Experimental Program for a Super Tau-Charm Factory

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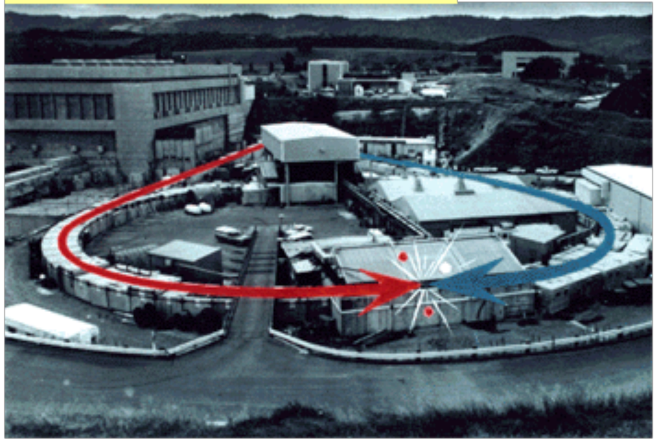
(On behalf of the STCF working group)

Dedicated Tau-Charm Factories

ADONE, FRASCATI
'69-'93

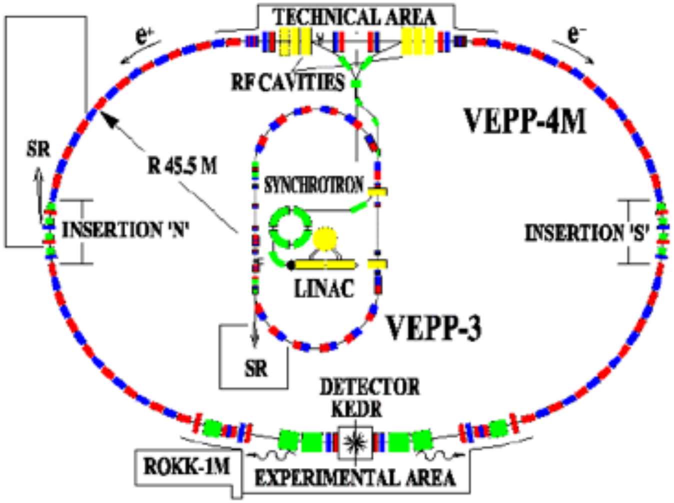
SPEAR, SLAC, '72-'90
6×10^{29} $cm^{-2}.s^{-1}$



BEPC, IHEP, '90-'04
5×10^{30} $cm^{-2}.s^{-1}$

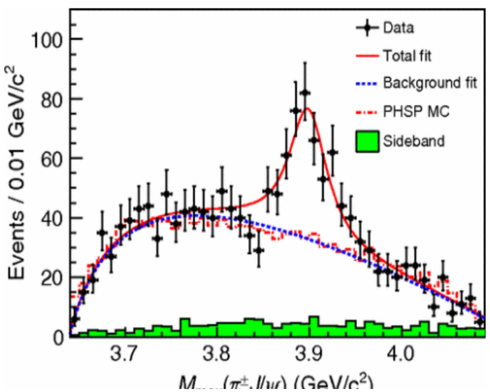
CESRc, Cornell, '04-'08
7×10^{31} $cm^{-2}.s^{-1}$

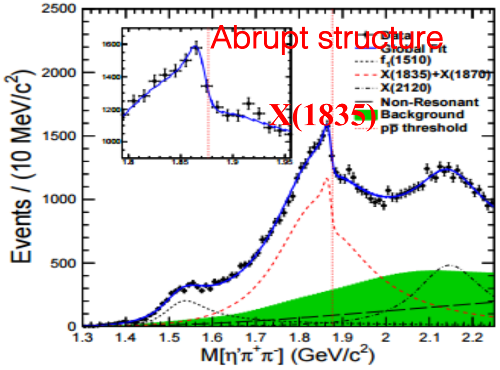
VEPP-4M, Novosibisk, '02-'12
1×10^{30} $cm^{-2}.s^{-1}$



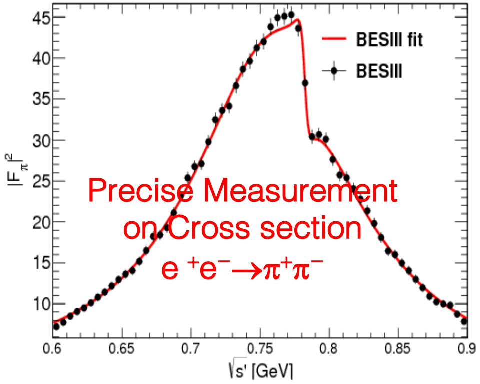
BEPCII, IHEP, **'08-'2X(?)**
1×10^{33} $cm^{-2}.s^{-1}$

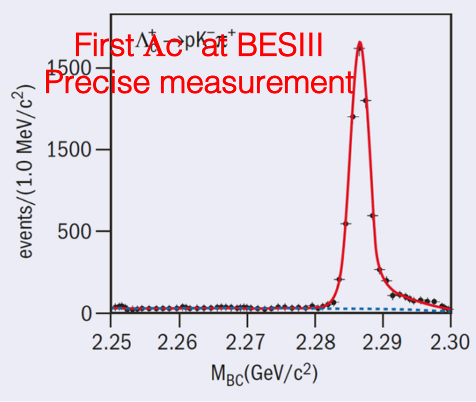
Fruitful BEPCII/BESIII Results



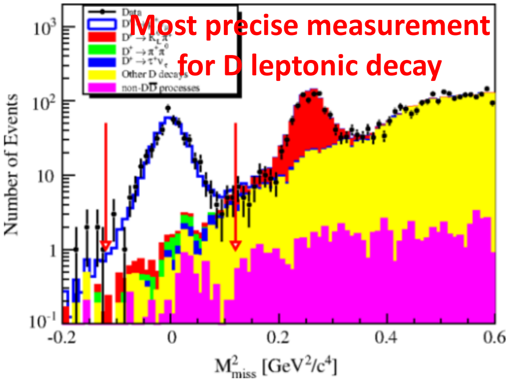

Abrupt structure

X(1835)

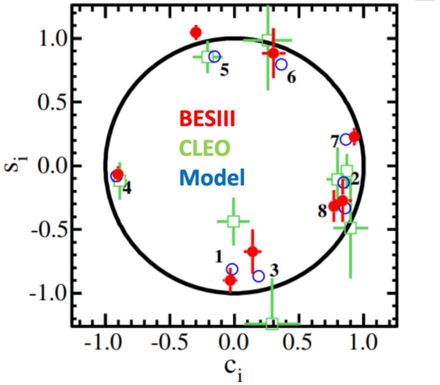

Precise Measurement on Cross section $e^+e^-\to\pi^+\pi^-$

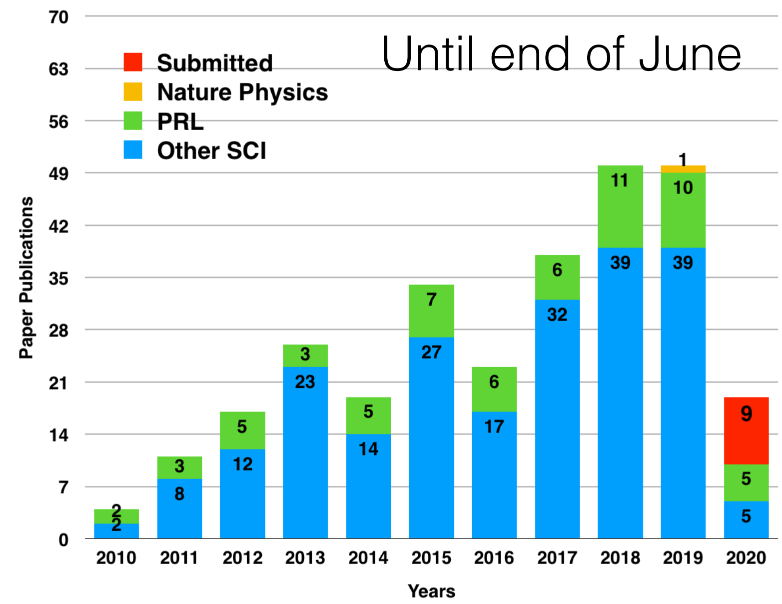

First Λ_c at BESIII

Precise measurement


Most precise measurement for D leptonic decay

Optimal binning scheme used for γ




Until end of June

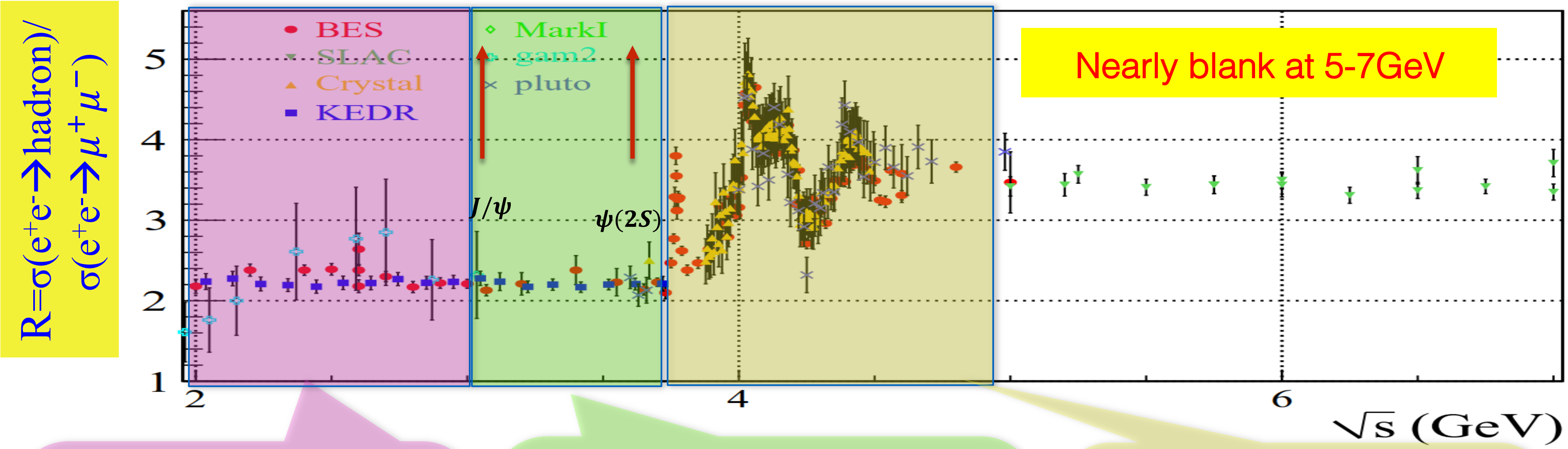
>300 publications

τ-*c* facility in China

- 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 major upgrade.
- Physics study limited by the Statistics (luminosity), collision energy up to 4.9 GeV ……
- Many of the physics can be covered by ISR at Belle II
- BEPCII/BESIII will end her mission in 5 - 8(?) years

A Super Tau-Charm Factory (STCF) is the nature extension and a viable option for a post-BEPCII HEP project in China

Broad Physics at τ-charm 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 $D_{(s)}$ mesons
- f_D and f_{Ds}
- D_0-D_0 mixing and CPV
- Charmed baryons

☐ Unique features： Rich of resonances, Threshold characteristics, Quantum Correlation, Low-background, Kinematic constrains

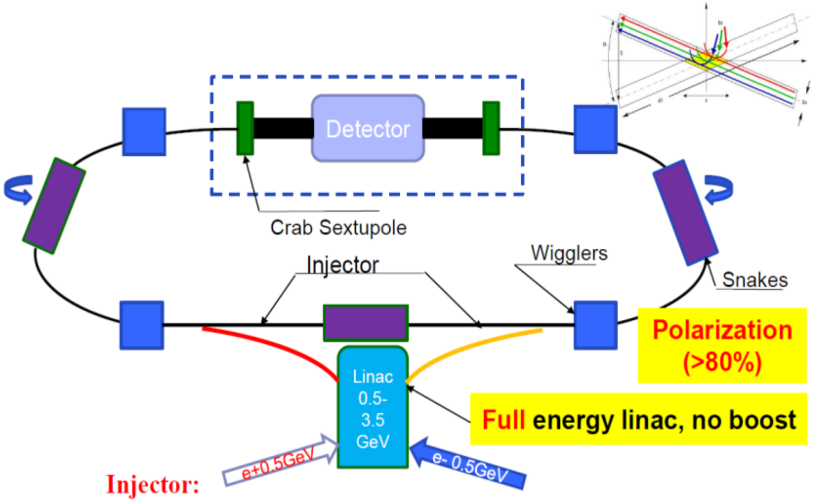
BEPCII and STCF in China

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**

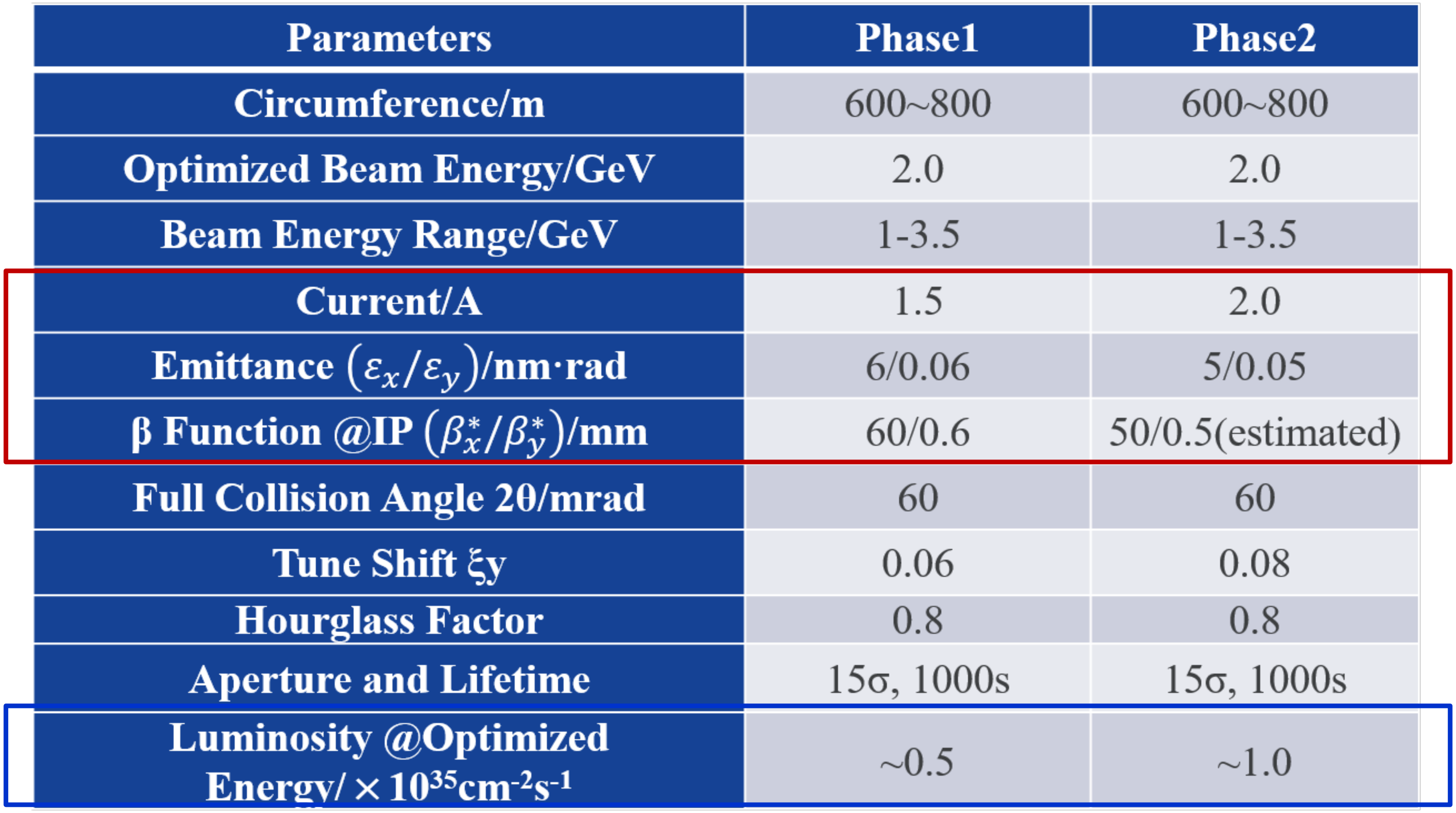


Injector:

- e+, a convertor, a linac and a damping ring, 0.5GeV
- e-, a polarized e- source, accelerated to 0.5GeV

1 ab^{-1} data expected per year

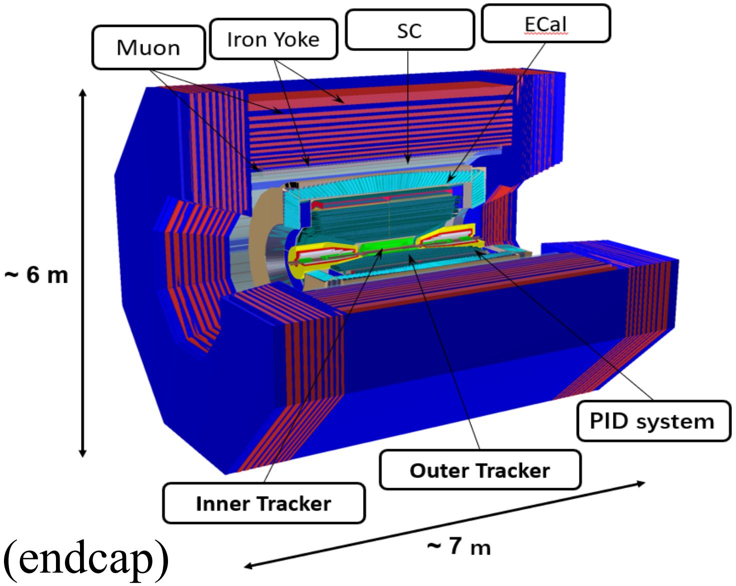
Machine parameters

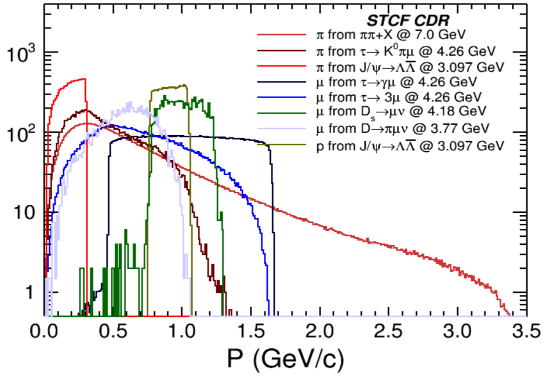


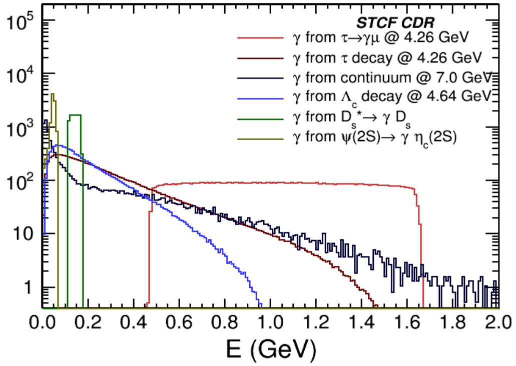
Parameters	Phase1	Phase2
Circumference/m	600~800	600~800
Optimized Beam Energy/GeV	2.0	2.0
Beam Energy Range/GeV	1-3.5	1-3.5
Current/A	1.5	2.0
Emittance $(\varepsilon_x/\varepsilon_y)$/nm·rad	6/0.06	5/0.05
β Function @IP (β_x^*/β_y^*)/mm	60/0.6	50/0.5(estimated)
Full Collision Angle 2θ/mrad	60	60
Tune Shift ξy	0.06	0.08
Hourglass Factor	0.8	0.8
Aperture and Lifetime	15σ, 1000s	15σ, 1000s
Luminosity @Optimized Energy/×10^{35}cm^{-2}s^{-1}	~0.5	~1.0

STCF Detector

- ☐ **Inner Tracker**
  - ➢ ~0.15% X0 / layer
  - ➢ σxy ~ 50 μm
- ☐ **Out Tracker**
  - ➢ σxy~130 um, σp/p~0.5%@1GeV/c
  - ➢ dE/dx ~ 6%
- ☐ **PID system**
  - ➢ π/K (K/*p*) 3-4σ separation up to 2 GeV/c
- ☐ **Electromagnetic Calorimeter**
  - ➢ Range: 0.02 – 3 GeV
  - ➢ Resolution (1 GeV): 2.5% (barrel) and 4% (endcap)
- ☐ **Muon system**
  - ➢ π suppression power: >10 and lower to 0.4 GeV/c







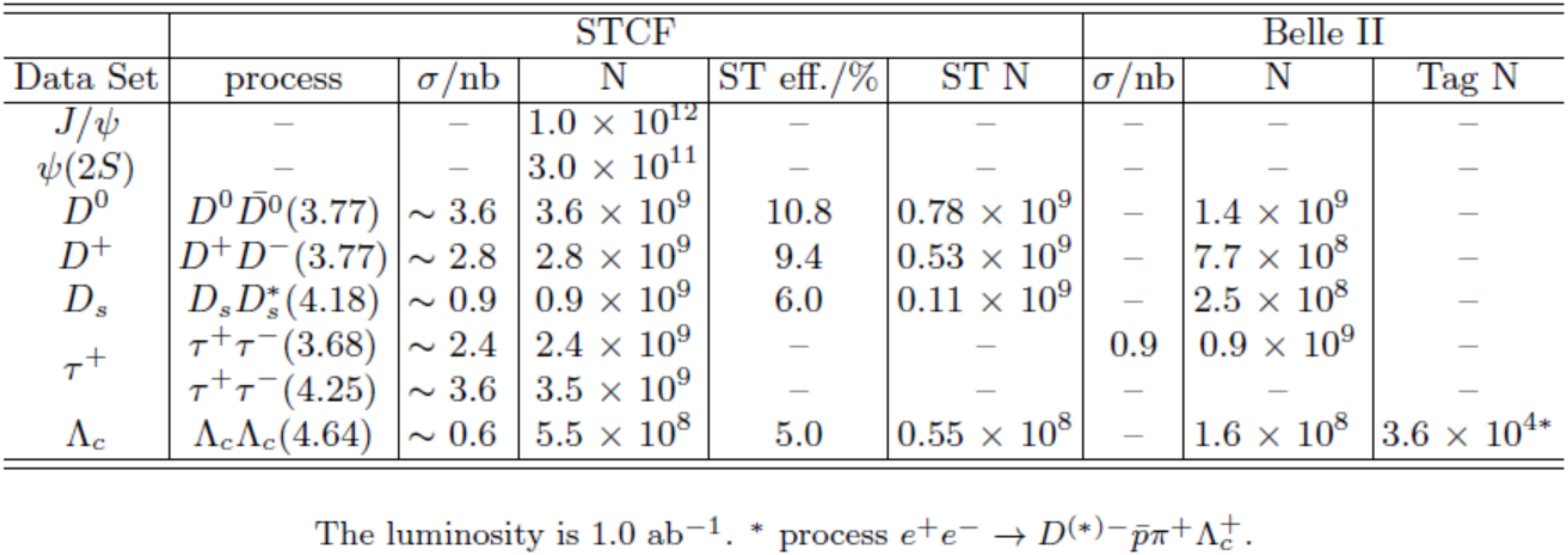
Physics @ STCF

- ***Precise test of SM***
  - R Scan, Hadron form factor (nucleon, Λ, π), $\Delta\alpha_{QED}$, a_u
  - tau lepton decays, lepton universality test
  - CKM matrix, Decay constants (f_D/f_{Ds}), form factors
  - D mixing, CPV and strong phase
- ***New physics(tiny/forbidden in SM)***
  - Rare charmonium decays ：LFV, LNV, BNV…
  - Rare charm decay : FCNC, LFV, LNV, invisible
  - Rare tau decay : FCNC, LFV, LNV
  - Rare light meson decay : $\eta/\eta'/\omega/\phi$
- ***CP Violation***
  - CPV in tau or charm: tiny in SM
  - CP violation in hyperon and *c*-ed hadrons
- ***hadron physics***
  - hadron spectroscopy
  - hadron-pair threshold effects
  - Glueball: direct test of QCD at low energy
  - Multiquark, exotics, hybrids…..
  - Charmonium(-like) spectroscopy
  - Charmed baryon decays
- ***Exotic phyics***
  - Light dark matter : light Higgs boson(a_0), U boson
  - New interactions

- 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.

Data samples

Data samples with 1 ab^{-1} integral luminosity



	STCF					Belle II		
Data Set	process	σ/nb	N	ST eff./%	ST N	σ/nb	N	Tag N
J/ψ	–	–	1.0×10^{12}	–	–	–	–	–
$\psi(2S)$	–	–	3.0×10^{11}	–	–	–	–	–
D^0	$D^0\bar{D}^0(3.77)$	~ 3.6	3.6×10^9	10.8	0.78×10^9	–	1.4×10^9	–
D^+	$D^+D^-(3.77)$	~ 2.8	2.8×10^9	9.4	0.53×10^9	–	7.7×10^8	–
D_s	$D_sD_s^*(4.18)$	~ 0.9	0.9×10^9	6.0	0.11×10^9	–	2.5×10^8	–
τ^+	$\tau^+\tau^-(3.68)$	~ 2.4	2.4×10^9	–	–	0.9	0.9×10^9	–
	$\tau^+\tau^-(4.25)$	~ 3.6	3.5×10^9	–	–	–	–	–
Λ_c	$\Lambda_c\Lambda_c(4.64)$	~ 0.6	5.5×10^8	5.0	0.55×10^8	–	1.6×10^8	$3.6 \times 10^{4*}$

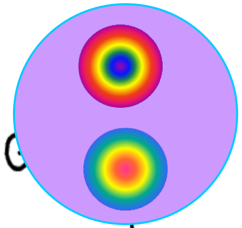
The luminosity is 1.0 ab^{-1}. * process $e^+e^- \to D^{(*)-}\bar{p}\pi^+\Lambda_c^+$.

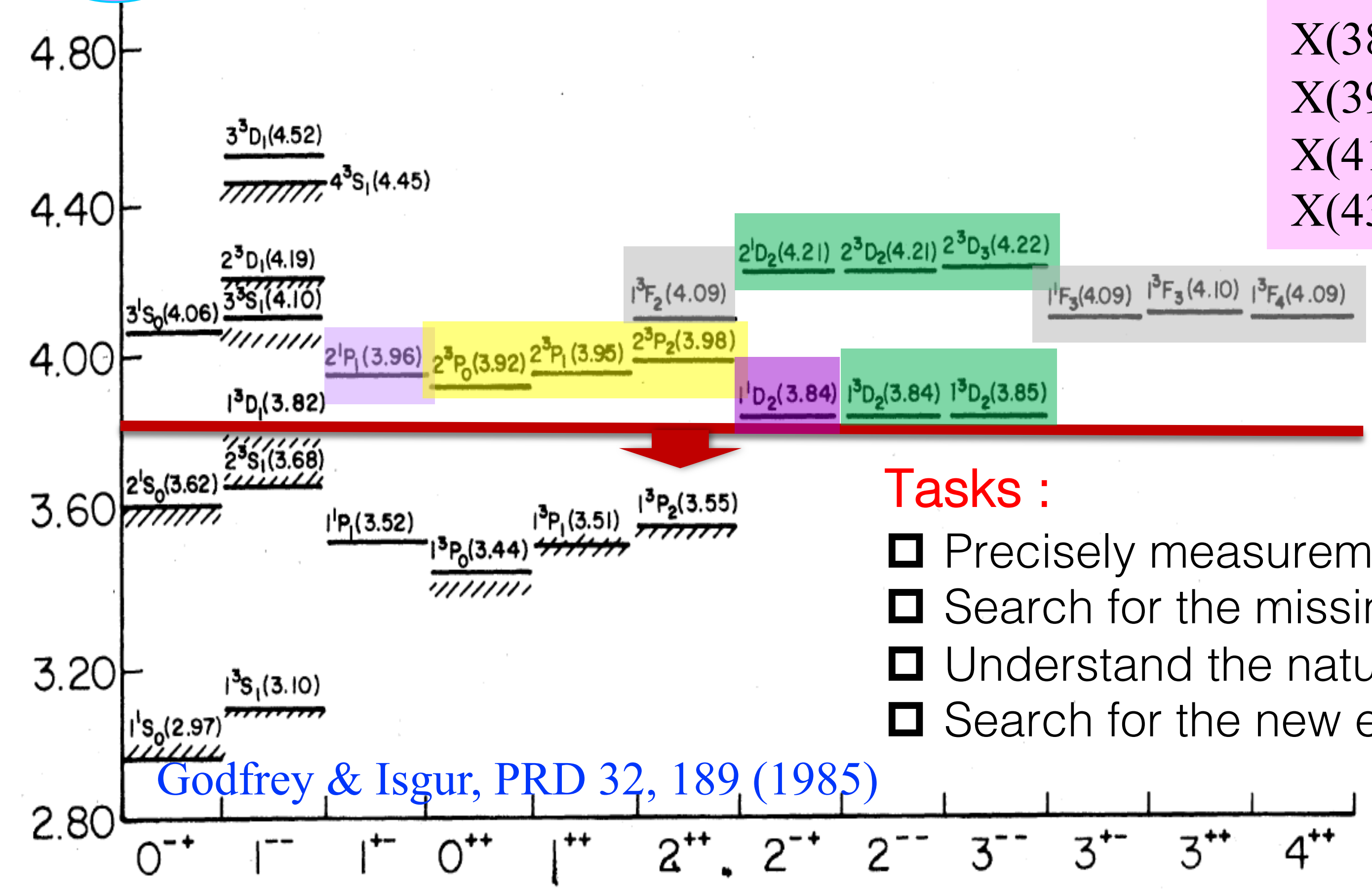
- Belle-II (50/ab) has 50~100 times more statistics
- STCF is expected to have higher detection efficiency
- STCF has low backgrounds for productions at threshold

Charmonium (Like) Spectroscopy

Excellent platform to explore the QCD

Fruitful results in past decade, a new territory to study exotic hadrons





Godfrey & Isgur, PRD 32, 189 (1985)

X(3872)
X(3940)
X(4160)
X(4350)

Y(3940)
Y(4008)
Y(4260)
Y(4360)
Y(4660)

Z(3900)
Z(4020)
Z(4050)
Z(4200)
Z(4250)
Z(4430)

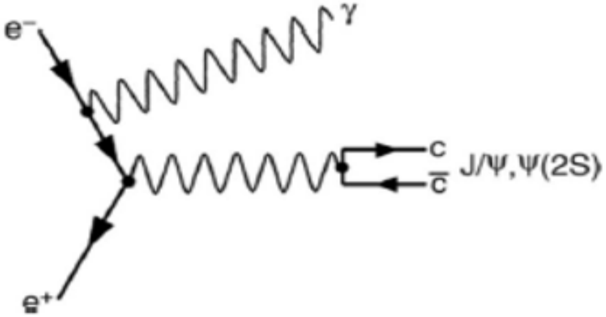
Tasks :

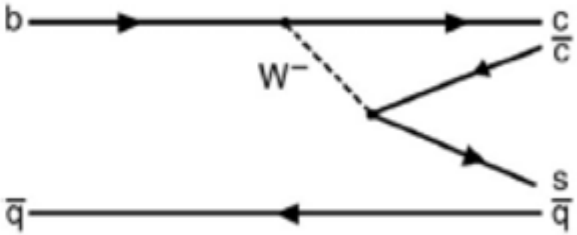
- ☐ Precisely measurement the transition
- ☐ Search for the missing states
- ☐ Understand the nature of unknown states
- ☐ Search for the new exotic states

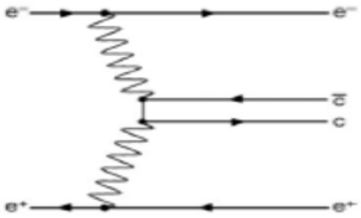
Charmonium (Like) Spectroscopy

Charmonium (Like) states are prominently produced in e^+e^- collision and B decays,

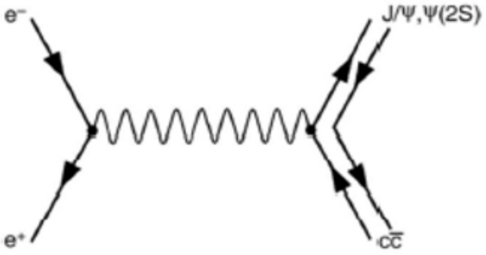
Thus are complementary between τ-C factory and B factory.



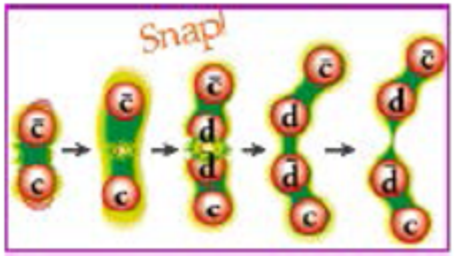




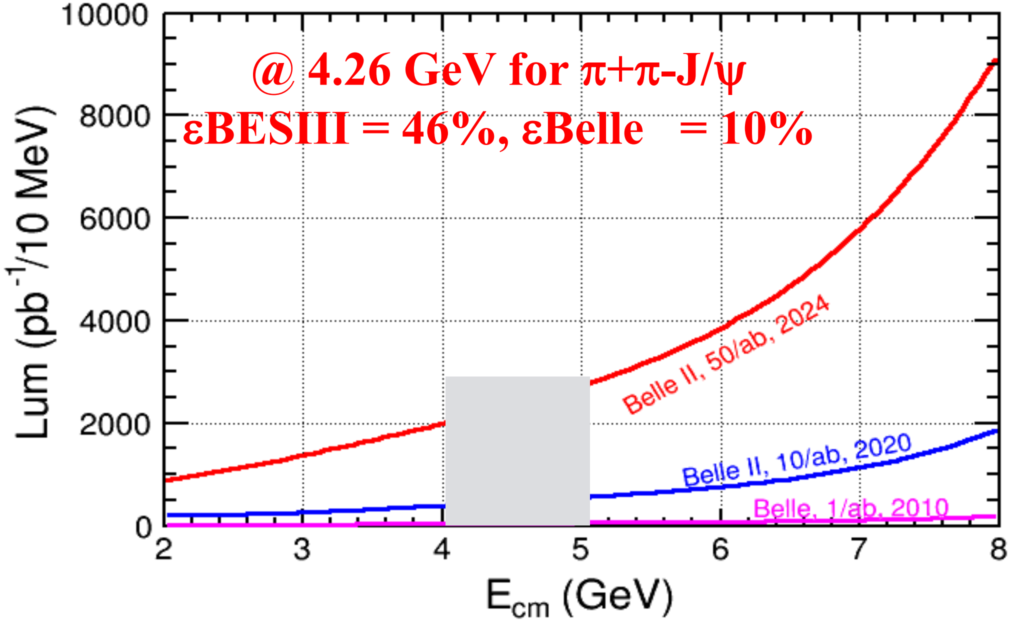
2γ production



Double charmonium production



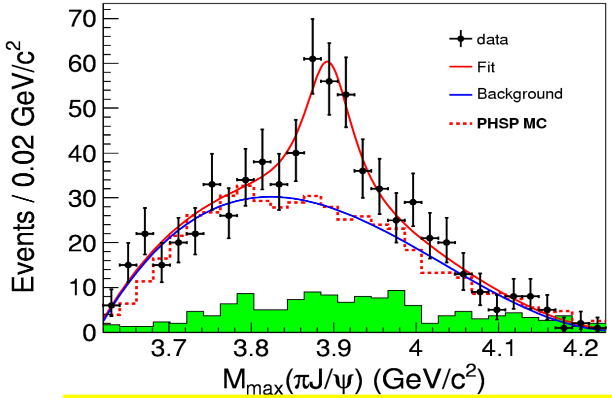
Charmonium (Like) Spectroscopy at STCF



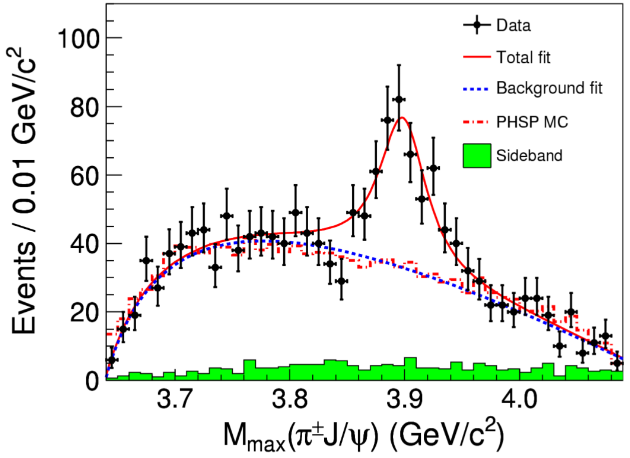
@ 4.26 GeV for π+π-J/ψ

εBESIII = 46%, εBelle = 10%

Belle with ISR: PRL110, 252002
967 fb-1 in 10 years running time



BESIII at 4.260 GeV: PRL110, 252001
0.525 fb-1 in one month running time



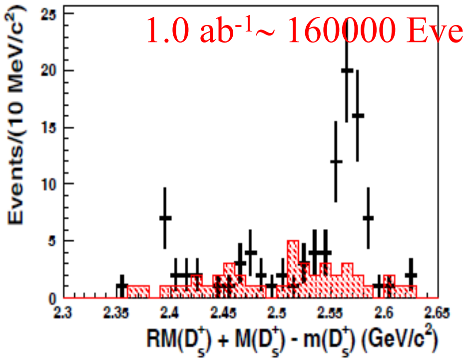
- B factory : Total integrate effective luminosity between 4-5 GeV is 0.23 ab^{-1} for 50 ab^{-1} data
- τ-C factory : scan in 4-5 GeV, 10 MeV/step, every point have 10 fb^{-1}/year, 5 time of Belle II for 50 ab-1 data
- τ-C factory have much higher efficiency and low background than B Factory

Facilities for Charm Study

- ☐ LHCb: huge x-sec, boost, 9fb^{-1} now (x40 current B-factories)
- ☐ B-factories (Belle(-II), BaBar): more kinematic constrains, clean environment, ~100% trigger efficiency
- ☐ τ-C factory : Low backgrounds and high efficiency, Quantum correlations and CP-tagging are unique
  - ☐ STCF :
    - 4×10^9 pairs of $D^{\pm,0}$ and 10^8 Ds pairs per year
      - 10^{10} charm from Belle II/year
    - Highlighted Physics programs
      - Precise measurement of (semi-)leptonic decay (f_D, f_{Ds}, CKM matrix…)
      - $D^0-\bar{D}^0$ 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

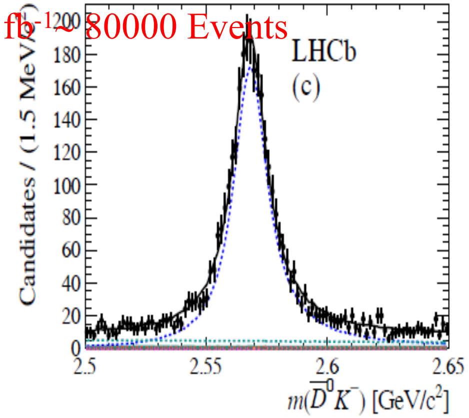
Features in studying charm hadron decays

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



0.5 fb^{-1} ~ 80 Events

1.0 ab^{-1}~ 160000 Events



3.0 fb^{-1}~ 4000 Events

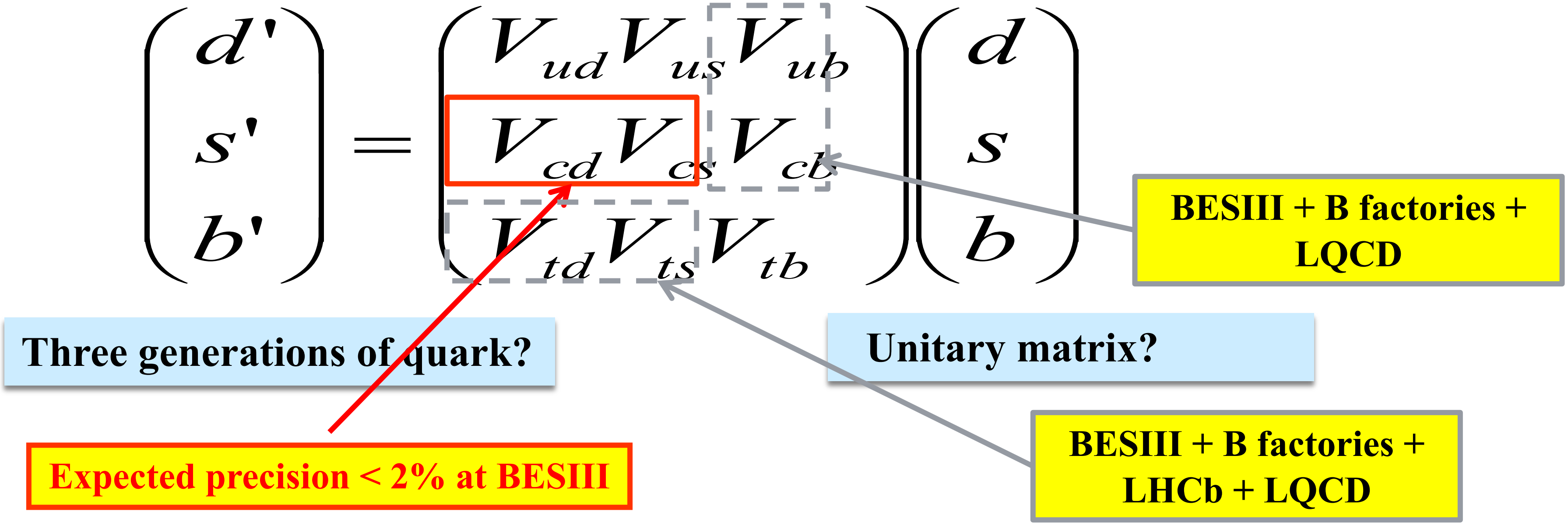
60 fb^{-1}~ 80000 Events

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

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?

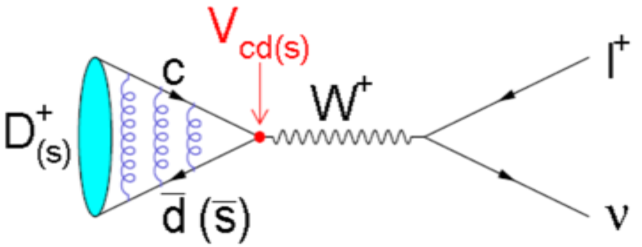
Expected precision < 2% at BESIII

BESIII + B factories + LHCb + LQCD

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

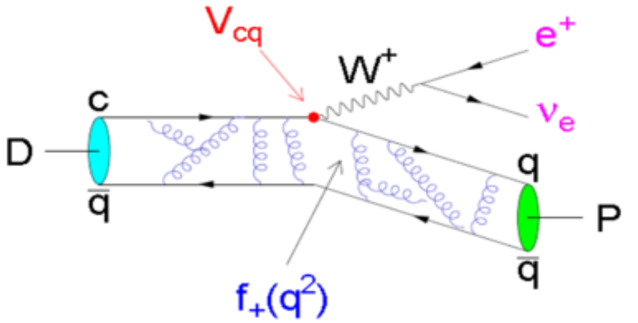
$D_{(s)}$ (Semi-)Leptonic decay

Purely Leptonic:



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

Semi-Leptonic:

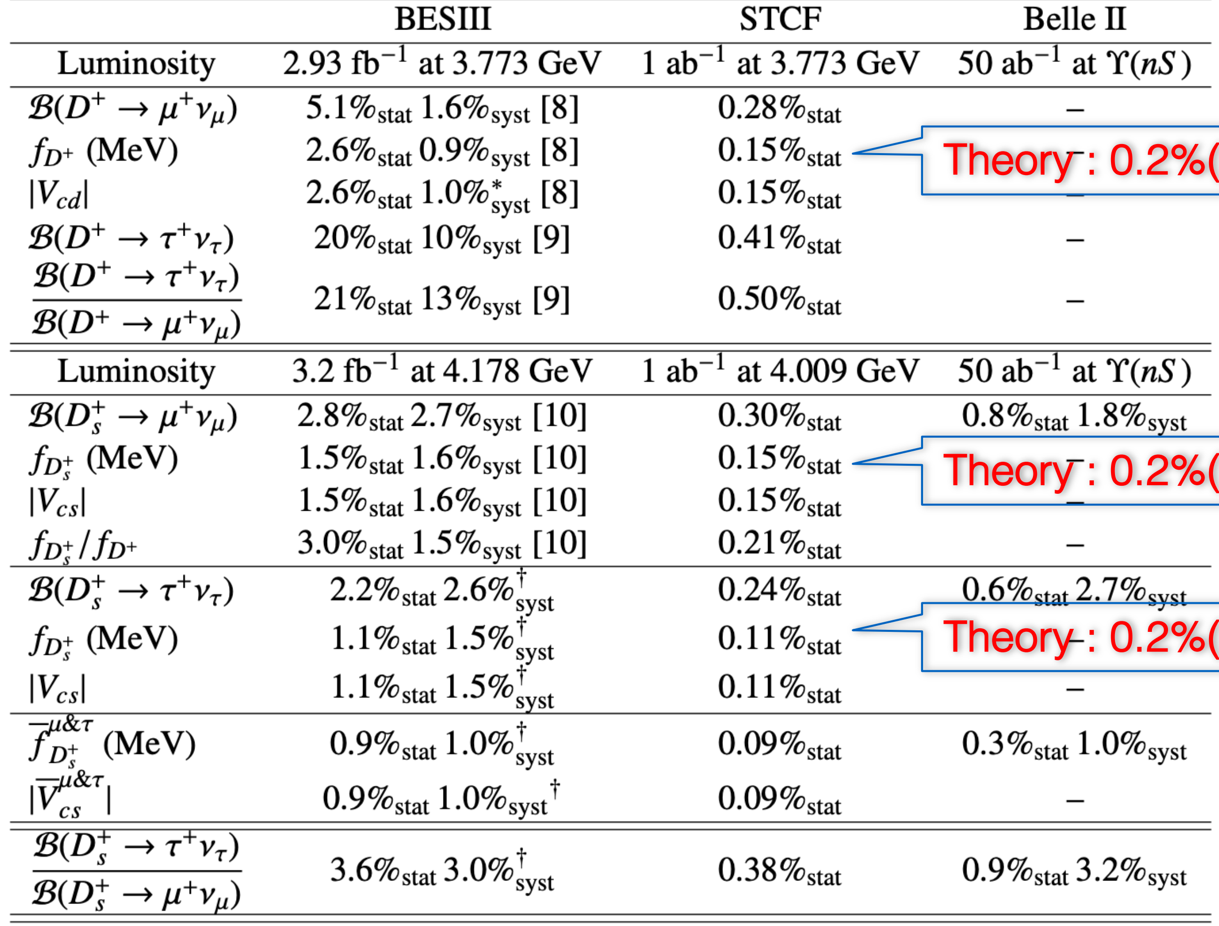


$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cs(d)}|^2 p^3_{K(\pi)} |f_+^{K(\pi)}(q^2)|^2$$

Directly measurement : $|V_{cd(s)}|$ x $f_{D(s)}$ or $|V_{cd(s)}|$ x FF

- ☐ Input $f_{D(s)}$ or $f^{k(\pi)}(0)$ from LQCD $\Rightarrow$ $|V_{cd(s)}|$
- ☐ Input $|V_{cd(s)}|$ from a global fit $\Rightarrow$ $f_{D(s)}$ or $f^{k(\pi)}(0)$
- ☐ Validate LQCD calculation of Input $f_{B(s)}$ and provide constrain of CKM-unitarity

$D_{(s)}$ Leptonic decay



	BESIII	STCF	Belle II
Luminosity	2.93 fb^{-1} at 3.773 GeV	1 ab^{-1} at 3.773 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D^+ \to \mu^+\nu_\mu)$	$5.1\%_{\rm stat}\ 1.6\%_{\rm syst}$ [8]	$0.28\%_{\rm stat}$	–
f_{D^+} (MeV)	$2.6\%_{\rm stat}\ 0.9\%_{\rm syst}$ [8]	$0.15\%_{\rm stat}$	
$\lvert V_{cd}\rvert$	$2.6\%_{\rm stat}\ 1.0\%^{*}_{\rm syst}$ [8]	$0.15\%_{\rm stat}$	–
$\mathcal{B}(D^+ \to \tau^+\nu_\tau)$	$20\%_{\rm stat}\ 10\%_{\rm syst}$ [9]	$0.41\%_{\rm stat}$	–
$\frac{\mathcal{B}(D^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D^+ \to \mu^+\nu_\mu)}$	$21\%_{\rm stat}\ 13\%_{\rm syst}$ [9]	$0.50\%_{\rm stat}$	–
Luminosity	3.2 fb^{-1} at 4.178 GeV	1 ab^{-1} at 4.009 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	$2.8\%_{\rm stat}\ 2.7\%_{\rm syst}$ [10]	$0.30\%_{\rm stat}$	$0.8\%_{\rm stat}\ 1.8\%_{\rm syst}$
$f_{D_s^+}$ (MeV)	$1.5\%_{\rm stat}\ 1.6\%_{\rm syst}$ [10]	$0.15\%_{\rm stat}$	
$\lvert V_{cs}\rvert$	$1.5\%_{\rm stat}\ 1.6\%_{\rm syst}$ [10]	$0.15\%_{\rm stat}$	–
$f_{D_s^+}/f_{D^+}$	$3.0\%_{\rm stat}\ 1.5\%_{\rm syst}$ [10]	$0.21\%_{\rm stat}$	–
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$2.2\%_{\rm stat}\ 2.6\%^{\dagger}_{\rm syst}$	$0.24\%_{\rm stat}$	$0.6\%_{\rm stat}\ 2.7\%_{\rm syst}$
$f_{D_s^+}$ (MeV)	$1.1\%_{\rm stat}\ 1.5\%^{\dagger}_{\rm syst}$	$0.11\%_{\rm stat}$	
$\lvert V_{cs}\rvert$	$1.1\%_{\rm stat}\ 1.5\%^{\dagger}_{\rm syst}$	$0.11\%_{\rm stat}$	–
$\overline{f}^{\mu\&\tau}_{D_s^+}$ (MeV)	$0.9\%_{\rm stat}\ 1.0\%^{\dagger}_{\rm syst}$	$0.09\%_{\rm stat}$	$0.3\%_{\rm stat}\ 1.0\%_{\rm syst}$
$\lvert\overline{V}^{\mu\&\tau}_{cs}\rvert$	$0.9\%_{\rm stat}\ 1.0\%_{\rm syst}{}^{\dagger}$	$0.09\%_{\rm stat}$	–
$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)}$	$3.6\%_{\rm stat}\ 3.0\%^{\dagger}_{\rm syst}$	$0.38\%_{\rm stat}$	$0.9\%_{\rm stat}\ 3.2\%_{\rm syst}$

Theory : 0.2%(0.1% expected)

Theory : 0.2%(0.1% expected)

Theory : 0.2%(0.1% expected)

* assuming Belle II improved systematics by a factor 2

Stat. uncertainty is closed to theory precision
Sys. is challenging

Lepton Flavor Universality

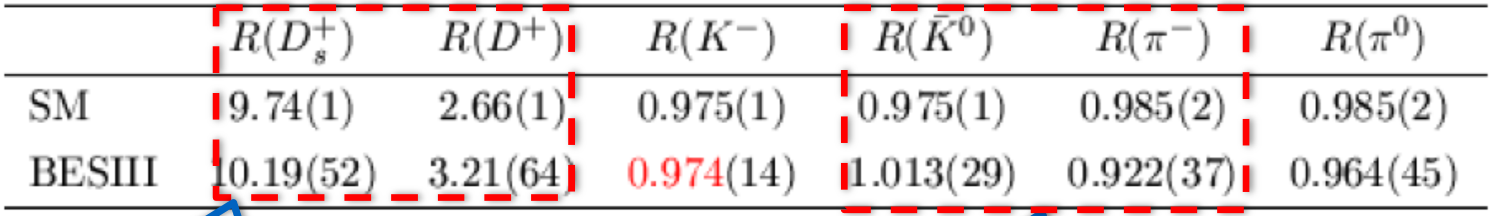
LFU is critical to test the SM and search for new physics beyond the SM

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:

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



	$R(D_s^+)$	$R(D^+)$	$R(K^-)$	$R(\bar{K}^0)$	$R(\pi^-)$	$R(\pi^0)$
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)

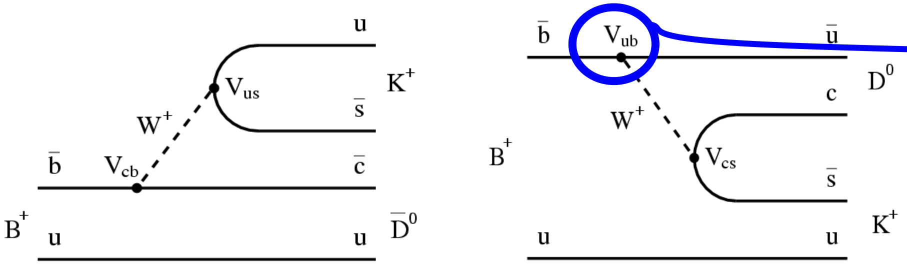
BESIII
preliminary
1σ difference

BESIII
publication
~2σ difference

- Large uncertainty from BESIII, dominant by statistically limited
- STCF would improve them significantly

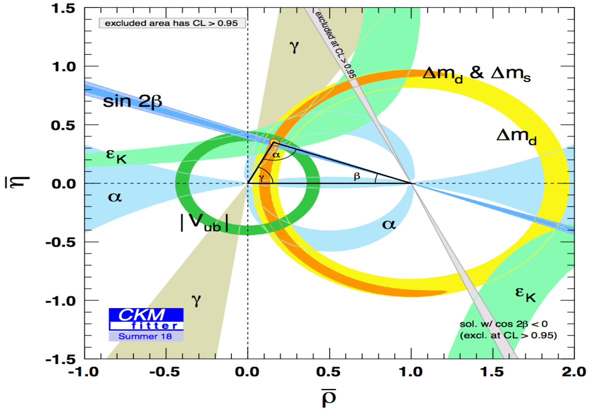
Determination of γ/ϕ_3 angle

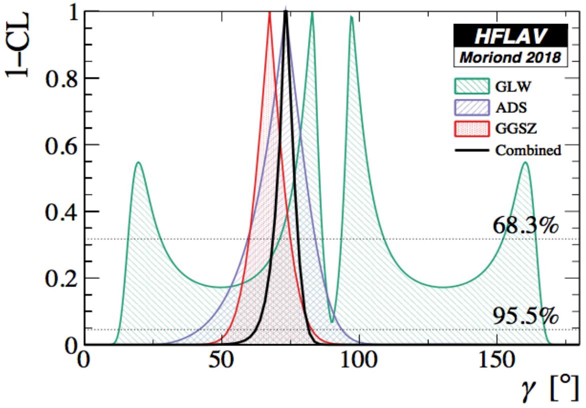
- The cleanest way to extract γ is from B→DK decays:



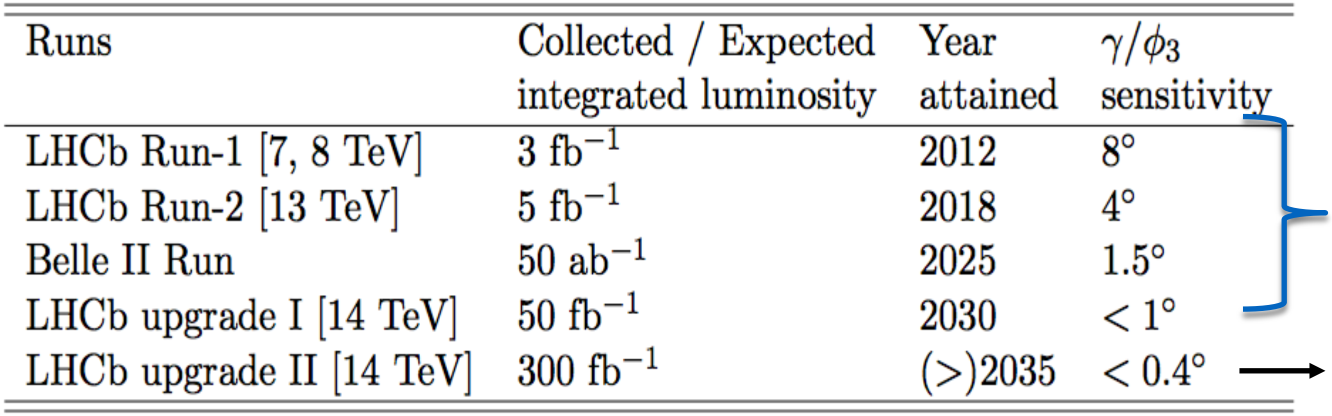
$$\frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \overline{D^0} K^+)} \equiv r_B e^{i(\delta_B + \phi_3)}$$

  - 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	$< 1°$
LHCb upgrade II [14 TeV]	300 fb^{-1}	(>)2035	$< 0.4°$

BESIII 20/fb:

$\sigma(\gamma) \sim 0.4^{\circ}$

→ 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. $D^0 \rightarrow K_S\pi^0$, $D^0 \rightarrow \pi^+\pi^-$

- ☐ Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \rightarrow K^+\pi^-$

  - With 1 ab^{-1} @ STCF : $\sigma(\cos\delta_{K\pi}) \sim 0.007$; $\sigma(\delta_{K\pi}) \sim 2^{\circ}$ ➔ $\sigma(\gamma) < 0.5^{\circ}$

- ☐ 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 reduces the contribution of *D* Dalitz model to a level of $\sim 0.1^{\circ}$

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

STCF provide a unique place for the study of D^0-$\bar{D}^0$ mixing and CPV by means of quantum coherence of D^0 and $\bar{D}^0$ produced through

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

- ☐ 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 parameters and CPV parameters with 1 ab^{-1} data at 4009 MeV via coherent (C-even and C-odd) and incoherent process
- ☐ $\Delta A_{CP} \sim 10^{-3}$ for KK and ππ channels

D^0 mixing and CPV parameters

- Three kinds of $D^0\bar{D}^0$ samples can be used @4009MeV
  - **Quantum-incoherent flavor specific D^0 samples: $D^{*+} \to D^0\pi^+$**
    - Help to improve precision of strong-phase difference measurement
    - Be used to constrain the charm mixing and CPV parameters
  - **Quantum-coherent C-even $D^0\bar{D}^0$ samples: $D^{*0}\bar{D}^0 \to D^0\bar{D}^0\gamma$**
    - Be used to perform charm mixing and CPV parameters measurements
      - The interference effect, containing mixing and CPV, is doubled compare to incoherent case
    - Help to constrain the strong-phase difference and CP fraction measurements
  - **Quantum-coherent C-odd $D^0\bar{D}^0$ samples: $D^{*0}\bar{D}^0 \to D^0\bar{D}^0\pi^0$**
    - Same as $D^0\bar{D}^0$ samples @3770, improve precision of strong-phase difference measurements and CP fraction measurements

Precision estimation

	1/ab @4009 MEV (only QC | QC+incoherent) (preliminary estimation)		BELLEII(50/ab) [PTEP2019, 123C01]	LHCb(50/fb) (SL | Prompt) [arXiv:1808.08865]	
$x(\%)$	0.036	0.035	0.03	0.024	0.012
$y(\%)$	0.023	0.023	0.02	0.019	0.013
r_{CP}	0.017	0.013	0.022	0.024	0.011
$\alpha_{CP}(^\circ)$	1.3	1.0	1.5	1.7	0.48

- The only QC results: contains $D^0 \to K_S\pi\pi, D^0 \to K^-\pi^+\pi^0$ and general CP tag decay channels
- The QC+incoherent results: combines coherent and incoherent D^0 meson samples
- The BELLE II and LHCb results only contain incoherent $D^0 \to K_S\pi\pi$ channel

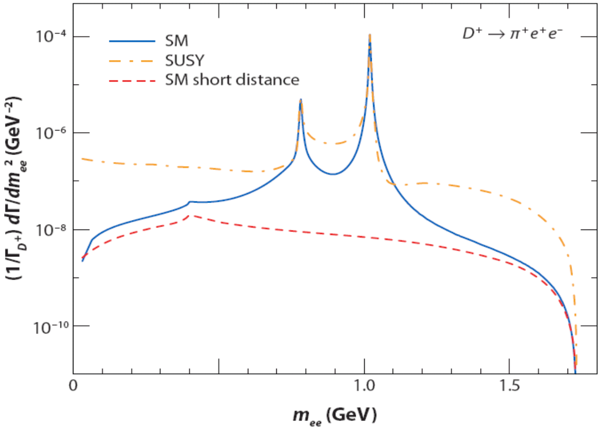
Charm rare decays

- FCNC suppressed by GIM mechanism in SM:
  - Short distance : interested, computable by pQCD, directly test SM

$$\mathcal{B}_{D^0\to X_u^0 e^+e^-} \simeq 8\cdot 10^{-9}$$

$$\mathcal{B}_{D^+\to X_u^+ e^+e^-} \simeq 2\cdot 10^{-8}$$

  - Long distance effect can enhance the rate to $10^{-6}\sim10^{-7}$, dominantly.
  - Allow with sizeable decay rate in NP



  - $1ab^{-1}$ @ STCF can achieve the sensitivity to $10^{-8}\sim10^{-9}$, tested SM strictly
  - Can discriminate NP from SM by measuring :
    - $D\to Vl^+l^-$: AFB asymmetry
    - $D\to Pl^+l^-$: line shape of dilepton mass, to reveal the interference effect between long-distance and FCNC weak amplitude (NP amplitude);

- LFV, LNV and BNV decays are forbidden in the SM. However, NP models can allow at sizable levels.
  - STCF: $10^{-8}\sim10^{-9}$ ➔ stringent constrains to NP models

More detail MC simulation are necessary!

Precision study of the *c*-ed baryon decay

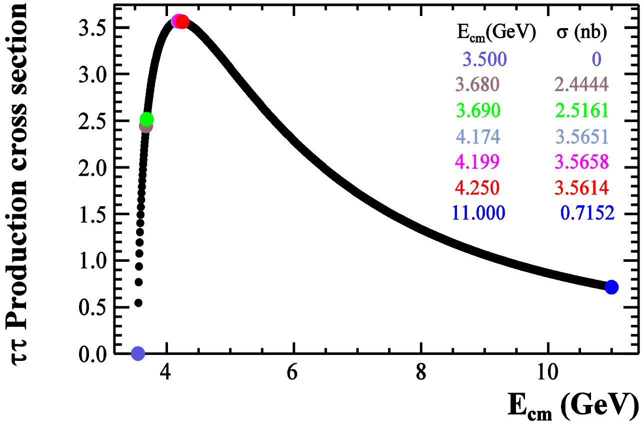
Era of precision study of the charmed baryon (Λ_c, Ξ_c and Ω_c) decays
to help developing more reliable QCD-derived models in charm sector

- ☐ **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, less than 20 are observed!)
- ☐ Rare decays: LFV, BNV, FCNC

STCF will provide very precise measurements of their overall decays, up to the unprecedented level of $10^{-6}\sim10^{-7}$

τ Lepton Physics

- ☐ X sec grows from 0.1nb near threshold to 3.5 nb at 4.25 GeV
  - 1×10^8 tau pairs/year at threshold (0.1 nb)
  - 3.5×10^9 tau pairs/year at 4.25 GeV (3.5 nb)
  - 10^{10} τ pairs per year for Belle II (1 nb)



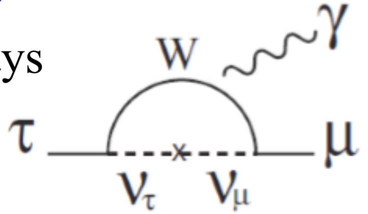
- ☐ Highlighted Physics program
  - τ properties : m_τ, $(g\text{-}2)_\tau/2$
  - SM properties : universality test, Michel parameters, α_s, V_{us}
  - CPV test : $\tau^-\to K_S^0\pi^-\nu_\tau$, T-odd triple product in polarization beam
  - LFV : $\tau\to\ell\gamma$, $\ell\ell\ell$, ℓh

- ☐ Comparison to Belle II
  - – Threshold effect is important for controlling and understanding background
  - – Relatively high efficiency
  - – Longitudinal polarization of the initial beams will significantly increase sensitivity in searches for CPV in lepton decays.

LFV decay $\tau \to \gamma\mu$

- The charged LFV processes can occur through oscillations in loops
- Immeasurable small rates (10^{-54}-10^{-49}) for all the LFV μ and τ decays

$$\mathfrak{B}(l_1 \to l_2\gamma) \propto \alpha\left(\frac{\Delta m^2}{m_W^2}\right)^2$$



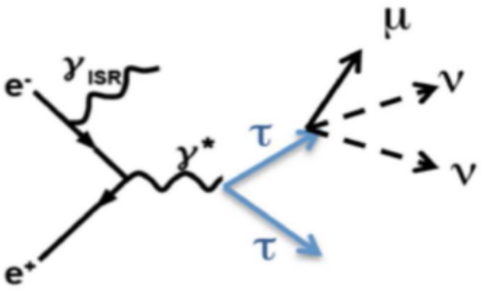
- Many extensions of SM naturally introduces cLFV at order ~$10^{-7} - 10^{-10}$ (an crucial place to test BSM)

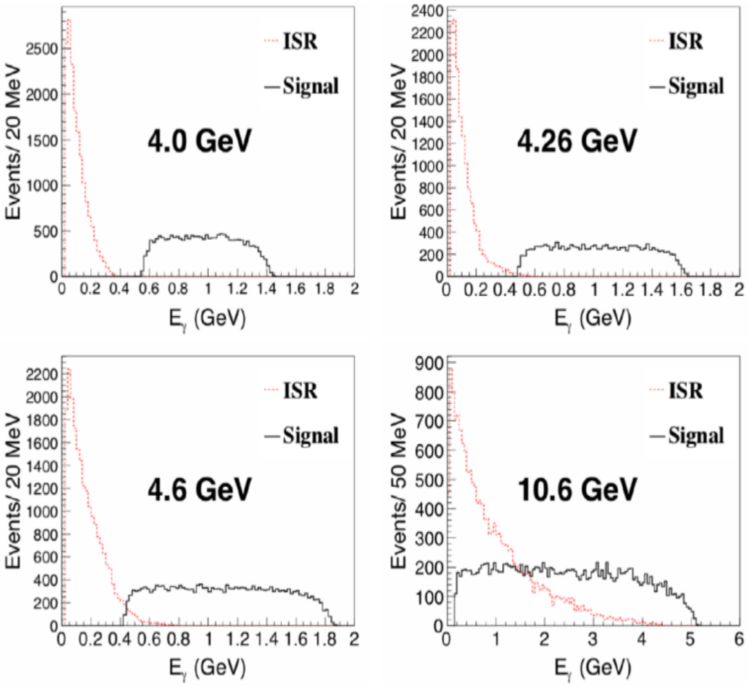
B Factory :

☐ Dominant background :

$\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$ with ISR

☐ BaBar : $B(\tau^- \to \gamma\mu^-) < 4.5\times10^{-8}$





Belle II with 50 ab^{-1} : $\boldsymbol{B(\tau^- \to \gamma\mu^-) < 6\times10^{-9}}$

STCF with 10 ab^{-1} : $\boldsymbol{B(\tau^- \to \gamma\mu^-) < 7\times10^{-9}}$

CPV in τ decay

- There is no direct CP violation in hadronic tau decays at the tree level within SM
- The CPV source in $\boldsymbol{K^0-\bar{K}^0}$ mixing produces a difference in tau decay rate

In theory: $$A_Q = \frac{B(\tau^+ \to K_S^0\pi^+\bar{\nu}_\tau) - B(\tau^- \to K_S^0\pi^-\nu_\tau)}{B(\tau^+ \to K_S^0\pi^+\bar{\nu}_\tau) + B(\tau^- \to K_S^0\pi^-\nu_\tau)} = (+0.36 \pm 0.01)\%$$

BaBar experiment: $$A_{CP}(\tau^- \to K_S\pi^-\nu[\geq 0\pi^0]) = (-0.36 \pm 0.23 \pm 0.11)\%$$

2.8σ away from the SM prediction

Theorist try to reconcile the deviation, but not coverage even NP included

- The sensitivity of decay rate asymmetry in $\boldsymbol{\tau \to K_s\pi\nu}$ decays at √s = 4.26 GeV with 1 ab^{-1} integrated luminosity is tested based on MC study with no CP violation:
  a preliminary sensitivity is evaluated to be : $\boldsymbol{A_{CP} = (0.009 \pm 0.059)\%}$

STCF can provide a crucial validation since the background can be well controlled

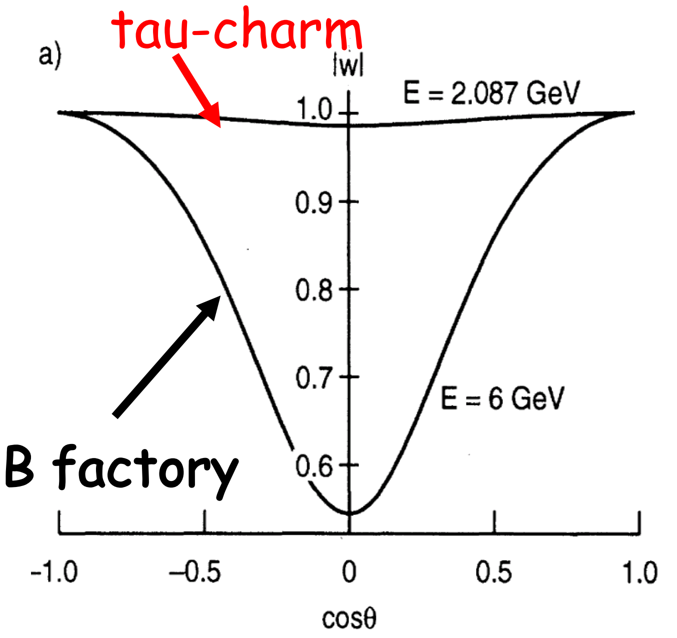
CPV in τ decays with polarized beam

New T-odd observables

Use T-odd rotationally invariant triple products in >=2 hadrons

such as $\tau^-\to\pi^-\pi^0\nu_\tau/k^-\pi^0\nu_\tau$, $\tau^-\to\pi^-\pi^+\pi^-\nu_\tau/K^-\pi^+\pi^-\nu_\tau$

Polarized τ sourced from polarized beam



Polarized τ are necessary

Figure of Merits

$$\begin{aligned}\text{merit} &= \text{luminosity} \times \bar{w}_Z \times \text{ total cross section}\\ &\propto \text{luminosity} \times (w_1 + w_2)\\ &\quad \times \sqrt{1-a^2}a^2(1+2a)\ ,\end{aligned}$$

Y. S. TSAI, PRD 51 (1995) 3172

BESIII @ 4.25 ($10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) FOM=1

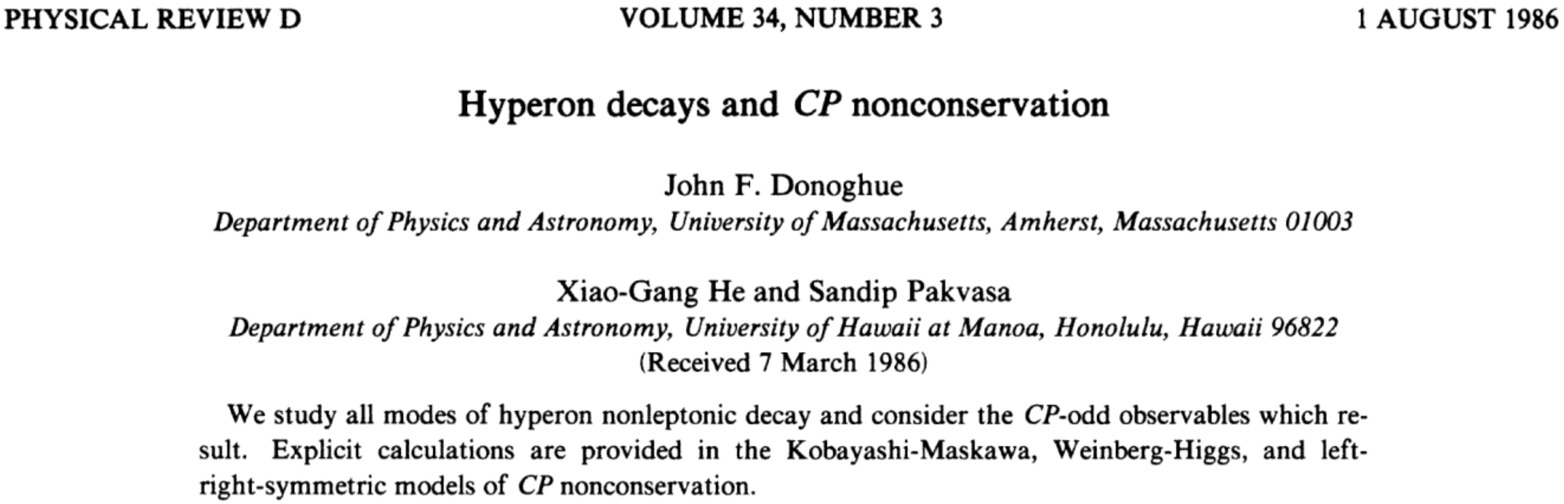
STCF @ 4.25 ($10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) FOM=100

SuperKEKB @ ($8\mathrm{x}10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) FOM=52

Experimental challenge: reconstruction of τ (No secondary vertices)

CPV in hyperon decays

- In 1958, Okubo: CPV in hyperon-antihyperon allows ⇒ “Okubo effect”(Direct CPV) Phys. Rev. 109, 984 (1958).
- In 1959, Pais: extended Okubo’s proposal to asymmetry parameters in Λ and Λ decays. Phys. Rev. Lett. 3, 242 (1959).
- In the 1980s, a number of calculations were made. CKM predictions, CPV in Λ: $\mathbf{10^{-4} \sim 10^{-5}}$
- One example: Phys. Rev. D34, 833 (1986).



PHYSICAL REVIEW D VOLUME 34, NUMBER 3 1 AUGUST 1986

Hyperon decays and *CP* nonconservation

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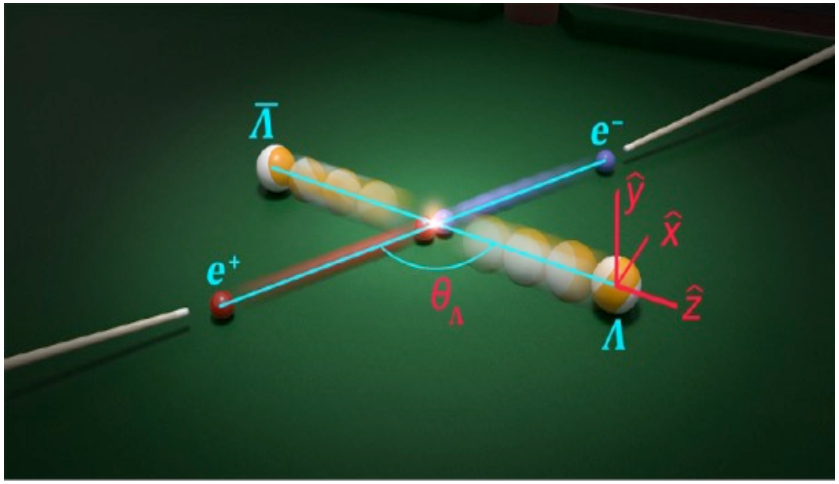
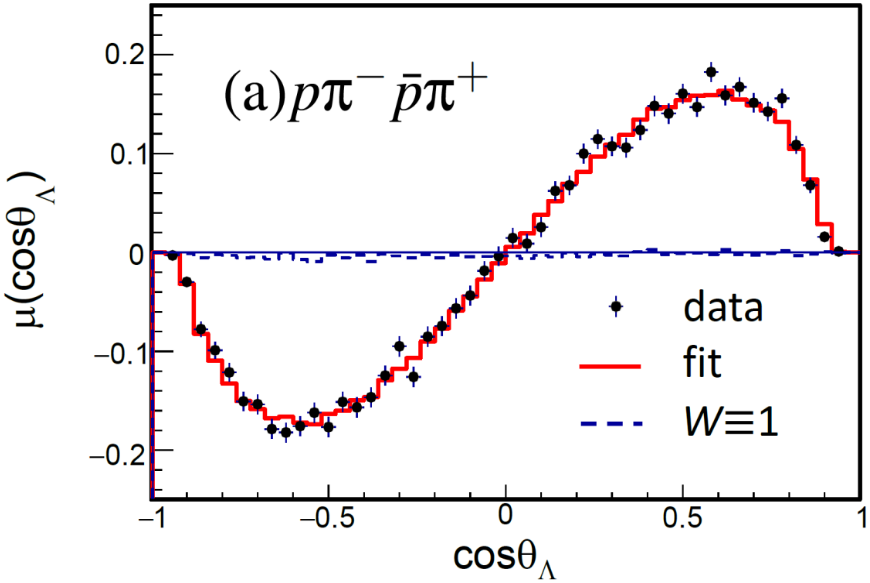
(Received 7 March 1986)

We study all modes of hyperon nonleptonic decay and consider the *CP*-odd observables which result. Explicit calculations are provided in the Kobayashi-Maskawa, Weinberg-Higgs, and left-right-symmetric models of *CP* nonconservation.

Spin polarization of Λ in $J/\psi \to \Lambda\bar{\Lambda}$

Nature Phys. **15**, 631 (2019)





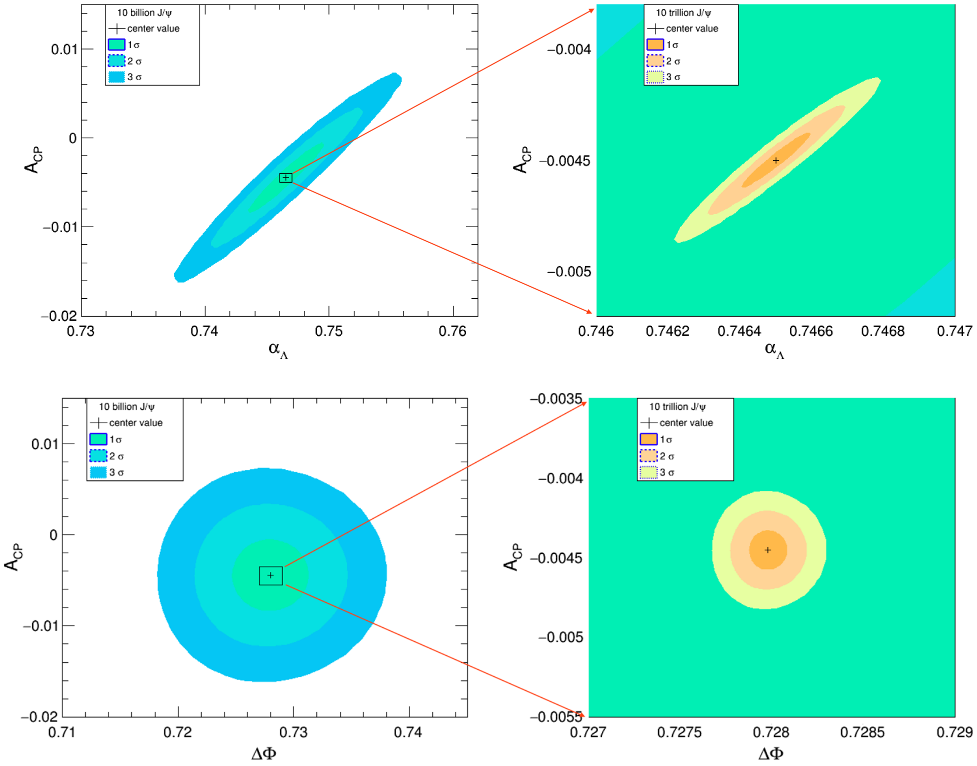
1.31 B J/ψ events
Quantum correlation in Λ pair

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [14]
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [16]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [16]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [16]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

CPV test $A_{CP} = \dfrac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$

Λ hyperon A_{CP} sensitivities

- 4 trillion J/ψ events ⇒ $A_{CP}\sim10^{-4}$
  - Luminosity optimized at J/ψ resonance
  - Luminosity of STCF: × 100
  - 2 – 3 years data taking
  - No polarization beams are needed
- Beam energy trick
  ⇒ small beam energy spread
  ⇒ J/ψ cross-section: × 10 ⇒ $A_{CP}\sim10^{-5}$?
- Challenge: Systematics control, spin procession effect in magnet



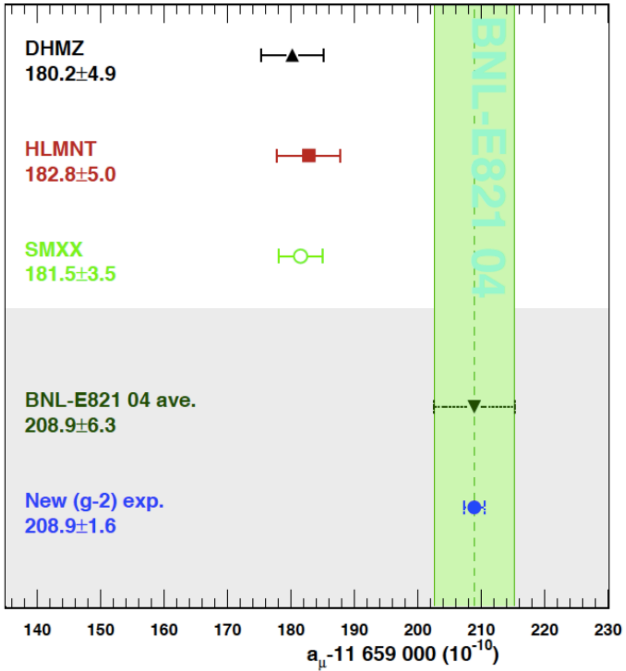
R and QCD Physics

- Detailed study of exclusive processes $e^+ e^- \to (2\text{-}10)h$, $h=\pi, K, \eta, p\ldots$
  Scan between 2-7GeV and ISR $\sqrt{s}<2$GeV
  - Meson Spectroscopy
  - Intermediate dynamics
  - Search for exotic states (tetraquarks, hybrids, glueballs)
  - Form factors
- High precision determination of $R=\sigma(e^+ e^- \to \text{hadrons})/\sigma(e^+ e^- \to \mu^+\mu^-)$ at low energies and fundamental quantities
  - $(g_\mu-2)/2$, 92% from < 2GeV, 7% from 2-5GeV
  - $\alpha(M_z)$, 19.0% from < 2GeV, 18.1% from 2-5GeV
  - QCD parameters (charm quark masses)
- Inclusive cross section $e^+ e^- \to h + X$
  - QCD parameters (α_s, quark and gluon condensates)
  - Fragmentation functions; MLLA/LPHP prediction
  - Spin alignment of vector
- Two photon Physics
  - Measurement of $\Gamma_{\gamma\gamma}$ for $J^{PC} = 0^{-+}, 0^{++}, 2^{-+}, 2^{++}$ states
  - Study of $\gamma\gamma^* \to R$, $R = 1^{++}$
  - Transition Form Factors in $\gamma^*\gamma^* \to R$
  - Cross section of $\gamma\gamma \to$ hadrons

Impact on $(g_\mu\text{-}2)/2$

At present, the anomalous magnetic moment of the muon $a_\mu = (g-2)_\mu/2$ are known with an uncertainty of about one half per million!

$$
\begin{aligned}
a_\mu^{\mathrm{SM}} &= (11\,659\,180.2 \pm 4.9)\cdot 10^{-10}\ , \\
a_\mu^{\mathrm{exp}} &= (11\,659\,208.9 \pm 6.3)\cdot 10^{-10}\ .
\end{aligned}
$$

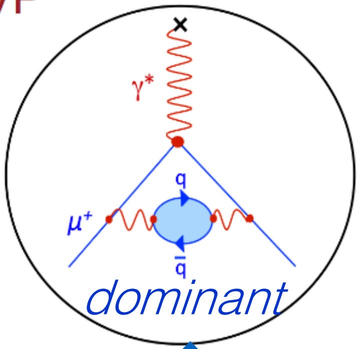


SM-Exp: 3.5σ difference

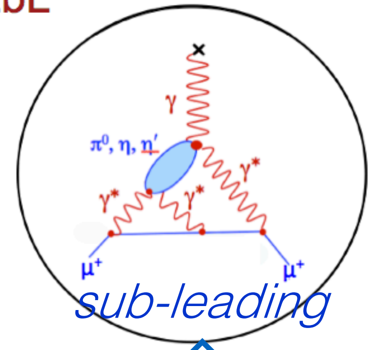
Sensitive to probe new physics.

Data-driven approach:
reduce model uncertainty to 10-20%

HVP

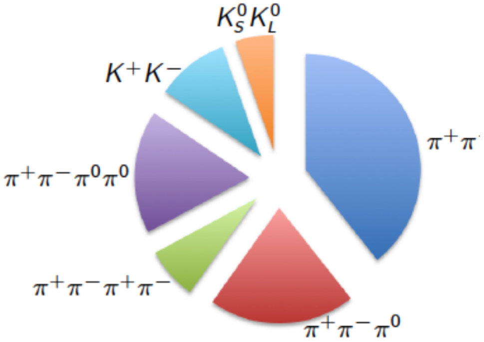


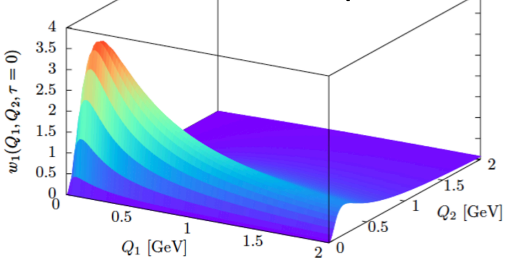
HLbL



- $e^+e^- \rightarrow \gamma_{ISR} hadrons$

- $\gamma\gamma * \rightarrow \mathrm{M}$
- $e^+e^- \rightarrow \gamma M$
- $M \rightarrow \gamma e^+e^-$





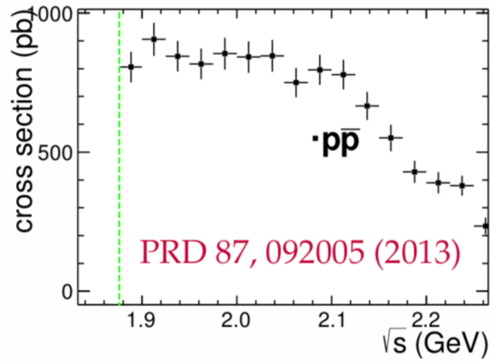
High Luminosity of STCF will largely improve the SM precisions

The threshold production of baryon pair

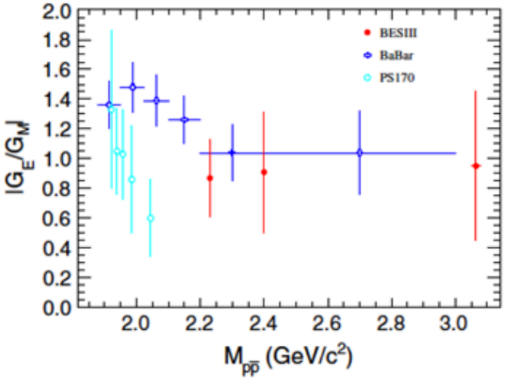
The Born cross section of the reaction $e^+e^- \to \gamma^* \to B\bar{B}$ can be parameterized in terms of electromagnetic form factors:

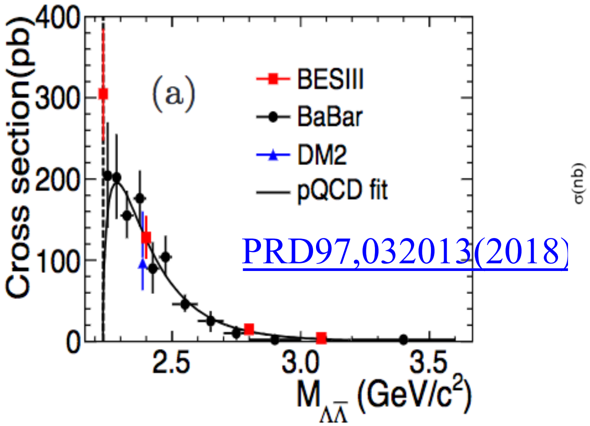
$$\sigma_{B\bar{B}}(q) = \frac{4\pi\alpha^2 C\beta}{3q^2}[|G_M(q)|^2 + \frac{1}{2\tau}|G_E(q)|^2]$$

- Baryon velocity $\beta = \sqrt{1 - 4m_B^2c^4/q^2}$, $\tau = q^2/(4m_B^2c^4)$
- For charged B, the Coulomb factor C will results in a non-zero cross section at threshold

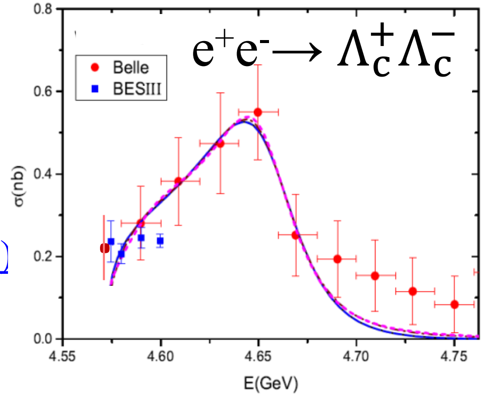


PRD 87, 092005 (2013)





PRD97,032013(2018)

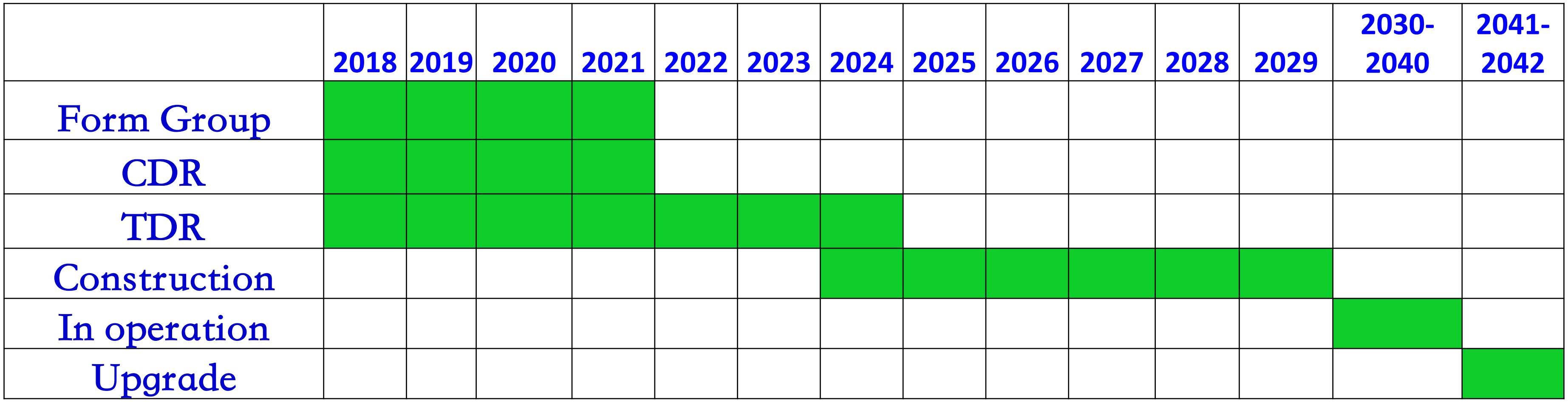


$e^+e^- \longrightarrow \Lambda_c^+\bar{\Lambda}_c^-$

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

100x more statistics at STCF will much enhance the understandings of these 'unexpected' threshold enhancement!

Tentative Plan



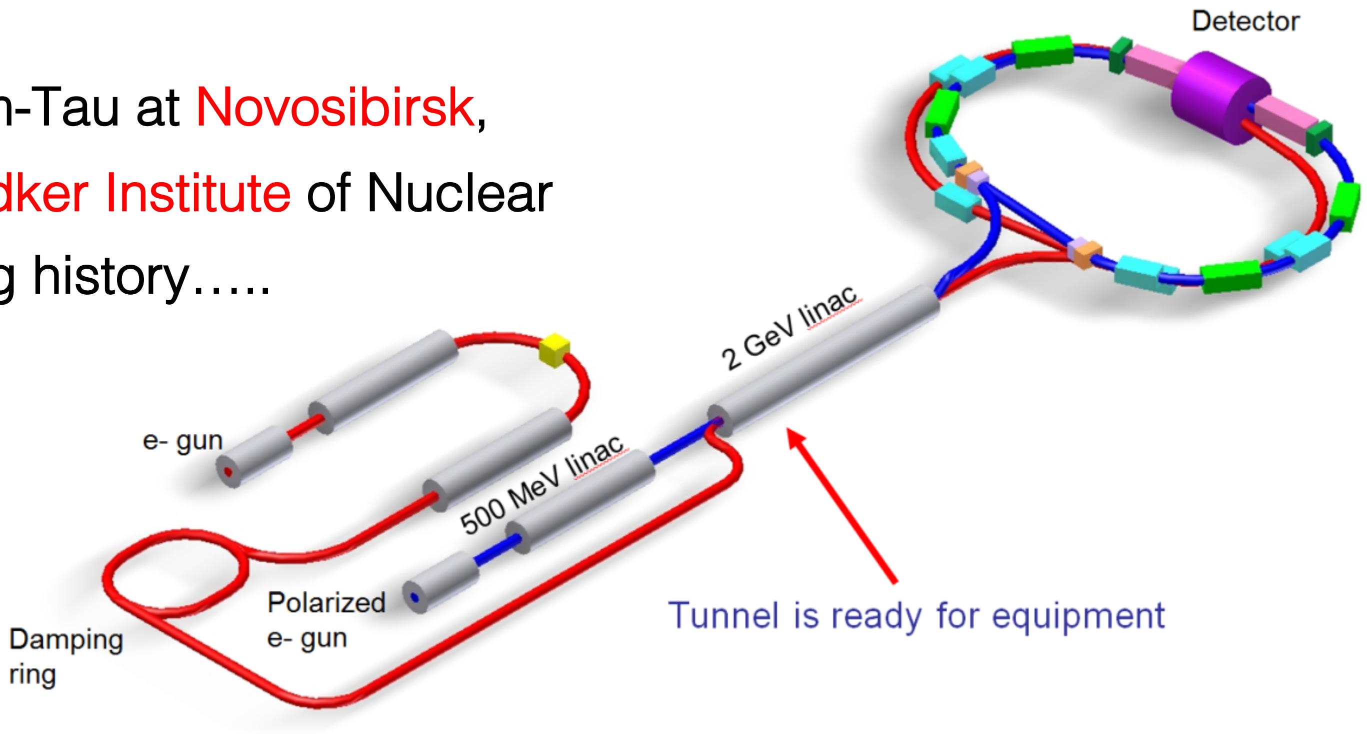
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030-2040	2041-2042
Form Group	🟩	🟩	🟩	🟩										
CDR	🟩	🟩	🟩	🟩										
TDR	🟩	🟩	🟩	🟩	🟩	🟩	🟩							
Construction							🟩	🟩	🟩	🟩	🟩	🟩		
In operation													🟩	
Upgrade														🟩

R&D budget: 200M RMB
Total budget: 4B RMB
(estimated in 2014)

单位：亿元	
eLinac	4.0+1.0 (阻尼环)
Electron ring	7.0
Positron ring	7.0
束线	1.2
实验谱仪	8.0
低温	1.0
配套设施	1.8
装置土建	6.0
不可预见	3.0
合计	40

International Collaboration

Super Charm-Tau at Novosibirsk, RUSSIA, Budker Institute of Nuclear Physics Long history…..



Tunnel is ready for equipment

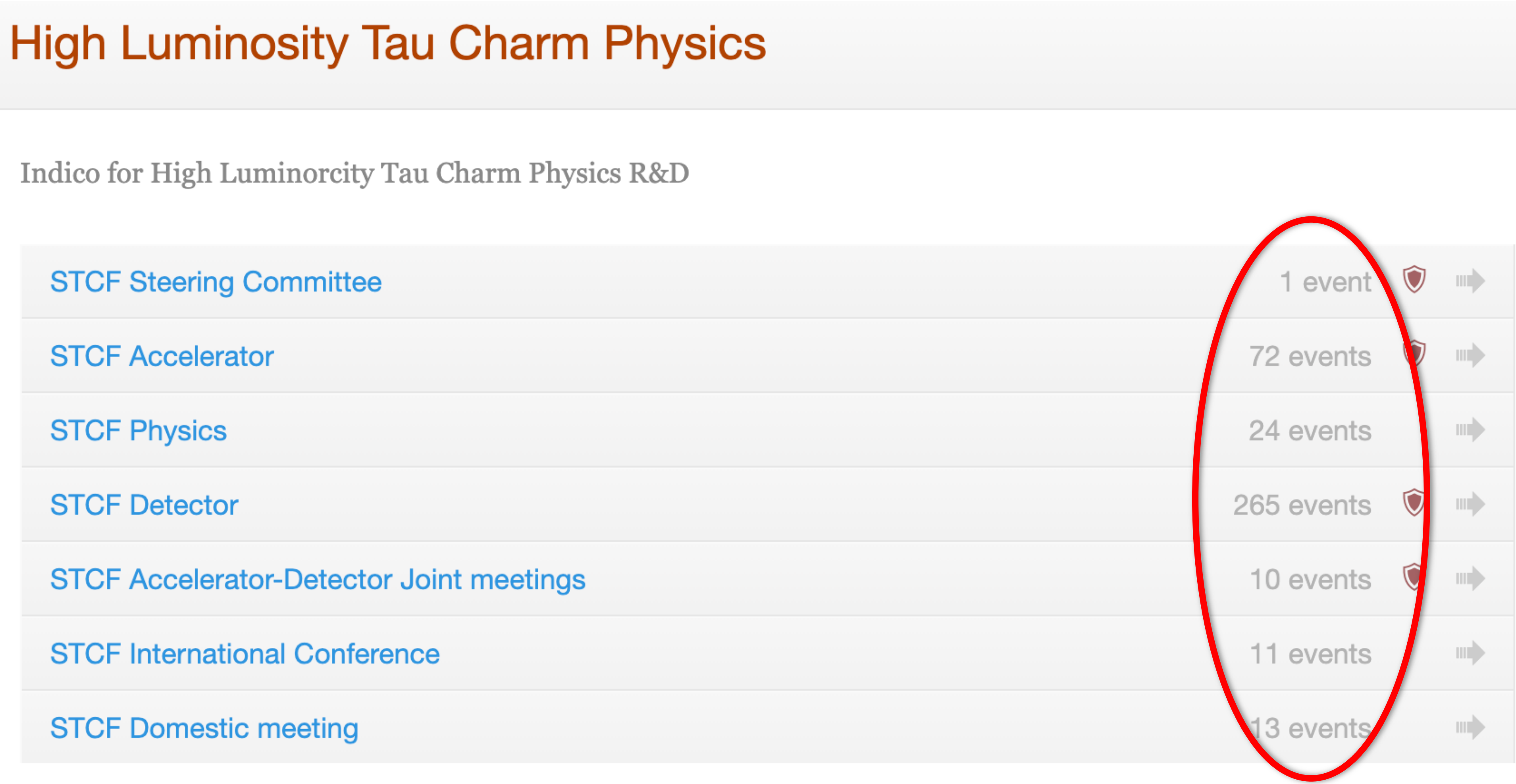
- Pre-Agreement of Joint effort on R&D, details are under negotiation
- Joint workshop between China, Russia, and Europe
  - 2018 UCAS (March), Novosibirsk (May), Orsay (December)
  - 2019 Moscow(September)

Strategy& Activities

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

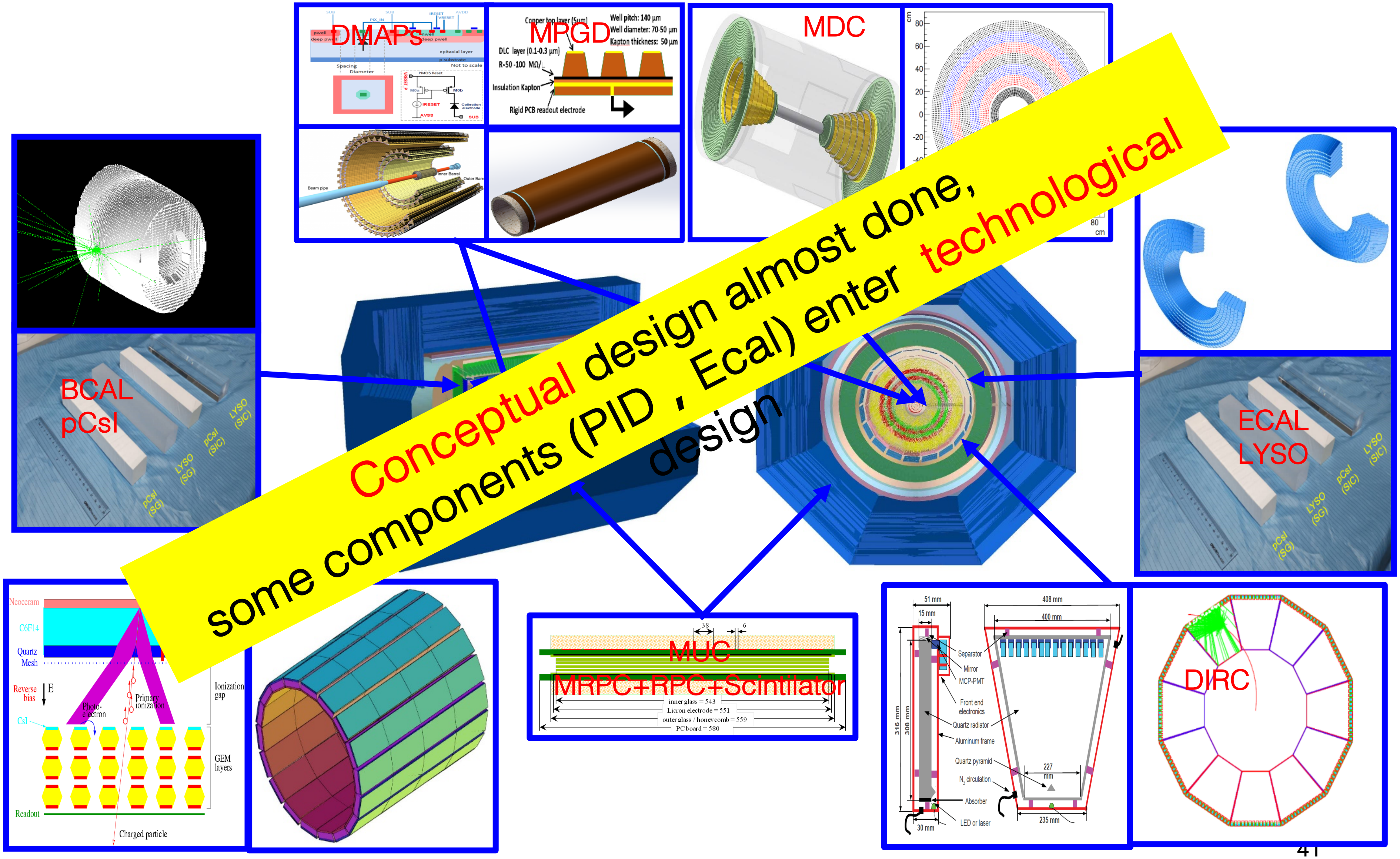


High Luminosity Tau Charm Physics

Indico for High Luminorcity Tau Charm Physics R&D

STCF Steering Committee	1 event
STCF Accelerator	72 events
STCF Physics	24 events
STCF Detector	265 events
STCF Accelerator-Detector Joint meetings	10 events
STCF International Conference	11 events
STCF Domestic meeting	13 events

Spectrometer



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

Summary

- **STCF** is **one of the crucial precision frontier**
- **Important playground for studying non-perturbtive QCD and search for new physics**
  - 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.
- Complementary to Belle-II and LHCb in understanding the QCD/EW models and searching for new physics
- Project organization is setup and a working group is toward for CDR/TDR

Thank you!

谢谢！

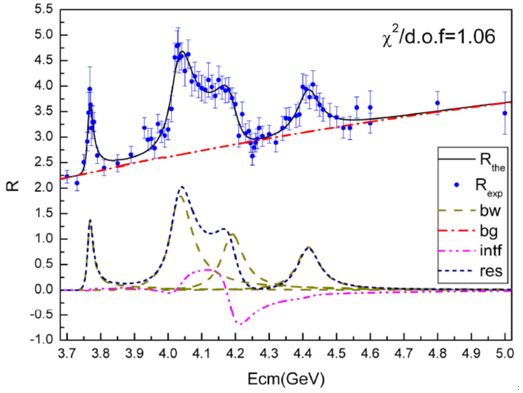
Charmonium(-like) states @ STCF

- ψ/Y/hybrid(ccg) (1^{--}) produced in the e^+e^- collision
  - To determine the resonance parameters for the excited ψ or Y state
  - Precisely measure the x-sec of inclusive/exclusive final states at different energy points
- Charge parity c=+ states produced via radiative transition from vector ψ/Y
  - The decay rate $\psi(nS/nD)\to\gamma X(3872)$, X(3940)…
  - Search for $\chi_{cJ}(2P)$、$\chi_{cJ}(3P)$、$\eta_c(3S)$、 $\eta_c(4S)$、 …

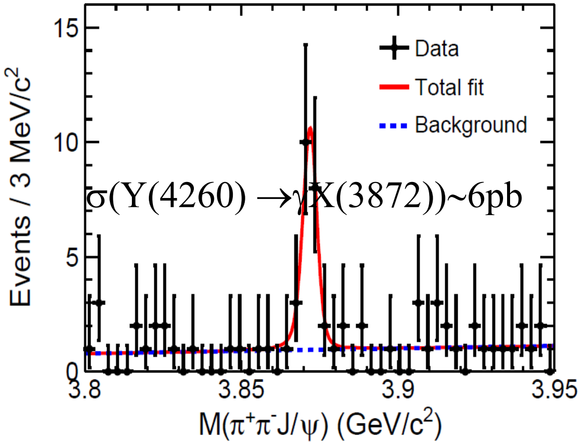
    $B(\psi(3S)\to\gamma\chi'_{cJ}) = (7, 3, 1) \times 10^{-4}$ for J=2,1,0

    [Rev. Mod. Phys. 80, 1161 (2008)]
- Search for new states from hadronic transition
  - To search for Zc, Zcs, hc(2P) ….

PLB 660, 315 (2008)



PRL 112, 092001 (2014)



$\sigma(Y(4260)\to\gamma X(3872))$~6pb

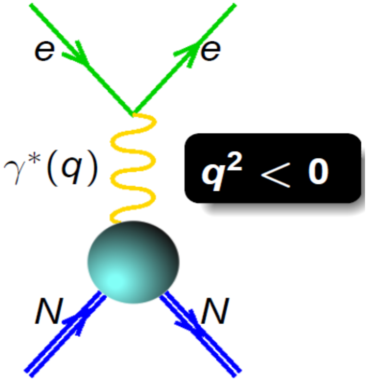
Nucleon Electromagnetic Form Factors (NEFFs)

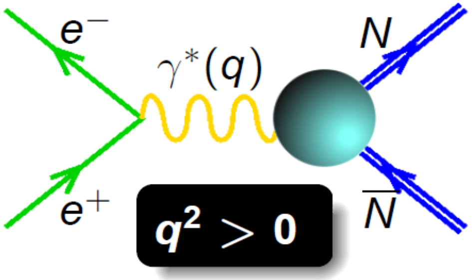
Spatial distributions of electric charge and current inside the nucleon

$eN \rightarrow eN$

$e^+e^- \leftrightarrow N\overline{N}, \Lambda\overline{\Lambda}$

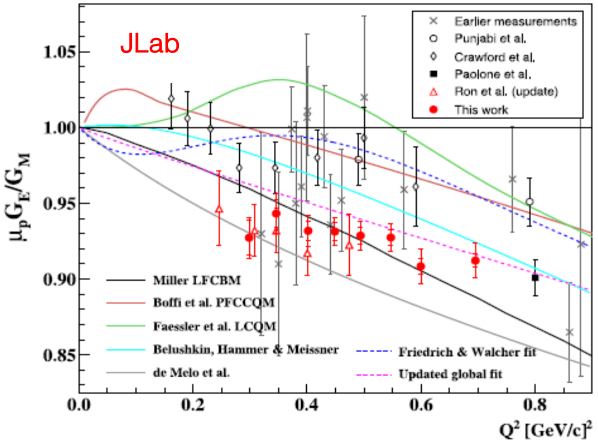
Space-like:
FF real

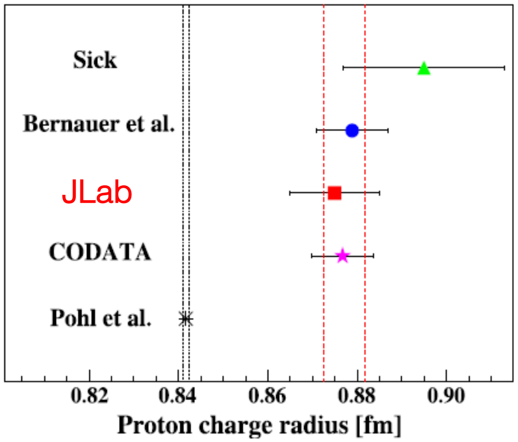




Time-like:
FF complex

Complete picture of nucleon structure requires space-like and time-like FF





Space-Like

FF

1% Precision

Collins Fragmentation Function (FF)

J. C. Collins, Nucl. Phys. B396, 161 (1993)

$$D_{hq^\uparrow}(z, P_{h\perp}) = D_1^q(z, P_{h\perp}^2) + \boxed{H_1^{\perp q}(z, P_{h\perp}^2)} \frac{(\hat{\mathbf{k}} \times \mathbf{P}_{h\perp}) \cdot \mathbf{S}_q}{z M_h},$$

***D*1: the un-polarized FF**

***H*1: Collins FF**

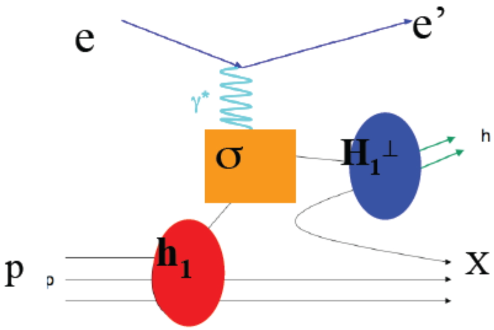
→ describes the fragmentation of a transversely polarized quark into a spin-less hadron *h*.

→ depends on $z = 2E_h/\sqrt{s}$,

→ leads to an azimuthal modulation of hadrons around the quark momentum.

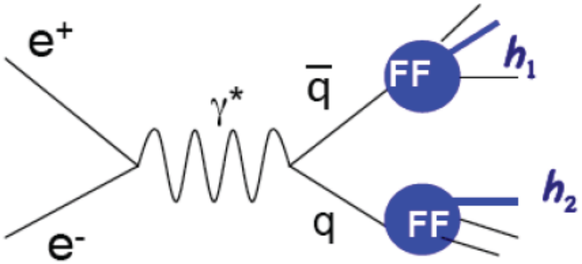
SIDIS

Transversity ⊗ Collins FF



e+ e-

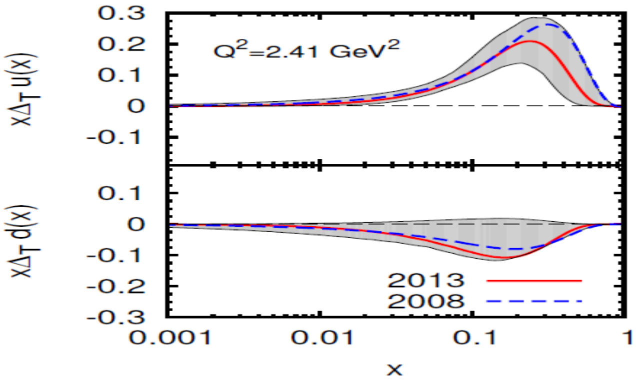
Collins FF ⊗ Collins FF



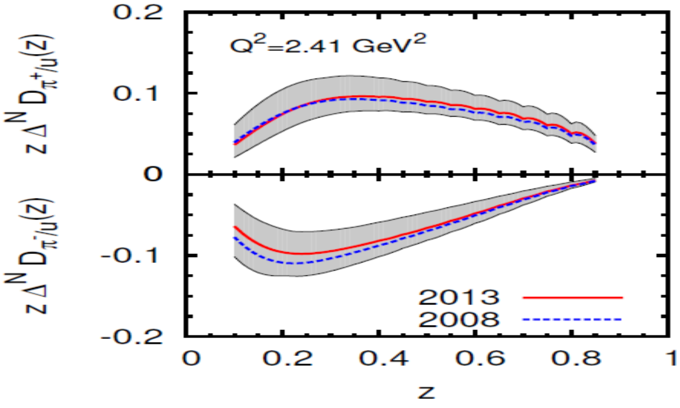
Collins Fragmentation Function (FF)

Anselmino et al., PRD 87, 094019 (2013)
Using data from HERMES, COMPASS, Belle

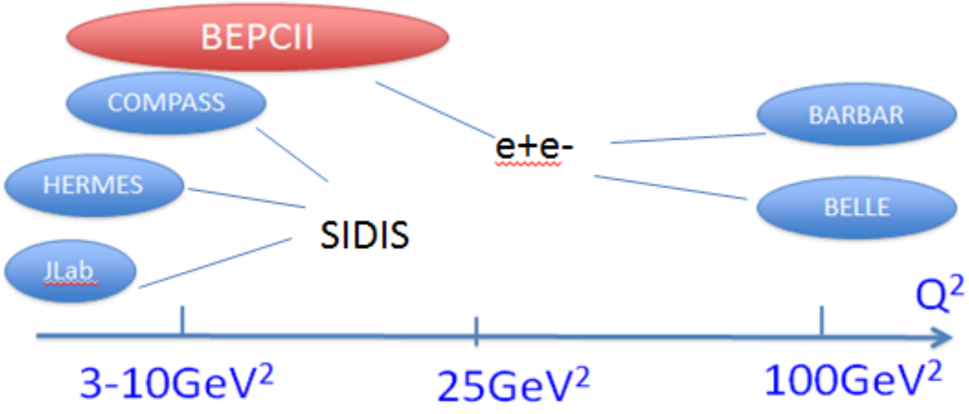
Transversity



Collins pion FF

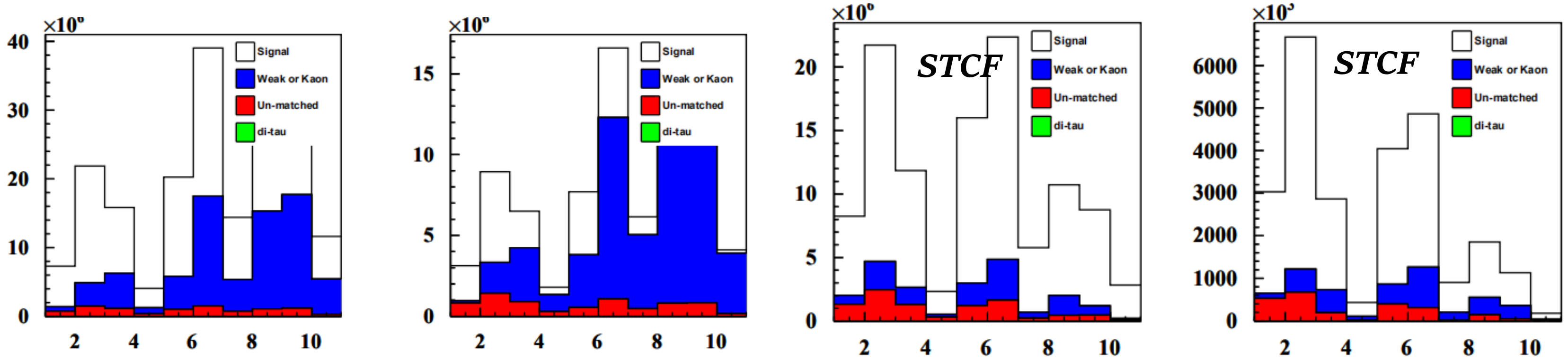


- ☐ The Q^2 evolution of Collins FFs was assumed following the extrapolation in the unpolarized FF, and this has not been validated.
- ☐ Low Q^2 data from e+e- collider is useful.
- ☐ **BEPCII / STCF**
  - **Similar Q2 coverage with SIDIS in EicC**



Collins Fragmentation Function (FF) at STCF

- STCF is a perfect machine for studying Collins effect
- Poor performance for the traditional de/dx & TOF PID system for tracks > 0.8GeV
- This measurement suffer from systematic uncertain from $K-\pi$ mis-PID.
- The mis-PID is even worse in the case of KK Collins measurement.
- With 2.5 fb^{-1} 7GeV $q\bar{q}$ MC ($\sigma \approx 5\text{nb}$ LundArlw), we study Collins effect at STCF.



Blue: $\pi-K$ mis-PID in KK Collins measurement.
Left) de/dx&TOF. Right) a 1% mis-PID set in FastSim

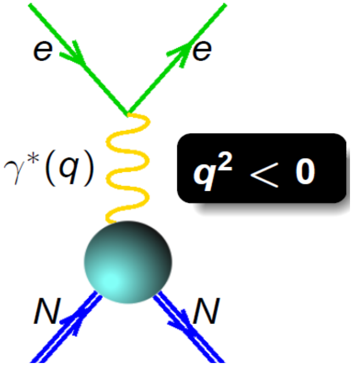
- By setting the $K-\pi$ mis-PID at 1%, we obtain:
  - The statistical uncertainty for 25fb^{-1} MC is ~10^{-3} to 10^{-2}
  - The statistical uncertainty for 1ab^{-1} MC is ~10^{-4} to 10^{-3}

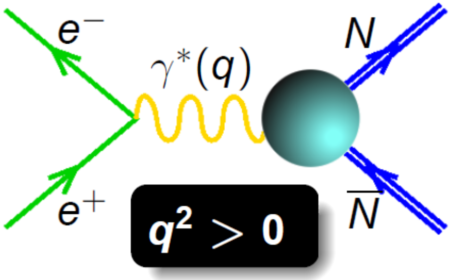
Nucleon Electromagnetic Form Factors (NEFFs)

Spatial distributions of electric charge and current inside the nucleon

$e^+e^- \leftrightarrow N\bar{N}$, ΛΛ

Space-like:
FF real





Time-like:
FF complex

Vector current, **two form factors** (F_1 and F_2)

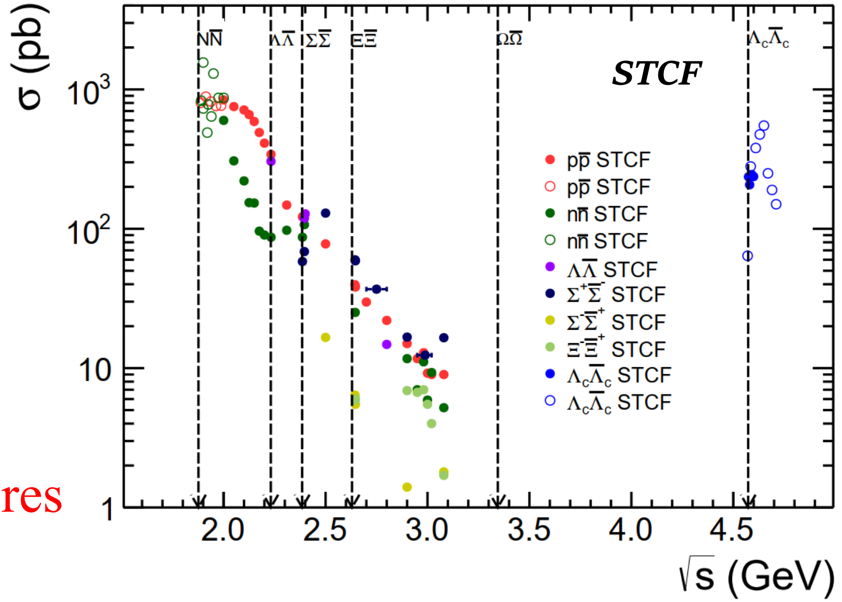
$$\Gamma_\mu = e\bar{u}(p')[F_1(q^2)\gamma_\mu + \frac{\kappa}{2M_N}F_2(q^2)i\sigma_{\mu\nu}q^\nu]u(p)e^{iqx}$$

Dirac	**Pauli**
$F_1^p(q^2=0)=1$	$F_2^p(q^2)=1$
$F_1^n(q^2=0)=0$	$F_2^n(q^2)=1$

Sachs

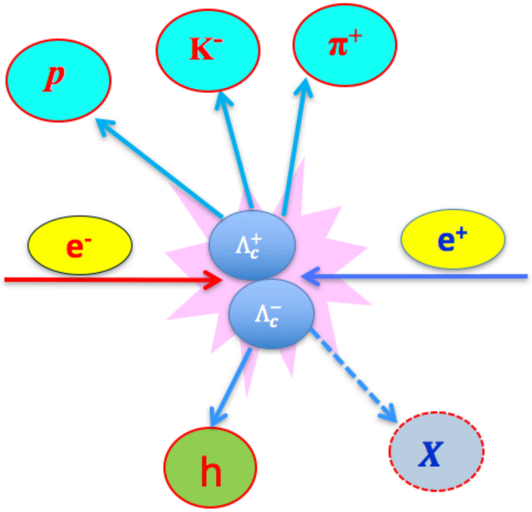
$$G_E = F_1 + \frac{\kappa q^2}{4M^2}F_2 \qquad G_M = F_1 + \kappa F_2$$

Complete picture of the nucleon structure requires space-like and time-like FF measurements!

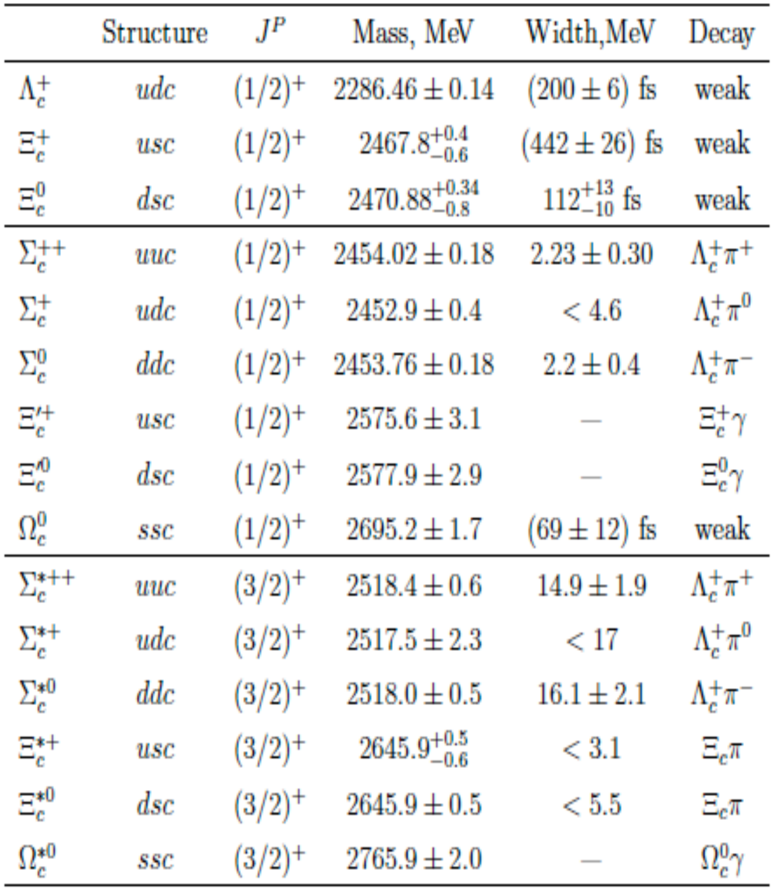


Charmed Baryons

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



- Systematic measurement of absolute decay BFs with well controlled systematics and low backgrounds
- Thorough studies on the charmed baryon spectroscopy



	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	$\Lambda_c^+\pi^-$
$\Xi_c^{\prime +}$	usc	$(1/2)^+$	2575.6 ± 3.1	—	$\Xi_c^+\gamma$
$\Xi_c^{\prime 0}$	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
Σ_c^{*++}	uuc	$(3/2)^+$	2518.4 ± 0.6	14.9 ± 1.9	$\Lambda_c^+\pi^+$
Σ_c^{*+}	udc	$(3/2)^+$	2517.5 ± 2.3	< 17	$\Lambda_c^+\pi^0$
Σ_c^{*0}	ddc	$(3/2)^+$	2518.0 ± 0.5	16.1 ± 2.1	$\Lambda_c^+\pi^-$
Ξ_c^{*+}	usc	$(3/2)^+$	$2645.9^{+0.5}_{-0.6}$	< 3.1	$\Xi_c\pi$
Ξ_c^{*0}	dsc	$(3/2)^+$	2645.9 ± 0.5	< 5.5	$\Xi_c\pi$
Ω_c^{*0}	ssc	$(3/2)^+$	2765.9 ± 2.0	—	$\Omega_c^0\gamma$

CP Violation in τ Decay

- CP violation is observed in B and K sectors, but not observed in lepton sector yet.
- Strongly suppressed in the SM ($A_{CP} \leq 10^{-12}$)
- A discovery of CPV in the tau sector would be a clean signature of NP
- One of the most promising CPV channels is $\tau^- \to K_S \pi^- \nu$

$$\mathcal{A}_\tau = \frac{\Gamma(\tau^+ \to \pi^+ K^0_S \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K^0_S \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K^0_S \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K^0_S \nu_\tau)}$$

  - SM CP asymmetry from K_S-K_L mixing is expected to be : [PLB 625, 2005; JHEP 1204 (2012) 002]

$$\mathcal{A}_\tau^{\rm SM} \simeq 2{\rm Re}(\epsilon) \simeq (0.36 \pm 0.01)\%$$

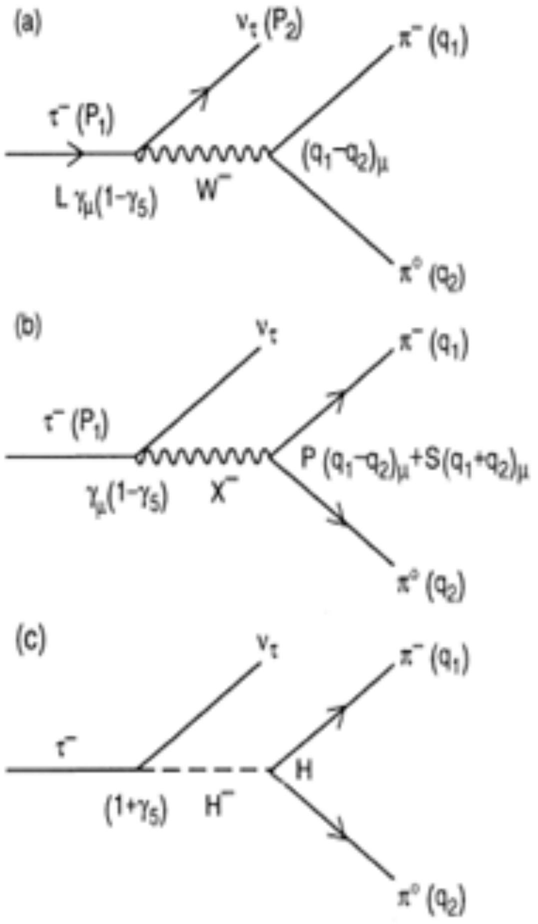
  - BaBar measurement [PRD 85, 099904] : 2.8σ from SM!

$$\mathcal{A}_\tau = (-0.36 \pm 0.23 \pm 0.11)\%$$

  - Belle measurement [PRL 107, 131801]: does not see any asymmetry at the *0.2 - 0.3% level*

$$A_{cp} = (1.8 \pm 2.1 \pm 1.4) \times 10^{-3} \ @ \ W \sim [0.89\text{-}1.11] \text{ GeV}$$

$$|{\rm Im}(\eta_S)| < 0.026 \text{ or better}$$



Charge Higgs, new Scalar,
W_L-W_R Mixings, LeptonQuarks?

τ EDM

- ☐ The τ magnetic and electric dipole moments may play an important role in elucidating the nature of this heavy lepton.
- ☐ If BSM exists in the lepton sector, tau lepton is an ideal test case, since it is expected to couple more strongly to BSM.
- ☐ Detect BSM through loop diagrams, and through its interference with the SM process – high statistics is needed. Ideal experiments: current (Belle II) and STCF

Belle II:

$\mathcal{L}$	1 ab^{-1}	10 ab^{-1}	50 ab^{-1}
$\lvert d_\tau^{NP} \rvert$ (e cm)	1.43×10^{-18}	4.51×10^{-19}	2.02×10^{-19}

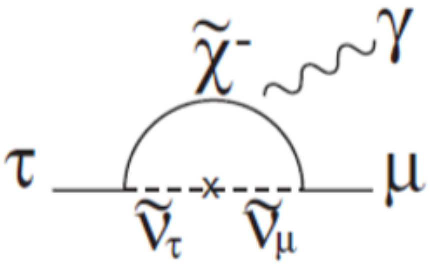
STCF (without polarized beams):

Time of data accumulation	1 year	5 years	10 years
$\lvert d_\tau^{NP} \rvert$ (e cm)	5.14×10^{-19}	2.30×10^{-19}	1.62×10^{-19}

LFV: a gateway to BSM

- Many extensions of SM naturally introduces cLFV at order ~**10^{-7} – 10^{-10}** (an crucial place to test BSM)

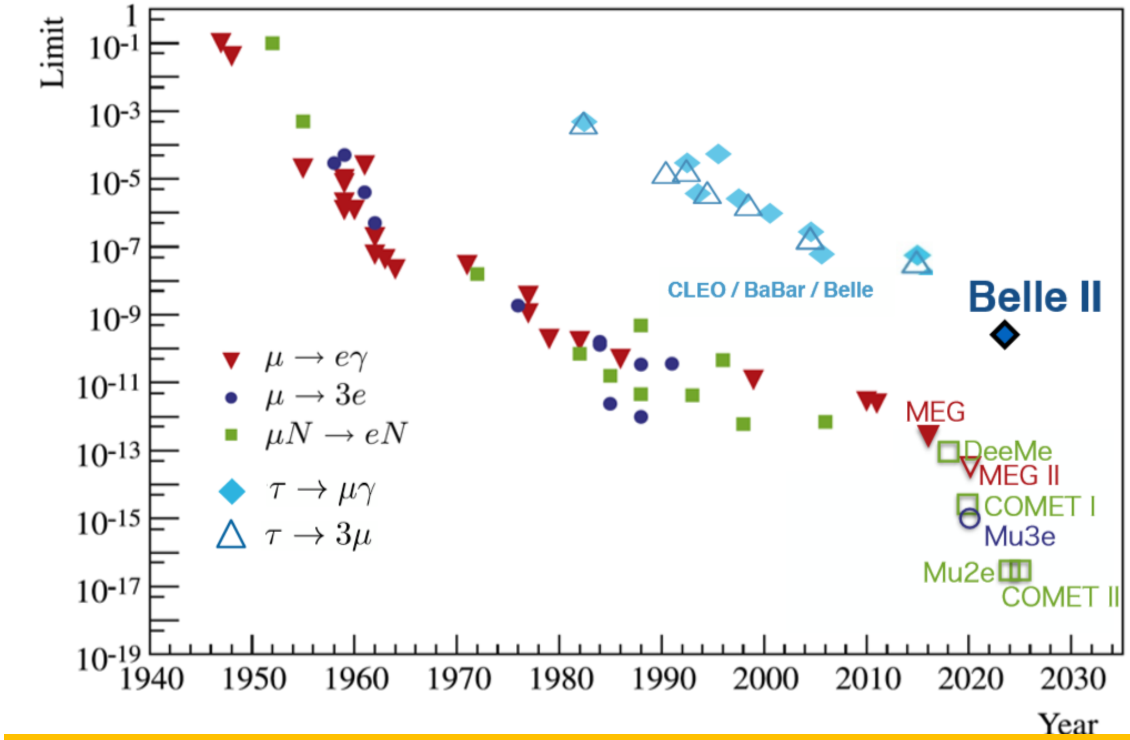
Model	Ref.	$\tau\to\mu\gamma$	$\tau\to\mu\mu\mu$
SM + heavy majorana	PRD 66.034008	10^{-9}	10^{-10}
Non-universal Z’	PLB 547(3)252	10^{-9}	10^{-8}
SUSY + seesaw	PRL 89:241802	10^{-10}	10^{-7}
SM + 4th generation	arXiv.1006.5306	10^{-8}	10^{-8}



- τ—the heaviest charged lepton:
  - Strength of interaction relate to new physics is naively expected to be mass-dependent
  - $\tau\to l\gamma$ and $\tau\to lll$ are golden mode, which are expected to have largest branching fraction

Evolution of limits

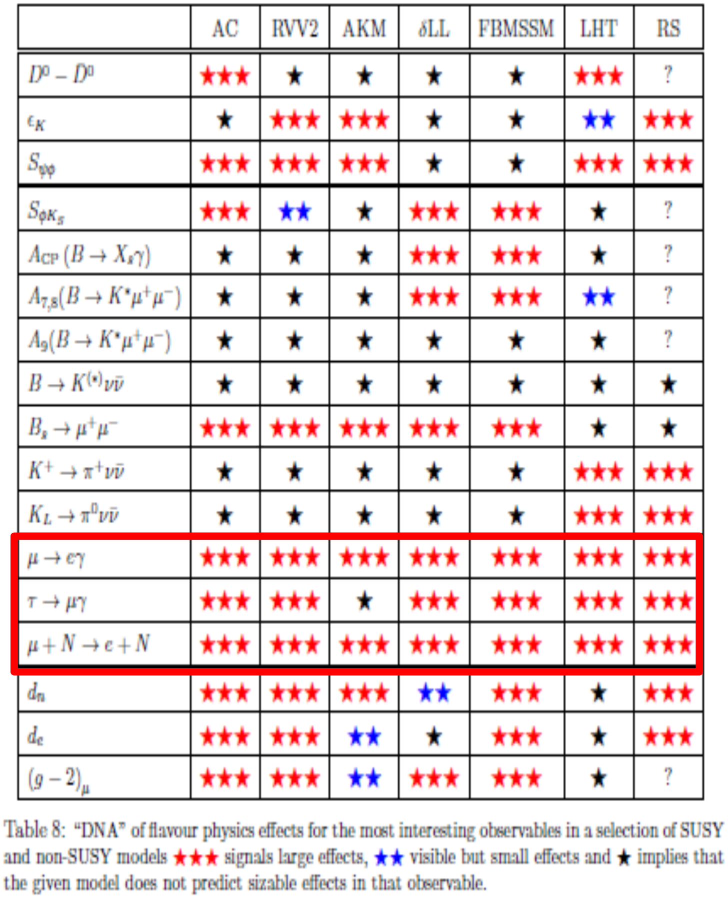
- Very rich experimental programme with substantial improvements expected in near future.
- Remarkable progress expected on Muon LFV searches.
- B factories expected to be the most powerful for tau LFV .



How about LFV at Super tau-charm factory?

cLFV Decay τ→ℓγ

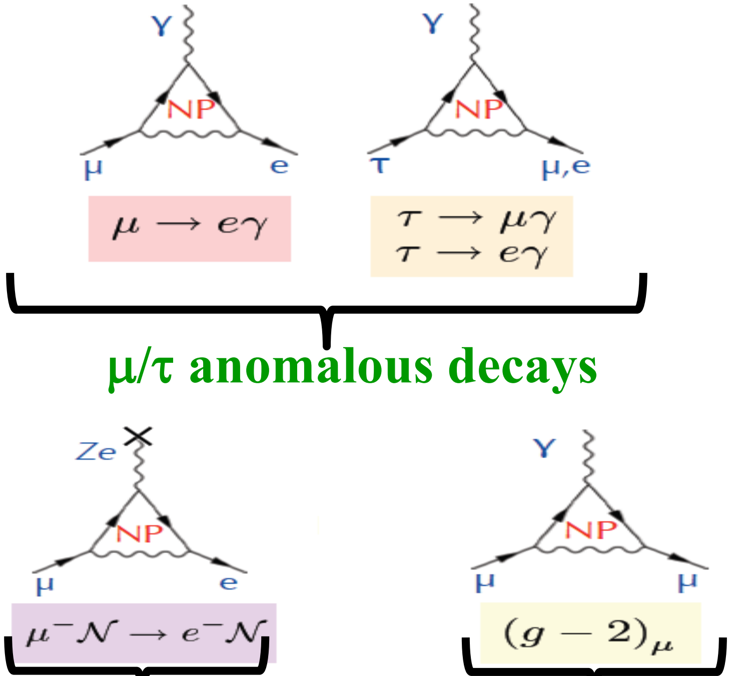
- No evidence of new physics been found at high energy frontier.
- important and complementary to search for new physics in the precision frontier.



	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0-\bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\rm CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

Table 8: "DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

W. Altmannshofer et al. arXiv : 0909.1333



$\mu \to e\gamma$

$\tau \to \mu\gamma$
$\tau \to e\gamma$

μ/τ anomalous decays

$\mu^- \mathcal{N} \to e^- \mathcal{N}$

$(g-2)_\mu$

μ → e conversion

Anomalous magnetic moment

In τ-charm factory, τ→μγ decay is a golden mode to search for NP

	BES III 10^{33} cm^{-2}s^{-1}	STCF 10^{35}cm^{-2}s^{-1} (1ab^{-1})
J/ψ	10×10^{9}	10×10^{11}
$\psi(2S)$	3×10^{9}	3×10^{11}
D(3.773GeV)	6×10^{7}	6×10^{9}
Ds (4.17 GeV)	1×10^{7}	1×10^{9}
$\tau^+\tau^-$ (3.68GeV)		2.4×10^{9}
$\tau^+\tau^-$ (4.25GeV)	3×10^{7}	3.5×10^{9}
$\Lambda_c^+\Lambda_c^-$(4.64GeV)	3×10^{6}	6×10^{8}

Charm mixing and CPV parameters

- For quantum-incoherent D^0 meson samples[1]:

$$\overline{P}'\left(m_{12}^2, m_{13}^2\right) = a_0\overline{P} + a_1 r_{CP}^{-2} P + r_{CP}^{-1}\sqrt{P\overline{P}}\left(C^- a_2 + S^- a_3\right)$$

$$\begin{aligned}
r_{CP}e^{i\alpha_{CP}} &= \frac{q}{p}, \\
S^{\pm} &= \sin\left(\Delta\delta_D \pm \alpha_{CP}\right), \\
C^{\pm} &= \cos\left(\Delta\delta_D \pm \alpha_{CP}\right),
\end{aligned}$$

$$\begin{aligned}
a_0 &= \frac{1}{2}\left(\frac{1}{1-y_D^2} + \frac{1}{1+x_D^2}\right) \\
&= 1 + \frac{1}{2}\left(-x_D^2 + y_D^2\right) + O\left((x_D+y_D)^3\right), \\
a_1 &= \frac{1}{2}\left(\frac{1}{1-y_D^2} - \frac{1}{1+x_D^2}\right) \\
&= \frac{1}{2}\left(x_D^2 + y_D^2\right) + O\left((x_D+y_D)^3\right), \\
a_2 &= \frac{y_D}{1-y_D^2} = y_D + O\left((x_D+y_D)^3\right), \\
a_3 &= \frac{x_D}{1+x_D^2} = x_D + O\left((x_D+y_D)^3\right).
\end{aligned}$$

- For quantum-coherent $D^0\overline{D}^0$ samples:

$$\begin{aligned}
P_{corr}^{\mathcal{C}}\left(\left(m_{12}^2\right)_1, \left(m_{13}^2\right)_1, \left(m_{12}^2\right)_2, \left(m_{13}^2\right)_2\right) = {} & b_0^{\mathcal{C}}\left[P_1\overline{P}_2 + \overline{P}_1 P_2 + 2\mathcal{C}\sqrt{P_1\overline{P}_1 P_2\overline{P}_2}\left(C_1C_2 + S_1S_2\right)\right] \\
& + b_1^{\mathcal{C}}\left[r_{CP}^{-2}P_1P_2 + r_{CP}^{2}\overline{P}_1\overline{P}_2 + 2\mathcal{C}\sqrt{P_1\overline{P}_1 P_2\overline{P}_2}\left(C_1^+C_2^+ - S_1^+S_2^+\right)\right] \\
& + b_2^{\mathcal{C}}\left[\sqrt{P_2\overline{P}_2}C_2^+\left(r_{CP}\overline{P}_1 + r_{CP}^{-1}P_1\right) + \mathcal{C}\sqrt{P_1\overline{P}_1}C_1^+\left(r_{CP}\overline{P}_2 + r_{CP}^{-1}P_2\right)\right] \\
& + b_3^{\mathcal{C}}\left[\sqrt{P_2\overline{P}_2}S_2^+\left(r_{CP}\overline{P}_1 - r_{CP}^{-1}P_1\right) + \mathcal{C}\sqrt{P_1\overline{P}_1}S_1^+\left(r_{CP}\overline{P}_2 - r_{CP}^{-1}P_2\right)\right],
\end{aligned}$$

$$\begin{aligned}
b_0^{\mathcal{C}} &= \frac{1}{2}\left[\frac{1+\mathcal{C}y_D^2}{\left(1-y_D^2\right)^2} + \frac{1-\mathcal{C}x_D^2}{\left(1+x_D^2\right)^2}\right] \approx a_0 + \frac{\mathcal{C}+1}{2}\left(-x_D^2 + y_D^2\right) \\
b_1^{\mathcal{C}} &= \frac{1}{2}\left[\frac{1+\mathcal{C}y_D^2}{\left(1-y_D^2\right)^2} - \frac{1-\mathcal{C}x_D^2}{\left(1+x_D^2\right)^2}\right] \approx (\mathcal{C}+2)\,a_1, \\
b_2^{\mathcal{C}} &= \frac{(1+\mathcal{C})\,y_D}{\left(1-y_D^2\right)^2} \approx (1+\mathcal{C})\,a_2, \\
b_3^{\mathcal{C}} &= \frac{(1+\mathcal{C})\,x_D}{\left(1+x_D^2\right)^2} \approx (1+\mathcal{C})\,a_3,
\end{aligned}$$

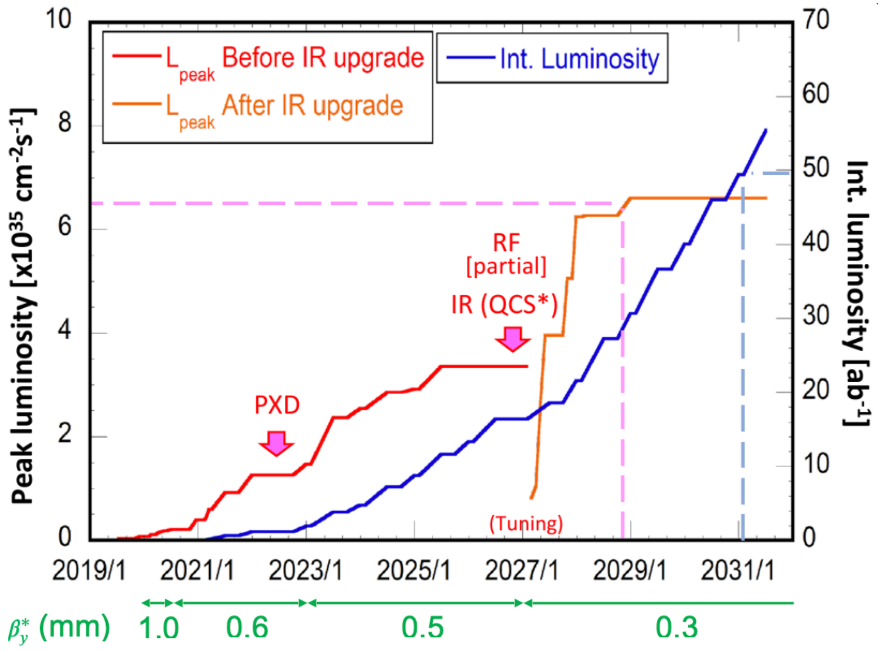
Integral Luminosity of STCF

- No Synchrotron radiation mode, assume running time 9 months/year
- Assume data taking efficiency 90%

$$0.5 \times 10^{35}\text{cm}^{-2}\text{s}^{-1} \times 86400\text{s} \times 270\text{days} \times 90\% \sim \mathbf{1.0ab^{-1}/year}$$

10 years data taking, total 20 ab^{-1} conservatively

Excellent opportunities for the τ-charm physics



at Belle II

- each 1 ab^{-1} dataset provides
  - $\sim 1.1 \times 10^9$ $B\bar{B} \Rightarrow$ a B-factory;
  - $\sim 1.3 \times 10^9$ $c\bar{c} \Rightarrow$ a charm factory;
  - $\sim 0.9 \times 10^9$ $\tau^+\tau^- \Rightarrow$ a τ factory;
  - wide $E_{\text{CM}}^{\text{eff.}}$=[0.5-10] GeV via ISR.