# Open Charm Physics at BESIII


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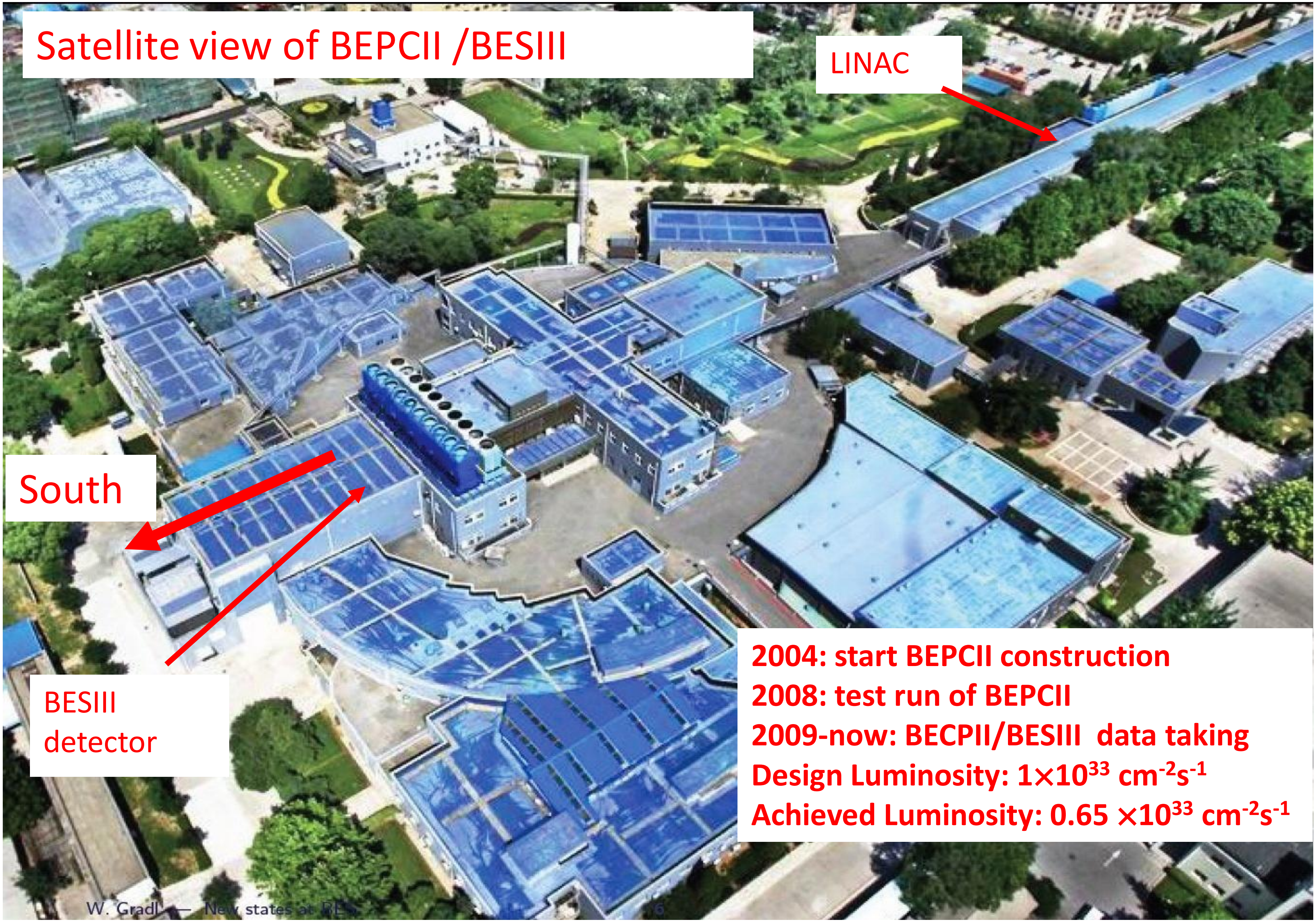
# Outline

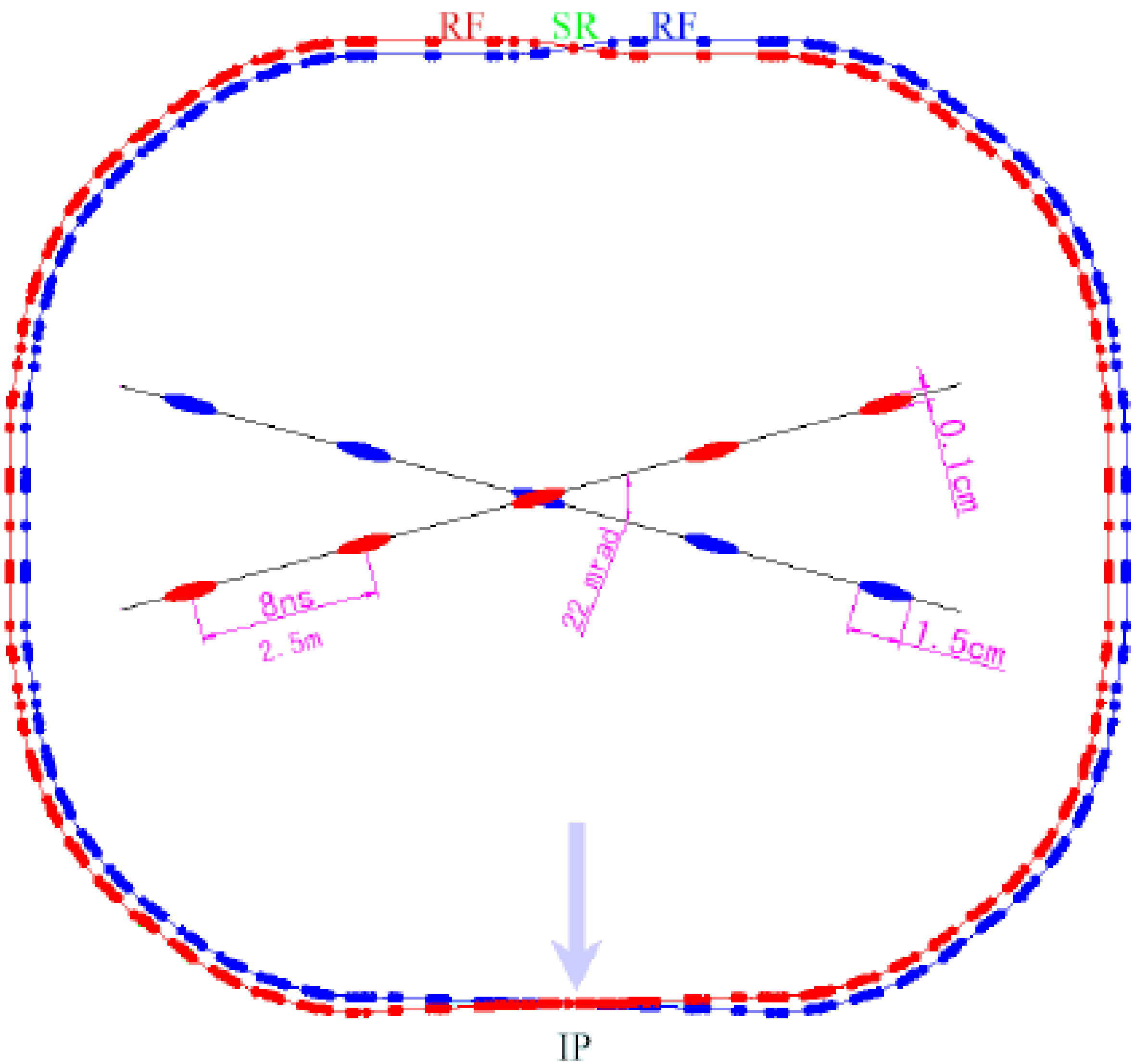
- Introduction to the BESIII experiment
- Major Charm Physics at BESIII
- Physics Analysis being done
- Summary

# Satellite view of BEPCII /BESIII




**2004: start BEPCII construction**
**2008: test run of BEPCII**
**2009-now: BECPII/BESIII data taking**
**Design Luminosity: $1\times10^{33}$ $cm^{-2}s^{-1}$**
**Achieved Luminosity: $0.65\times10^{33}$ $cm^{-2}s^{-1}$**

# BEPCII Storage Ring




**Beam energy:**
1.0-2.3 GeV

**Design Luminosity:**
$1 \times 10^{33}$ $cm^{-2}s^{-1}$

**Optimum energy:**
1.89 GeV

**Energy spread:**
$5.16 \times 10^{-4}$

**No. of bunches:**
93

**Bunch length:**
1.5 cm

**Total current:**
0.91 A

**Circumference :**
237m

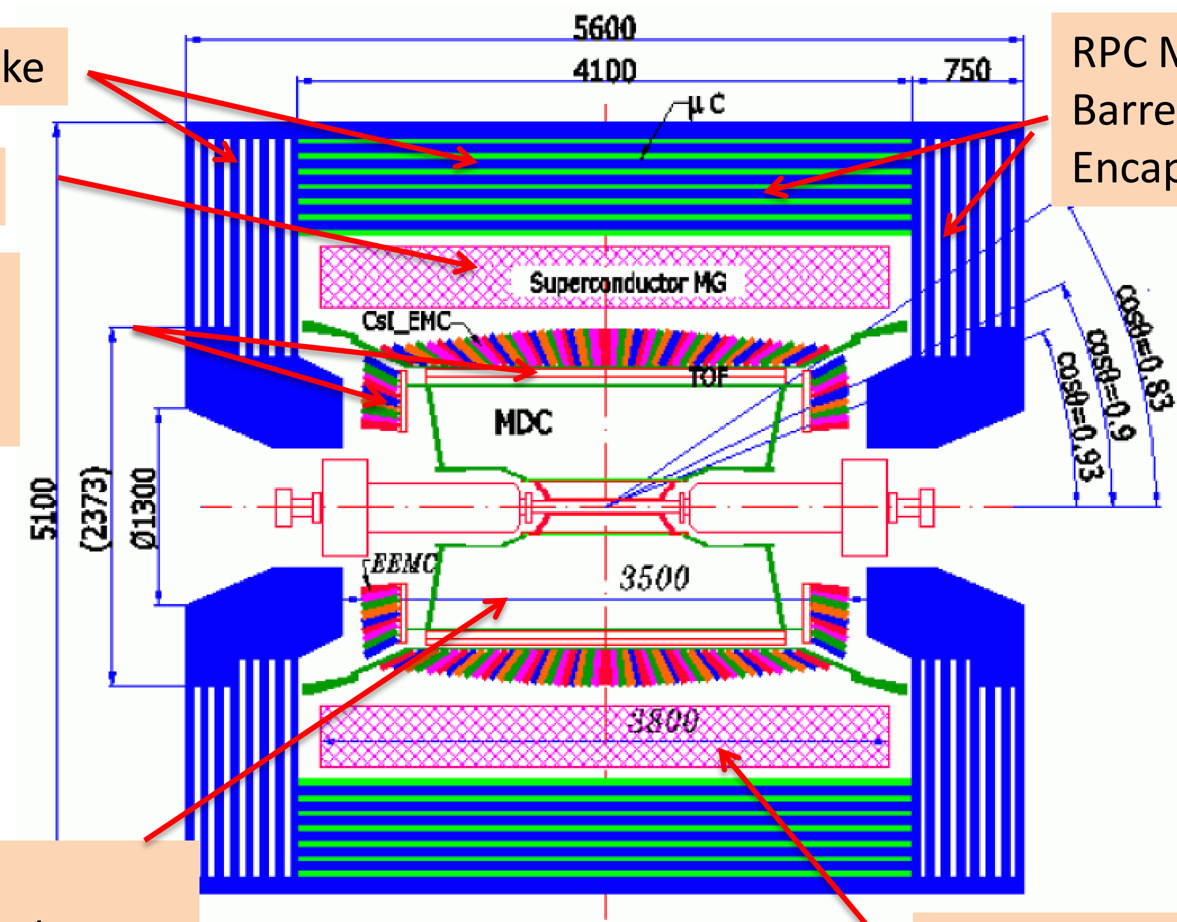
# BESIII Detector

Magnet yoke

SC magnet (1T)

Time-of-flight(TOF)
$\sigma_{T(barrel)}$ : 90 ps
$\sigma_{T(endcap)}$: 100 ps

RPC Muon Counter
Barrel : 9 layers
Encaps: 8 layers




Drift chamber:
small sell & He-based gas
$\sigma_p/p$ = 0.5% @ 1 GeV
$\sigma_{(dE/dx)}/dE/dx$ ~ 6% @ 1GeV

EMC CsI(Tl)
$\sigma_E$ /E ~2.5% @ 1 GeV

# Data Samples

## So far BESIII has collected :

| Type | BES-III ($\times 10^6$) | BES-II ($\times 10^6$) | CLEO-c ($\times 10^6$) |
|---|---|---|---|
| $J/\psi$ | 225 | 58 | – |
| $\psi(3686)$ | 106 | 14 | 27 |
| DDbar | ~18.3(2.9 $fb^{-1}$) | 0.2(0.03 $fb^{-1}$) | 5.4(0.8$fb^{-1}$) |
| $D_sD_s$ | ~0.5$fb^{-1}$@4.01 | – | Scan |
| $D_sD_s^*$ | – | – | 0.55(0.6$fb^{-1}$) |

## BESIII will collect:

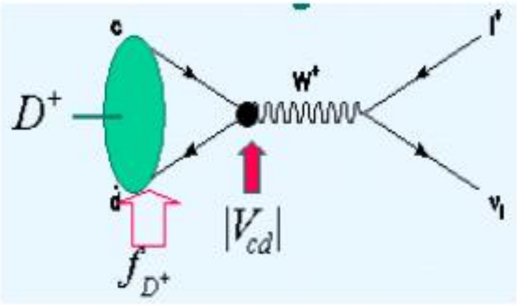
- more $J/\psi$, $\psi'$, $\psi(3770)$

  Approved: 1 billion for $J/\psi$ and (0.7-1.0) billion for $\psi'$ & off peak
- data at higher energies (for XYZ searches, R scan and $D_s$ physics)

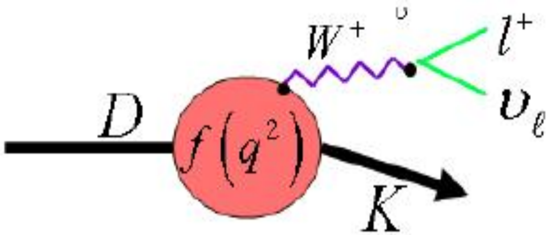
# Major Charm Physics

**Charm plays important role in understanding the Standard Model in two respects.**

- **Precision Measurements**
  - ✓ Leptonic decay of $D^+$ and $D_s^+$
    - ➡ decay constant $f_D$ and $f_{Ds}$




  - ✓ Semileptonic decay of D mesons
    - ➡ $|V_{cs}|$, $|V_{cd}|$ and form factors




  - ✓ Absolute hadronic branching fractions
    - ➡ To normalize the B and D decays

**Can be used to Improve measurements in $|V_{ub}|$ and $\Delta m_d$ & $\Delta m_s$ .**

# Major Charm Physics

**Measurement of $|V_{cs(d)}|$ plays an important role in understanding the dynamics of quark mixing**

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ \boxed{V_{cd} \quad V_{cs}} & & V_{cb} \\ V_{tb} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

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

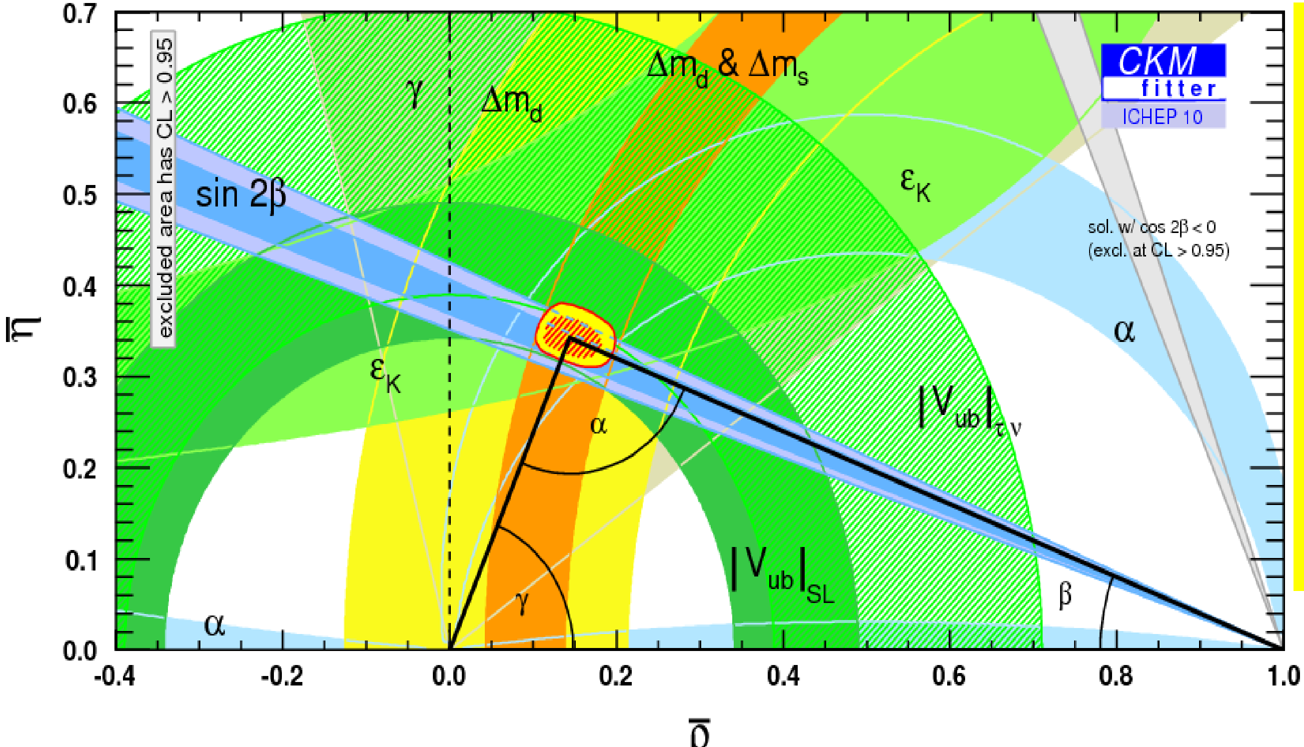
Weak eigenstates     CKM     mass eigenstates

**Four quark mixing parameters ($\lambda$, A, $\rho$, $\eta$) reside in CKM matrix**

**To understand 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.**

# Major Charm Physics

The constraints in the $(\bar{\rho}, \bar{\eta})$ plan of Bd UT including the most recent inputs in the global CKM fit.




The width of the band for $|V_{ub}|$, $\Delta m_d$ & $\Delta m_s$ are mainly dominated by the theoretical errors in calculating B & $B_s$ decay constant $f_B$, $f_{Bs}$ and B semileptonic form factors.

Charm can be used to calibrate the QCD calculations. If the QCD passed the test with the charm data, the theoretical uncertainties in calculating the B form factors and decay constants can be reduced, which in turn help to reduce the width of band for $|V_{ub}|$, $\Delta m_d$ & $\Delta m_s$.

# Major Charm Physics

- **Probe for New Physics**
  - ✓ **$D^0\bar{D}^0$ mixing**
  - ✓ **Searching for CP violation decays of D mesons**
  - ✓ **Searching for rare decays of D mesons**

Precision measurements on charm decays can be served as precisely test of the SM.

# Advantage of Open Charm at Threshold

**$e^+e^-$ colliders at threshold: CLEO-c, BESIII**

$$e^+e^- \rightarrow \psi(3770) \rightarrow \text{DDbar}$$

**Benefits for charm physics at threshold**

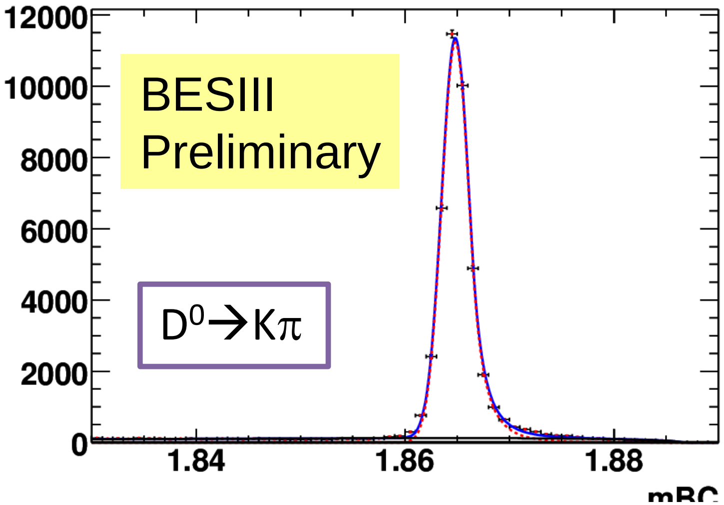
- Clean
- Initial energy and quantum number
- D and Dbar can be fully reconstructed
- Absolute measurement

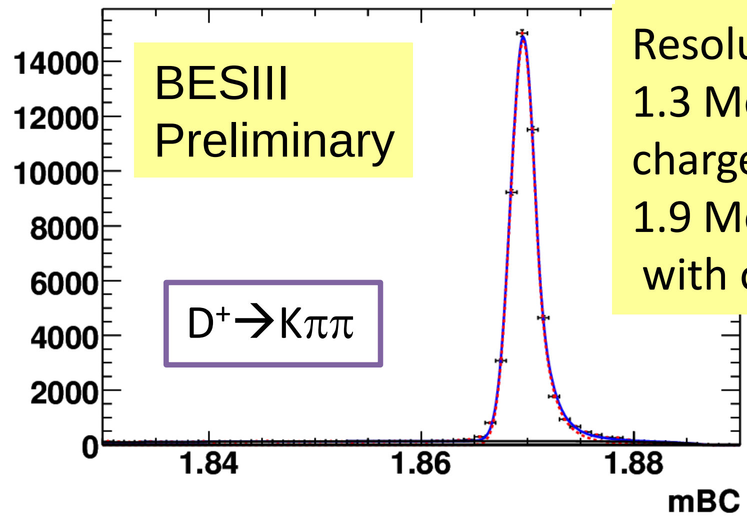
# Singly Tagged $\bar{D}^0/D^-$ events

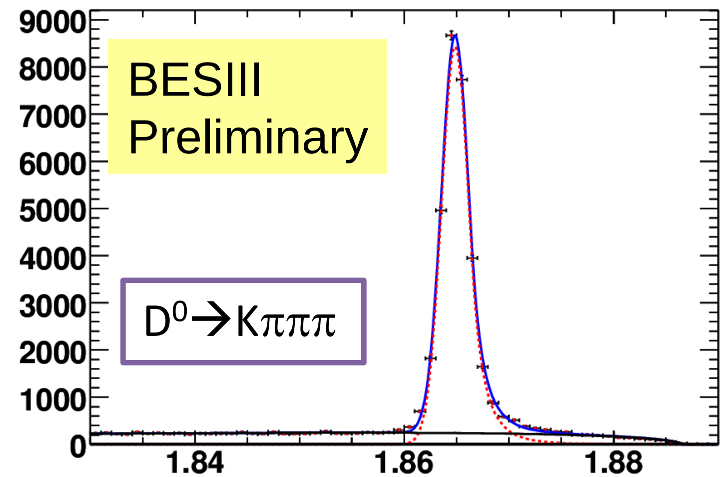
- **Beam constraint mass distribution**

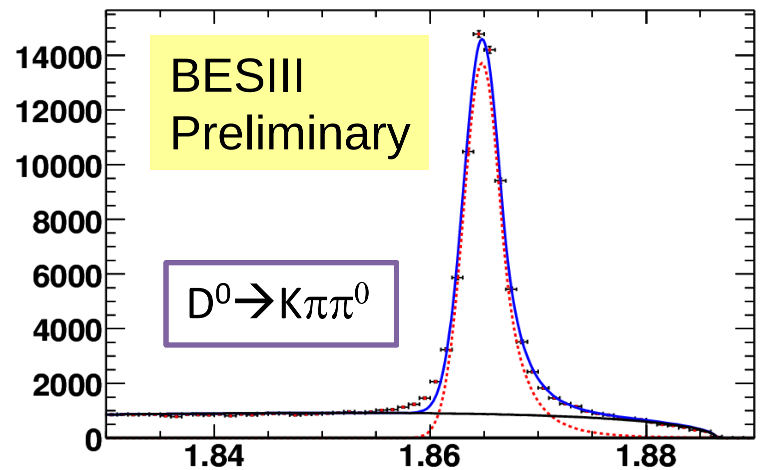
$$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$$

Resolution:
1.3 MeV for pure charged modes;
1.9 MeV for modes with one $\pi^0$.



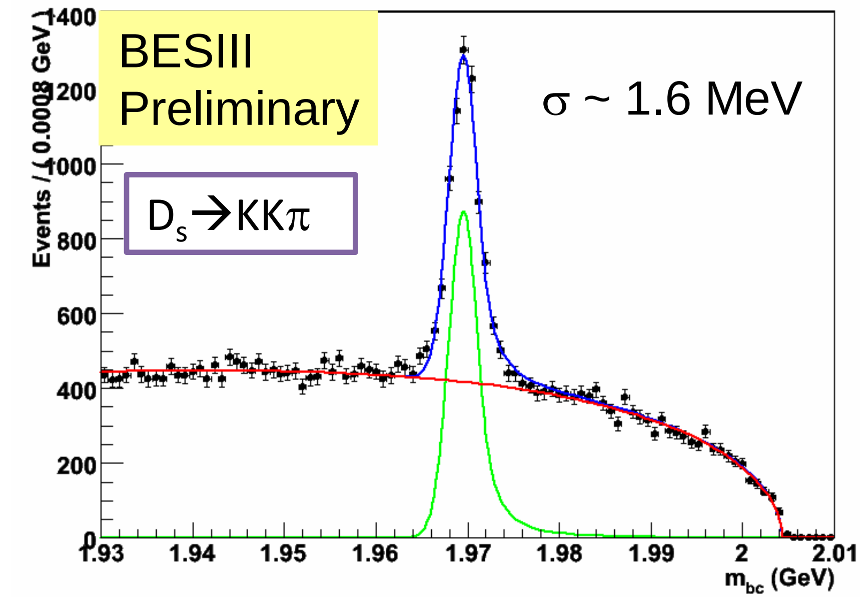



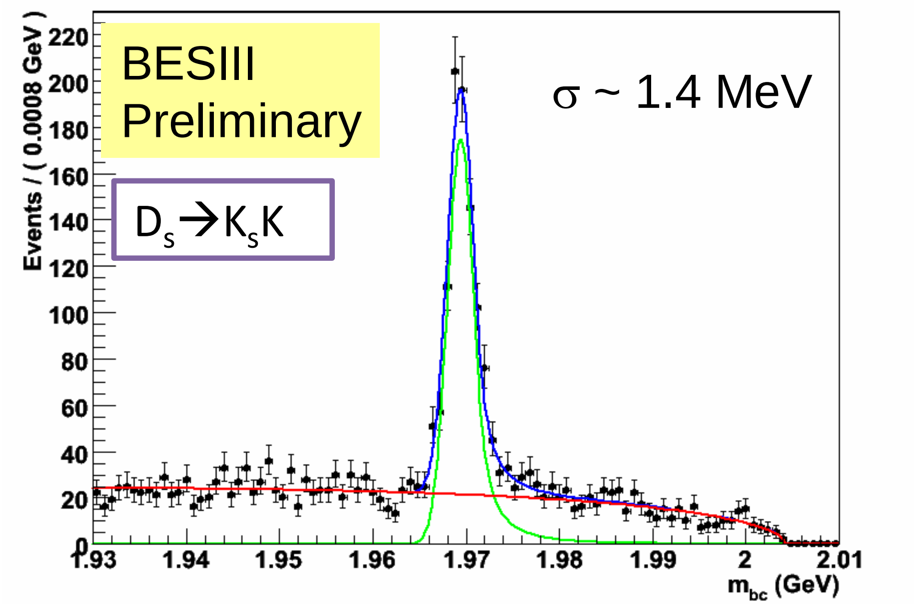

By analyzing part of data taken @ 3.773 GeV

# Singly Tagged $D_s$ events

- Beam constraint mass distribution

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




By analyzing part of data taken @ 4.01 GeV

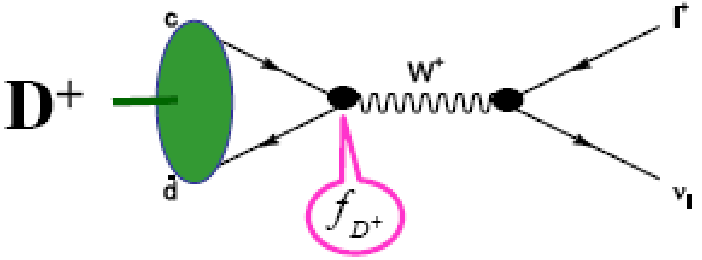
# Leptonic Decay

## Leptonic Analysis

- ✓ $D^+ \rightarrow \mu^+\nu_\mu$, $e^+\nu_e$ and $\tau^+\nu_\tau$
- ✓ $D_s^+ \rightarrow \mu^+\nu_\mu$, $e^+\nu_e$ and $\tau^+\nu_\tau$

## Motivations

- ✓ extract out $f_D$ & $f_{Ds}$, which in turn be used to calibrate LQCD.
- ✓ $R=(f_{Bs}/f_B)/(f_{Ds}/f_D)\sim 1$. $f_{Ds}/f_D$ can be used to estimate $f_{Bs}/f_B$.



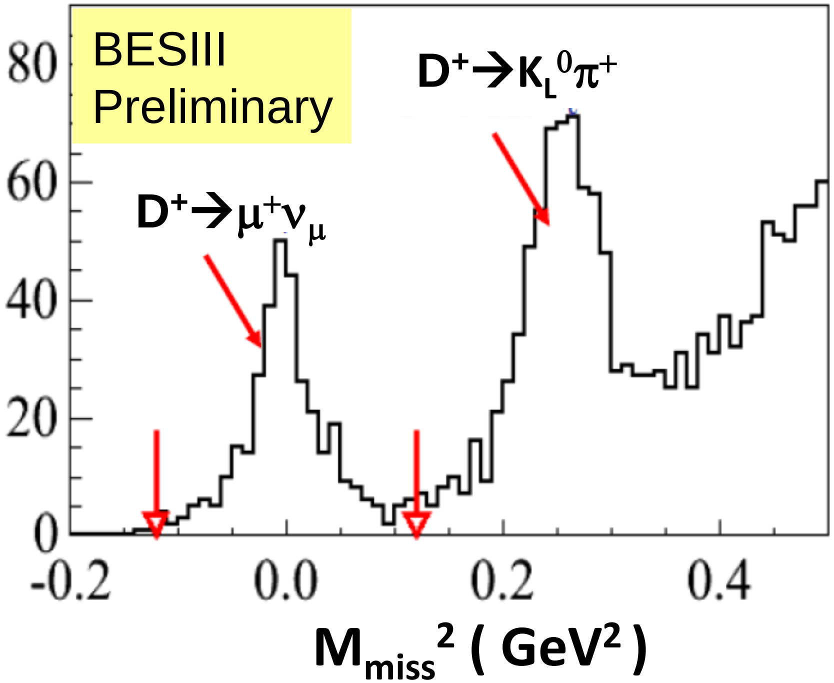

All strong interaction effects between the two quarks within the $D^+$ meson is simply factorized into one parameter, the decay constant $f_{D+}$.

The decay constant of $f_D$ is related to the decay rate by

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

# Leptonic Decay

## ✓ Candidate events for $D^+ \rightarrow \mu^+ \nu_\mu$




$$M_{miss}^2 = E_{miss}^2 - |\vec{p}|_{miss}^2$$

**With 4 fb$^{-1}$ data at BESIII**

$$\frac{\Delta f_{D^+}}{f_{D^+}} = \sqrt{(\frac{\Delta B}{2B})^2_{\rm sta} + (\frac{\Delta \tau_D}{2\tau_D})^2 + (\frac{\Delta |V_{\rm cd}|}{|V_{\rm cd}|})^2}$$

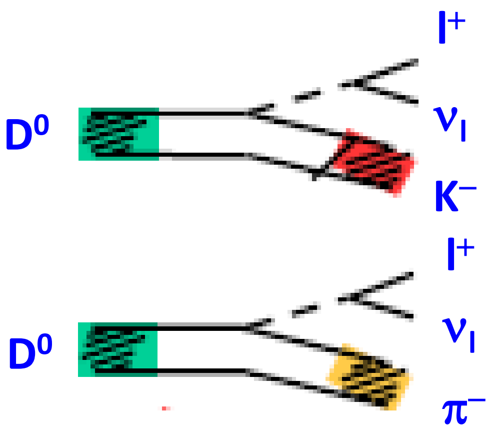
- $\frac{\Delta \tau_D}{\tau_D} \sim 0.7\%$ [PDG10]
- $\frac{\Delta B}{B}_{\rm sta} \sim 4.9\%$ [4 fb$^{-1}$ data]
- $|V_{\rm cd}| = 0.2252 \pm 0.0007$ [HPQCD]

➡ $\frac{\Delta f_{D^+}}{f_{D^+}} \sim 2.5\%$

# Semileptonic Decay

## ☐ Semileptonic Analysis

- ✓ $D^0 \to K^- l^+ \nu_l, \pi^- l^+ \nu_l$ ($l = e, \mu$)
- ✓ $D^+ \to \omega/\phi e^+ \nu_e$
- ✓ $D^+ \to \pi^0 e^+ \nu_e, \eta e^+ \nu_e,$




## ☐ Motivations

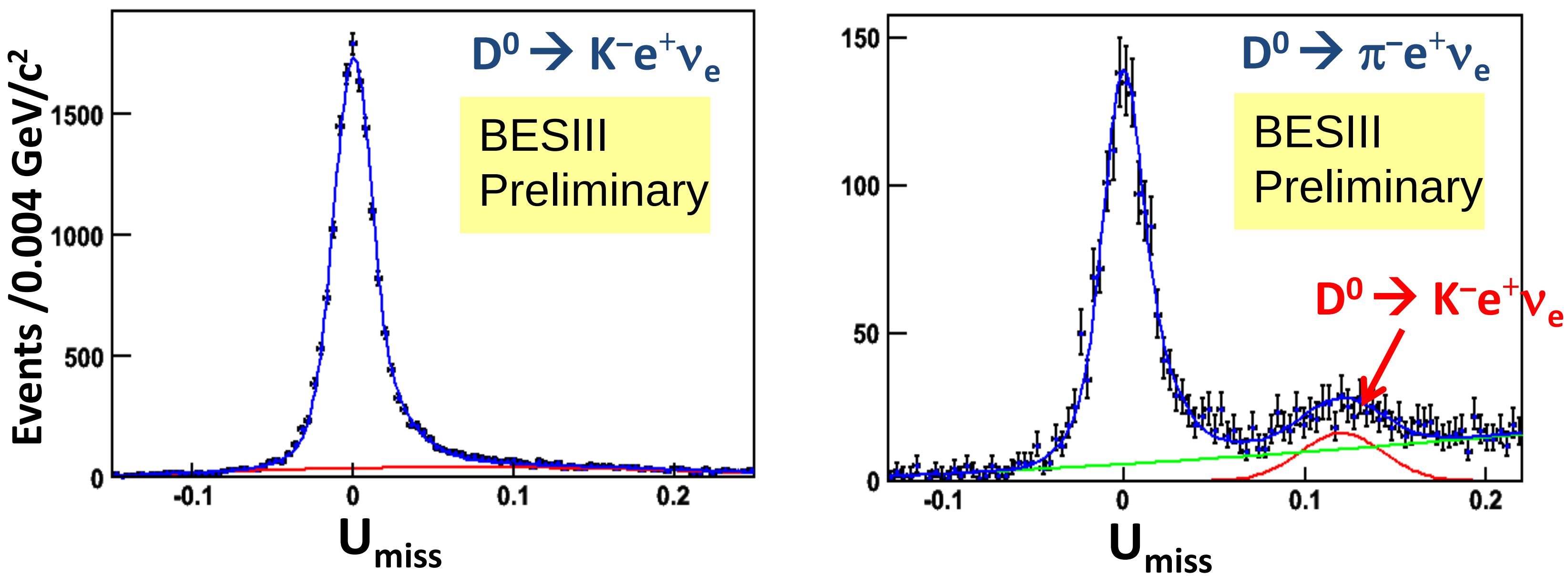
- ✓ extract out the form factor, which in turn be used to calibrate LQCD calculations .
- ✓ extract the $|V_{cs}|$ and $|V_{cd}|$, can be used to test the sides $B_d$ unitary triangles and provide indication for new physics.

For pseudo-scalar decays, the decay rate $\Gamma$ relates to form factor and CKM elements by

$$\frac{d\Gamma(D \to Pl\upsilon)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cs(d)}|^2 \; p_P^3 \, | f_+(q^2) |^2$$

# Semileptonic Decay

✓ **Candidate events for $D^0 \to K(\pi)^- e^+ \nu_e$**




$U_{miss} = E_{miss} - p_{miss}$ .

$$E_{miss} = E_{cm} - \sum_{i=1}^{N} \sqrt{\left|\overrightarrow{p_i}\right|^2 + m_i^2} \quad \text{and} \quad P_{miss} = \left| -\sum_{i=1}^{N} \overrightarrow{p_i} \right|$$

By analyzing part of data taken @ 3.773 GeV

# Prospect for measurements at BESIII

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

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

$$\Gamma(D\to Ke\nu_e)=\frac{\mathrm{B}(D\to Ke\nu_e)}{\tau_{\mathrm{D}}}=1.53|V_{cs}|^2|f_+^K(0)|^2\times10^{11}s^{-1}$$

$$\Gamma(D\to \pi e\nu_e)=\frac{\mathrm{B}(D\to \pi e\nu_e)}{\tau_{\mathrm{D}}}=3.01|V_{cd}|^2|f_+^\pi(0)|^2\times10^{11}s^{-1}$$

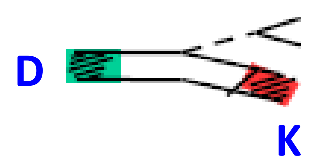
To extract $V_{cs}$ & $V_{cd}$ need form factor from theory.

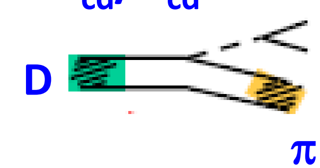
## ✓ $|V_{cs}|$ and $|V_{cd}|$ at BESIII

$$\frac{\Delta|V_{\rm cq}|}{|V_{\rm cq}|}=\sqrt{(\frac{\Delta B}{2B})^2_{\rm sta}+(\frac{\Delta B}{2B})^2_{\rm sys}+(\frac{\Delta\tau_D}{2\tau_D})^2+(\frac{\Delta f}{f})^2}$$

- $\frac{\Delta\tau_D}{\tau_D}\sim0.4\%$ [PDG10]
- $\frac{\Delta B}{B}_{\rm sta}\sim0.6\%,\ 1.6\%$ [4 $\mathrm{fb}^{-1}$ data]
- $\frac{\Delta B}{B}_{\rm sys}\sim1.0\%$ [expected]
- $\frac{\Delta f}{f}\sim2.5$ [HPQCD]

$\Delta V_{cs}/V_{cs}$~ 2.6% $\Delta V_{cd}/V_{cd}$~ 2.7%



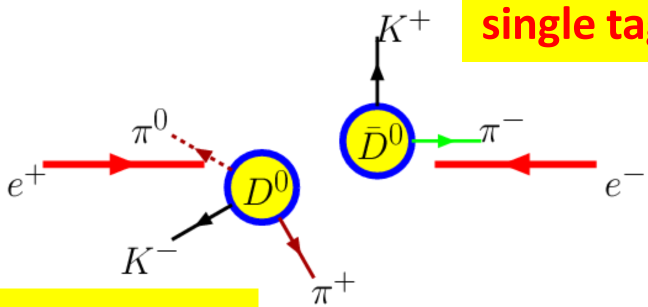

PDG10: $\Delta V_{cs}/V_{cs}$~ 3.5% $\Delta V_{cd}/V_{cd}$~ 4.8%

# Absolute Branching fraction Measurement

- Br[$D^0 \to K^-\pi^+$] and Br[$D^+ \to K^-\pi^+\pi^+$]

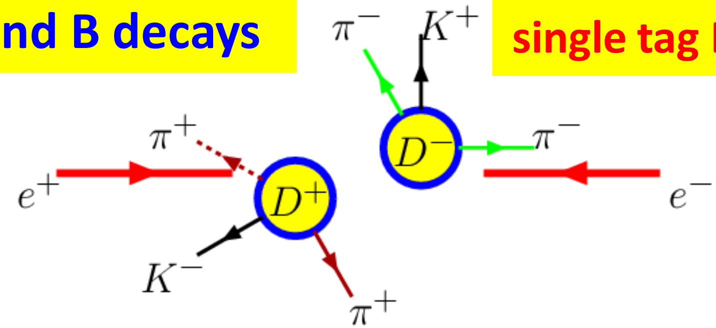
✓ Normalize decay branching fractions for D and B decays

single tag D⁰bar




double tag D⁰

single tag D⁻




double tag D⁰

MARK-III method

- single tag events $N_i^s = N_{D\bar{D}} B_i \varepsilon_i - \sum_{j=1}^{N} (N_{D\bar{D}} \varepsilon_{i,j}^i B_i B_j)$
- double tag events $N_{i,j}^d = N_{D\bar{D}} B_i B_j \varepsilon_{i,j}$

$$\chi^2 = \sum_{i=1}^{N} \left(\frac{N_i^s - N_i^{s,\exp}}{\sigma_{N_i^s}}\right)^2 + \sum_{i=1,j=1}^{N,N} \left(\frac{N_{i,j}^d - N_{i,j}^{d,\exp}}{\sigma_{N_{i,j}^d}}\right)^2$$

- branching fraction for hadronic decays

# Other topics going on

- Dalitz plot analysis
  - ✓ $D^0 \rightarrow K^- \pi^+ \pi^0$
  - ✓ $D^+ \rightarrow K_S{}^0 \pi^+ \pi^0$
- Search for CP violation through T-violation
  - ✓ $D^+ \rightarrow K^+ K^- \pi^+ \pi^0$
  - ✓ $D^+ \rightarrow K_S{}^0 K^+ \pi^+ \pi^-$

# Summary

- BESIII is accumulating data at a record speed.

- More precisely measurements will come out soon at BESIII.
  - Precise measurement on decay constant $f_{D+}$& $f_{Ds}$
  - Precise measurement on form factors and CKM matrix
  - Precise measurement on absolute branching fractions
  - Search for CP or T violation in D-meson decays
  - ……

TNANKS!!