Prospects of Charm Physics at τ-c Facility

Hai-ping Peng

penghp@ustc.edu.cn

State Key Laboratory of Particle Detection and Electronics (SKLPE)

University of Science and Technology of China (USTC)

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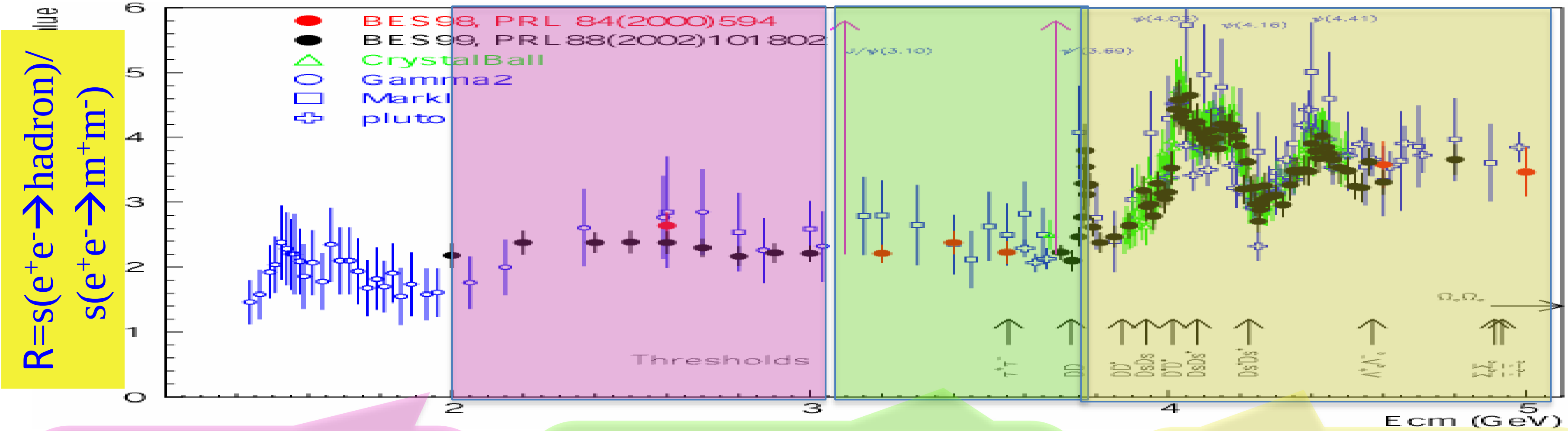
Broad Physics at τ-c Energy Region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- Physics with D mesons
- f_D and f_{Ds}
- D_0-D_0 mixing
- Charm baryons

- **Unique features**：Rich of resonance, Threshold characteristics, Quantum Correlation
- **Abundant physics**

BEPCII

Upgrade of BEPC (started 2004, first collisions July 2008)	
Beam energy	1 GeV to 2.3 GeV
Optimum energy	1.89 GeV
Single beam current	0.91 A
Crossing angle	±11 mrad

Design luminosity $1 \times 10^{33}\,\mathrm{cm^{-2}s^{-1}}$

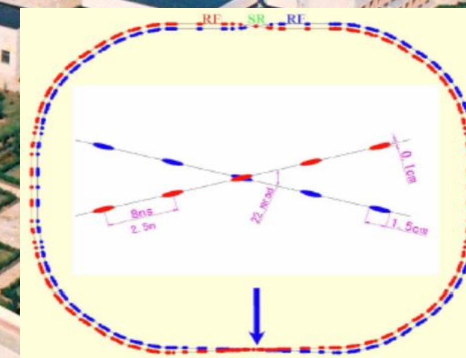
Achieved in 2016

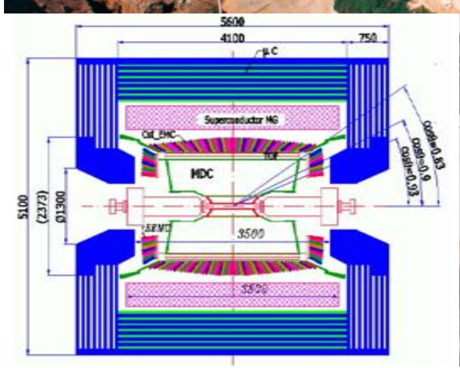
Beam energy measurement:

Laser Compton backscattering

$\Delta E/E \approx 2 \times 10^{-5}$

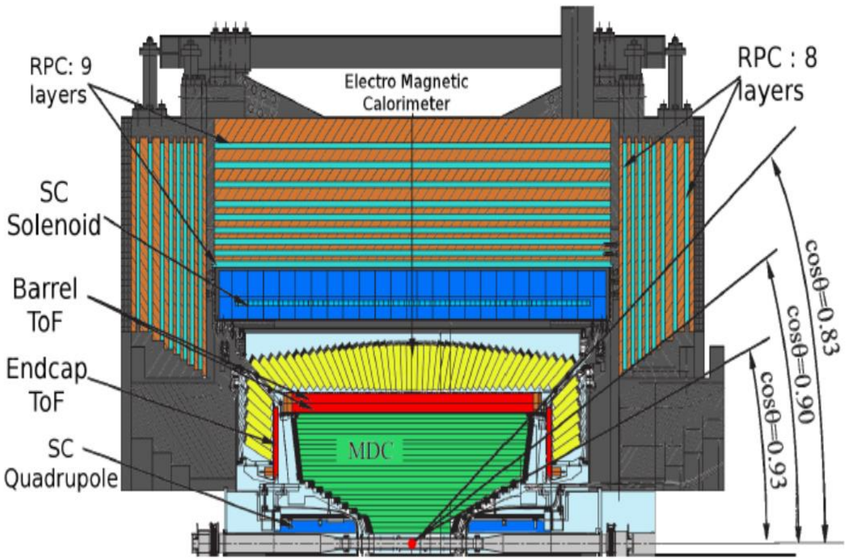
(contributes ≈ 50 keV to m_τ uncertainty)

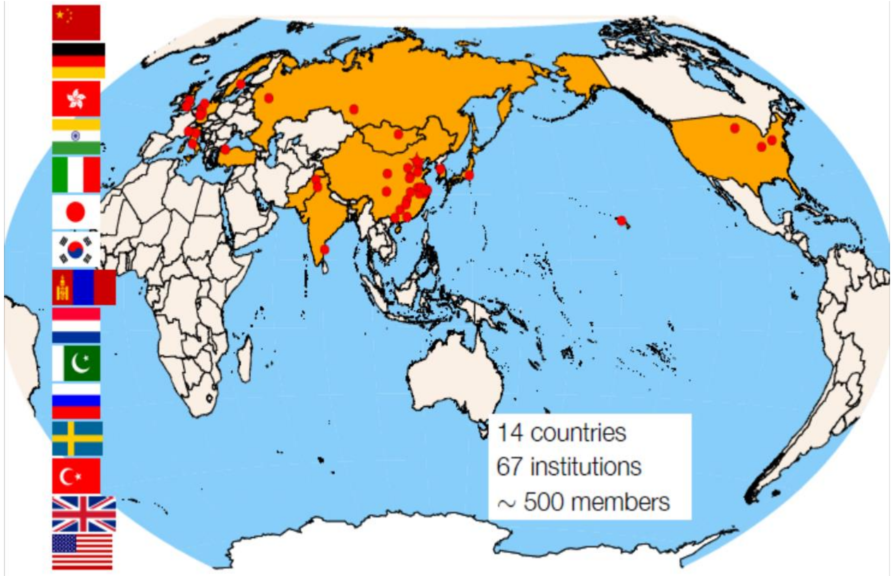




BESIII Experiment

BESIII detector





The BESIII Collaboration 2019

10 years data taking at BESIII

Data sets collected so far include

- 10×10^9 J/ψ events
- 448×10^6 ψ' events
- scan data between 2.0 and 3.08 GeV, and above 3.735 GeV
- large datasets for XYZ studies

Unique data sets for open charm:

$\sqrt{s}$ / GeV	$\mathcal{L}$ / fb^{-1}	
3.77	2.93	$D\bar{D}$
4.008	0.48	DD^*, $\psi(4040)$, $D_s^+D_s^-$
4.18	3.2	$D_sD_s^*$
4.6	0.59	$\Lambda_c^+\bar{\Lambda}_c^-$

Limitation for BEPCII/BESIII

- BEPCII/BESIII have run 10 years, and are playing a leading role in tau-charm physics area.
- Limited by length of storage ring, no space and potential for the upgrade.
- Physics study limited by the Statistics (luminosity), CME ……
- Challenged by Belle II

A Super τ-charm Facility is the nature extension and a viable option for a post-BEPCII HEP project in China

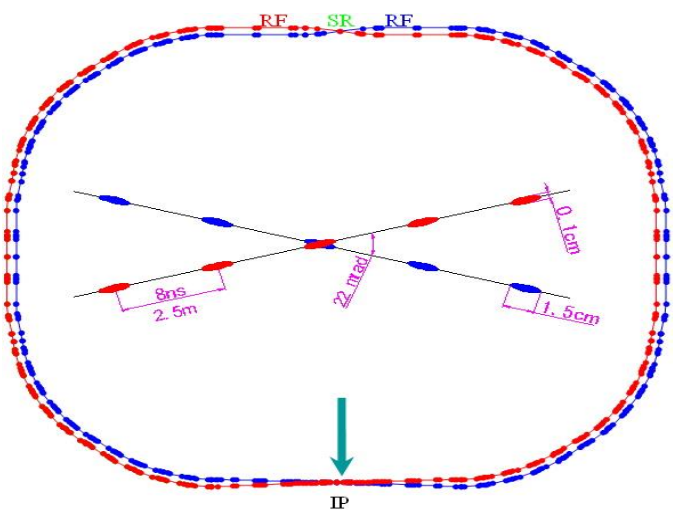
BEPCII vs STCF in China

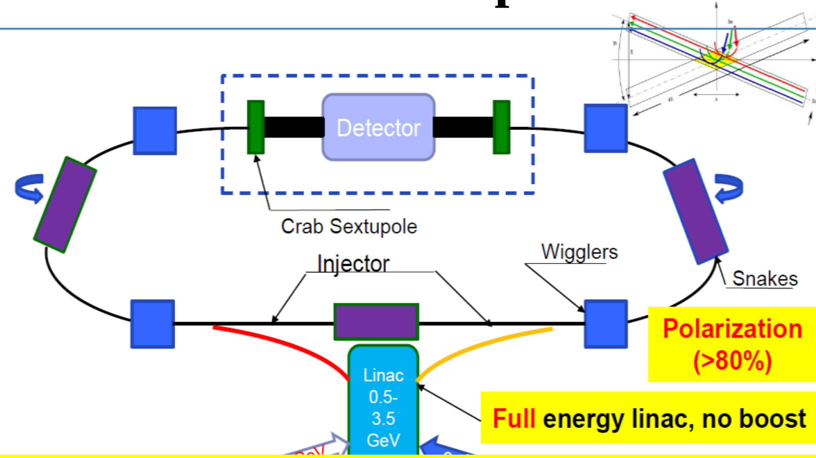
BEPCII

- Peak luminosity 0.6-1×10^{33} $cm^{-2}s^{-1}$ at 3.773 GeV
- Energy range E_{cm} = 2 – 4.6 GeV
- No Polarization

Designed STCF

- Peak luminosity 0.5-1×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
- Energy range E_{cm} = 2–7 GeV
- Potential to increase luminosity and realize beam polarization



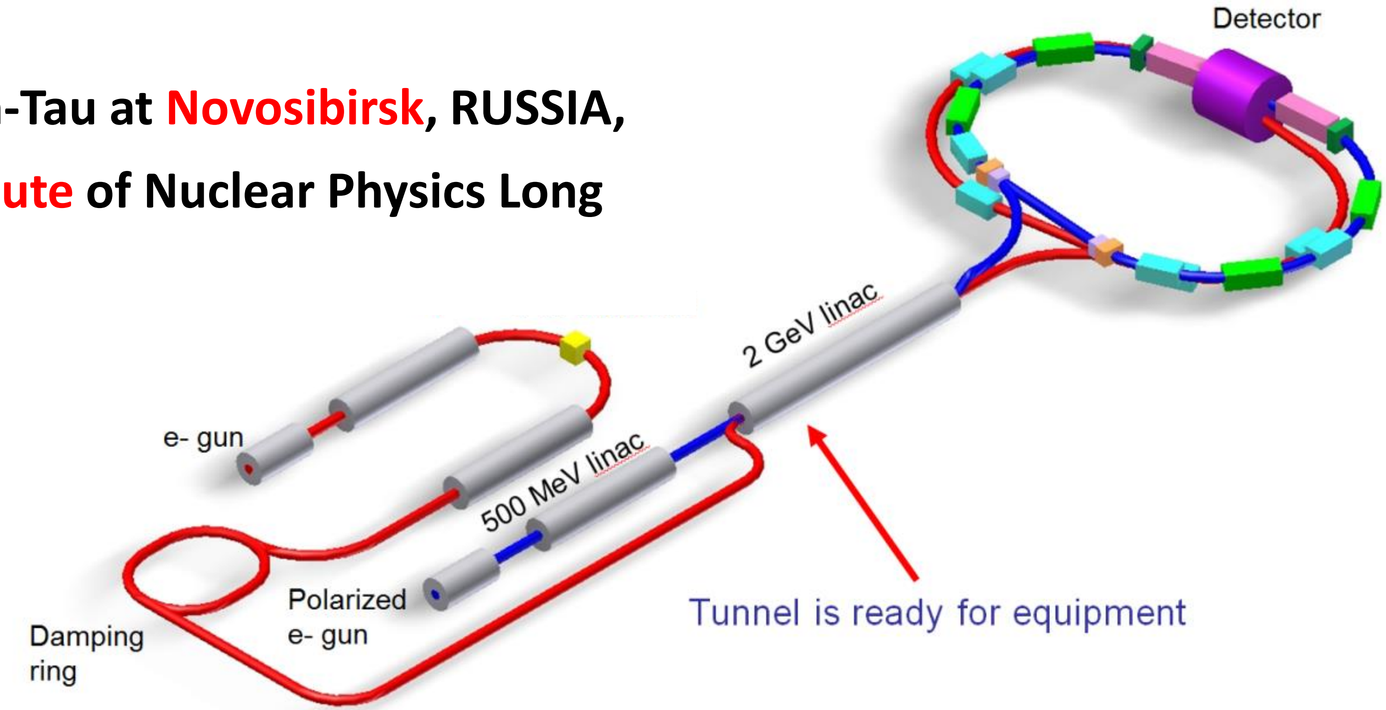


1 ab^{-1} data is expected per years

International Collaboration

Super Charm-Tau at Novosibirsk, RUSSIA,

Budker Institute of Nuclear Physics Long history…..



- **Pre-Agreement of Joint effort on R&D, details are under negotiation**
- **Joint workshop between China, Russia, and Europe**
  - **2018 UCAS (March), Novosibirsk (May), Orsay (December)**
  - **2019 Moscow(September)**

Strategy& Activities of STCF at China

CDR → TDR → project application → construction → commissioning

- Strategy: focus on CDR (3 years) and TDR (6 years) depend on the available resources. the construction site open.
- Webpage: http://wcm.ustc.edu.cn/pub/CICPI2011/futureplans/
- Domestic Workshops (2011, 12, 13, 14, 16)
- International Workshops (2015, 18)
- 2015 Fragrance Hill-Science Conference (No. 533)
- Report to USTC Scientific Committee and USTC presidents
- Report to local government
- Form the Organization (including project manager, physics/detector/accelerator work groups ….)
- Regular weekly meetings for Accelerator/Detector/physics !

Activities

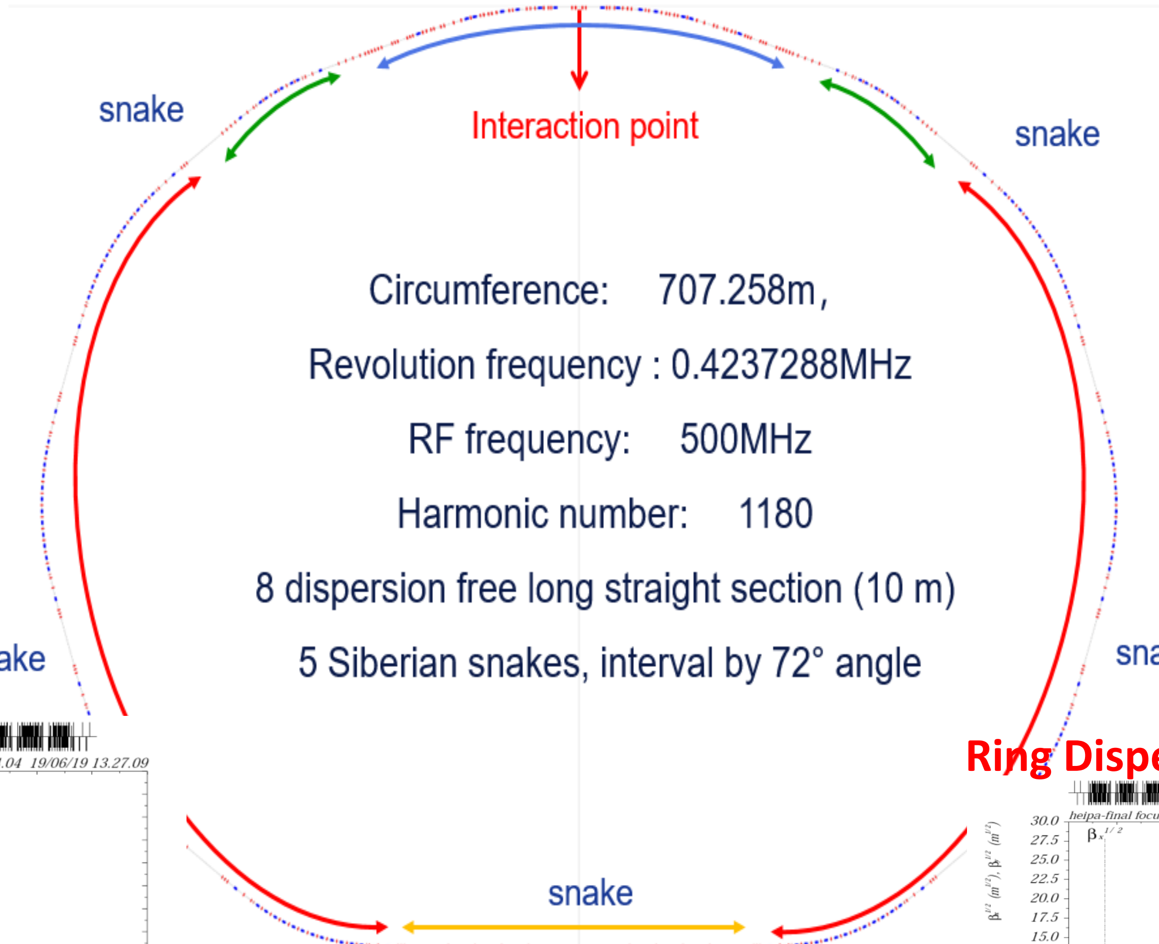
High Luminosity Tau Charm Physics

Indico for High Luminorcity Tau Charm Physics R&D

STCF Steering Committee	1 event
STCF Accelerator	27 events
STCF Physics	6 events
STCF Detector	99 events
STCF Accelerator-Detector Joint meetings	4 events
STCF International Conference	7 events
STCF Domestic meeting	7 events

Lattice with FODO-Like Arc

1. Interaction region
2. Long arc section
3. Short arc section
4. Technical section



Circumference: 707.258m,

Revolution frequency : 0.4237288MHz

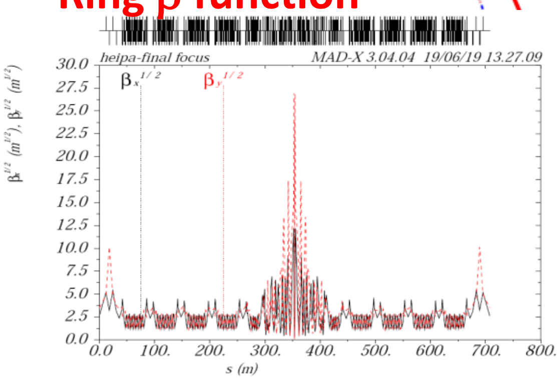
RF frequency: 500MHz

Harmonic number: 1180

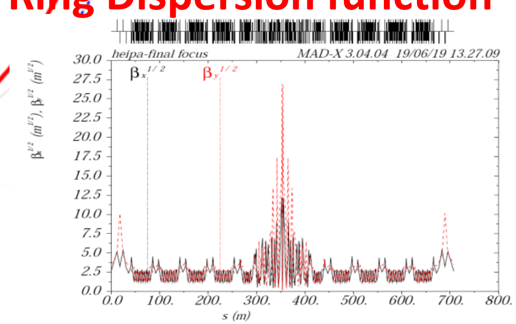
8 dispersion free long straight section (10 m)

5 Siberian snakes, interval by 72° angle

Ring β function

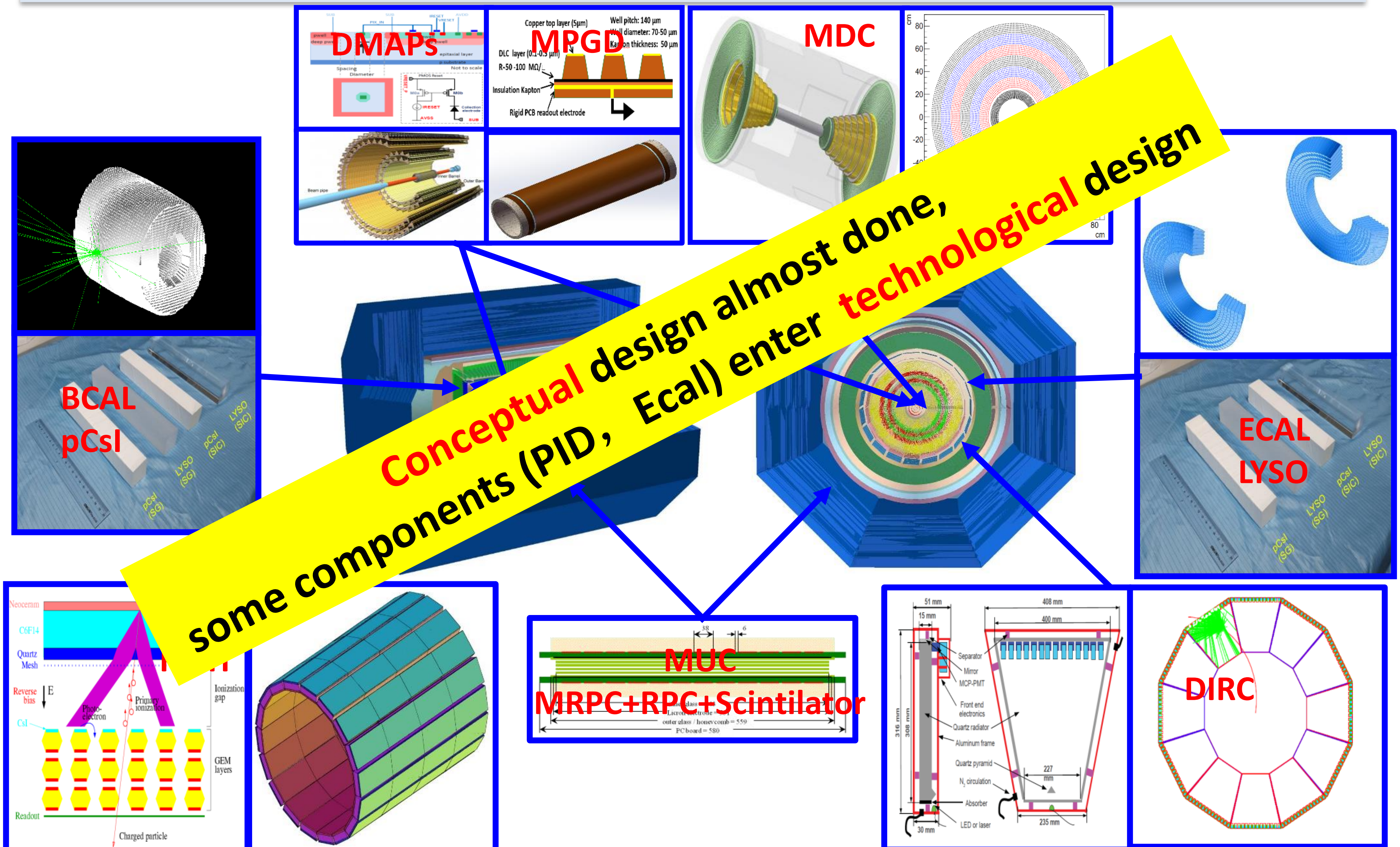


Ring Dispersion function



Spectrometer

Conceptual design almost done, some components (PID， Ecal) enter technological design



Facilities for Charm Study

- **LHCb:** Hadron collider, huge cross, energy boost

  9 fb^{-1} until now, 50 fb^{-1} upgrade I,

  World's largest sample of c-hadron decay in charged modes

- **B-factories** (Belle(-II), BaBar): e^+e^- collider

  ~ 1 ab^{-1} Belle, 50 ab^{-1} Belle-II (2024)

  more kinematic constrains, clean environment,

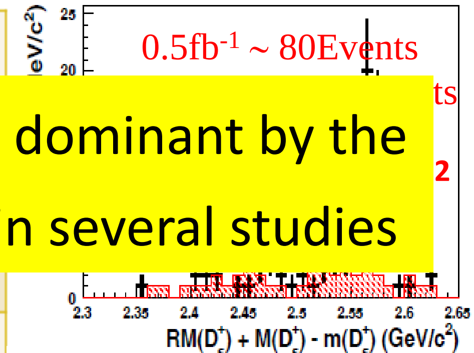
  ~100% trigger efficiency

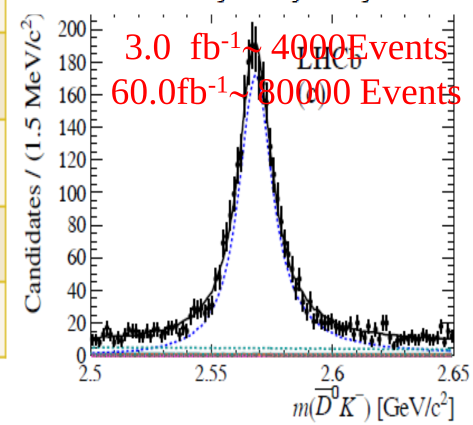
- **τ-charm factories** (BESIII, STCF): e^+e^- collider

Features for Charm Study

	STCF	Belle(-II)	LHCb
Systematic error	★★★★★	★★★	★★
Completeness	★★★★★	★★★	★
(Semi)-Leptonic mode	★★★★★	★★★	★
Neutron/K_L mode	★★★★★	★★	☆
Photon-involved	★★★★★	★★★★★	☆
Absolute measurement	★★★★★	★★★	☆

Most are precision measurements, which are mostly dominant by the systematic uncertainty STCF has overall advantages in several studies





- Belle II (50 ab^{-1}) has ~20 times more statistics in production comparing to STCF 1 ab^{-1}
- STCF is expected to have higher detection efficiency. It's double tag yields expected to be ~20 times more than Belle II
- STCF has low backgrounds for productions at threshold

STCF for Charm Study

- 4×10^9 pairs of $D^{\pm,0}$ and 10^7~$10^8 D_s$ pairs per year (1 ab^{-1})
  - 10^{10} charm from Belle II/year
- Highlighted Physics programs
  - Precise measurement of (semi-)leptonic decay (f_D, f_{Ds}, CKM matrix…)
  - $D^0 - \overline{D}^0$ mixing, CPV
  - Rear decay (FCNC, LFV, LNV….)
  - Excite charm meson states D_J, D_{sJ} (mass, width, J^{PC}, decay modes)
  - Charmed baryons (J^{PC}, Decay modes, absolute BF)
  - Light meson and hyperon spectroscopy studied in charmed hadron decays

Precision measurement of CKM elements

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

- A precise test of EW theory
- New physics beyond SM?

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

BESIII + B factories + LQCD

Three generations of quark?

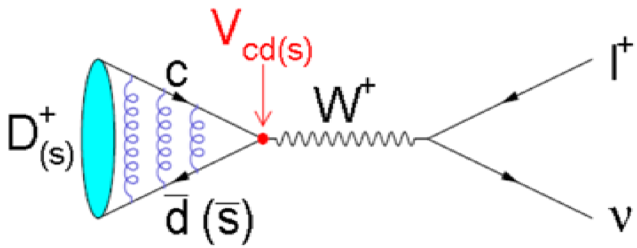
Unitary matrix?

Expected precision < 2% at BESIII

BESIII + B factories + LHCb + LQCD

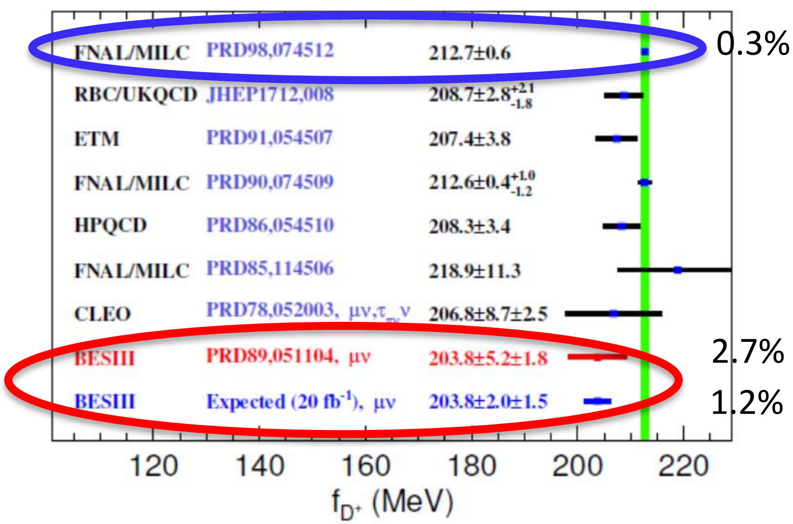
A direct measurement of $V_{cd(s)}$ is one of the most important task in charm physics

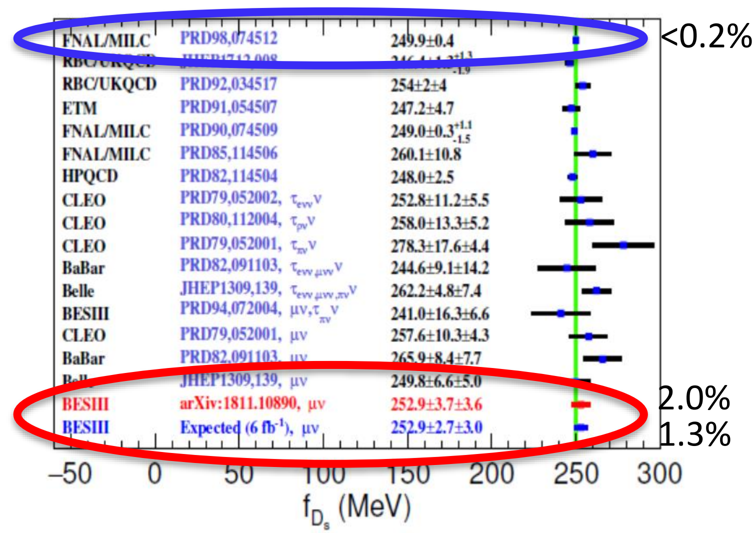
$D_{(s)}$ Leptonic decay



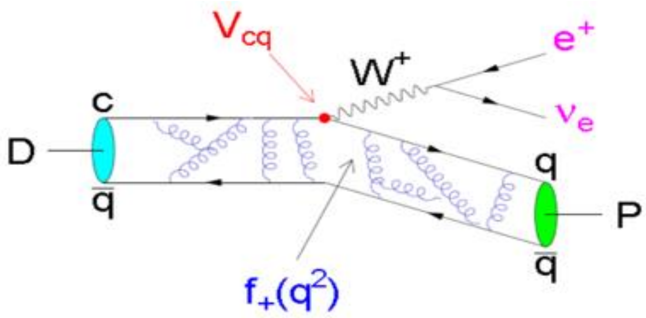
$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi} \mid V_{cd(s)} \mid^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

- Extract decay constant $f_{D(s)}$ incorporates the strong interaction effects
- To validate Lattice QCD calculation of $f_{B(s)}$ and provide constrain of CKM-unitarity
- Directly measurement : $|V_{cd(s)}|$ x $f_{D(s)}$
  - Input $f_{D(s)}$ from LQCD ⇒ $|V_{cd(s)}|$, or Input $|V_{cd(s)}|$ from a global fit ⇒ $f_{D(s)}$





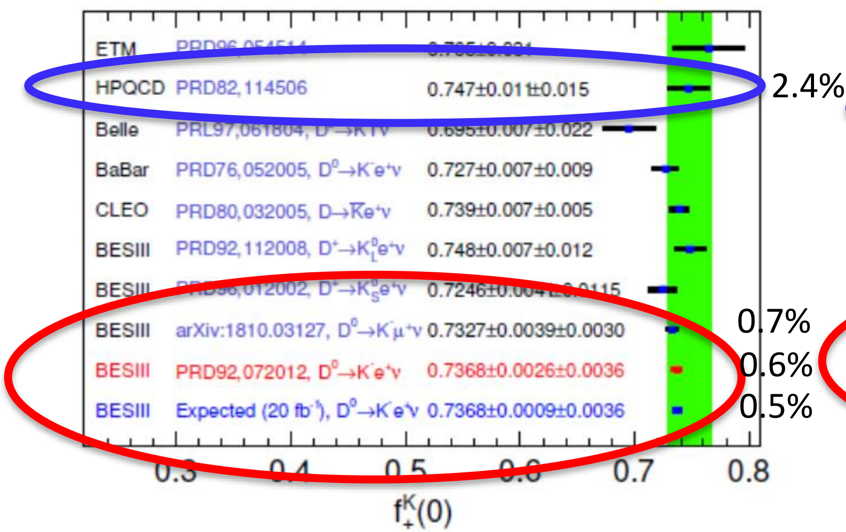
$D_{(s)}$ Semi-Leptonic decay

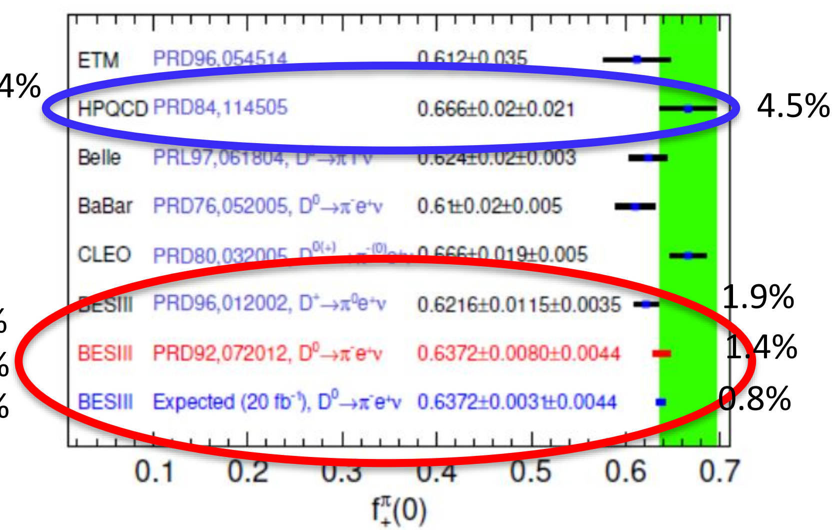


$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{cs(d)}|^2 p_{K(\pi)}^3 |f_+^{K(\pi)}(q^2)|^2$$

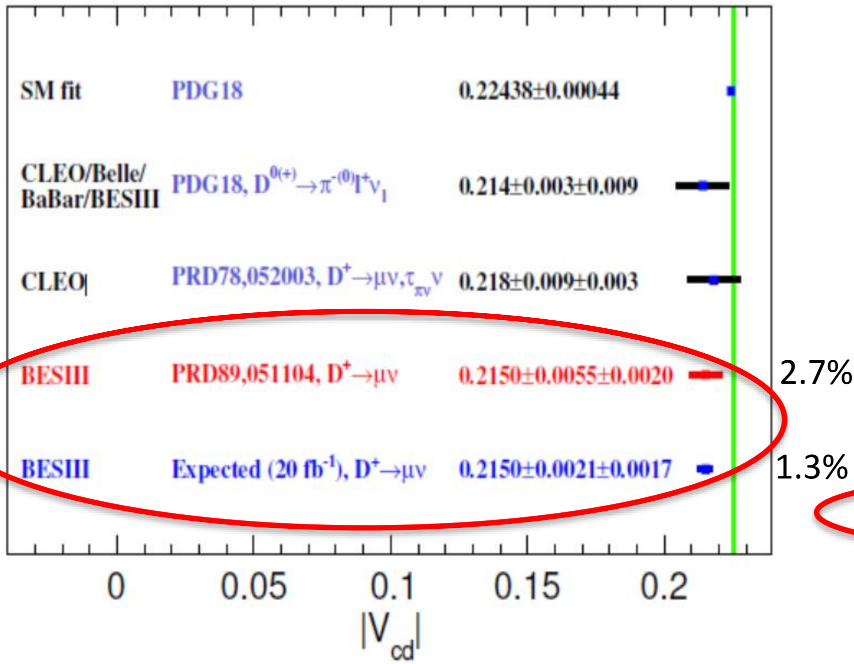
Directly measurement : $|V_{cd(s)}| \times f^{k(\pi)}(0)$

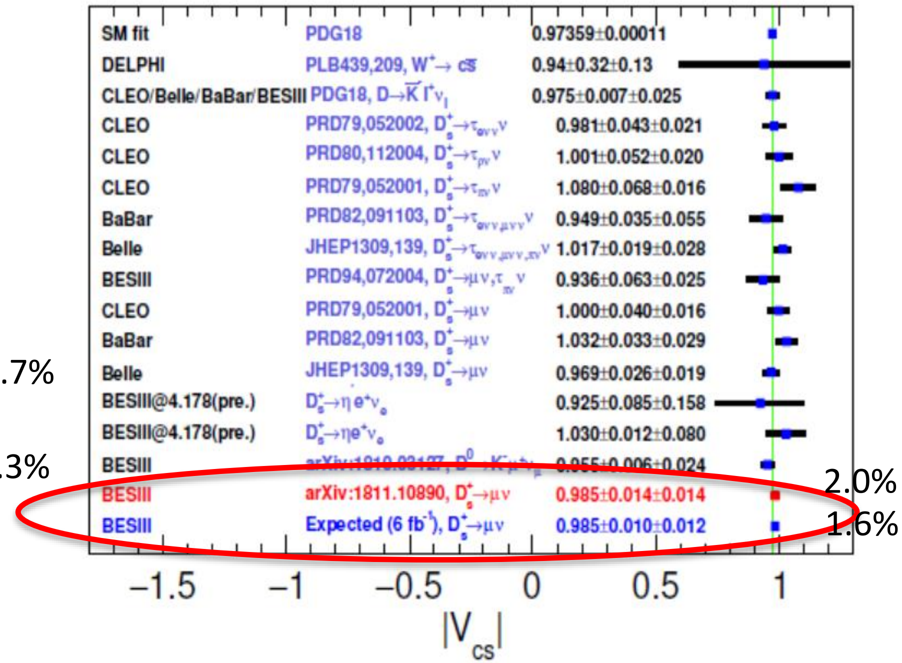
– Input $f^{k(\pi)}(0)$ from LQCD $\Rightarrow$ $|V_{cd(s)}|$, or Input $|V_{cd(s)}|$ from a global fit $\Rightarrow$ $f^{k(\pi)}(0)$





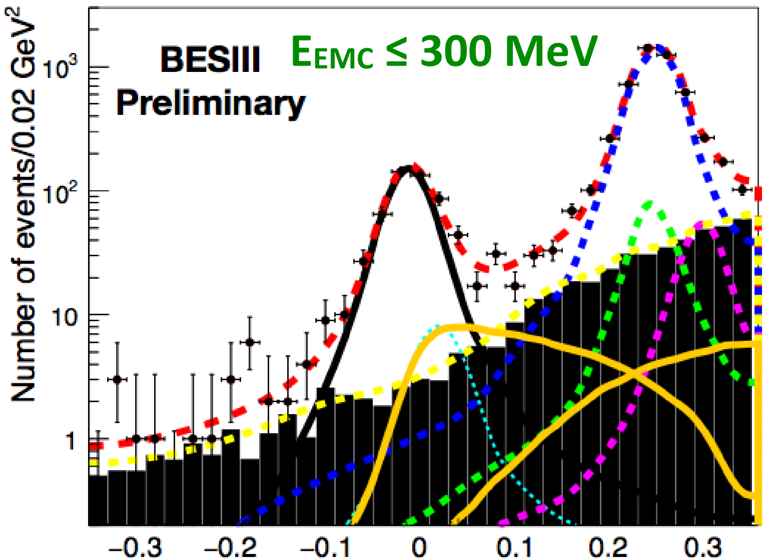
$V_{cd(s)}$ Measurement

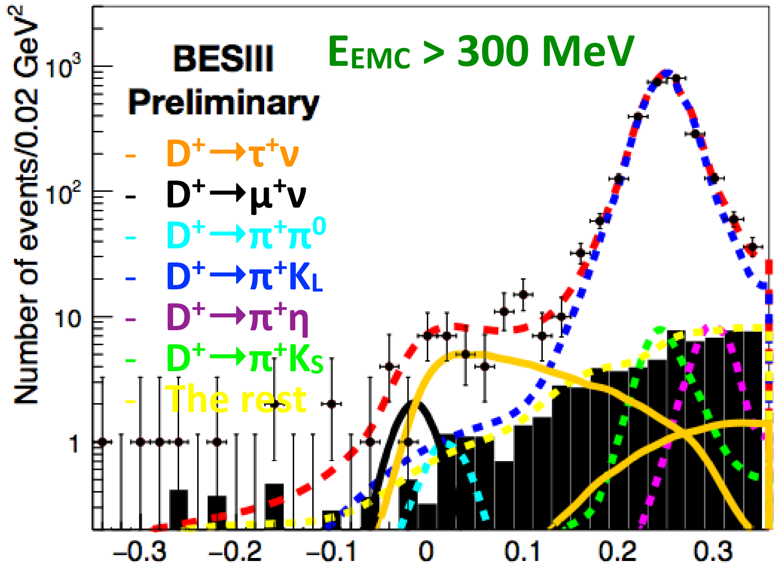




- The **best approach** to measure $|V_{cd(s)}|$ from pure **leptonic decays** from BESIII
- Semi-leptonic decay suffer large **uncertainty** of **FF** from LQCD calculation

$D^+_{(S)} \to \tau\nu_\tau$ Decay





- 137±27 $D^+ \to \tau^+(\to \pi^+ \bar{\nu}_\tau)\nu_\tau$ events.
- > 4σ statistical significance. First evidence!
- $BF(D^+ \to \tau^+\nu_\tau) = [1.20\pm0.24(stat.)]\times10^{-3}$.

Expected to have comparable sensitivity with $D^+_{(S)} \to \mu\nu_\mu$ by combining different τ lepton decay modes

Lepton Flavor universality

LFU is critical to test the SM and search for new physics beyond SM

Purely Leptonic:

$$R_{D^+_{(s)}} = \frac{\Gamma(D^+_{(s)} \to \tau^+\nu_\tau)}{\Gamma(D^+_{(s)} \to \mu^+\nu_\mu)} = \frac{m^2_{\tau^+}\left(1 - \frac{m^2_{\tau^+}}{m^2_{D^+_{(s)}}}\right)^2}{m^2_{\mu^+}\left(1 - \frac{m^2_{\mu^+}}{m^2_{D^+_{(s)}}}\right)^2}.$$

Semi-Leptonic:

$$R_{\mu/e} = \frac{\Gamma_{D\to h\mu\nu_\mu}}{\Gamma_{D\to h e\nu_e}}$$

	$R(D_s^+)$	$R(D^+)$	$R(K^-)$	$R(\bar{K}^0)$	$R(\pi^-)$	$R(\pi^0)$
SM	9.74(1)	2.66(1)	0.975(1)	0.975(1)	0.985(2)	0.985(2)
BESIII	10.19(52)	3.21(64)	0.974(14)	1.013(29)	0.922(37)	0.964(45)

BESIII preliminary
1σ difference

BESIII publication
$\sim 2\sigma$ difference

Large uncertainty from BESIII, dominant by statistically limited

$D_{(s)}$ Leptonic decay

	BESIII	STCF	Belle II
Luminosity	2.92 fb^{-1} at 3.773 GeV	1 ab^{-1} at 3.773 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D^+ \to \mu^+\nu_\mu)$	$5.1\%_{\rm stat.}$ $1.6\%_{\rm syst.}$ [6]	$0.28\%_{\rm stat.}$	–
f_{D^+} (MeV)	$2.6\%_{\rm stat.}$ $0.9\%_{\rm syst.}$ [6]	$0.15\%_{\rm stat.}$	[illegible]
$\lvert V_{cd}\rvert$	$2.6\%_{\rm stat.}$ $1.0\%^{*}_{\rm syst.}$ [6]	$0.15\%_{\rm stat.}$	[illegible]
$\mathcal{B}(D^+ \to \tau^+\nu_\tau)$	$20\%_{\rm stat.}$ $10\%^{\dagger}_{\rm syst.}$ [7]	$0.41\%_{\rm stat.}$	[illegible]
$\frac{\mathcal{B}(D^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D^+ \to \mu^+\nu_\mu)}$	$21\%_{\rm stat.}$ $10\%^{\dagger}_{\rm syst.}$ [7]	[illegible]	[illegible]
Luminosity	3.2 fb^{-1} at 4.178 [illegible]	[illegible]	[illegible]
$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	$2.8\%_{\rm stat.}$ [illegible]	[illegible]	[illegible] $1.8\%_{\rm syst.}$
$f_{D_s^+}$ (MeV)	[illegible]	[illegible]	[illegible]
$\lvert V_{cs}\rvert$	[illegible]	[illegible]	–
[illegible]	[illegible]	$0.21\%_{\rm stat.}$	–
[illegible]	[illegible]	$0.24\%_{\rm stat.}$	$0.6\%_{\rm stat.}$ $2.7\%_{\rm syst.}$
[illegible]	[illegible] $1.5\%^{\dagger}_{\rm syst.}$	$0.11\%_{\rm stat.}$	[illegible]
[illegible]	$1.1\%_{\rm stat.}$ $1.5\%^{\dagger}_{\rm syst.}$	$0.11\%_{\rm stat.}$	–
[illegible] (MeV)	$0.9\%_{\rm stat.}$ $1.0\%^{\dagger}_{\rm syst.}$	$0.09\%_{\rm stat.}$	$0.3\%_{\rm stat.}$ $1.0\%_{\rm syst.}$
$\lvert V_{cs}^{\mu\&\tau}\rvert$	$0.9\%_{\rm stat.}$ $1.0\%^{\dagger}_{\rm syst.}$	$0.09\%_{\rm stat.}$	–
$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)}$	$3.6\%_{\rm stat.}$ $3.0\%^{\dagger}_{\rm syst.}$	$0.38\%_{\rm stat.}$	$0.9\%_{\rm stat.}$ $3.2\%_{\rm syst.}$

Theory : 0.2%(0.1% expected)

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Stat. uncertainty is closed to theory precision

Sys. is challenging

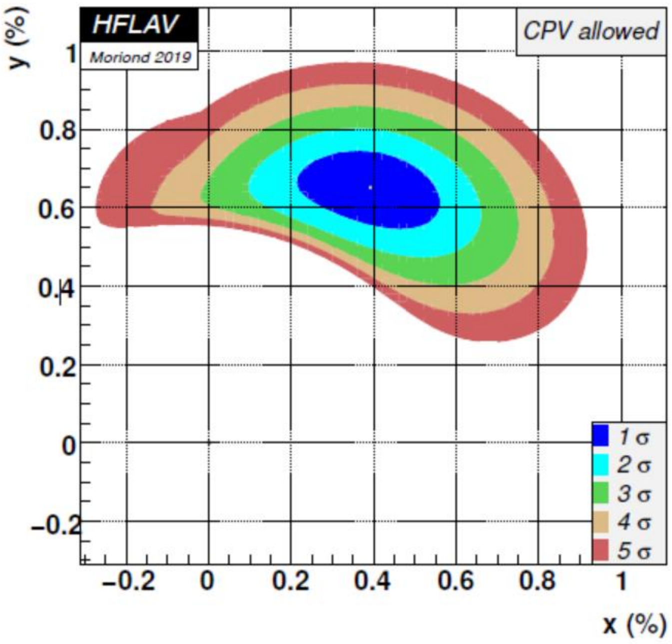
* Assume $f_{D(s)}$ with 0.2% uncertainty; + preliminary results; assume Belle II improved systematics by a factor 2

D^0–$\bar{D}^0$ Mixing and CPV

D^0–$\bar{D}^0$ pair produced coherently :

$$\psi(3770) \to (D^0\bar{D}^0)_{CP=-} \text{ or } \psi(4140) \to D^0\bar{D}^{*0} \to \pi^0(D^0\bar{D}^0)_{CP=-} \text{ or } \gamma(D^0\bar{D}^0)_{CP=+}$$

Therefore obtain useful constraints on D^0–$\bar{D}^0$ mixing and CPV parameters



- Global fit of the measurement :
  - $D^0 \to K^{(*)+}\ell^-\bar{\nu}_\ell,\ K^+K^-,\ \pi^+\pi^-,\ K^+\pi^-,\ K^+\pi^-\pi^0,$ $K^+\pi^-\pi^+\pi^-,\ K^0_S\pi^+\pi^-,\ K^0_S K^+K^-$ *etc*
  - their CP conjugate proceses
  - the coherent decays : $\psi(3770) \to D^0\bar{D}^0 \to f_1 f_2$
- Obtained 95% confidence-level :

$$0.4\times10^{-3} \lesssim x \lesssim 6.2\times10^{-3}$$

$$5.0\times10^{-3} \lesssim y \lesssim 8.0\times10^{-3}$$

- Consistent with the theoretical estimation

$D^0 – \bar{D}^0$ Mixing and CPV

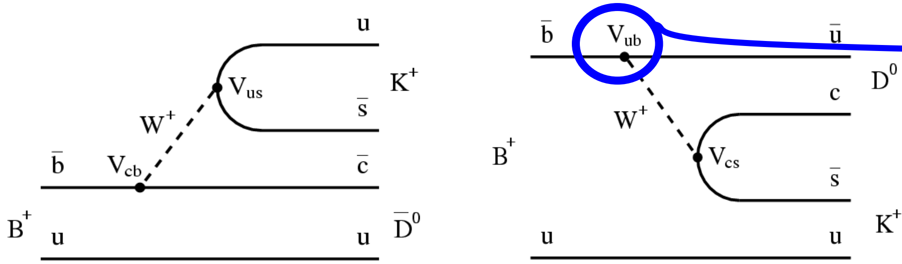
D^0-$\overline{D}^0$ mixing and CPV

- Mixing rate $R_M = \frac{x^2+y^2}{2} \sim 10^{-5}$ with 1 ab^{-1} data at 3.773 GeV via same charged final states $(K^{\pm}\pi^{\mp})(K^{\pm}\pi^{\mp})$ or $(K^{\pm}l^{\mp}v)(K^{\pm}l^{\mp}v)$
- Mixing parameter $(x, y) \sim 0.05\%$ with 1 ab^{-1} data at 4.040 by $e^+e^- \to \gamma D^0\overline{D}^0$
- $\Delta A_{CP} \sim 10^{-3}$ for KK and ππ channels

The accurate values might not help much to clarify to the long distance effects in on D^0–$\overline{D}^0$ mixing, but will help a lot to probe the presumably small effects of CPV in neutral charmed decays

Determination of γ/ϕ_3 angle

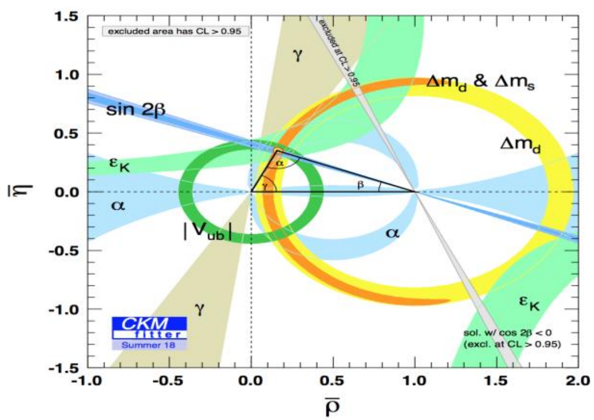
- The cleanest way to extract γ is from $B \rightarrow DK$ decays:

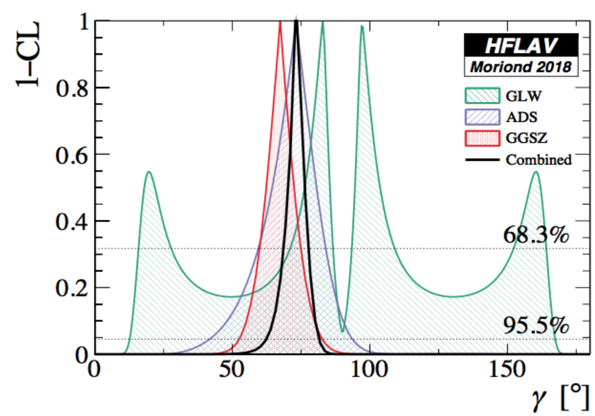


$$\frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \overline{D^0} K^+)} \equiv r_B e^{i(\delta_3 + \phi_3)}$$

  – Interference between tree-level decays; theoretically clean
  – current uncertainty $\sigma(\gamma) \sim 5^0$
  – however, theoretical relative error $\sim 10^{-7}$ (very small!)

- Information of *D decay strong phase* is needed
  – Best way is to employ quantum coherence of DD production at threshold





Determination of γ/ϕ_3 angle

Runs	Collected / Expected integrated luminosity	Year attained	γ/ϕ_3 sensitivity
LHCb Run-1 [7, 8 TeV]	3 fb^{-1}	2012	8°
LHCb Run-2 [13 TeV]	5 fb^{-1}	2018	4°
Belle II Run	50 ab^{-1}	2025	1.5°
LHCb upgrade I [14 TeV]	50 fb^{-1}	2030	$< 1^\circ$
LHCb upgrade II [14 TeV]	300 fb^{-1}	(>)2035	$< 0.4^\circ$

BESIII 20/fb: $\sigma(\gamma) \sim 0.4^o$

→ **STCF is needed!**

Three methods for exploiting interference (choice of D^0 decay modes):

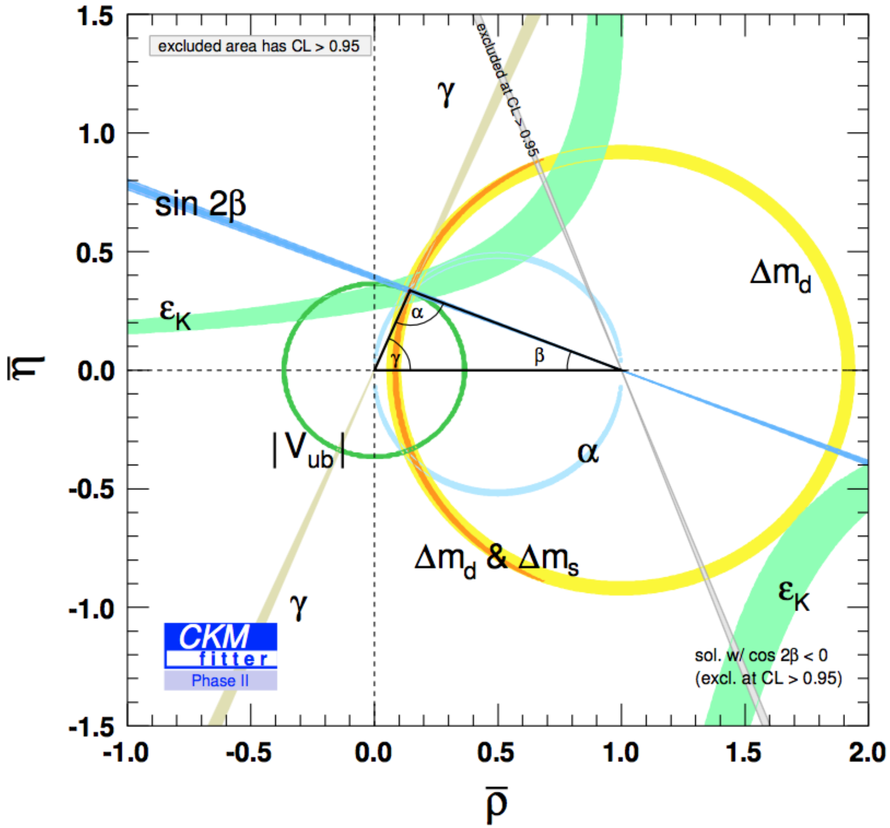
- Gronau, London, Wyler (GLW): Use CP eigenstates of $D^{(*)0}$ decay,

  e.g. $D^0 \to K_s\pi^0$, $D^0 \to \pi^+\pi^-$

- Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+\pi^-$
  - With 1 ab^{-1} @ STCF : $\sigma(\cos\delta_{K\pi}) \sim 0.007$; $\sigma(\delta_{K\pi}) \sim 2^o$ ➔ $\sigma(\gamma) < 0.5^o$
- Giri, Grossman, Soffer, Zupan (GGSZ): Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_s\pi^+\pi^-$; high statistics; need precise Dalitz model
  - STCF would provide important constraints to reduces the contribution of *D* Dalitz model to a level of $\sim 0.1^o$

Scenario beyond 2035

STCF will provide complementary information on the strong phase and allow detailed comparison of the γ results from different decay modes



Decay mode	Quantity of interest
$D \to K^0_S \pi^+\pi^-$	c_i and s_i
$D \to K^0_S K^+K^-$	c_i and s_i
$D \to K^\pm\pi^\mp\pi^+\pi^-$	R, δ
$D \to K^+K^-\pi^+\pi^-$	c_i and s_i
$D \to \pi^+\pi^-\pi^+\pi^-$	F_+ or c_i and s_i
$D \to K^\pm\pi^\mp\pi^0$	R, δ
$D \to K^0_S K^\pm\pi^\mp$	R, δ
$D \to \pi^+\pi^-\pi^0$	F_+
$D \to K^0_S \pi^+\pi^-\pi^0$	F_+, c_i and s_i
$D \to K^+K^-\pi^0$	F_+
$D \to K^\pm\pi^\mp$	δ

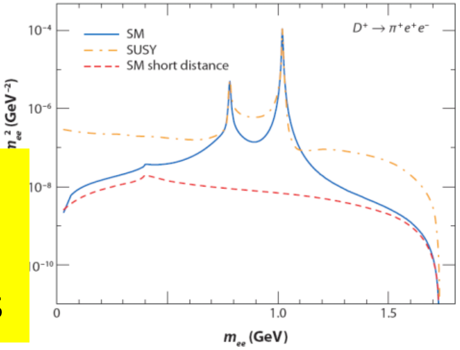
Charmed Rare Decays

high luminosity, clean environment and excellent detector performance
Great potential to search for rare and forbidden charmed decays
May serve as a useful tool for probing new physics beyond the SM

- FCNC, suppressed by GIM mechanism, only occurred via the loop diagrams :
  - Short distance : interested, computable by pQCD, directly test SM
  - Long distance effect can enhance the rate to $10^{-6} \sim 10^{-7}$, dominantly.
  - Some typical FCNC channel :

$Br(D^0 \to \gamma\gamma) < 8.5\times10^{-7}$ (SM $\sim 1\times10^{-8}$)
$Br(D^0 \to \mu^+\mu^-) < 6.2\times10^{-9}$ (SM $\sim 3\times10^{-13}$)
$Br(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (9.6\pm1.2)\times10^{-7}$
$Br(D^0 \to K^+K^-\mu^+\mu^-) = (1.54\pm0.32)\times10^{-7}$
$Br(D^0 \to \pi^+K^-\mu^+\mu^-) = (4.2\pm0.4)\times10^{-6}$

Non-trivial contribution from long distance effects

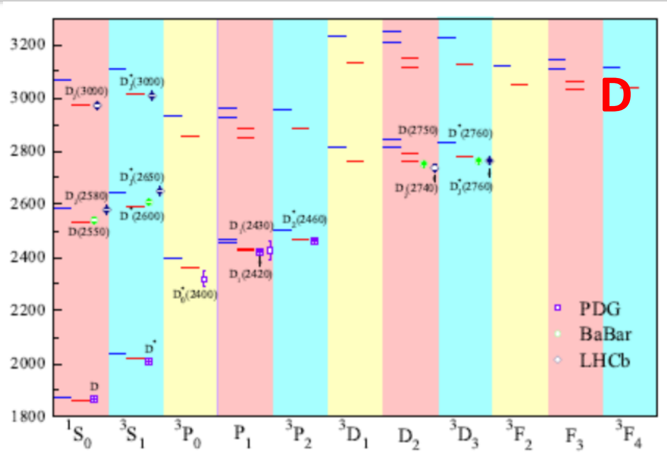


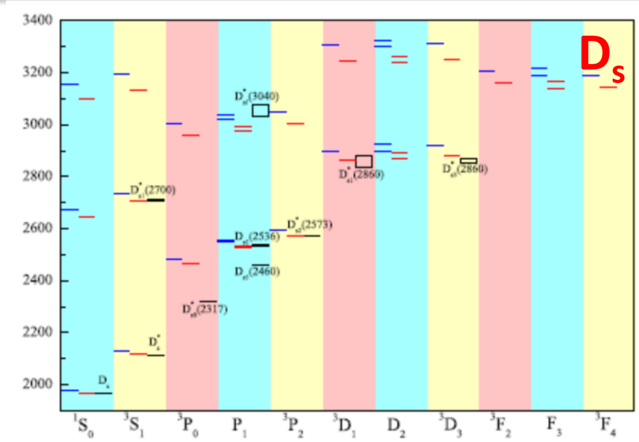
  - $1ab^{-1}$ @ STCF can achieve the sensitivity to $10^{-8} \sim 10^{-9}$, tested SM strictly
  - Allow with sizeable decay rate in NP, discriminate NP from SM by measuring :
    - $D \to V l^+ l^-$: AFB asymmetry
    - $D \to P l^+ l^-$: line shape of dilepton mass, to reveal the interference effect between long-distance and FCNC weak amplitude (NP amplitude);
  - Best constrain on rare decays with invisible particles ($D \to \pi^0 / \gamma\nu\bar{\nu}$)

Charmed Rare Decays

- LFV, LNV and BNV are forbidden in the SM, NP allow at sizable levels.
  - No evidence has been found so far
  - Typical experimental bounds on LFV are at level 10^{-6} to 10^{-5}
  - STCF: 10^{-8}~10^{-9} ➔ stringent constrains to NP models

Charmed Meson Spectroscopy





Status :

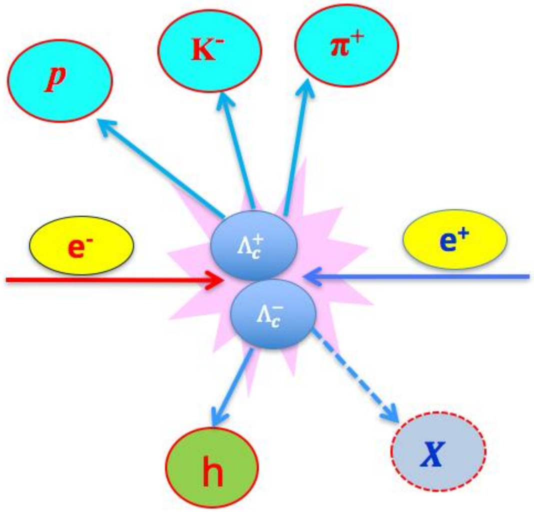
- All 1S and 1P states have been observed, but almost missing for other quantum states
- Many excited open-charm states observed, but controversial in their nature
  - Narrow $D_{sJ}^{*}(2632)$ Observed by SELEX, but not in CLEO, BaBar and FOCUS
  - The unexpected low masses of $D_{s0}^{*}(2317)$ and $D_{s1}^{*}(2460) \Rightarrow$ $D^{(*)}K$ molecule

STCF:

- Excited states D** can be produced via $e^+e^- \to D^{**}\overline{D}^{(*)}(\pi)$ in CME 4.1~6 GeV
- Higher mass D** hadronic or radiative decays to lower open-charm states
- Systematic study on D** spectra provide important data to explore the non pQCD dynamics

Charmed Baryon (B_c^+)

Charmed baryons are produced via $e^+e^- \to B_{1c}B_{2c}$ with $B_{ic} = n_1n_2c$



	Structure	J^P	Mass, MeV	Width,MeV	Decay
Λ_c^+	udc	$(1/2)^+$	2286.46 ± 0.14	(200 ± 6) fs	weak
Ξ_c^+	usc	$(1/2)^+$	$2467.8^{+0.4}_{-0.6}$	(442 ± 26) fs	weak
Ξ_c^0	dsc	$(1/2)^+$	$2470.88^{+0.34}_{-0.8}$	112^{+13}_{-10} fs	weak
Σ_c^{++}	uuc	$(1/2)^+$	2454.02 ± 0.18	2.23 ± 0.30	$\Lambda_c^+\pi^+$
Σ_c^+	udc	$(1/2)^+$	2452.9 ± 0.4	< 4.6	$\Lambda_c^+\pi^0$
Σ_c^0	ddc	$(1/2)^+$	2453.76 ± 0.18	2.2 ± 0.4	$\Lambda_c^+\pi^-$
$\Xi_c'^+$	usc	$(1/2)^+$	2575.6 ± 3.1	–	$\Xi_c^+\gamma$
$\Xi_c'^0$	dsc	$(1/2)^+$	2577.9 ± 2.9	–	$\Xi_c^0\gamma$
Ω_c^0	ssc	$(1/2)^+$	2695.2 ± 1.7	(69 ± 12) fs	weak

Systematic study the charmed baryon spectroscopy and precisely measure the transition widths provide an excellent ground for studying the dynamics of light quarks in the environment of a heavy quark

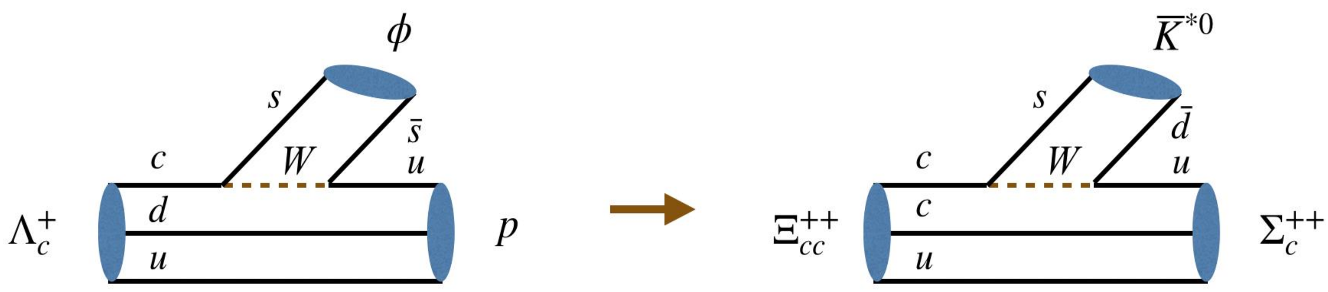
A theoretical Framework for charmed Hadrons

Topological diagrams + Symmetries + Experimental inputs

⇒ to understand the decaying dynamics, predicting double-charm baryon decays, CPV, etc. (predictive power)

- Λ_c^+ decays used for global analysis

  ⇒ $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$ are large enough for observation.



$Br(\Lambda_c^+ \to p\phi)/|V_{us}|^2$ = 2 % → $Br\left(\Xi_{cc}^{++} \to \Sigma_c^{++} \overline{K}^{*0}\right)$ = O(%)

↓

$\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+ K^- \pi^+$

Λ_c^+ decays ⇒ Stronger predictive power

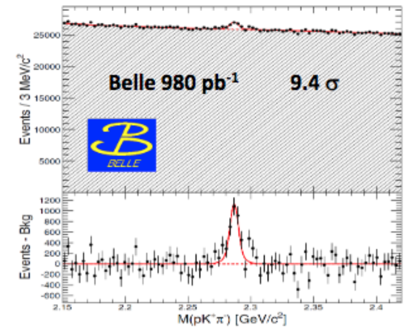
Lots of activities on Λ_c^+ decays

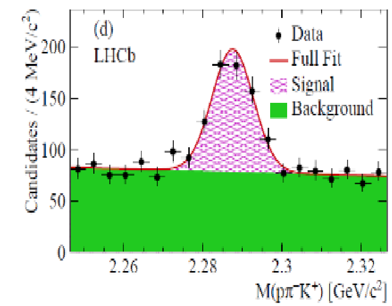
$\Lambda_c^\pm$ EPJC77, 895 PRL113, 042002

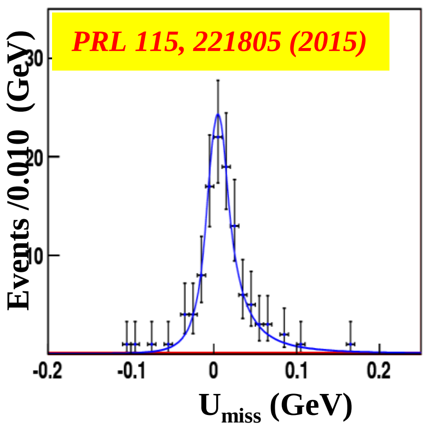
Mode	HFLAV 2016 (%)	BESIII (%)	PDG 2014 (%)	BELLE (%)
pK_S^0	[illegible]	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	6.46 ± 0.24	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	2.03 ± 0.12	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	1.69 ± 0.11	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	5.05 ± 0.29	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	1.28 ± 0.06	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	7.09 ± 0.36	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	3.73 ± 0.21	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	1.31 ± 0.07	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	1.25 ± 0.09	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	4.64 ± 0.24	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	1.77 ± 0.21	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	
$\Lambda e^+\nu_e$	3.18 ± 0.32	$3.63 \pm 0.38 \pm 0.20$	2.1 ± 0.6	

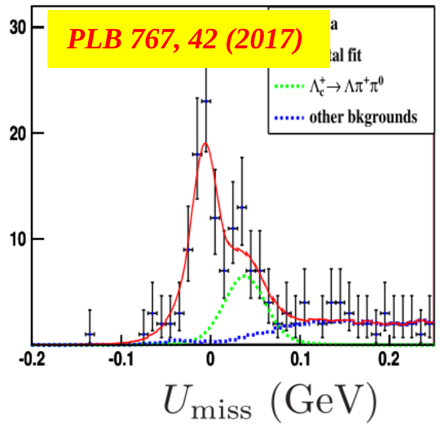
Observation of DCS decay $\Lambda_c^+ \to p\pi^- K^+$

PRL 117, 011801(2016) JHEP03, 043(2018)

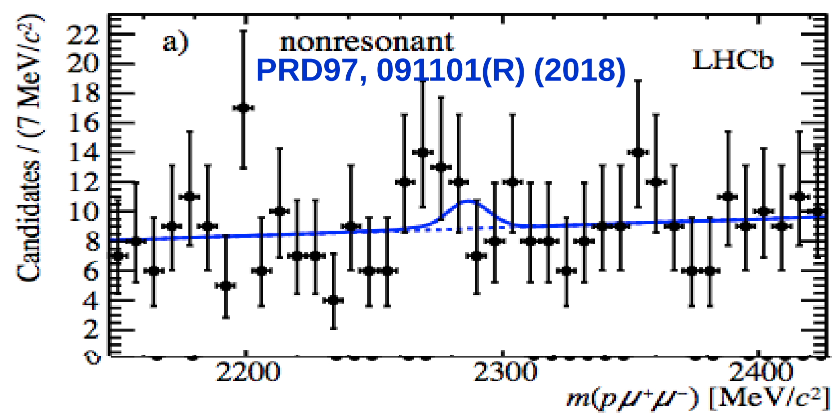








$\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 7.7\ (9.6) \times 10^{-8}$



$\Gamma[\Lambda_c^+ \to \Lambda\mu^+\nu_\mu]/\Gamma[\Lambda_c^+ \to \Lambda e^+\nu_e] = 0.96 \pm 0.16 \pm 0.04$

STCF: *reduced the uncertainty by two orders of magnitu*

➔ provides stringent LFU test

$$\Delta A_{CP}^{\rm wgt} = A_{CP}(pK^-K^+) - A_{CP}^{\rm wgt}(p\pi^-\pi^+) = (0.30 \pm 0.91 \pm 0.61)\,\%,$$

LHCb, JHEP 03, 182 (2018)

Single Charmed baryon in PDG

Absolute branching fractions measurement at threshold production will be important

Ξ_c^+: relative to $\Xi^- 2\pi^+$

	Mode	Fraction (Γ_i / Γ)
No absolute branching fractions have been measured. The following are branching to $\Xi^- \pi^+$ .Cabibbo-favored ($S = -2$) decays – relative to $\Xi^- \pi^+$		
Γ_1	$p 2 K_S^0$	0.087 ± 0.021
Γ_2	$\Lambda \overline{K}^0 \pi^+$	
Γ_3	$\Sigma(1385)^+ \overline{K}^0$	1.0 ± 0.5
Γ_4	$\Lambda K^- 2\pi^+$	0.323 ± 0.033
Γ_5	$\Lambda \overline{K}^*(892)^0 \pi^+$	< 0.16
Γ_6	$\Sigma(1385)^+ K^- \pi^+$	< 0.23
Γ_7	$\Sigma^+ K^- \pi^+$	0.94 ± 0.10
Γ_8	$\Sigma^+ \overline{K}^*(892)^0$	0.81 ± 0.15
Γ_9	$\Sigma^0 K^- 2\pi^+$	0.27 ± 0.12
Γ_{10}	$\Xi^0 \pi^+$	0.55 ± 0.16
Γ_{11}	$\Xi^- 2\pi^+$	**DEFINEDAS1**
Γ_{12}	$\Xi(1530)^0 \pi^+$	< 0.10
Γ_{13}	$\Xi^0 \pi^+ \pi^0$	2.3 ± 0.7
Γ_{14}	$\Xi^0 \pi^- 2\pi^+$	1.7 ± 0.5
Γ_{15}	$\Xi^0 e^+ \nu_e$	$2.3^{+0.7}_{-0.8}$
Γ_{16}	$\Omega^- K^+ \pi^+$	0.07 ± 0.04
Cabibbo-suppressed decays – relative to $\Xi^- \pi^+$		
Γ_{17}	$p K^- \pi^+$	0.21 ± 0.04
Γ_{18}	$p \overline{K}^*(892)^0$	0.116 ± 0.030
Γ_{19}	$\Sigma^+ \pi^+ \pi^-$	0.48 ± 0.20
Γ_{20}	$\Sigma^- 2\pi^+$	0.18 ± 0.09
Γ_{21}	$\Sigma^+ K^+ K^-$	0.15 ± 0.06

Ξ_c^0: relative to $\Xi^- \pi^+$

	Mode	Fraction (Γ_i / Γ)
No absolute branching fractions have been measured. The following are bran… $= -2$) decays – relative to $\Xi^- \pi^+$		
Γ_1	$p K^- K^- \pi^+$	0.34 ± 0.04
Γ_2	$p K^- \overline{K}^*(892)^0$	0.21 ± 0.05
Γ_3	$p K^- K^- \pi^+$ (no $\overline{K}^{*0}$)	0.21 ± 0.04
Γ_4	ΛK_S^0	0.210 ± 0.028
Γ_5	$\Lambda K^- \pi^+$	1.07 ± 0.14
Γ_6	$\Lambda \overline{K}^0 \pi^+ \pi^-$	seen
Γ_7	$\Lambda K^- \pi^+ \pi^+ \pi^-$	seen
Γ_8	$\Xi^- \pi^+$	**DEFINEDAS1**
Γ_9	$\Xi^- \pi^+ \pi^+ \pi^-$	3.3 ± 1.4
Γ_{10}	$\Omega^- K^+$	0.297 ± 0.024
Γ_{11}	$\Xi^- e^+ \nu_e$	3.1 ± 1.1
Γ_{12}	$\Xi^- \ell^+$ anything	1.0 ± 0.5
Cabibbo-suppressed decays – relative to $\Xi^- \pi^+$		
Γ_{13}	$\Xi^- K^+$	0.028 ± 0.006
Γ_{14}	$\Lambda K^+ K^-$ (no ϕ)	0.029 ± 0.007
Γ_{15}	$\Lambda \phi$	0.034 ± 0.007

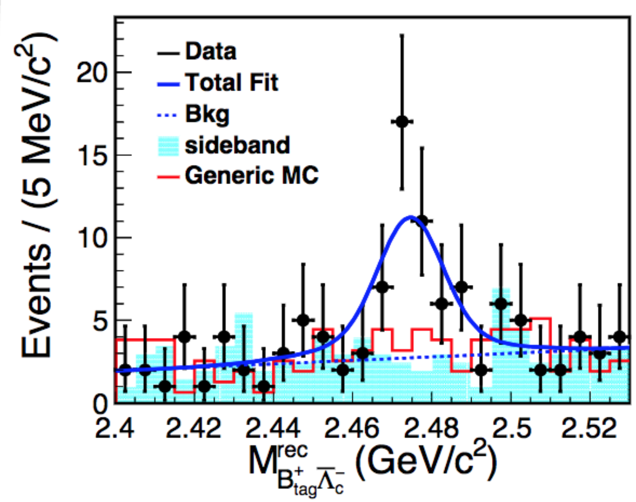
Ω_c^0: relative to $\Omega^- \pi^+$

Decay Modes

	Mode	Fraction (Γ_i / Γ)
No absolute branching fractions have been measured. The following are branching ra… .Cabibbo-favored ($S = -3$) decays – relative to $\Omega^- \pi^+$		
Γ_6	$\Xi^0 \overline{K}^0$	1.64 ± 0.29
Γ_7	$\Xi^0 K^- \pi^+$	1.20 ± 0.18
Γ_8	$\Xi^0 \overline{K}^{*0}$, $\overline{K}^{*0} \to K^- \pi^+$	0.68 ± 0.16
Γ_9	$\Xi^- \overline{K}^0 \pi^+$	2.12 ± 0.28
Γ_{10}	$\Xi^- K^- 2\pi^+$	0.63 ± 0.09
Γ_{11}	$\Xi(1530)^0 K^- \pi^+$, $\Xi^{*0} \to \Xi^- \pi^+$	0.21 ± 0.06
Γ_{12}	$\Xi^- \overline{K}^{*0} \pi^+$	0.34 ± 0.11
Γ_{13}	$\Sigma^+ K^- K^- \pi^+$	< 0.32
Γ_{14}	$\Lambda \overline{K}^0 \overline{K}^0$	1.72 ± 0.35

- First measurement of absolute BF of Ξ_c^0 at Belle **[arxiv:1811.09738]**

$$\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = (1.80 \pm 0.50 \pm 0.14)\%,$$



Precision study of the B_c decay

Era of precision study of the charmed baryon (Λ_c, Ξ_c and Ω_c) decays

to help developing more reliable QCD-derived models in charm sector

- Hadronic decays:
  to explore as-yet-unmeasured channels and understand full picture of intermediate structures in B_c decays, esp., those with neutron/Σ/Ξ particles
- Semi-leptonic decays:
  to test LQCD calculations and LFU
- CPV in charmed baryon: BP and BV two-body decay asymmetry, charge-dependent rate of SCS
- Charmed Baryons Spectroscopy : (63 P wave states from QM, 16 observed!)
- Rare decays: LFV, BNV, FCNC

STCF will provide very precise measurements of their overall decays, up to the unprecedented level of 10^{-6} ~10^{-7}

Summary

- **τ-c facilities have rich of physics program, play unique role in charmed physics, and is one of the crucial precision frontier.**

- **The R&D program of a Super τ-c Factory (STCF) is underway in China:**
  - double ring with circumference around 600~1000 m
  - e^+e^- collision with E_{cm} = 2 – 7 GeV, L = 1×10^{35} $cm^{-2}s^{-1}$

- **Welcome to join the efforts of STCF R&D program**

Summary

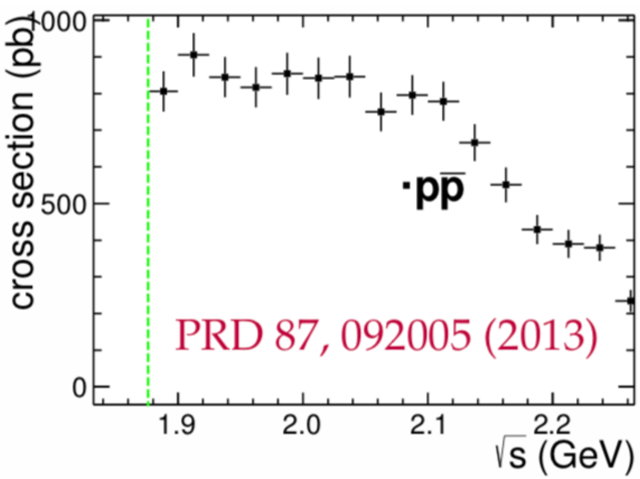
- **Super τ-c Factory (STCF):**
  - double ring with circumference around 600~1000 m
  - e^+e^- collision with $E_{cm} = 2 - 7$ GeV, $L = 1 \times 10^{35}\ cm^{-2}s^{-1}$
- **STCF is one of the crucial precision frontier**
  - rich of physics program
  - unique for physics with c quark and τ leptons,
  - important playground for study of QCD, exotic hadrons and search for new physics.
- **We initialized 10 M CNY (2018), 10-20M CNY(2019) for start R&D.**
- **Project organization is setup, a working group is toward for CDR/TDR**
- **An International collaboration is essential for promoting the project.**

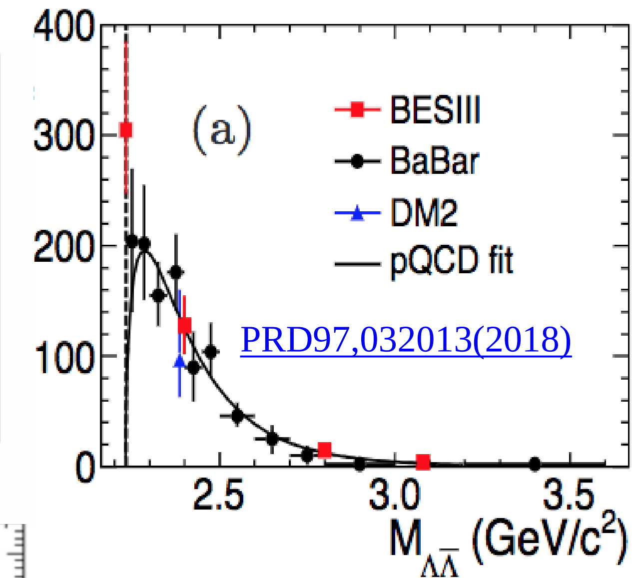
Welcome to join the effort

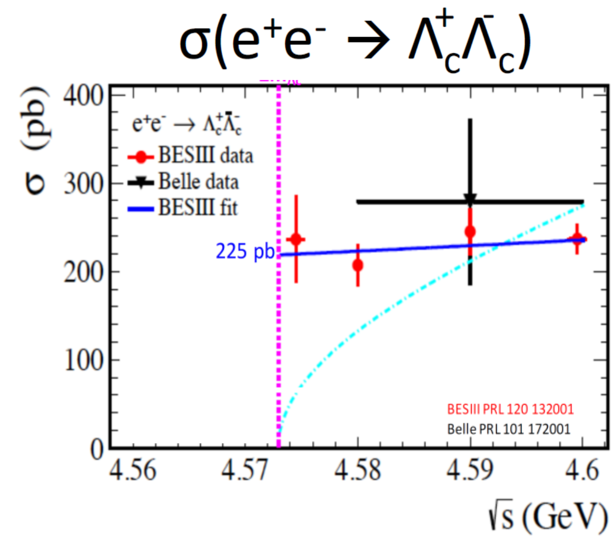
谢谢

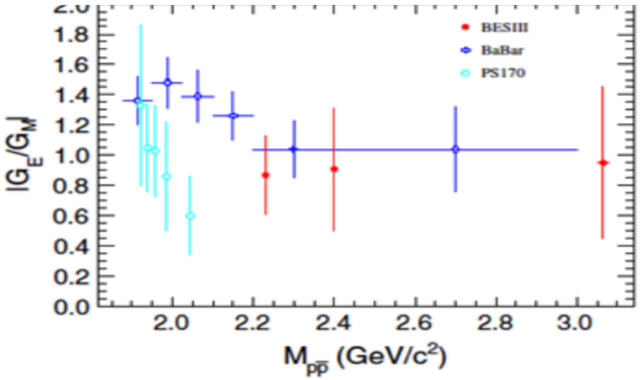
Thanks.

The threshold production of baryon pair









Form factor reflects spatial distributions of electric charge and current inside the nucleon

STCF: 100× more statistics will much enhance the understandings of these 'unexpected' threshold enhancement! (Study $e^+e^- \to$ $p\bar{p}, n\bar{n}, \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi\bar{\Xi}, \Omega\bar{\Omega}, \Lambda_c\overline{\Lambda_c}, \Sigma_c\overline{\Sigma_c}, \Xi_c\overline{\Xi_c}, \Omega_c\overline{\Omega_c}$ … @threshold)