Charm Physics at BESIII

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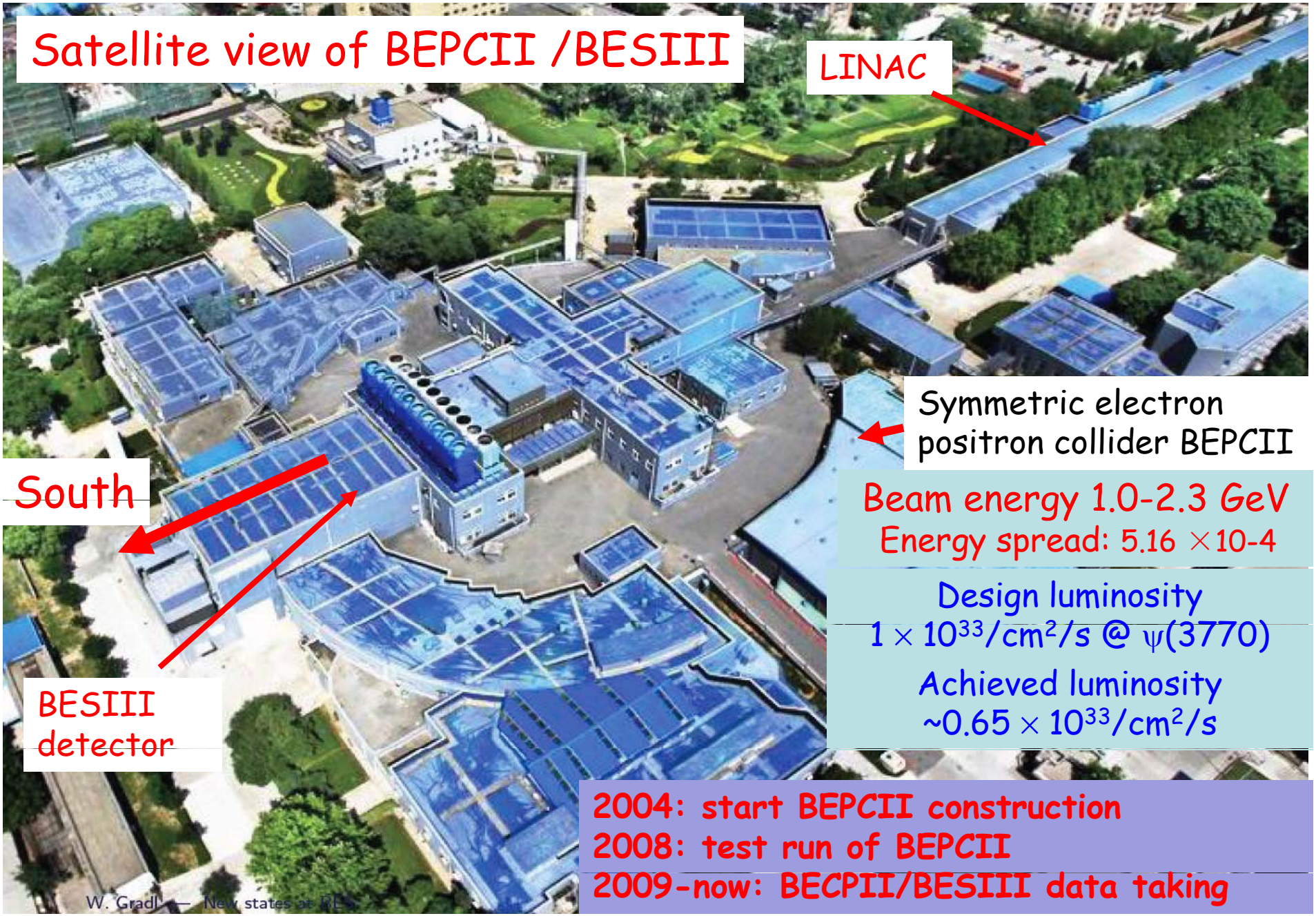
Outline

- Introduction of BEPCII and BESIII
- Charm prospects at BESIII and ongoing analysis
- Summary

Satellite view of BEPCII /BESIII



Beam energy 1.0-2.3 GeV
Energy spread: 5.16 $\times$10-4

Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$

Achieved luminosity
$\sim 0.65 \times 10^{33}/cm^2/s$

2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

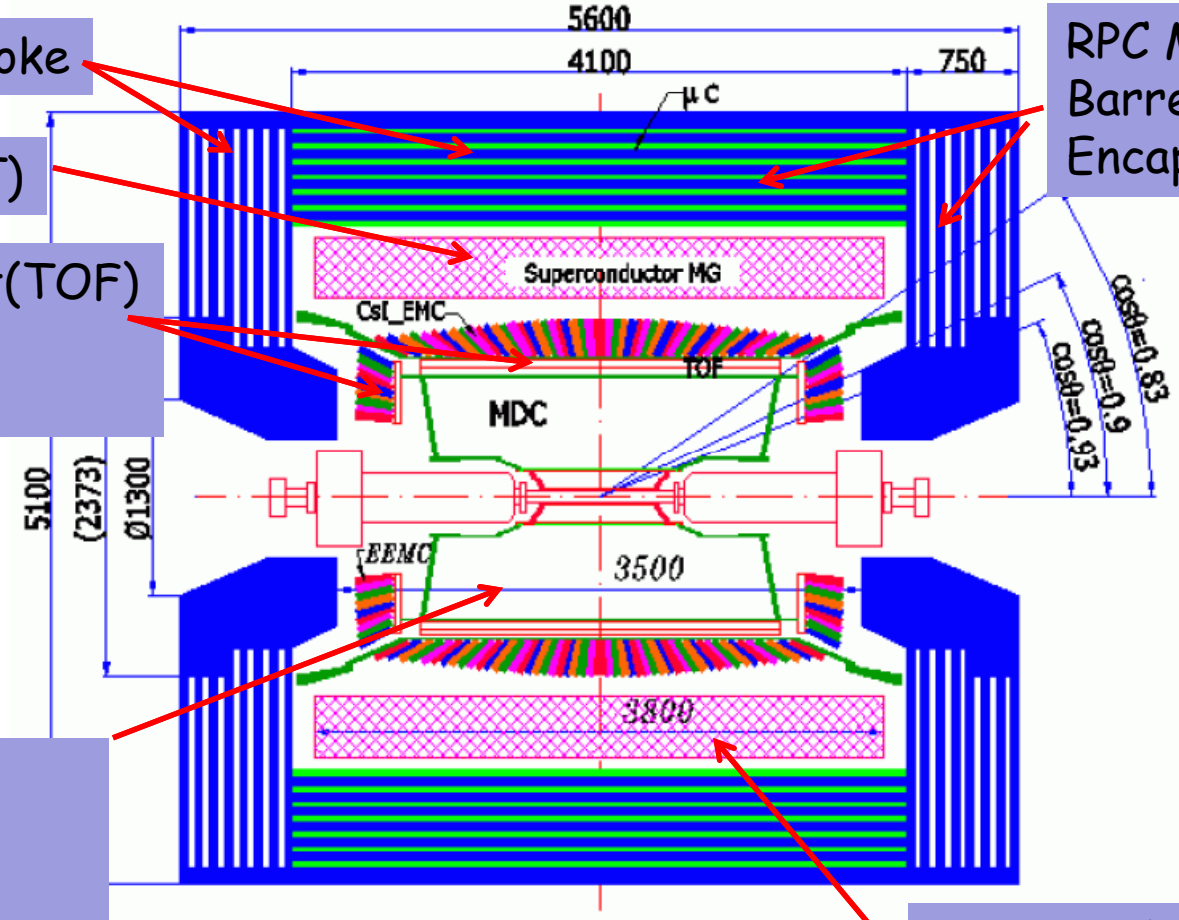
BESIII detector

Magnet yoke

SC magnet (1T)

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

Drift chamber
Small sell
& He-based gas
σ_p/p = 0.5% at 1 GeV
$\sigma_{(dE/dx)}/dE/dx$ ~ 6% at 1GeV



RPC Muon Counter
Barrel: 9 layers
Encaps: 8 layers

EMC CsI(Tl)
σ_E /E ~2.5% at 1 GeV

Data taken

- So far BESIII has collected :
  - 2009: 225 Million J/ψ
  - 2009: 106 Million ψ'
  - **2010-11: 2.9 fb^{-1} ψ(3770) (3.5 × CLEO-c 0.818fb^{-1})**
  - **May 2011: 0.5fb^{-1} @4010 MeV (one month) for Ds and XYZ spectroscopy**

- BESIII will also collect:
  - more J/ψ, ψ', ψ(3770)
  - data at higher energies （for XYZ searches, R scan and Ds physics）

Year	Running Plan
2012	J/ψ: 1 billion / ψ(2S): 0.5 billion (approved)
2013	4170 MeV: Ds decay R scan (E > 4 GeV)
2014	ψ(2S)/τ / R scan (E > 4 GeV)
2015	ψ(3770): 5-10 fb^{-1} (our final goal)

Red: to be approved by BESIII Collaboration

Measurements with tagged D mesons

- Purely leptonic decays
  - f_D and f_{Ds} decay constants
- Semileptonic decays
  - $|V_{cs}|$ and $|V_{cd}|$ CKM matrix elements, form factor
- Absolute branching fractions
- CP or T violation
- D-$\overline{D}$ mixing
  - Exploiting quantum correlations @ the ψ(3770)
- ...

Advantage of open charm at threshold

e^+e^- Colliders at threshold: CLEO-c, BESIII, Super-tau-charm

$e^+e^- \to \psi(3770) \to D^0\overline{D}^0$ $[C = -1]$ OR $e^+e^- \to \gamma^* \to D^0\overline{D}^0\gamma$ $[C = +1]$

Good for charm flavor physics:

- Threshold production: clean
- Known initial energy and quantum numbers
- Both D and Dbar fully reconstructed (double tag)
- Absolute measurements

Prospects for Charm at BESIII

precision measurements at BESIII after CLEO-c.

CLEO-c errors for D^0 /D^+ physics with 818 pb^{-1}@3770		BESIII ($5fb^{-1}$)
f_{D+} ($D^+ \to \mu^+ \nu$):	±4.1% (stat.) ± 1.2% (sys.)	±1.7% (stat.)
$f_\pi(0)$ ($D^0 \to \pi l \nu$):	±5.3% (stat.) ± 0.7%(sys.)	±2.1% (stat.)
BR($D^0 \to K\pi$):	±0.9% (stat.) ± 1.8%(sys.)	limited by sys.
BR($D^+ \to K\pi\pi$):	±1.1% (stat.) ± 2.0%(sys.)	limited by sys.

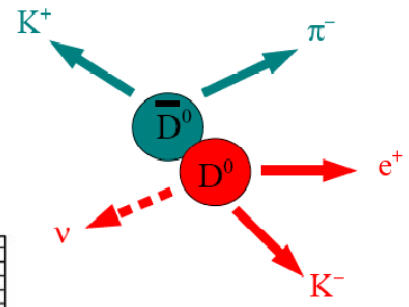
CLEO-c errors for D_s physics with 600pb^{-1}@4170 MeV		
f_{Ds} ($Ds^+ \to \mu^+ \nu, \tau\nu$):	±2.5% (stat.) ± 1.2% (sys.)	±0.9% (stat.)
BR($Ds^+ \to KK\pi$):	±4.2% (stat.) ± 2.9%(sys.)	±1.5% (stat.)

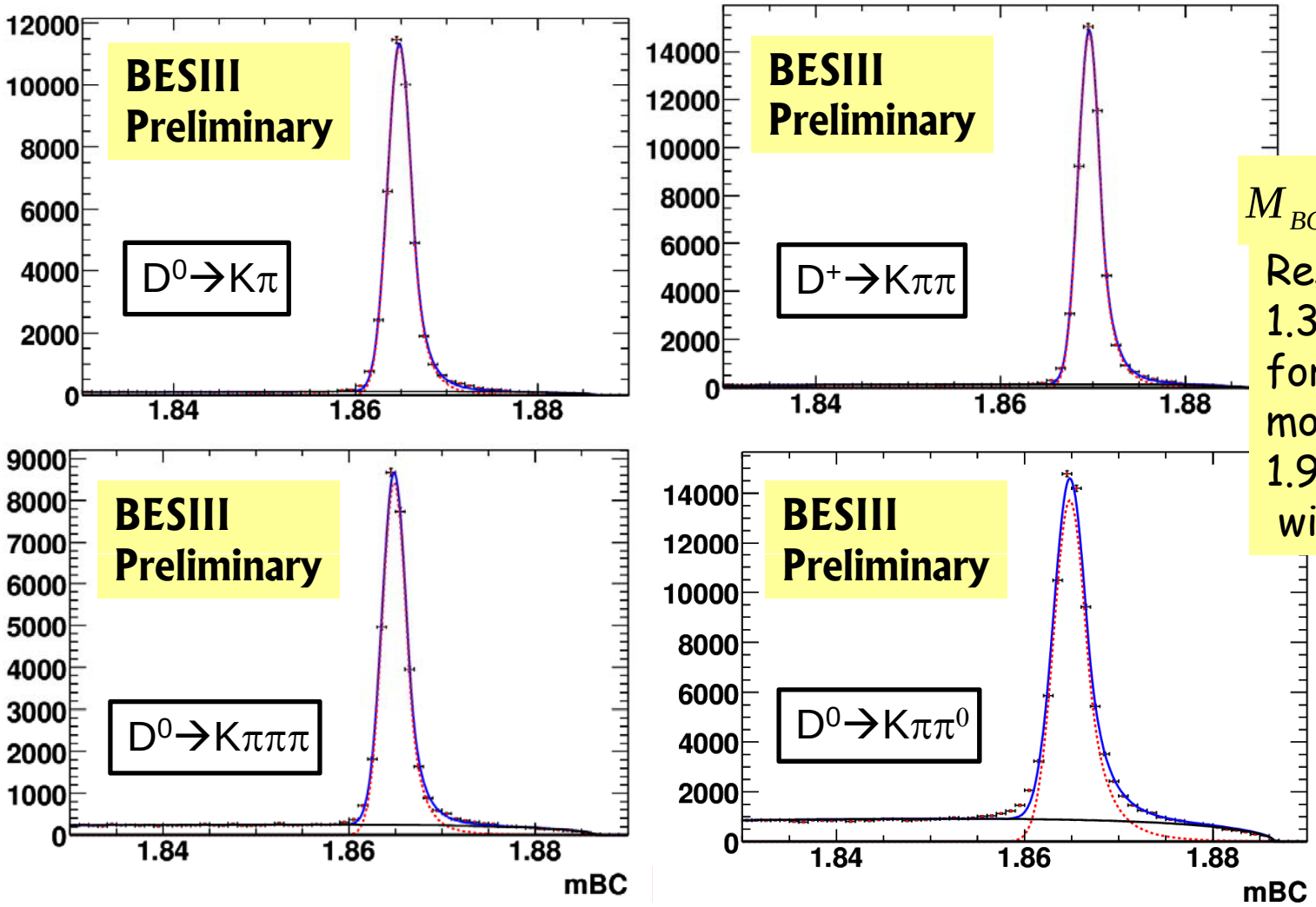
For Ds physics, BESIII are taking data at both 4010 and 4170 MeV:
4010 MeV (clean single tag, lower cross section 0.3 nb) → BESIII 0.5 fb^{-1}
4170MeV (dirty single tag, maximum cross section 0.9 nb) → CLEO-c 0.6 fb^{-1}

Significant gains will be made with increased luminosity at BESIII.

Clean single tag at BESIII

@ψ(3770) with 420pb^{-1} first clean single tagging sample:



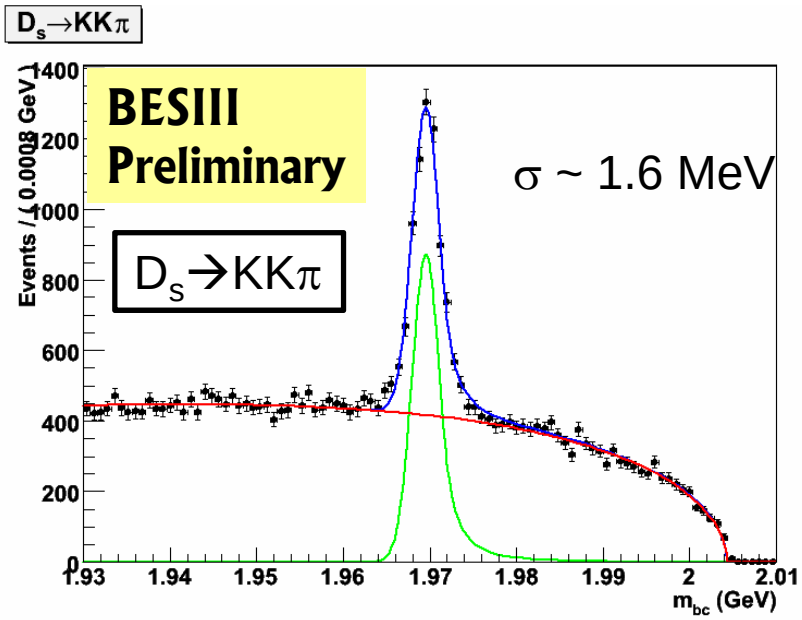


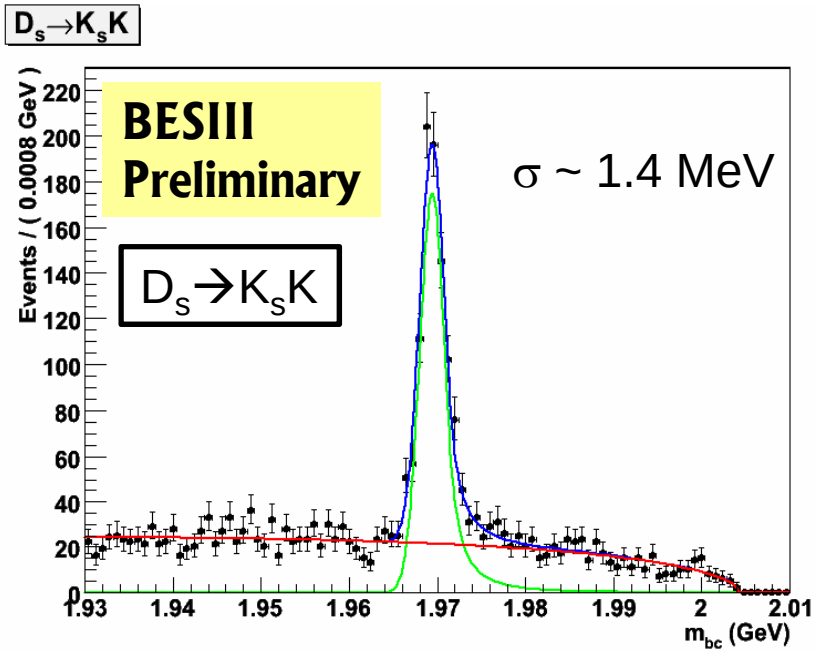
$$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$$

Resolution:
1.3 MeV
for pure charged modes;
1.9 MeV for modes with one π^0.

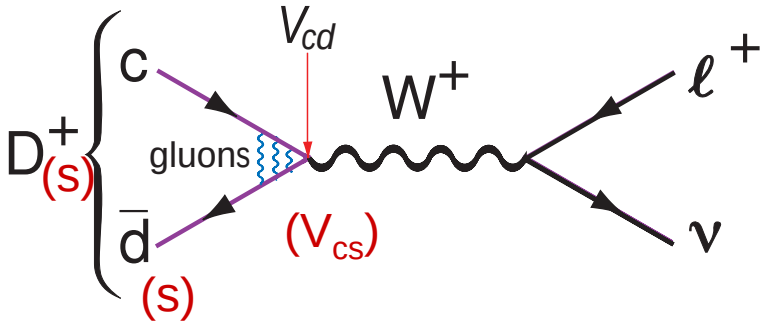
mBC of D_s Single Tag

part of data @ 4010 MeV





Leptonic decay

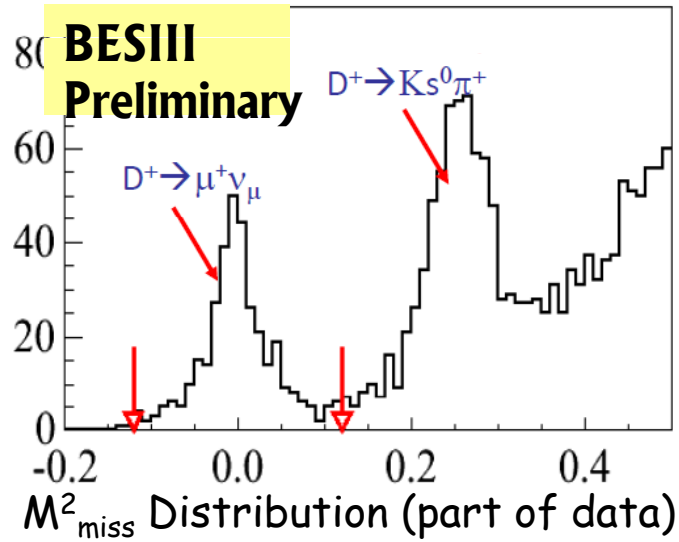


- Clean way to measure f_{D+} and f_{Ds} in SM
- Good agreement between expt. f_{D+} and LQCD calculations
- ~1.6σ difference between expt. f_{Ds} and LQCD calculations

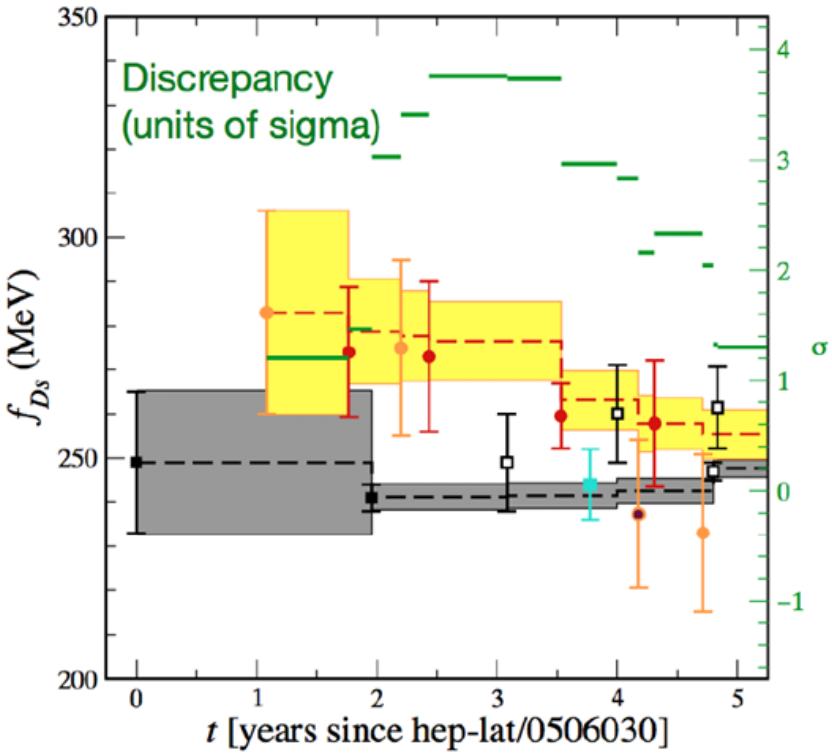
PhysRevD.82.114504

$$\Gamma(D_q^+ \to l^+\nu) = \frac{G_F^2}{8\pi} f_{D_q}^2 \, |V_{cq}|^2 \, m_l^2 \left(1 - \frac{m_l^2}{m_{D_q}^2}\right)^2 m_{D_q} \quad (q = d, s)$$

- Two ongoing measurements at BESIII:
  - $D^+ \to \mu^+\nu$
  - $D_s \to \mu^+\nu$



A brief history on f_{Ds}



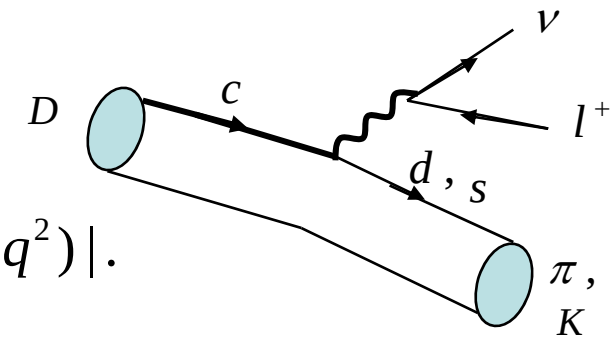
Kronfeld, arxiv:0912.0543+updates

- Gray: lattice three flavor avg.
- Yellow: expt. avg.
- Leftmost(t=0)result accompanied by successful prediction of f_{D+} by FNAL/MILC
- HPQCD2007(t~2) result provoke the "f_{Ds} puzzle" (3.8σ discrepency)
- Lattice avg. has come up
- Expt. avg has come down

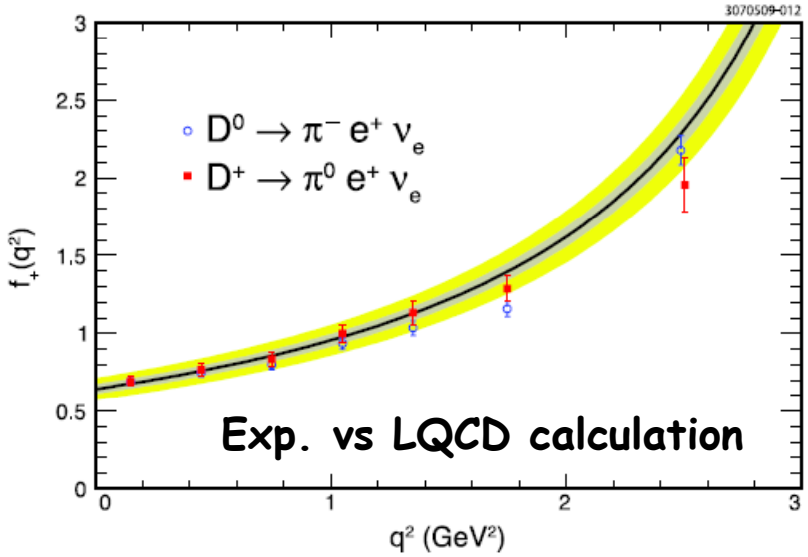
Semi-leptonic decay

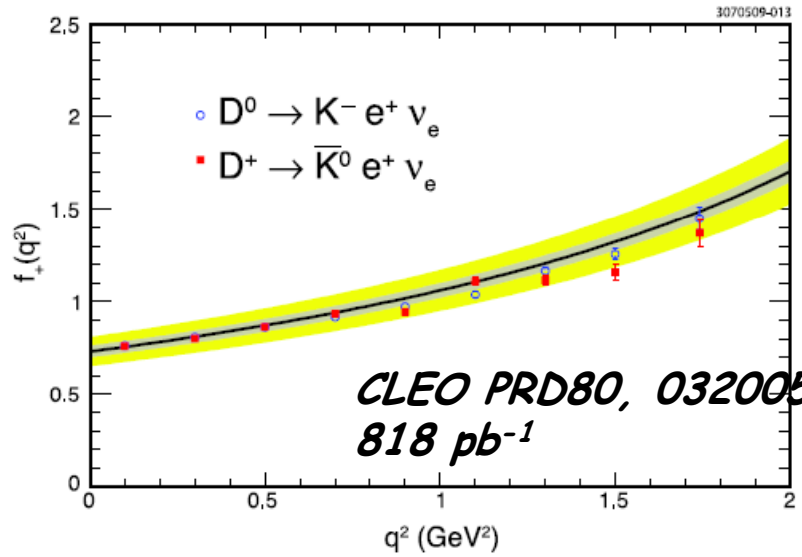
For pseudo-scalar meson:

$$\frac{d\Gamma(D \to K(\pi)e\upsilon)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cs(d)}|^2 \; p_{K(\pi)}^3 \; | f_+^{K(\pi)}(q^2) |.$$



$D \to \pi \; l^+ \nu, \quad D \to K \; l^+ \nu$





More data, better understood data, can have significant impact on these tests, especially at high q^2.

Semi-leptonic Analysis

- Three ongoing measurements:
  - $D^0 \rightarrow K^-/\pi^- e^+ \nu$
  - $D^+ \rightarrow \pi^0/\eta\, e^+ \nu$,
  - $D^+ \rightarrow \omega/\varphi\, e^+ \nu$, $\omega \rightarrow \pi^+\pi^-\pi^0$, $\varphi \rightarrow KK$
- Motivation:
  - Measure form factors and check theory
  - Test iso-spin symmetry in $D^0/D^+ \rightarrow \pi^-/\pi^0 e^+ \nu$
  - Branching fraction measurements (larger error for PDG value of $D^+ \rightarrow \omega e^+ \nu$, and only upper limit for $D^+ \rightarrow \varphi e^+ \nu$. can help studying ω-φ mixing.)

D Branch Fraction Measurement

- Motivation:

(1) Important to normalize decay fractions of D and B mesons
(2) Precise measurements of $\mathcal{B}(D^0 \rightarrow K\pi)$ and $\mathcal{B}(D^+ \rightarrow K\pi\pi)$ can directly improve precisions of CKM elements

- Current status:

(1) K/π tracking, π^0, K^0_s efficiency measurements
(2)PID efficiency measurement

- All other analyses at BESIII would benefit from systematics studies

CPV in D decay at BESIII

Direct CP violation in D decays is expected to be small in SM.

For CF and DCS decays direct CP violation requires New Physics.
Exception: $D^{\pm}\to K_{S,L}\pi^{\pm}$ with $A_{CP}=-3.3\times10^{-3}$.

For Singly Cabibbo Suppressed (SCS) decays SM CPV could reach 10^{-3}.

$$A_{CP} = \frac{\Gamma(D\to f)-\Gamma(\bar{D}\to \bar{f})}{\Gamma(D\to f)+\Gamma(\bar{D}\to \bar{f})}$$

D.S.Du , EPJC5,579(2007)
Y. Grossman et al
PRD75, 036008(2007)

Best limits:

Belle: $D^0\to K^+K^-,\pi^+\pi^-$
$A_{CP}(K^+K^-)=(0.43\pm0.30\pm0.11)\%$
$A_{CP}(\pi^+\pi^-)=(0.43\pm0.52\pm0.12)\%$

BABAR: $D^+\to K_S\pi^+$
$A_{CP}(K_S\pi^+)=(-0.44\pm0.13\pm0.10)\%$
CLEO-c : Ks $\pi^+\pi^0$
$A_{CP}(K_S\pi^+\pi^0)=(0.3\pm0.9\pm0.3)\%$

At BESIII, CP asymmetry can be tested with 10^{-3} sensitivity for many final states.

CP Violation with T-Odd Correlation

- Form T-odd correlation and difference of asymmetries
  - Look for T-violation assuming CPT invariance (Bigi hep-ph/0107102)
  - D meson four body decays
  - D→ KsKππ, KKππ

$$C_T \equiv \langle \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-}) \rangle$$

$$\bar{C}_T \equiv \langle \vec{p}_{K^-} \cdot (\vec{p}_{\pi^-} \times \vec{p}_{\pi^+}) \rangle$$

$$A_T = \frac{\Gamma_{D^0}(C_T > 0) - \Gamma_{D^0}(C_T < 0)}{\Gamma_{D^0}(C_T > 0) + \Gamma_{D^0}(C_T < 0)} \quad \text{and} \quad \overline{A}_T = \frac{\Gamma_{\overline{D}^0}(-\overline{C}_T > 0) - \Gamma_{\overline{D}^0}(-\overline{C}_T < 0)}{\Gamma_{\overline{D}^0}(-\overline{C}_T > 0) + \Gamma_{\overline{D}^0}(-\overline{C}_T < 0)}$$

- If T violation:

$$\mathcal{A}_T = \frac{A_T - \bar{A}_T}{2} \neq 0$$

- Ongoing analysis:
  - Look into $D^{+/-}$→ KsKππ, KKππ^0

Other Analysis at BESIII

- Dalitz plot analysis ($D^0 \to K\pi\pi^0$, $D^+ \to K^0_s\pi\pi^0$, $D^0 \to K\pi\eta$, $D^+ \to KK\pi$) :
  - Study the $K\pi$ system, search for the low mass scalar resonance κ
- $\psi(3770)$ cross section measurement
- $\psi(3770)$ line shape measurement
- …

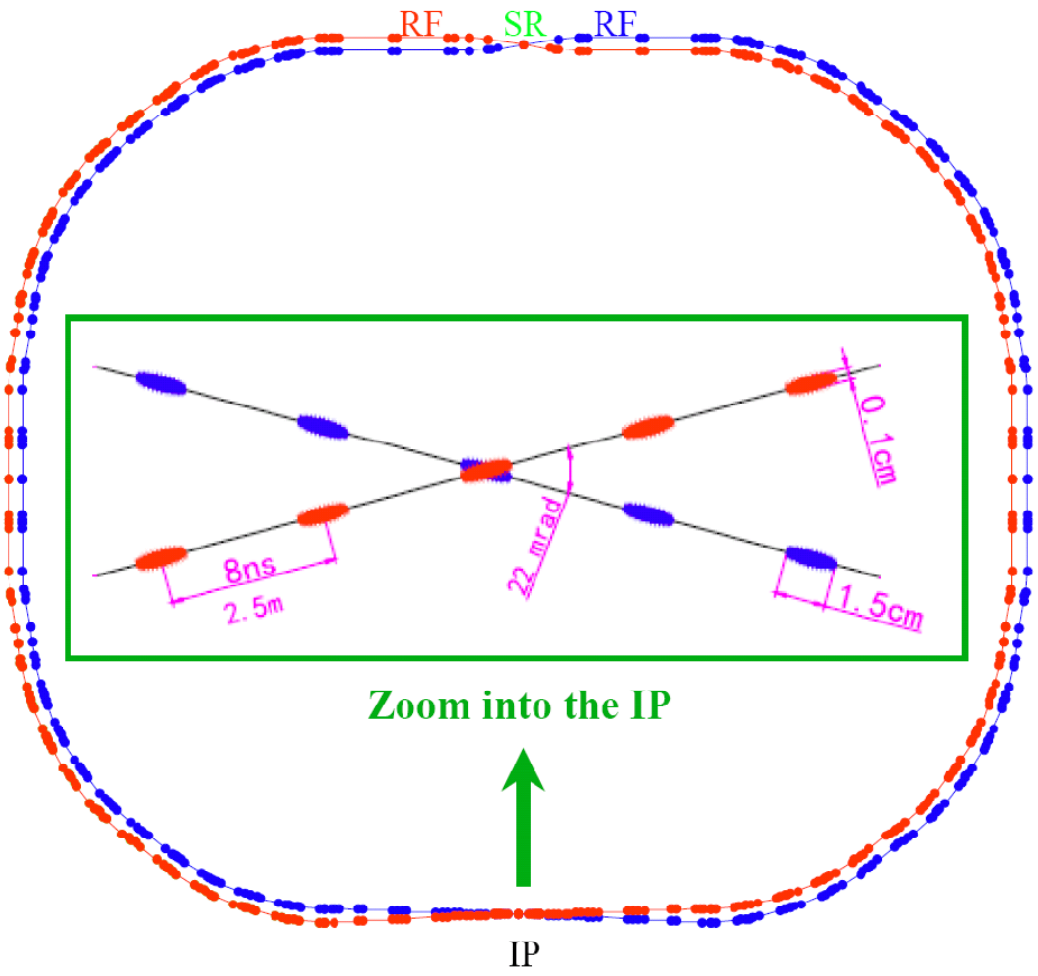
Summary

- BESIII is accumulating data at record speed
- Many unique opportunities for BESIII
  - Challenge SM with improved f_{D+} & f_{Ds} values
  - Measure form factor and check LQCD
  - Search for CP or T violation in D-meson decays
  - …

Thank you!

Backup

BEPCII storage rings



Beam energy:
1.0-2.3 GeV

Design Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Already achieved 2/3 of the design luminosity

Optimum energy:
1.89 GeV

Energy spread:
5.16×10^{-4}

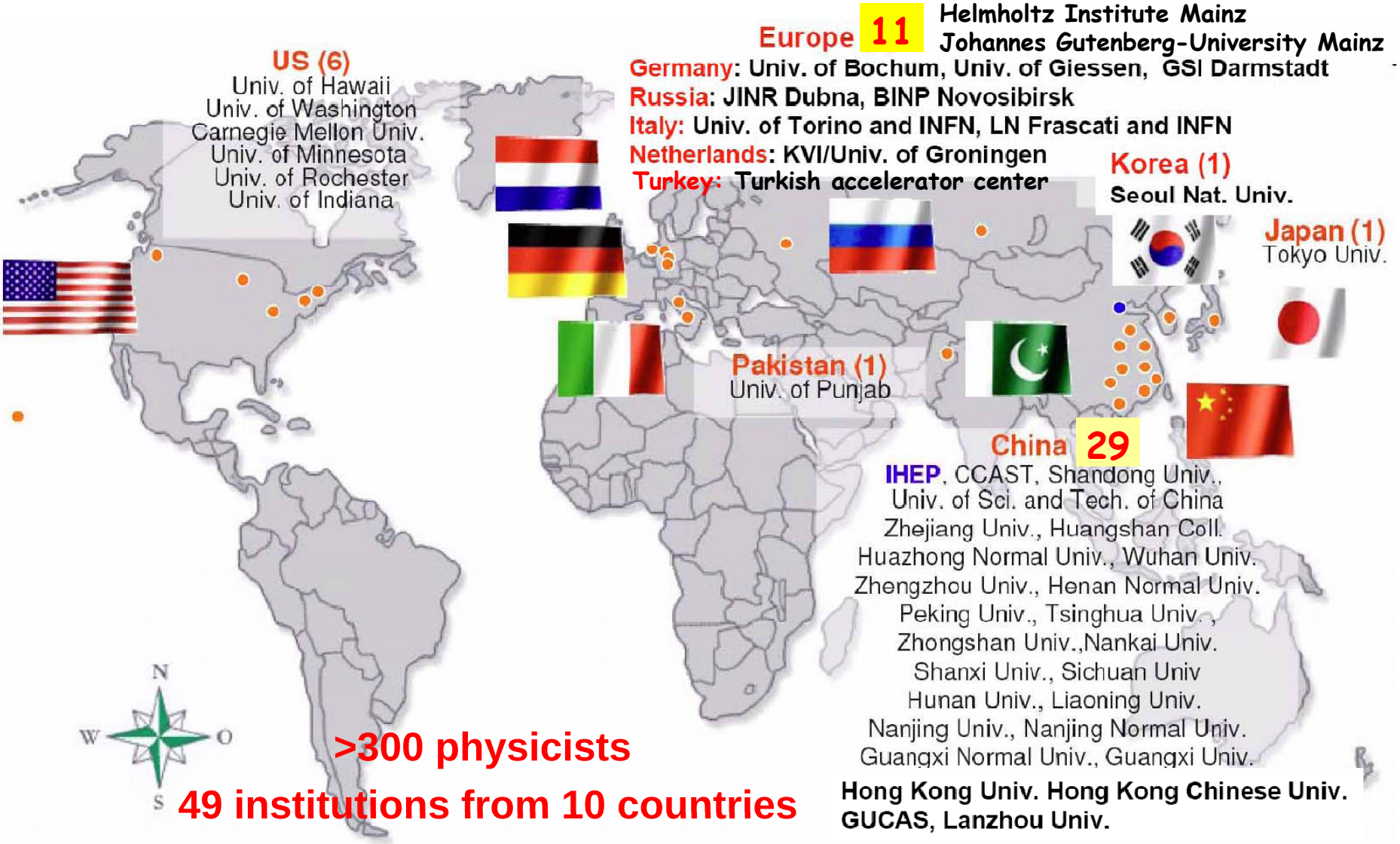
No. of bunches:
93

Bunch length:
1.5 cm

Total current:
0.91 A

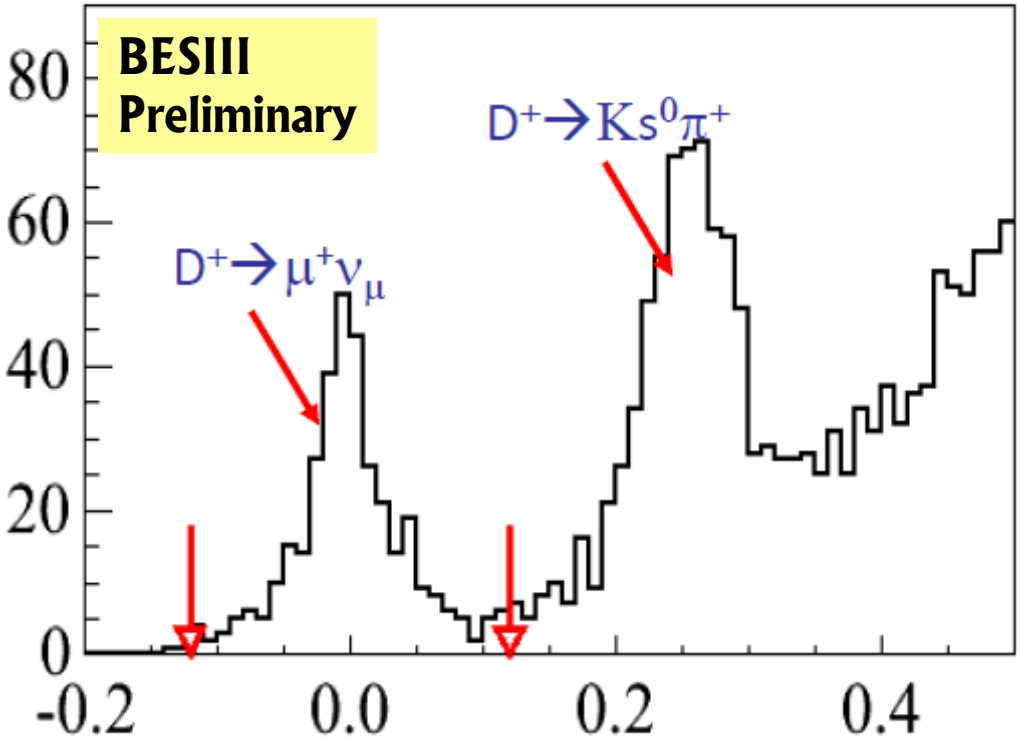
Circumference：
237m

BESIII Collaboration



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

- Tag side: 9 D^+ hadronic modes ($K\pi\pi$, $k\pi\pi\pi^0$, $K_s\pi$, etc)
- Signal side:
  1. one charged track only and muon PID satisfied
  2. no isolated EMC shower
- Key variable: $M^2_{miss} = E^2_{miss} - P^2_{miss}$



M^2_{miss} Distribution (part of data)

D-$\bar{D}$ mixing

Flavor oscillation in neutral D meson systems:

Mass eigenstates ≠ Flavor eigenstates

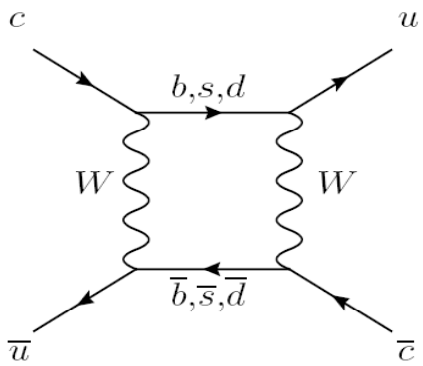
$$|D_1\rangle = p|D^0\rangle + q|\bar{D}^0\rangle$$
$$|D_2\rangle = p|D^0\rangle - q|\bar{D}^0\rangle$$
$$p \neq q \text{ if } CP \text{ violation}$$

Mixing parameters

$$x = \frac{M_1 - M_2}{\Gamma} \quad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$

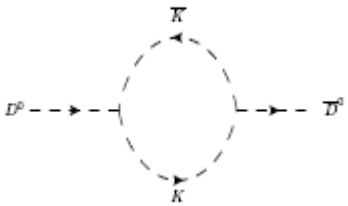
Mixing mechanism and x,y

- short distance contribution:
  - Well predicted by SM



GIM(for d,s) & CKM (for b) suppression

$y^{box} << x^{box} \sim 10^{-6}-10^{-5}$



- Long distance contribution:
  - Difficult to calculate
  - Depend on the size of $SU(3)_F$ breaking
  - Up to $O(10^{-3})$
- New physics can enhance D^0 mixing