutions from 10 countries



Bird view of BEPCII /BESIII
Linac
Storage ring
Beam energy 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}
Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$
BESIII detector
BSRF
IHEP, Beijing
2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

The BEPCII Storage ring



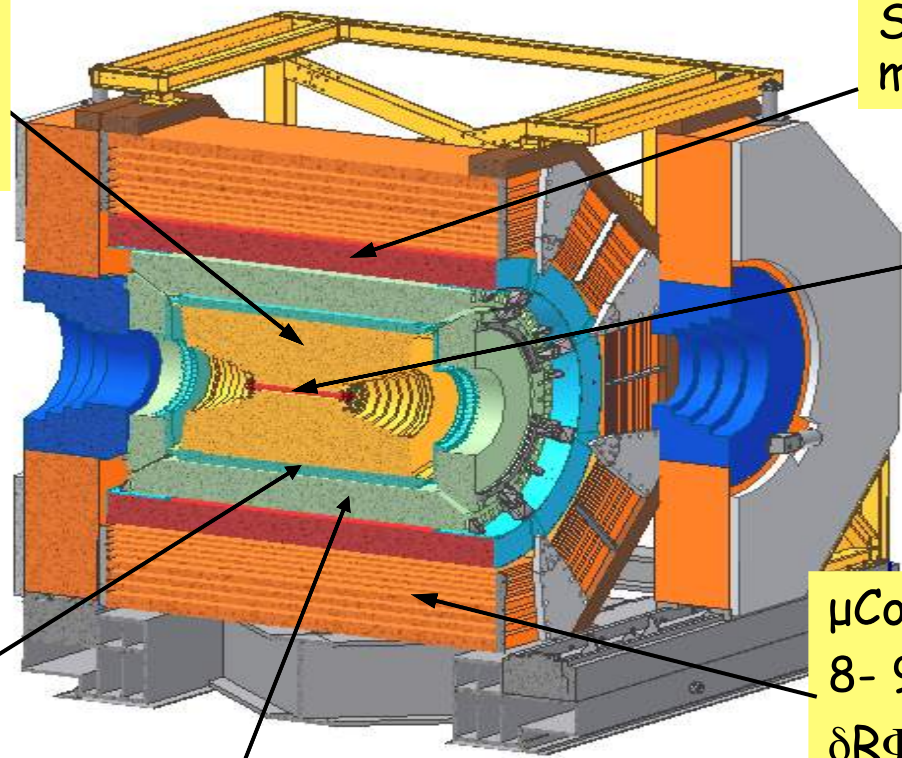
- ✓ Beam energy: 1.0-2.3 GeV
- ✓ Energy spread: 5.16×10^{-4}
- ✓ Optimum energy: 1.89 GeV
- ✓ Luminosity: 1×10^{33} $cm^{-2}s$
- ✓ No. of bunches: 93
- ✓ Bunch length: 1.5 cm
- ✓ Total current: 0.91 A
- ✓ SR mode: 0.25A@2.5GeV

The BESIII Detector

NIM A614, 345 (2010)

Drift Chamber (MDC)
$\sigma P/P$ ($^0/_0$) = 0.5%(1GeV)
$\sigma_{dE/dx}$ ($^0/_0$) = 6%

Super-conducting magnet (1.0 tesla)



Collision point

Time Of Flight (TOF)
σ_T: 90 ps Barrel
110 ps endcap

μCounter
8- 9 layers RPC
$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)
(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

BESIII commissioning

- July 19, 2008: first e+e- collision event at BESIII
- Nov., 2008: 14M $\psi(2S)$ events for detector calibration
- 2009: 106 M $\psi(2S)$ 4 times of CLEO-c
  225 M J/ψ 4 times of BESII
- 2010: 0.9 fb^{-1} $\psi(3770)$ } 3.5 x CLEO-c
- 2011: 2.0 fb^{-1} $\psi(3770)$ }
  0.5 fb^{-1} @ 4.01 GeV
- 2012: 5.0 pb^{-1} tau mass scan data
  400 M $\psi(2S)$ data
  1 B J/ψ data (till May 22, 2012)

World's largest samples of J/ψ, $\psi(2S)$ and $\psi(3770)$ (and still growing)

Peak luminosity reached 6.5×10^{32} @3770 MeV

Tentative future running plans (not Approved yet):

- 2013: Ds physics (@4170 MeV) + R scan (>4 GeV)
- 2014: $\psi(2S)/\tau$/R scan (>4 GeV)
- 2015: 5~10 fb^{-1} $\psi(3770)$ data

Physics Programs @ BESIII

Light hardron physics
- Meson & baryon spectroscopy
- Threshold effects
- Multiquark states
- Glueballs & hybrids
- Two-photon physics
- Form factors

Charm physics:
- Decay constant, f_D & f_{Ds}
- CKM matrix, form factors
- Rare decay
- D^0-D^{0bar} mixing and CPV
- charm meson production

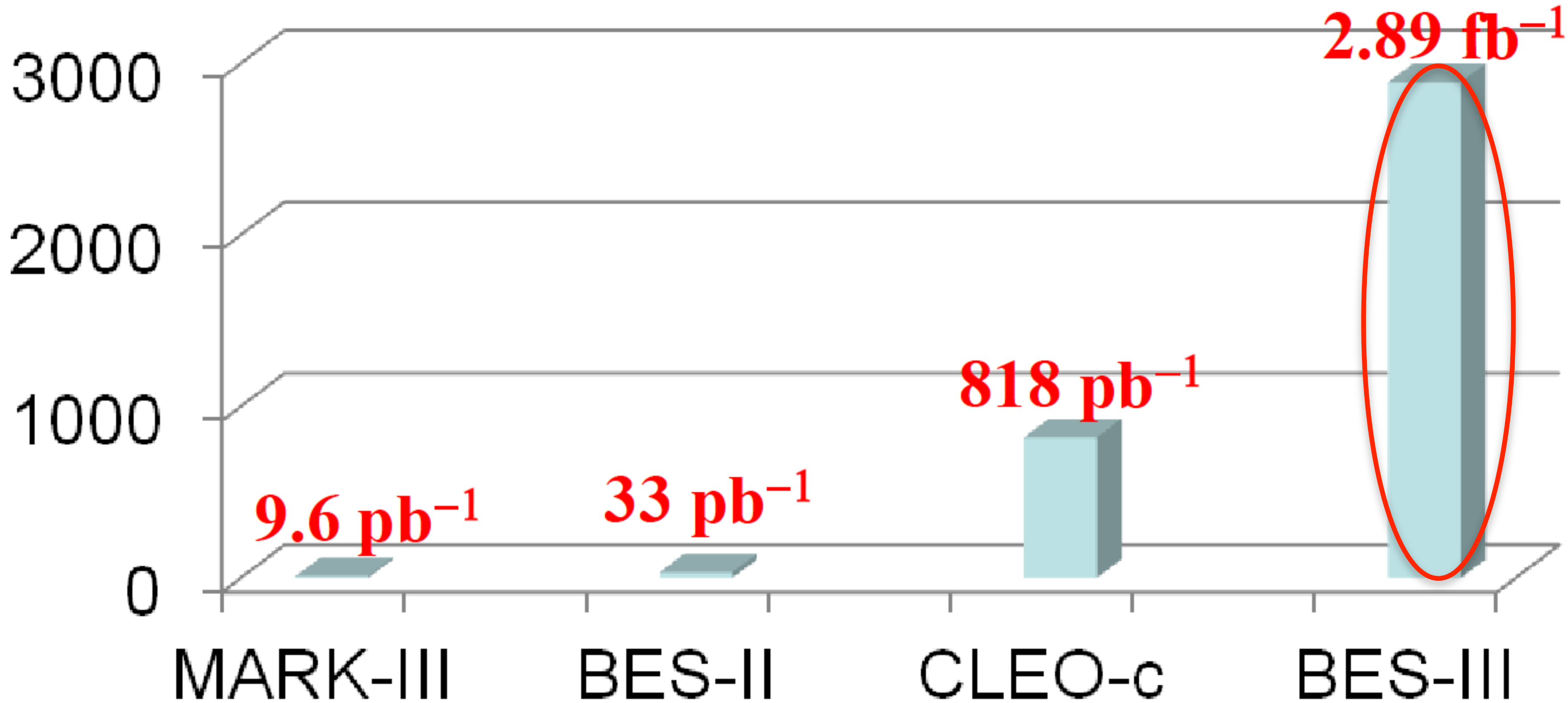
QCD & τ -physics:
- Precision R-measurement
- τ mass / τ decays

Charmonium physics:
- Precision spectroscopy
- Transitions and decays

XYZ meson physics:
- Y(4260) $\pi\pi h_c$ decays

Near threshold charm data

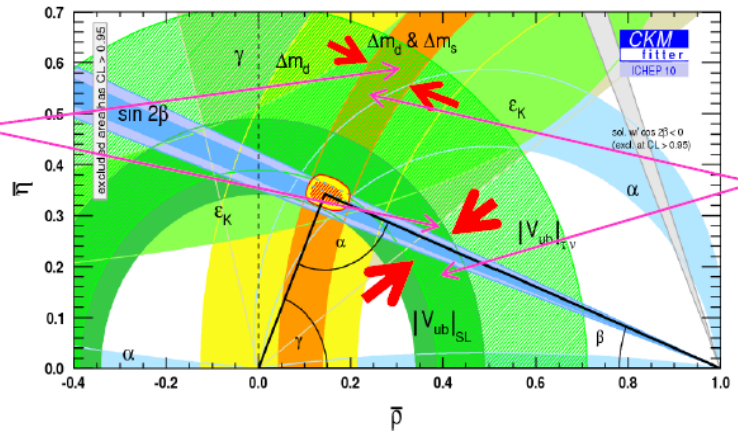
$\psi(3770)$ data samples in the world till 2012



1. Leptonic Decay: introduction

- D^+ leptonic decay plays important role in the understanding of the Standard Model
- Unitary triangle

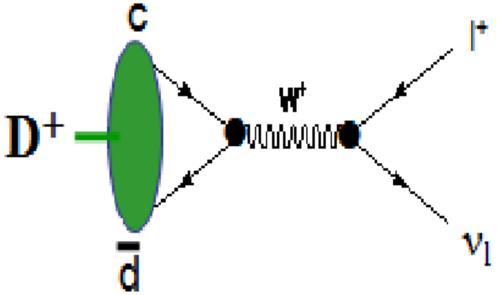
Widths of bands are dominated by errors of f_B and f_{Bs} from LQCD.



The widths of bands will be reduced if the LQCD pass the test with measured f_D, f_{Ds}.

- $f_{D(Ds)}$ test LQCD calculations of $f_{B(Bs)}$

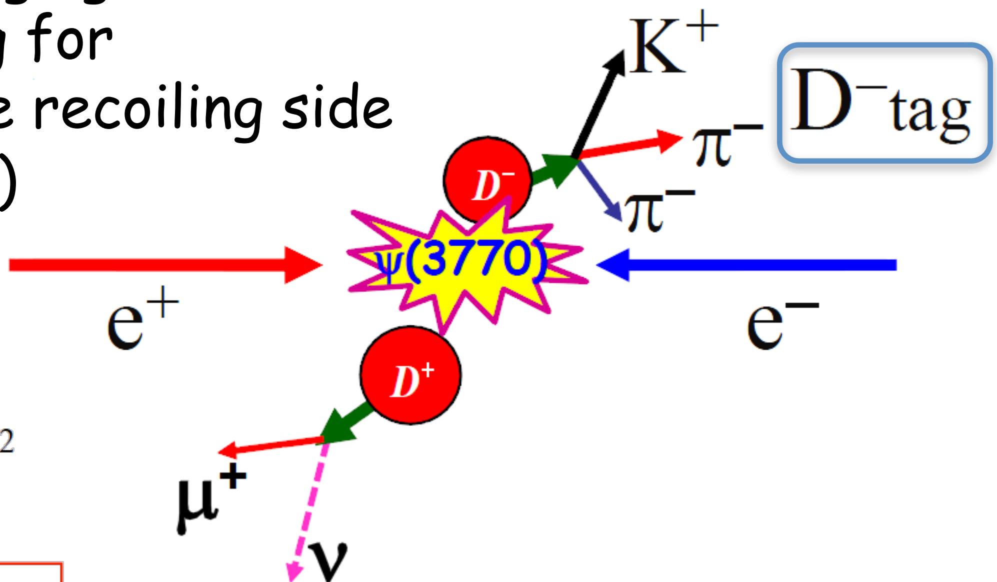
$$\Gamma_{SM}(D^+_{(s)} \to l^+\nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 |V_{cd(s)}|^2 f_{D^+_{(s)}}$$



- Narrow band in the triangle lead to precisely test the SM, and search for something new beyond the SM .

1. Leptonic Decay: technique

- ψ(3770) → DD events near threshold: D producted in pair
- Absolute measurement: tagging one D meson first, then searching for concerned final state in the recoiling side (charge conjugation implied)



Absolute measurement

$$M^2_{miss} = (E_{beam} - E_{\mu^+})^2 - (-\vec{p}_{D^-_{tag}} - \vec{p}_{\mu^+})^2$$

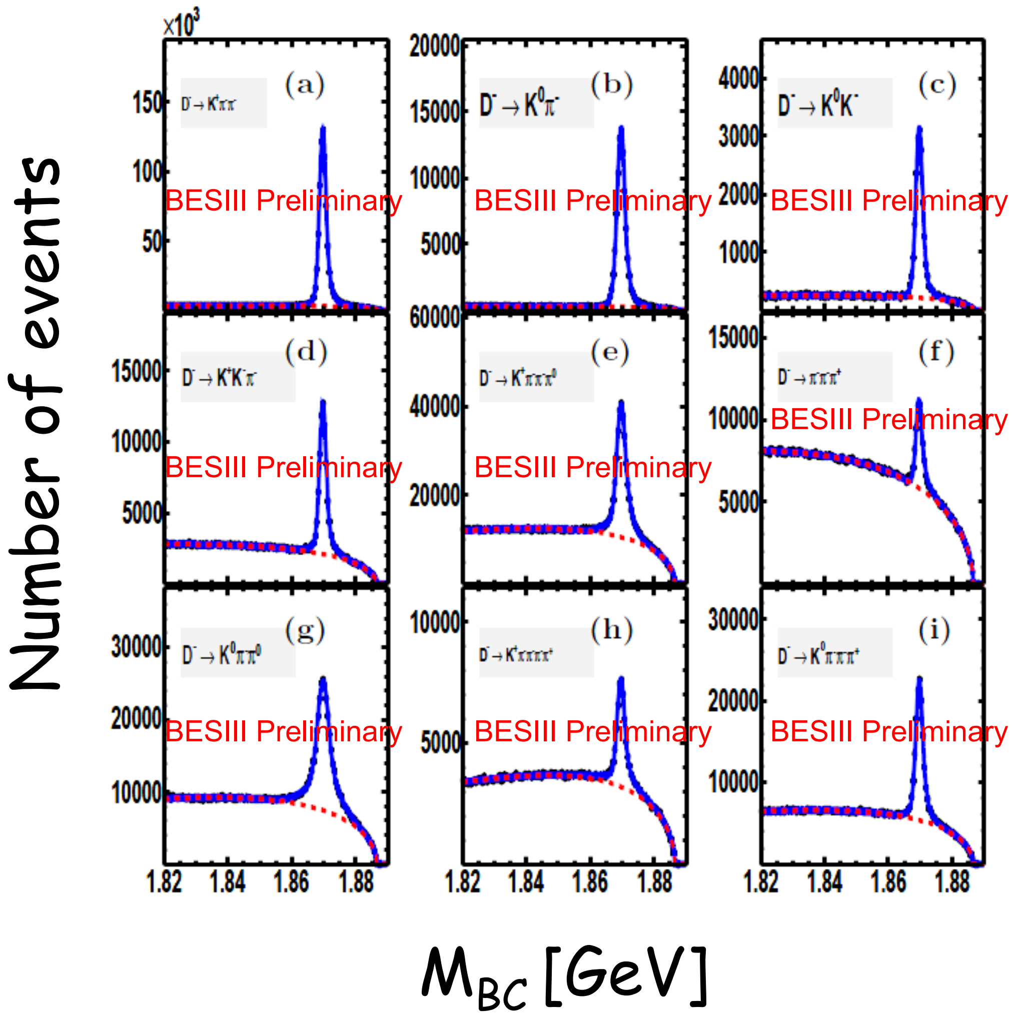
energy of μ^+	momentum of D_{tag}	momentum of μ^+

$$B(D^+ \to \mu^+\nu) = \frac{N_{D^+\to\mu^+\nu}}{N_{D^-_{tag}}\,\varepsilon_{D^+\to\mu^+\nu}}$$

Neutrino is reconstructed with missing energy and missing momentum of D^+ meson

1. Leptonic Decay: tagging side

- Totally 9 single tag modes



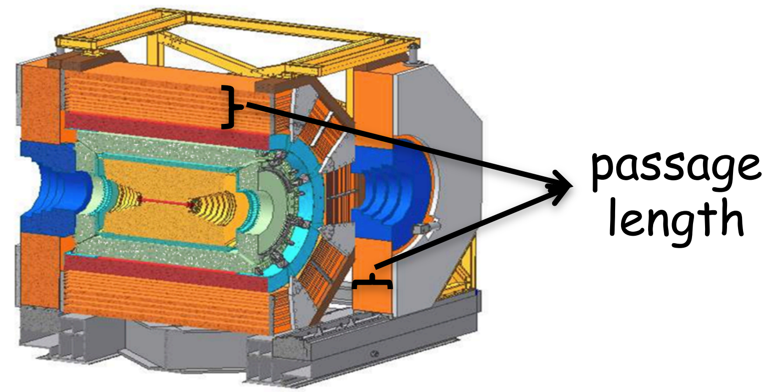
a) $D^- \to K^+\pi^-\pi^-$
b) $D^- \to K^0\pi^-$
c) $D^- \to K^0K^-$
d) $D^- \to K^+K^-\pi^-$
e) $D^- \to K^+\pi^-\pi^-\pi^0$
f) $D^- \to \pi^+\pi^-\pi^-$
g) $D^- \to K^0\pi^-\pi^0$
h) $D^- \to K^+\pi^+\pi^-\pi^-\pi^-$
i) $D^- \to K^0\pi^+\pi^-\pi^-$

$$N_{D^-_{Tag}} = (1.57 \pm 0.2)\times 10^6$$

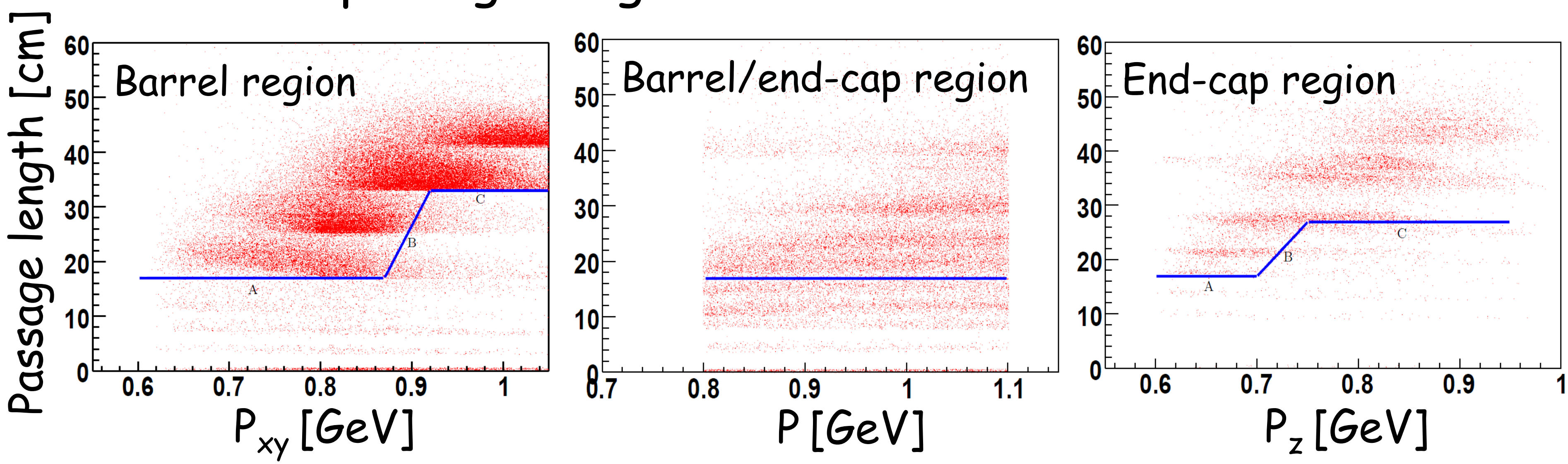
1. Leptonic Decay: recoiling side

- In recoiling side against the tagged D meson, it is required that:

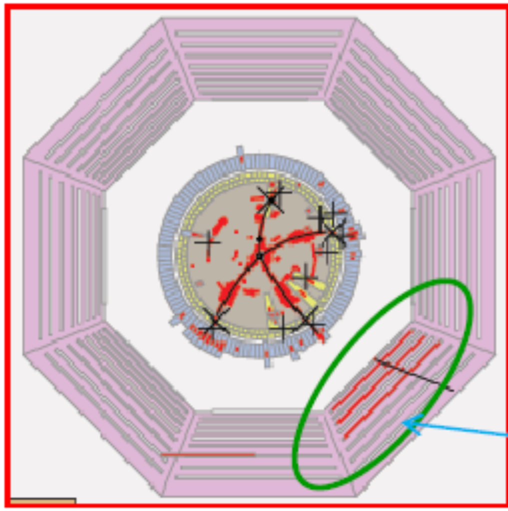
  1. only one charged track
  2. positively identified muon
  3. no isolated photon

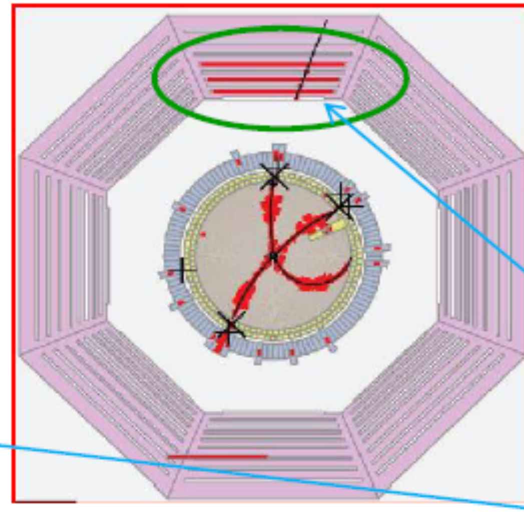


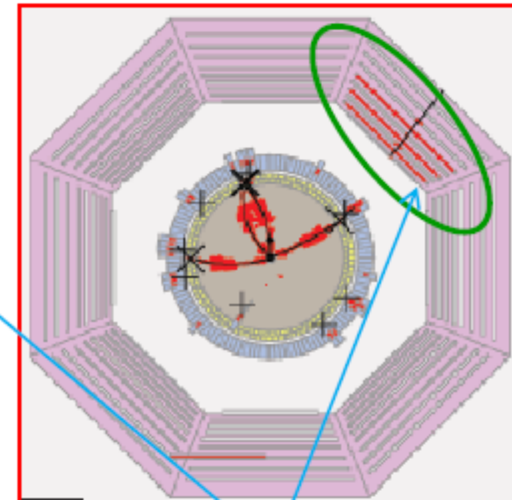
- Particle passage length in MUC sub-detector v.s. mom.

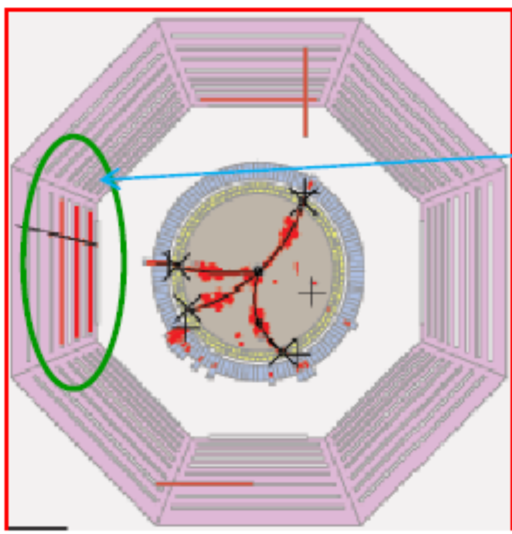


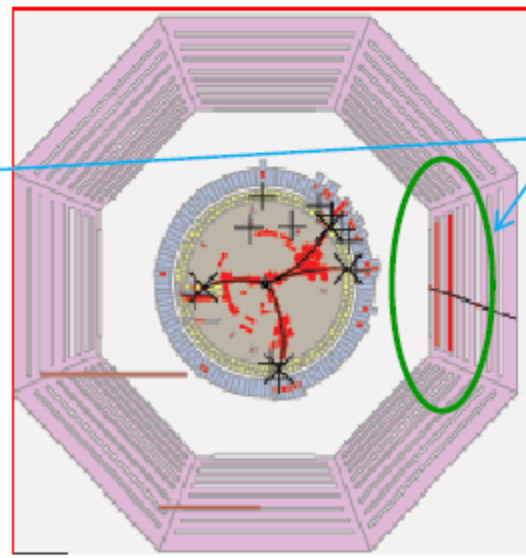
1. Leptonic Decay: event display







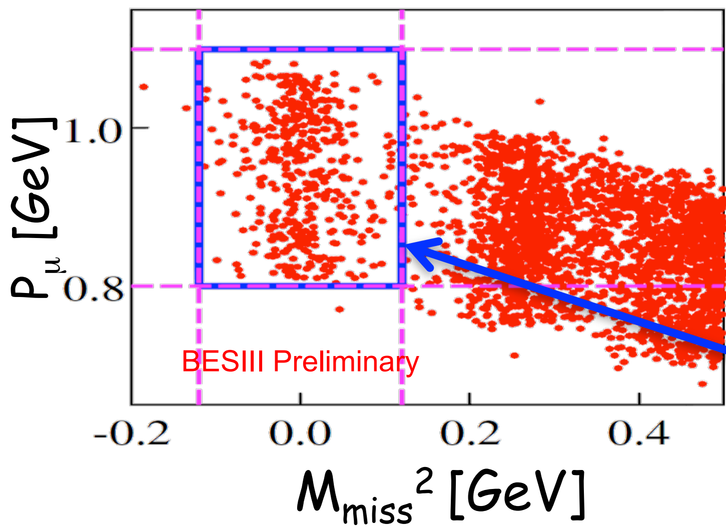


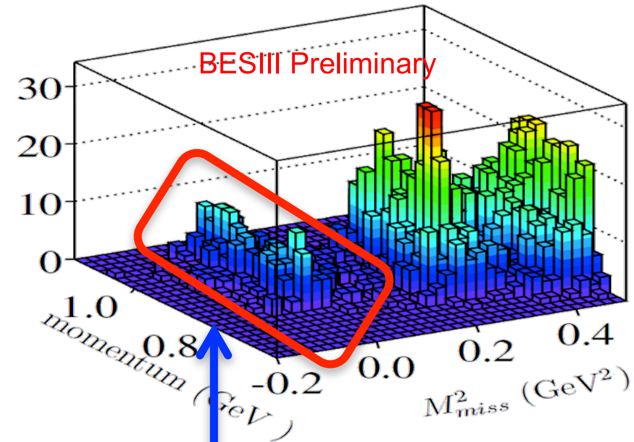


Muon can be well identified by MUC sub-detector

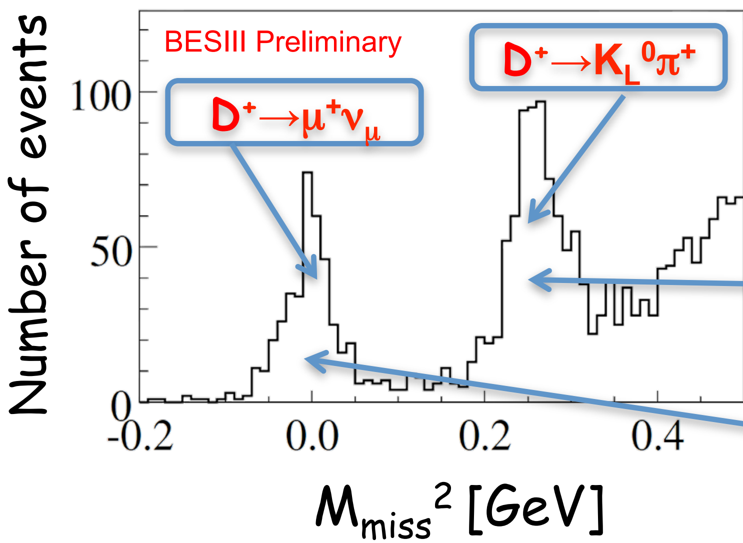
Each of the events is with a good μ hit in the μ chamber

1. Leptonic Decay: candidates





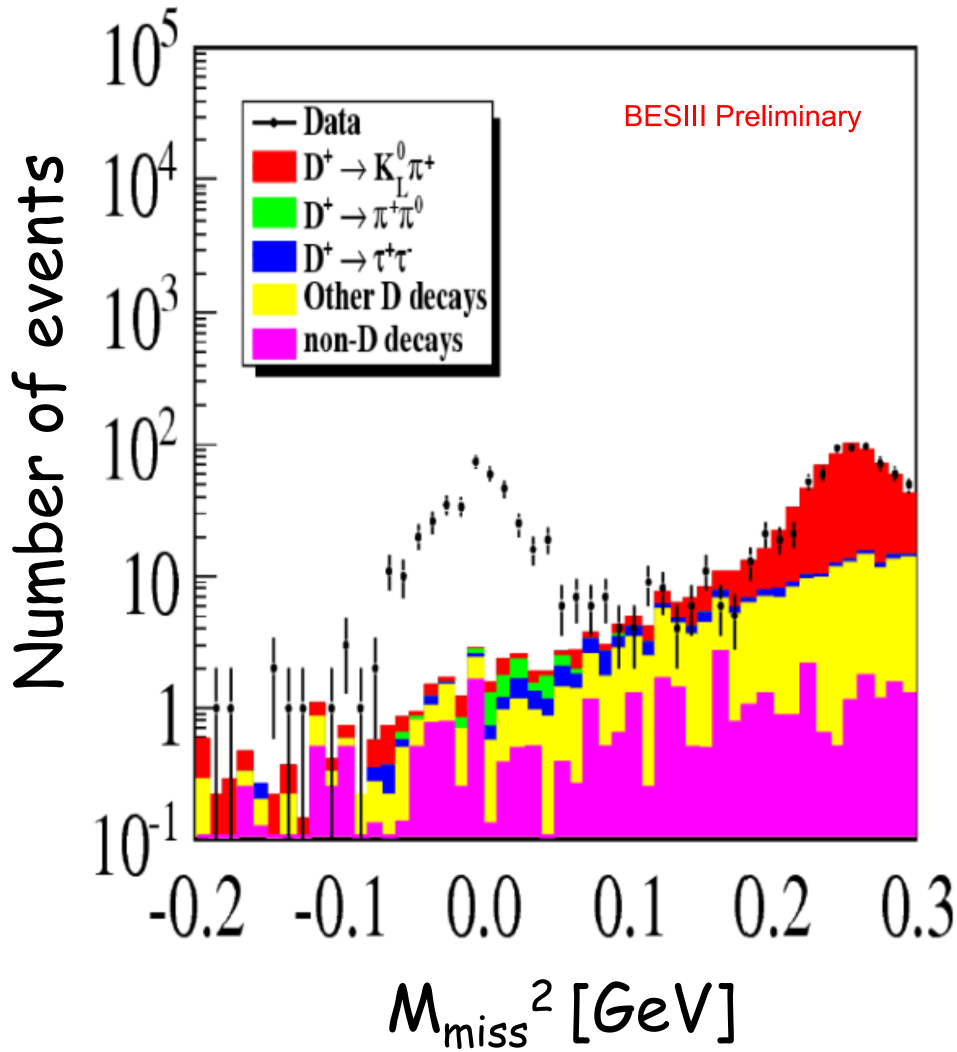
425 Candidates for $D^+ \to \mu^+ \nu_\mu$



K_L^0 escape from the detector

There are still some background

1. Leptonic Decay: background



Estimated with Monte Carlo events

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

1. Leptonic Decay: results

All preliminary !

- Branching fraction:
  $B(D^+ \to \mu^+ \nu_\mu) = (3.74 \pm 0.21 \pm 0.06) \cdot 10^{-4}$

$$\Gamma_{SM}(D^+_{(s)} \to l^+ \nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 |V_{cd(s)}|^2 f_{D^+_{(s)}}$$

- Decay constant:
  $f_{D+} = (203.91 \pm 5.72 \pm 1.97)$ MeV ⇐

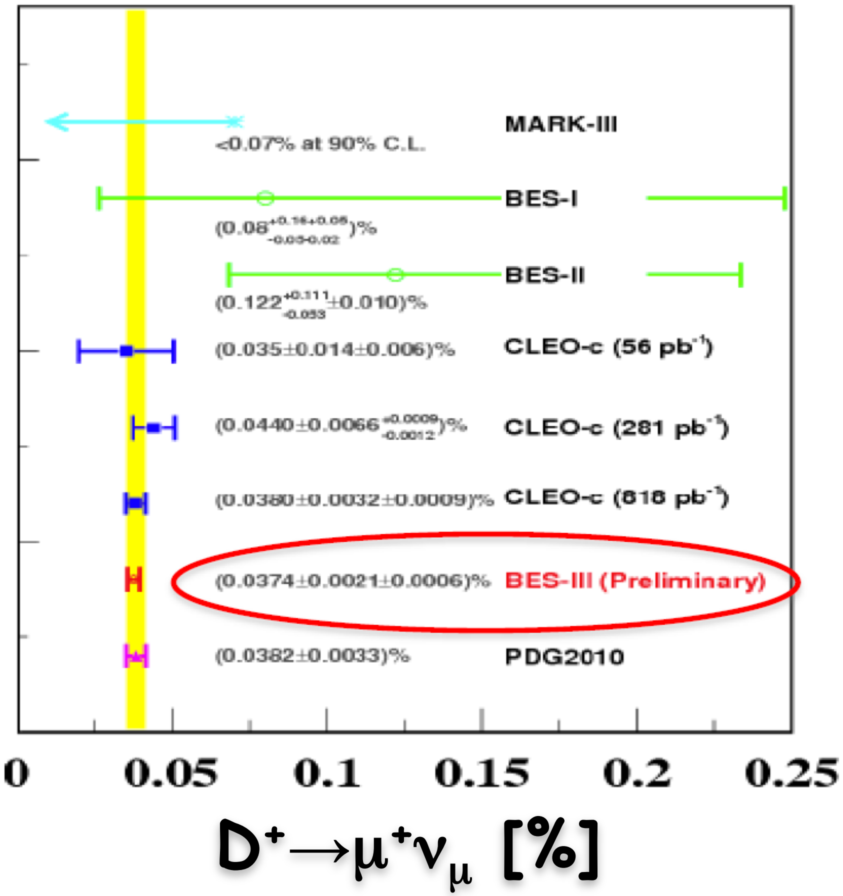
  $\tau_{D+} = (1040 \pm 7)$ fs,
  $M_{D+} = (1896.60 \pm 0.16)$ MeV
  $M_{\mu+} = (105.658 \pm 0.000)$ MeV
  $V_{cd} = 0.2252 \pm 0.0007$ (CKM-Fitter)

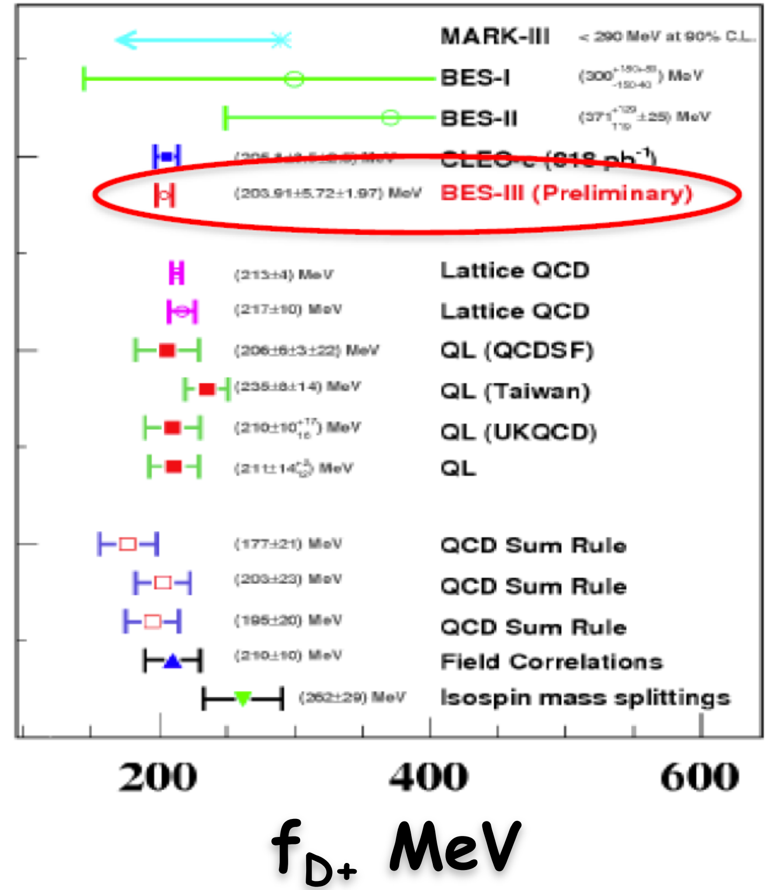
- Form factor:
  $|V_{cd}| = 0.222 \pm 0.006 \pm 0.005$ ⇐

  $\tau_{D+} = (1040 \pm 7)$ fs,
  $M_{D+} = (1896.60 \pm 0.16)$ MeV
  $M_{\mu+} = (105.658 \pm 0.000)$ MeV
  $f_{D+} = 207 \pm 4$ MeV (from LQCD)

Cited:
CKM-Fitter: PDG 2010
LQCD: Phys. Rev. Lett. 100, 062002 (2008)

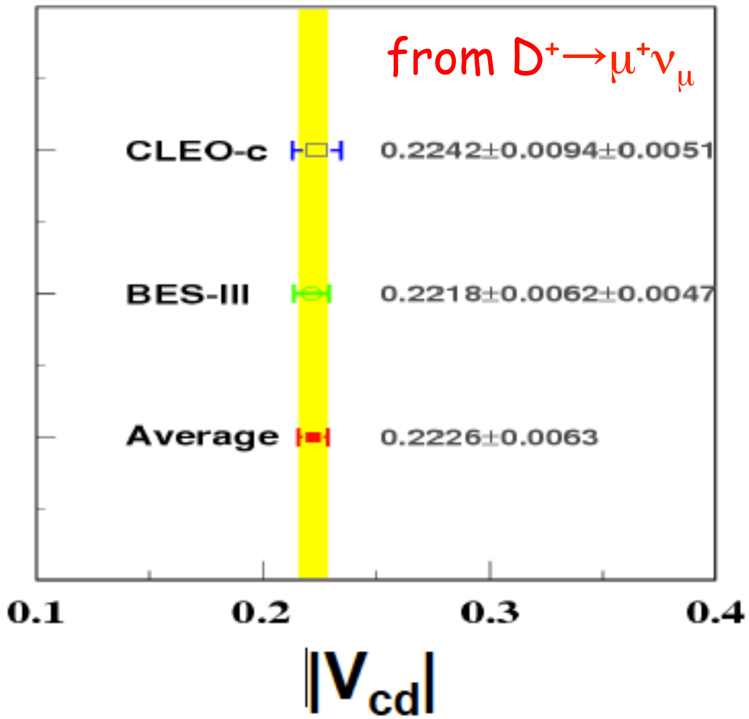
1. Leptonic Decay: results

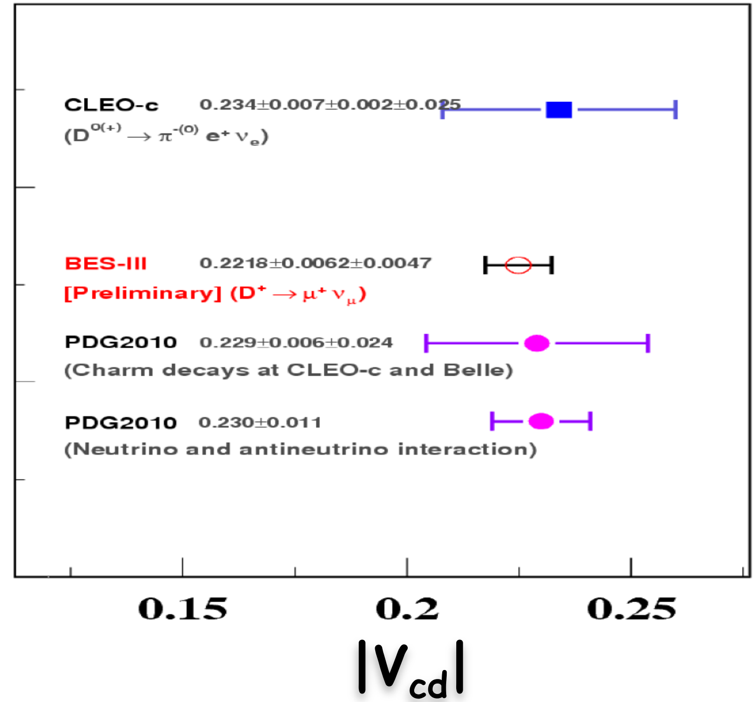




- The most precise measurement is provided by BESIII
- The errors are still dominated by statistics, needing more data taken at 3773 MeV.

1. Leptonic Decay: results





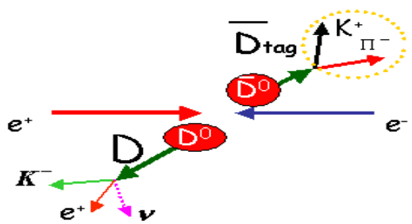
It is expected (B.A. Dobressu and A.S. Kronfeld, PRL 100, 241802 (2008)) if no nonstandard leptonic decay of $D^+_{(s)}$, one would obtain the same values of $|V_{cs}|/|V_{cd}|$ from the $D^+_{(s)}$ leptonic decays and D semi-leptonic decays.

2. Semi-leptonic Decays: tagging side

- Totally 4 single tag modes

- 923 pb^{-1} $\psi(3770)$ data analyzed
- Double tag technique ,

  tag side: right plots

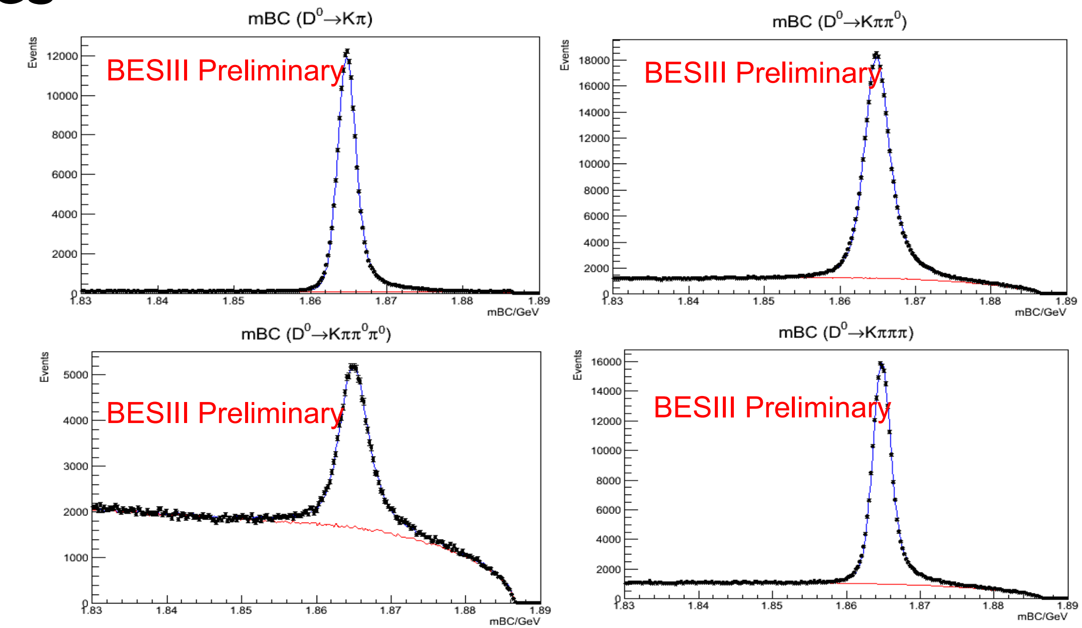


  recoil side: missing neutrino

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

- Simple differential decay rate function (massless lepton assumed)

$$\frac{\Delta\Gamma(D \to \pi(K)e\nu)}{dq^2} = \frac{G_F^2\,|V_{cd(s)}|^2}{24\pi^3}\,p^3\,|f_+(q^2)|^2$$



Mode	Data Yield	Fraction of All Tags (%)
$D^0 \to K^-\pi^+$	159,929 ± 413	20.7
$D^0 \to K^-\pi^+\pi^0$	323,348 ± 667	41.8
$D^0 \to K^-\pi^+\pi^0\pi^0$	78,467 ± 480	10.1
$D^0 \to K^-\pi^+\pi^-\pi^+$	211,910 ± 550	27.4

2. Semi-leptonic Decays: recoil side

- In recoiling side, selection of $D^0 \to K^- e^+ \nu_e$
  - Two oppositely-charged good tracks: K^- and e^+
  - Kaon and electron are identified
  - Electron has same charge as the tag side Kaon
  - Veto if any unmatched EMC shower is larger than 250 MeV (some background has extra π^0)

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  - Two oppositely-charged good tracks: π^- and e^+
  - Pion and electron are identified
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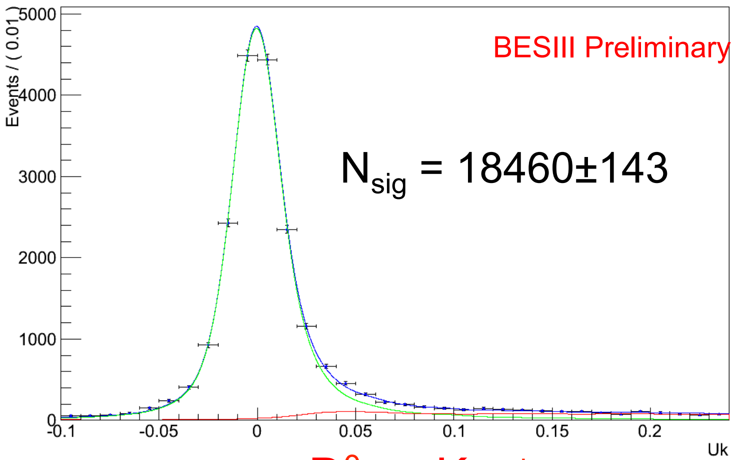
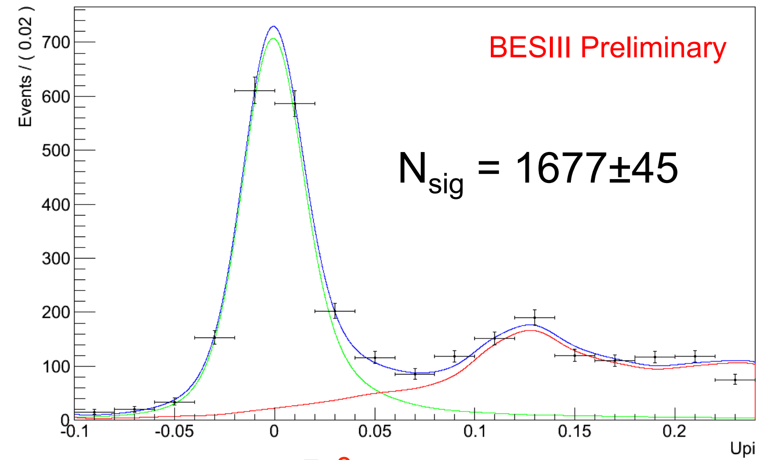
2. Semi-leptonic Decays: results



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



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

$$N^{obs}_{tag} = 2N_{D\bar{D}} B_{tag} \epsilon_{tag}$$

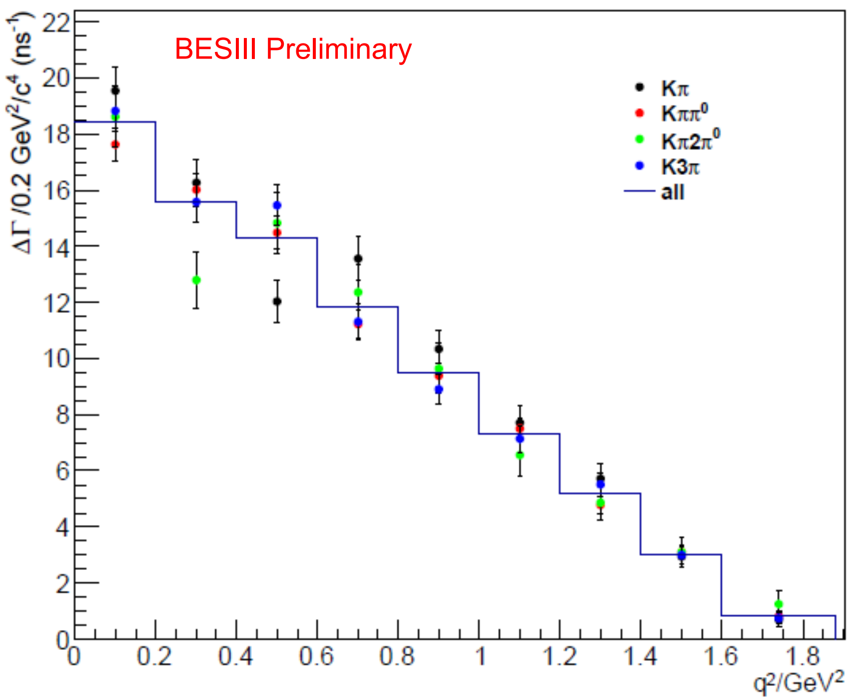
$$N^{obs}_{sig} = 2N_{D\bar{D}} B_{tag} B_{sig} \epsilon_{tag,sig}$$

$$\Longrightarrow B_{sig} = \frac{N^{obs}_{sig}}{\sum_\alpha N^{obs,\alpha}_{tag} \epsilon^{\alpha}_{tag,sig} / \epsilon^{\alpha}_{tag}},$$

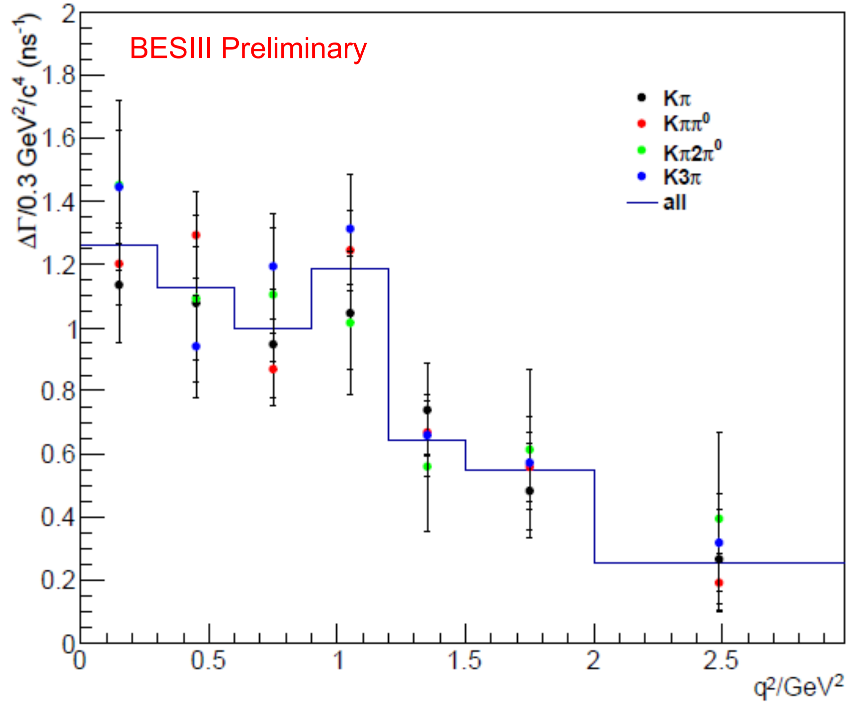
Mode	measured branching fraction(%)	PDG	CLEOc
$\bar{D}^0 \to K^+ e^- \bar{\nu}$	3.542 ±0.030±0.067	3.55 ±0.04	3.50 ±0.03 ±0.04
$\bar{D}^0 \to \pi^+ e^- \bar{\nu}$	0.288 ±0.008±0.005	0.289 ±0.008	0.288 ±0.008±0.003

2. Semi-leptonic Decays: results

- $\Gamma(q^2)$ results
  - Measured in each q^2 bin, by fitting U distribution
  - Compare results from each tag mode



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



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

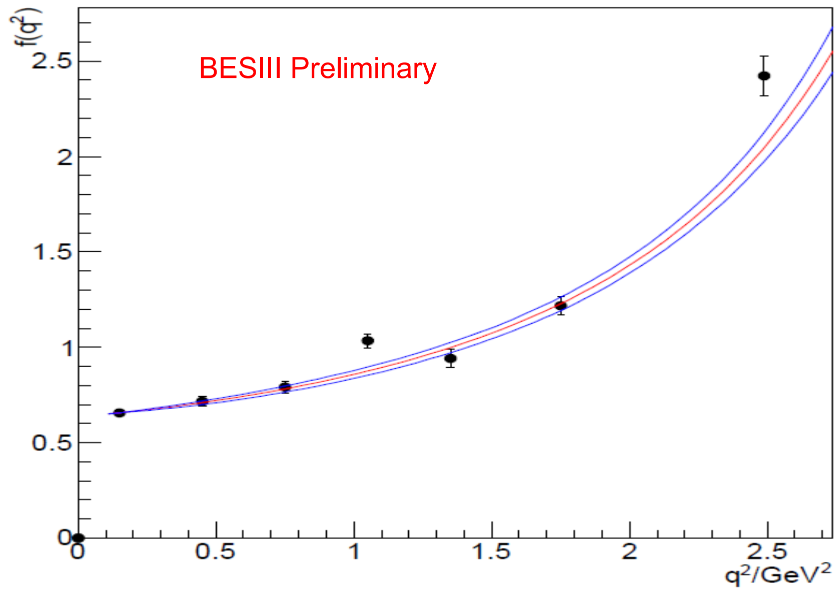
2. Semi-leptonic Decays: results

- $f(q^2)$ results

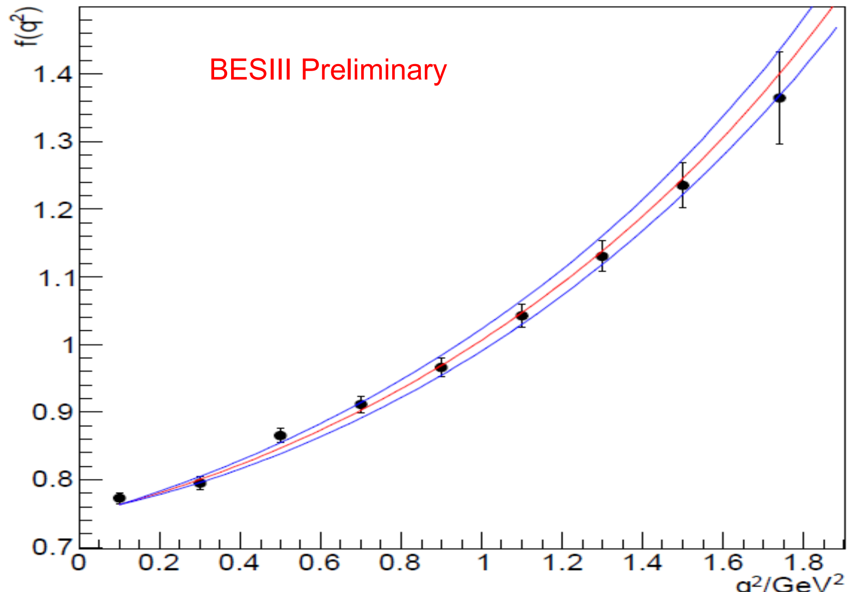
- Points: data with stat. error only
- Curves:

  f^{π} from Fermilab Lattice and MILC Collaboration, within one stat. error, **arXiv:1111.5471**;

  f^{K} from HPQCD Collaboration, within one stat. error, arXiv:1111.0225
- Here we only compare the shape ($f_+(0)$ not known)



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



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

2. Semi-leptonic Decays: results

- form factor parameterization

- Simple pole model:

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

- Modified pole model:
  Beciirevic and Kaidalov
  PLB 478, 417 (2000)

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

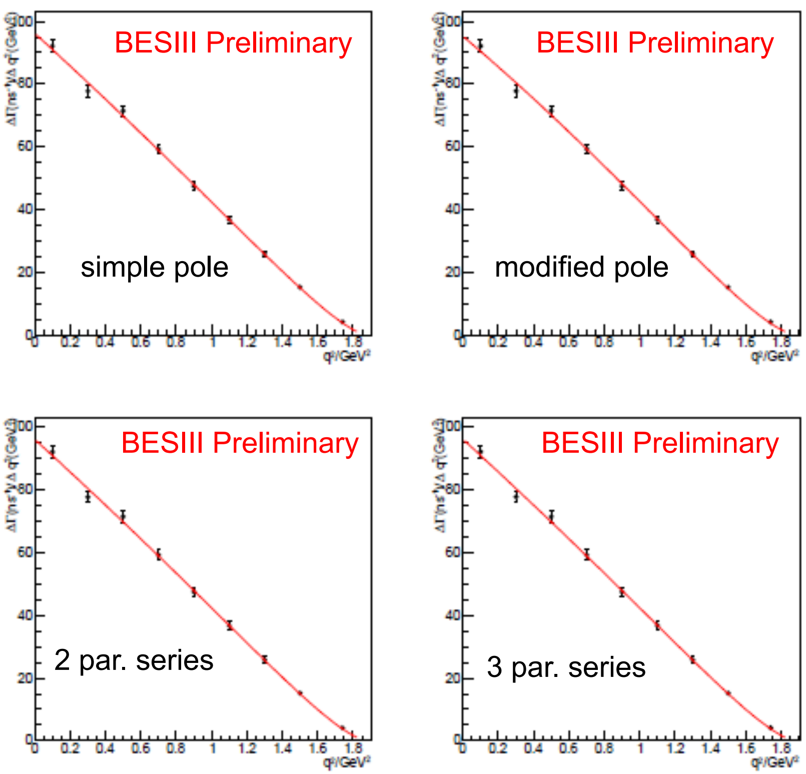
- Series expansion:
  Becher and Hill
  PLB 633, 61 (2006)

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

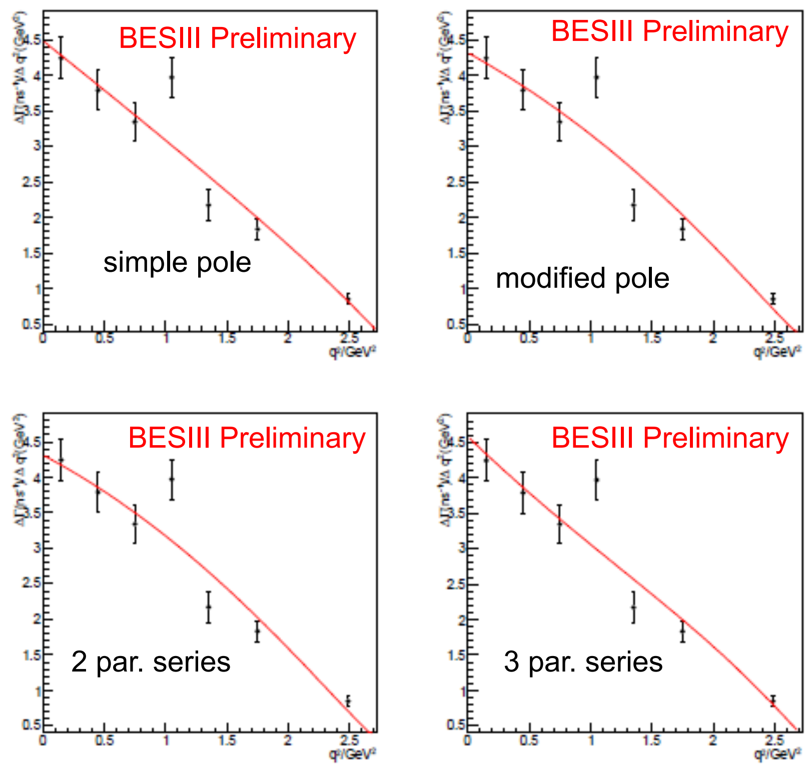
Could fit: $f_+(0)$, $r_1 = a_2/a_1$, $r_2 = a_3/a_1$

2. Semi-leptonic Decays: results

- form factor fit $$\chi^2 = \sum_{i,j=1}^{n} (\Delta\Gamma_i - g(q^2)_i)\ C_{ij}^{-1}\ (\Delta\Gamma_j - g(q^2)_j)$$



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



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

2. Semi-leptonic Decays: results

BESIII Preliminary   923 pb^{-1} $\psi(3770)$ data ~ 1/3 full data

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

3. Rare Decay: introduction

- Flavor Changing Neutral Current (i.e., $c \rightarrow u\,\gamma$) is forbidden at tree level. Besides, the u^{bar} quark also needs to annihilate with the u quark to produce the other photon
- Extremely suppressed: Unlike FCNC processes in the decays of K and B mesons (i.e., $s \rightarrow d\, l^+ l^-$, $b \rightarrow s\,\gamma$), in the decays of D mesons, the transitions are mediated by the lighter down-quark sector $\Rightarrow$ larger GIM suppression
- But such short-distance contributions are usually diluted by (very) large long-distance contributions
- The radiative decay, $D^0 \rightarrow \gamma\,\gamma$, is indeed such case.

3. Rare Decay: introduction

- How small (large) $D^0 \to \gamma\, \gamma$ is ?

- This small transition rate due to the short-distance effect is enhanced by long-distance effect, bringing the overall $B(D^0 \to \gamma\gamma)$ larger.
  within SM: $B(D^0 \to \gamma\gamma) \sim 10^{-8}$ or less (see Fajfer et. al. PRD 64, 074008 (2001))

- But, for instance, the minimal super-symmetric standard model says the rate would be enhanced by a factor of 100 by exchanging gluino (Prelovsek and Wyler, PLB500, 304 (2001)) or $B(D^0 \to \gamma\gamma) \sim 10^{-6}$.

3. Rare Decay: introduction

- What experiments have done ?

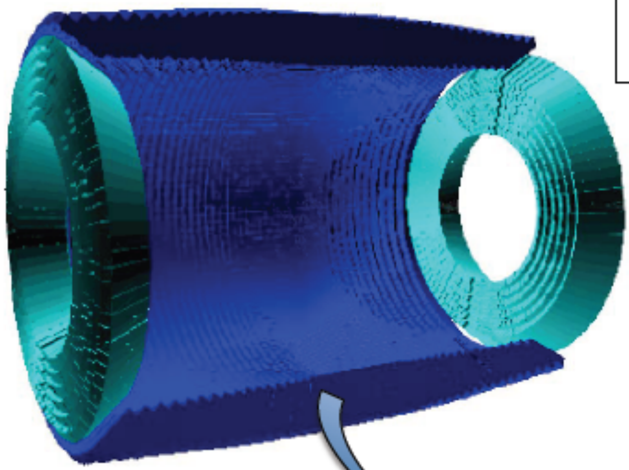
- CLEO-2 searched with 13.8 fb^{-1} around $\Upsilon(4S)$
  $\Rightarrow B(D^0 \to \gamma\gamma) < 2.9\times10^{-5}$ @ 90% C.L., PRL90, 101801 (2003)

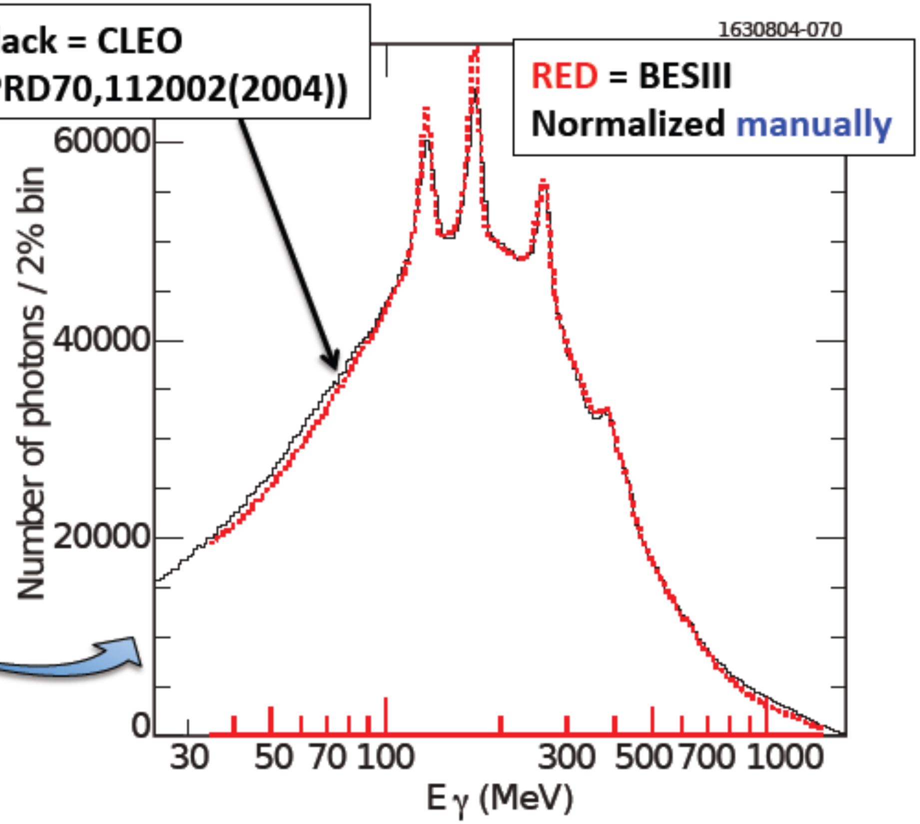
- CLEO-c also searched based on 818 pb^{-1} @$\psi(3770)$ [~6 M D^0 produced]
  $\Rightarrow B(D^0 \to \gamma\gamma) < 8.63\times10^{-6}$ @ 90% C.L. (Charm 2010)

- BaBar also has a result with 470.5 fb^{-1} around $\Upsilon(4S)$ [~201 M D^0 produced]
  $\Rightarrow B(D^0 \to \gamma\gamma) < 2.2\times10^{-6}$ @ 90% C.L. (arXiv:1110.6480).

3. Rare Decay: introduction

- BESIII has very good EMC sub-detector





Based on the photons detected in the Barrel section

Comparison of
inclusive photon energy spectrum based on $\psi(2S)$ data.
Three monochromatic photon lines are seen due to $\psi(2S) \rightarrow \gamma\,\chi_{cJ}$.

3. Rare Decay: analysis

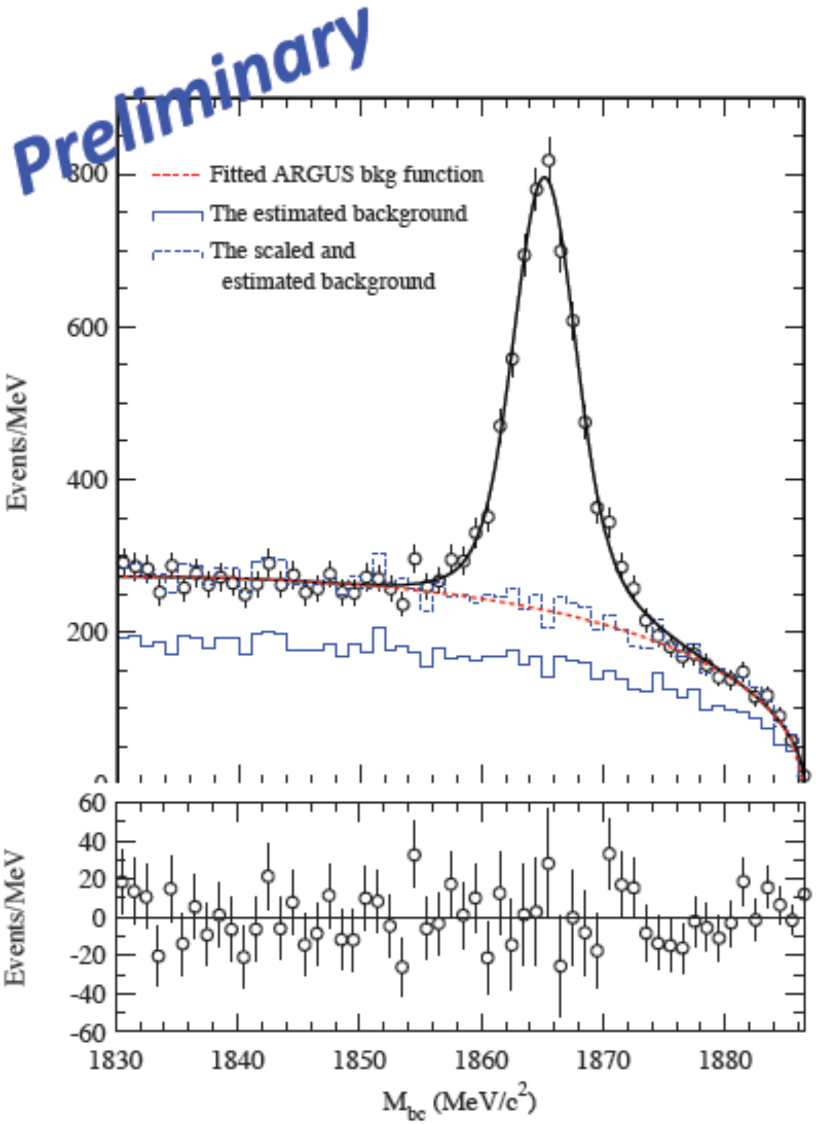
- Due to similar background components, we also study events from $D^0 \to \pi^0\pi^0$, and present our preliminary result in a form of :
  $B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0)$

- Analysis method is straight forward
  1. Reconstruct only one of the two D^0s from $\psi(3770)$ decay with two γs or π^0s for $D^0 \to \gamma\gamma$ or $D^0 \to \pi^0\pi^0$, respectively, where $\pi^0 \to \gamma\gamma$
  2. Conservation of energy and momentum is required
     $\Delta E = E_{candidate} - E_{beam}$ should be consistent with zero
     $M_{BC} = \sqrt{(E_{Beam}^2 - p_{candidate}^2)}$ should be consistent with M_{D0}

- Detail selection criteria are tuned based on MC samples

- Detection efficiencies are 23% and 12% for $D^0 \to \gamma\gamma$ and $D^0 \to \pi^0\pi^0$, respectively

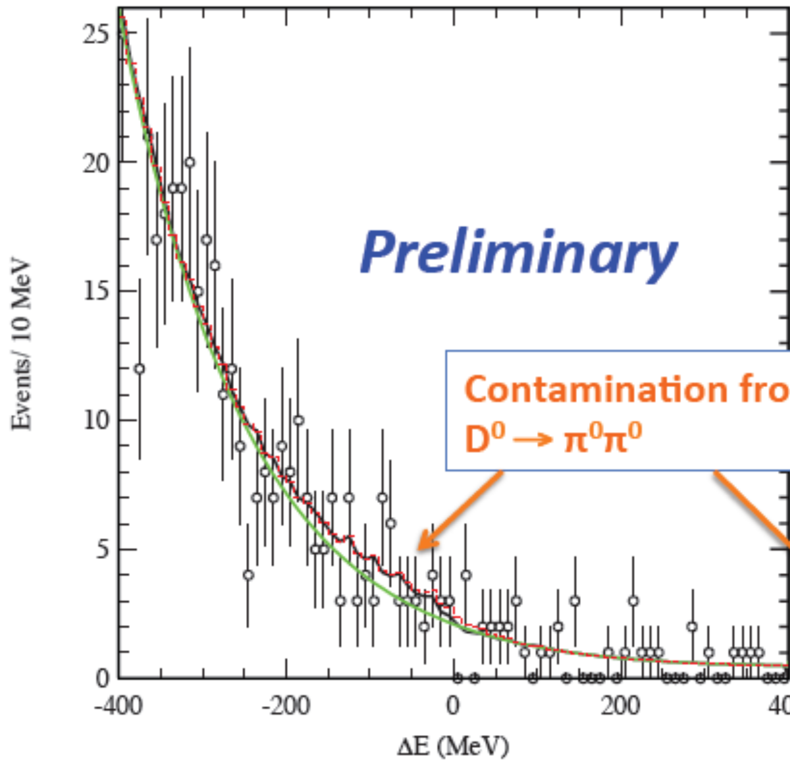
3. Rare Decay: analysis



- **4081±117 signal events.**
- **The resultant preliminary $B(D^0 \to \pi^0\pi^0)$ is consistent with the known value (PDG and the latest result from BaBar).**

- **The total MC-based background (solid-blue) underestimates the one seen in data: Needed to scale it UP(dashed-blue) by (49±2)% to match to data! We attribute this to poor simulation of "non-DDbar" components.**

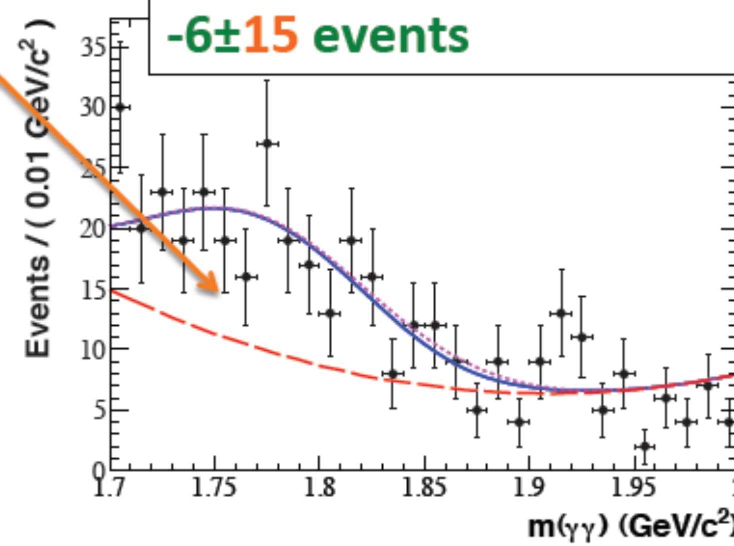
3. Rare Decay: analysis



Contamination from
$D^0 \to \pi^0\pi^0$

- Gives: -2.9±7.1 events
- No significant signals.

BaBar:hep-ex:1110.6480
-6±15 events



W.r.t. the BaBar's result:

- $BKG_{BESIII}/BKG_{BaBar} \sim 0.5$
- $\varepsilon_{BESIII}/\varepsilon_{BaBar} \sim 2$
- BUT, $N_{BESIII}(D^0)/N_{BaBar}(D^0) \sim 0.1$

3. Rare Decay: results

- With the signal events, $B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 5.8 \times 10^{-3}$ @ 90% C.L., including systematic uncertainty (rel. 12%) which is added to the Bayesian upper limit
- With the PDG value of $B(D^0 \to \pi^0\pi^0) = 8.0 \times 10^{-4}$, this U.L. corresponds to $B(D^0 \to \gamma\gamma) < 4.6 \times 10^{-6}$ @ 90% C.L.

Experiment	This work (BESIII, 2.9 fb^{-1})	Babar (arXiv: 1110.6480)	CLEO-c (preliminary)	PDG 2011 (online)
Result	4.6×10^{-6}	2.2×10^{-6}	8.63×10^{-6}	2.7×10^{-5}

- Improved results (i.e., systematic errors) on $B(D^0 \to \gamma\gamma)$ soon along with measurement on $B(D^0 \to \pi^0\pi^0)$
- Another double-tag technique is ongoing, which can reject most of the backgrounds and reduce systematic errors

Summary

- BESIII has been successfully operated since 2008:
  - World largest data sample of J/ψ, ψ′, ψ(3770), ψ(4040) already collected, more data in future ($D_s^{*+}D_s^-$ at 4170MeV coming soon).
- Some results on charm physics have been obtained,
  1. Leptonic decay: $B(D^+ \to \mu^+ \nu_\mu)$ = $(3.74 \pm 0.21 \pm 0.06) \cdot 10^{-4}$
     ($2.89\ fb^{-1}$) $f_{D+} = (203.91 \pm 5.72 \pm 1.97)$ MeV
     $|V_{cd}| = 0.222 \pm 0.006 \pm 0.005$
  2. Semileptonic decay: ($0.92\ fb^{-1}$)

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

  3. Rare decay: $B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 5.8 \times 10^{-3}$ @ 90% C.L.
- More topics, such as D^0-D^{0bar} mixing, CPV, rare decay, Cabibbo suppress decay, other semileptonic decays, are undergoing, 2012～2013 will be a harvest-time.


Thank you !

Backup

1. Leptonic Decay: detection efficiency

Considering the difference between these muon detection efficiencies measured from the data and the Monte Carlo sample, the overall efficiency for reconstruction of the purely leptonic decay for $D^+ \to \mu^+\nu_\mu$ in the system recoiling against the singly tagged D^- meson can be obtained by

$$\epsilon^{\rm DATA}_{D^+\to\mu^+\nu_\mu} = \epsilon^{\rm MC}_{D^+\to\mu^+\nu_\mu}\frac{\epsilon^{\rm DATA}_{\mu\rm ID}}{\epsilon^{\rm MC}_{\mu\rm ID}}. \tag{22}$$

Inserting $\epsilon^{\rm MC\ 1}_{D^+\to\mu^+\nu_\mu} = 0.7050\pm0.0024$, $\epsilon^{\rm DATA\ 1}_{\mu\ \rm ID} = 0.6658$ and $\epsilon^{\rm MC\ 1}_{\mu\ \rm ID} = 0.7394$ to Eq.(22) yields

$$\epsilon^{\rm DATA\ 1}_{D^+\to\mu^+\nu_\mu} = 0.6348 \pm 0.0022.$$

Similarly, inserting $\epsilon^{\rm MC\ 2}_{D^+\to\mu^+\nu_\mu} = 0.7179 \pm 0.0023$, $\epsilon^{\rm DATA\ 2}_{\mu\ \rm ID} = 0.6607$ and $\epsilon^{\rm MC\ 2}_{\mu\ \rm ID} = 0.7413$ to Eq.(22) yields

$$\epsilon^{\rm DATA\ 2}_{D^+\to\mu^+\nu_\mu} = 0.6398 \pm 0.0020.$$

To obtain the "true" efficiency for reconstructing $D^+ \to \mu^+\nu$ decays from the whole data sets taken in the two separate data taking years, we should weight the two efficiencies by the sizes of the data sets taken in the two years. The data size-weighted average efficiency is

$$\epsilon^{\rm DATA}_{D^+\to\mu^+\nu_\mu} = \frac{L^{\rm set1}\times\epsilon^{\rm DATA\ 1}_{\mu^+\nu_\mu} + L^{\rm set2}\times\epsilon^{\rm DATA\ 2}_{\mu^+\nu_\mu}}{L^{\rm set1}+L^{\rm set2}}, \tag{23}$$

where $L^{\rm set1}$ and $L^{\rm set2}$ are the integrated luminosity of the two data sets, respectively. Inserting the $L^{\rm set1} = 922$ pb^{-1}, $L^{\rm set2} = 1969$ pb^{-1}, $\epsilon^{\rm DATA\ 1}_{D^+\to\mu^+\nu_\mu}$ and $\epsilon^{\rm DATA\ 2}_{D^+\to\mu^+\nu_\mu}$ to Eq.(23) yields

$$\epsilon^{\rm DATA}_{D^+\to\mu^+\nu_\mu} = 0.6382\ \pm 0.0015.$$

which is the overall efficiency for reconstruction of the decay for $D^+ \to \mu^+\nu_\mu$ from the two data sets.

1. Leptonic Decay: systematic errors

Source	Systematic uncertainty [%]
Number of D^- tags ($N_{D^-_{tag}}$)	0.6
Muon tracking	0.5
μ selection	0.3
$E_{\gamma_{max}}$ cut	0.7
Muon momentum cut	0.1
M^2_{miss} cut	0.5
Background estimation	0.7
Monte Carlo statistics	0.2
Radiative correction	1.0
Total	1.7

3. Rare Decay: introduction

- In the standard model flavor changing neutral currents (FCNC) are forbidden at the tree level but can occur at higher loop level.
- $D^0 \to \gamma\gamma$ is dominated by long-distance effects

$$B(D^0 \to \gamma\gamma)^{(\mathrm{VMD})} \simeq (3.5\ ^{+4.0}_{-2.6}) \times 10^{-8}$$

- Branching ratio from short-distance effects

$$B(D^0 \to \gamma\gamma)^{(\mathrm{SD})} \simeq 3 \times 10^{-11}$$

- But in supersymmetric model , gluino exchange can enhance this rate by 2 orders (10^{-6}).
- The recent result from BABAR (arXiv:1110.6480) has been updated to $B(D^0 \to \gamma\gamma) < 2.2 \times 10^{-6}$ at 90% CL. (470.5fb^{-1} data at $\Upsilon(4S)$). We may not get to that low value on BESIII due to statistics.

3. Rare Decay: systematic errors

Systematic Uncertainties

The total relative systematic uncertainty of $B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0)$ is 12%.

This is dominated by:

- The syst. error from $D^0 \to \pi^0\pi^0$ measurement (~9%).
  This is currently under investigation and will improve.
  Also, in the future, we may not need to use $B(D^0 \to \pi^0\pi^0)$ to normalize $B(D^0 \to \gamma\gamma)$.
- Photon reconstructions simulation (~5%).
  π^0 suppression as well as radiative Bhabha suppression.
- Continuum (including Bhabha) suppression (~5%).
  See backup slide for more detail.
  Needed to suppress the most dominant background.