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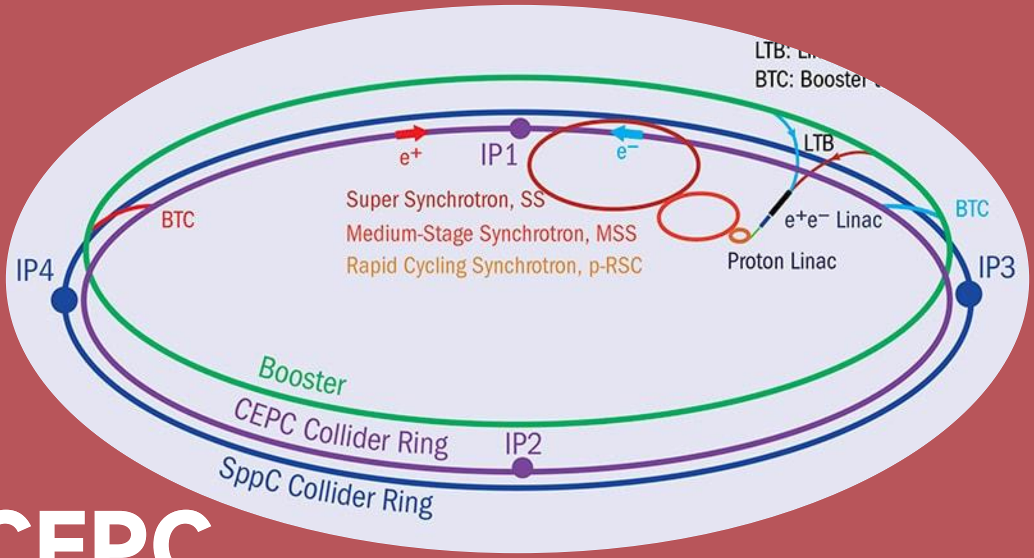

Production of Tcc via photon-photon fusion at CEPC

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Nov. 2025, Guangzhou

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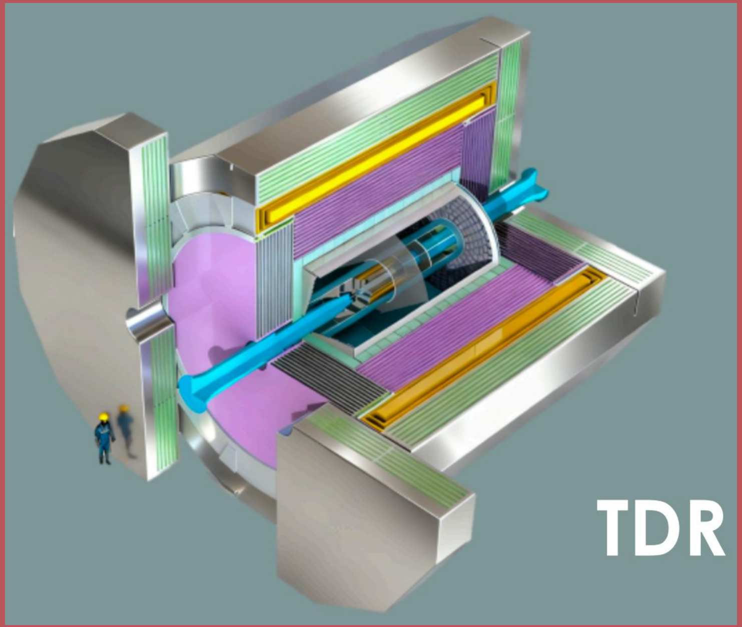


INTERNATIONAL WORKSHOP
ON THE HIGH ENERGY CIRCULAR ELECTRON POSITRON COLLIDER
CEPC 2025

Contents

01

Motivation

Motivation

Photon-photon physics at CEPC

Two photon energy spectrum

$$\frac{d(f_1 f_2)}{d\tau} = \int_{\frac{1}{2}ln\tau}^{-\frac{1}{2}ln\tau} f_1(\sqrt{\tau}e^{y_{cm}})\, f_2(\sqrt{\tau}e^{y_{cm}})$$

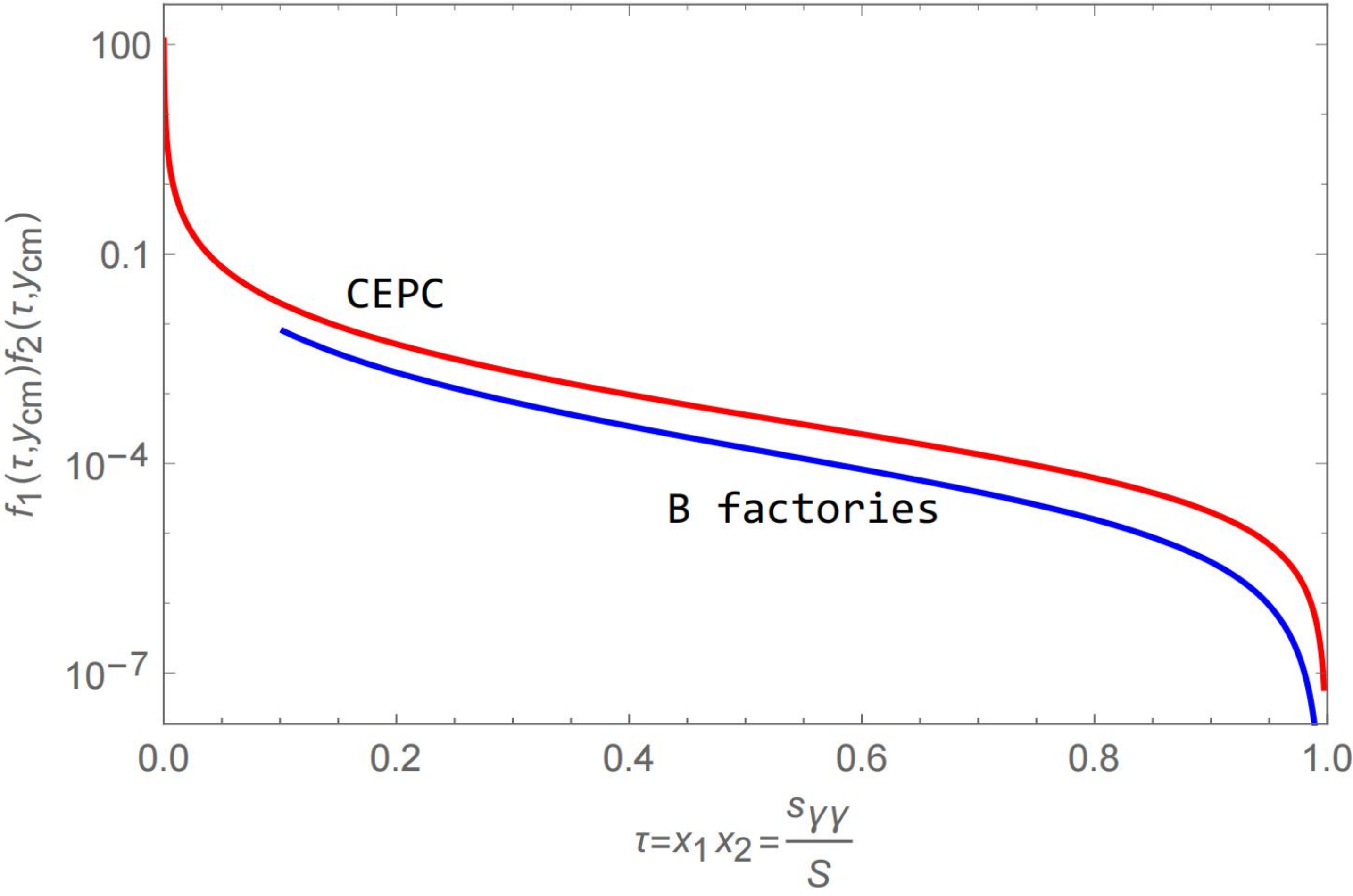
with WWA photon spectrum

$$f(x) = \frac{\alpha}{2\pi}\left(\frac{1+(1-x)^2}{x} ln\left(\frac{Q^2_{max}}{Q^2_{min}}\right) + 2m_e^2\left(\frac{1}{Q^2_{max}} - \frac{1}{Q^2_{min}}\right)\right)$$

$$x = \frac{E_\gamma}{E_e}$$

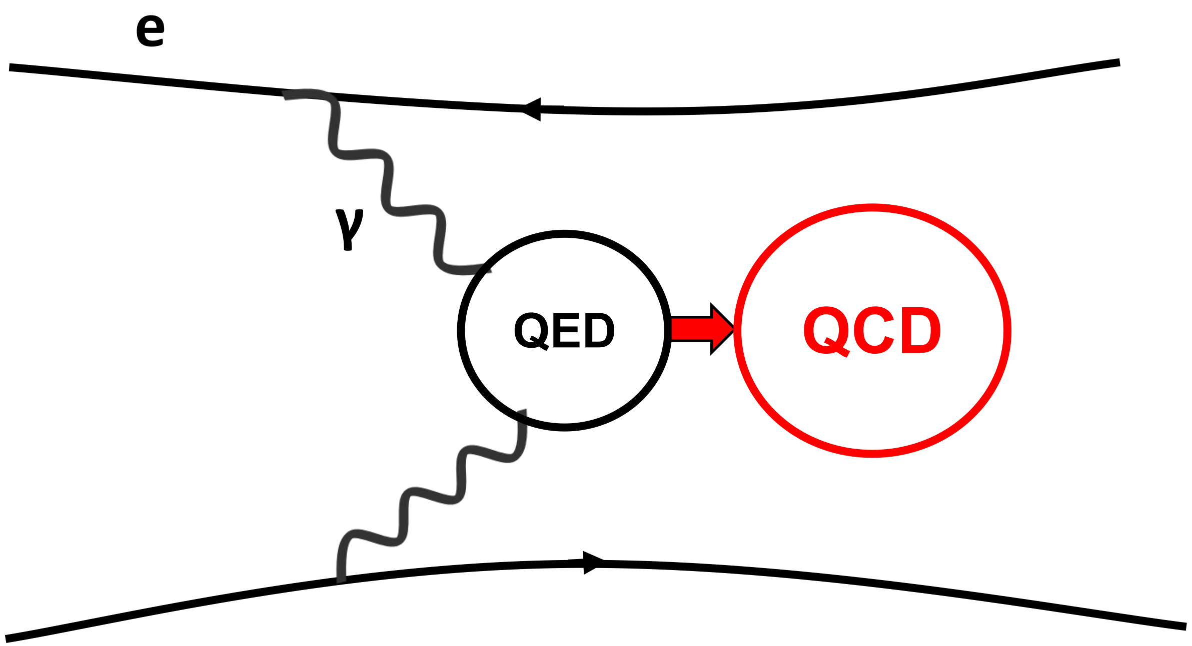
$$Q^2_{max} = (\theta_c\sqrt{S}/2)^2(1-x) + Q^2_{min}$$

$$Q^2_{min} = m_e^2 x^2/(1-x)$$



Motivation

QCD at CEPC



Clean enviroment enable measurements not possible at LHC

- No pileup,
- background under control

Motivation

Tcc Production:

perturbative & non-perturbative

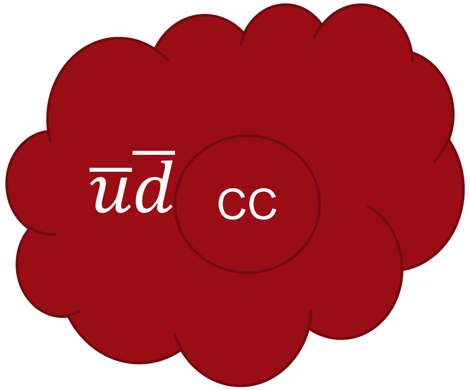
Perturbative creation of (anti-)charm quarks

$m_c \gg \Lambda_{QCD}$

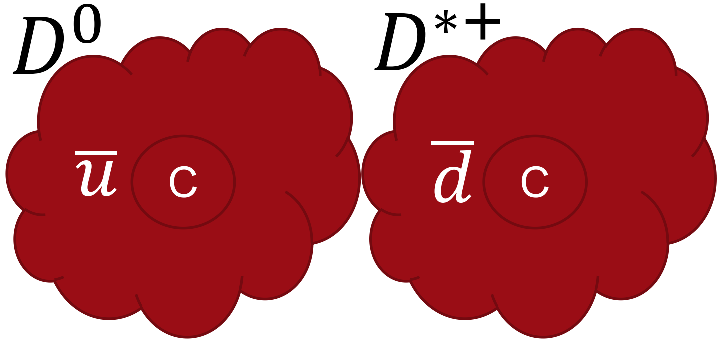
Non-perturbative transiton into (exotic) hadrons

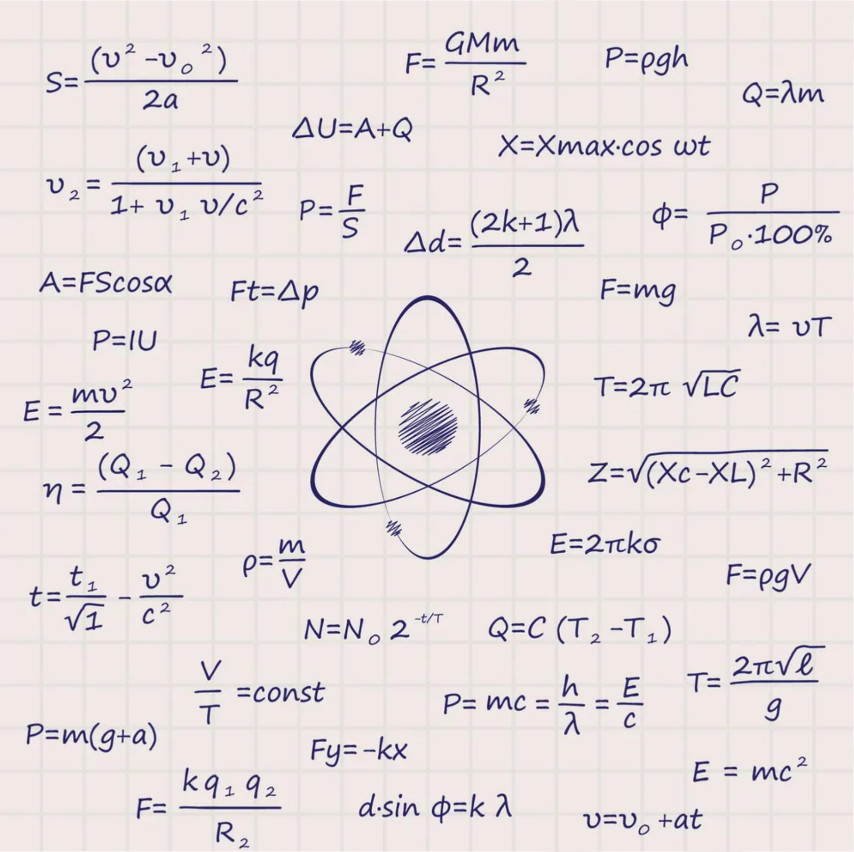
$\mu \ll \Lambda_{QCD}$

Tcc: compact tetraquark



Tcc: charm-meson molecule





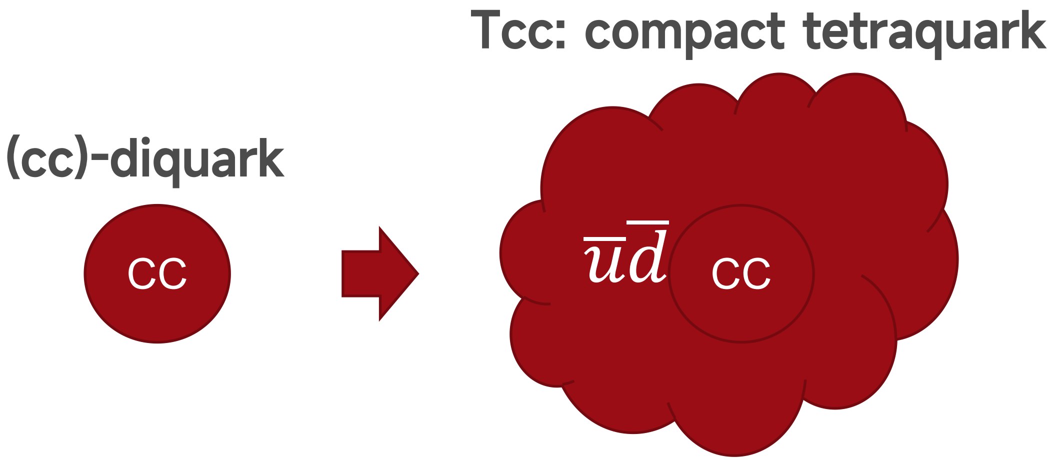
02 Formulism

Formulism

Diquark fragmentation model

Step 1: the perturbative production of the (cc)-diquark, which is of the non-relativistic nature.

Step 2: the nonperturbative hadronization of colored (cc)-diquark into Tcc.



Note: this fragmentation contribution becomes dominant only in the large pt region.

Formulism

Diquark fragmentation model

Step 1: (cc)-diquark production

- **Amplitudes**: amplitudes of diquark differ from those of quarkonium by a sign factor:

$$M_{diquark} = (-1)^{\rho+1} M_{meson}$$

ρ: counts of vector vertices in the reversed Fermion line

- **Color**: (cc)-diquark can be either color $\bar{3}$ or 6

$$C^{ijkl}_{\bar{3}\times 3} = \frac{1}{\sqrt{12}}\left(\delta_{ik}\delta_{jl} - \delta_{il}\delta_{jk}\right) \qquad C^{ijkl}_{6\times\bar{6}} = \frac{1}{\sqrt{24}}\left(\delta_{ik}\delta_{jl} + \delta_{il}\delta_{jk}\right)$$

Formulism

Diquark fragmentation model

Step 2: hadronization

- Model I: potential models, e.g. harmonic oscillator potential (HOP)

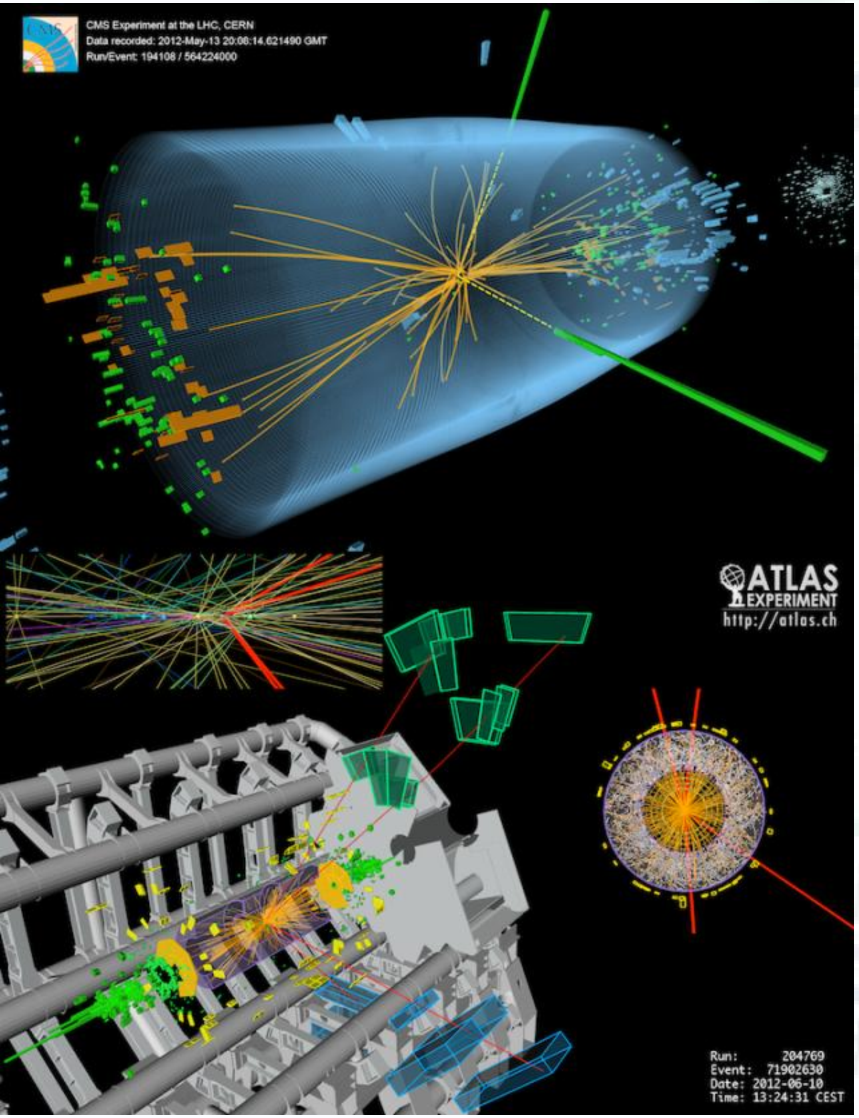
$$\mathcal{P}\left((cc)[n] \rightarrow T_{cc}[n]\right) \longrightarrow |\Psi_{T_{cc[n]}}(r=0)|^2 = \frac{|R_{T_{cc[n]}}(r=0)|^2}{4\pi}$$

- Model II: heavy diquark-antiquark symmetry (HDAS)

$$(cc)_{\bar{3}} \rightarrow T_{cc}(cc\bar{u}\bar{d}) \Longleftrightarrow \bar{c}_{3} \rightarrow \bar{\Lambda}_c^-(\bar{c}\bar{u}\bar{d})$$

$$\mathcal{P}\left((cc)[^3S_1]_{\bar{3}} \rightarrow T_{cc}[^3S_1]_{\bar{3}}\right) \longrightarrow |\Psi_{cc}(0)|^2 \times f(c \rightarrow \Lambda_c^+)$$

Note: transition probability in HDAS scheme is about 2.7% of that in HOP scheme.


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
ATLAS
EXPERIMENT
http://atlas.ch
Run: 204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST

03 Results

Results

Cross sections

Finding 1: cross secctions increase with center-of-mass energy.

Finding 2: strong dependece on charm quark mass m_c, and hadronization models.

Finding 3: contribution from $[^3S_1]_{\bar{3}}$ state dominates, while that from $[^1S_0]_6$ is negligible.

SuperKEKB σ: $\times 10^{-3}$ fb	$T_{cc}[^1S_0]_6$ (HOP)	$T_{cc}[^3S_1]_{\bar{3}}$ (HOP)	$T_{cc}[^3S_1]_{\bar{3}}$ (HDAS)
$m_c = 1.94$	0.13	20.94	0.57
$m_c = 1.7$	0.46	58.44	1.60
$m_c = 1.5$	1.24	134.94	3.68

CEPC σ: fb	$T_{cc}[^1S_0]_6$ (HOP)	$T_{cc}[^3S_1]_{\bar{3}}$ (HOP)	$T_{cc}[^3S_1]_{\bar{3}}$ (HDAS)
$m_c = 1.94$	3.46	124.94	3.41
$m_c = 1.7$	5.42	181.08	4.94
$m_c = 1.5$	8.47	261.52	7.14

ILC σ: fb	$T_{cc}[^1S_0]_6$ (HOP)	$T_{cc}[^3S_1]_{\bar{3}}$ (HOP)	$T_{cc}[^3S_1]_{\bar{3}}$ (HDAS)
$m_c = 1.94$	24.85	416.39	11.37
$m_c = 1.7$	35.15	577.87	15.78
$m_c = 1.5$	49.88	801.17	21.87

Results

Events

SuperKEKB, $\sqrt{s}$=10.6 GeV, L=8×10^{35} cm^{-2}s^{-1}: 5~10^{4} per year

CEPC, $\sqrt{s}$=240 GeV, L=10^{34} cm^{-2}s^{-1}: (0.7~27)×10^{3} per year

ILC, $\sqrt{s}$=500 GeV, L=2×10^{34} cm^{-2}s^{-1}: (0.7~17)×10^{4} per year

With branching fractions $Br(T_{cc} \to D^0 D^0 \pi^+) \approx 100\%$ $\quad Br(D^0 \to K^- \pi^+) \approx 4\%$

SuperKEKB: 0~16 per year

CEPC: 1~43 per year

ILC: 11~272 per year

Experimental study of Tcc at CEPC and ILC is promising.

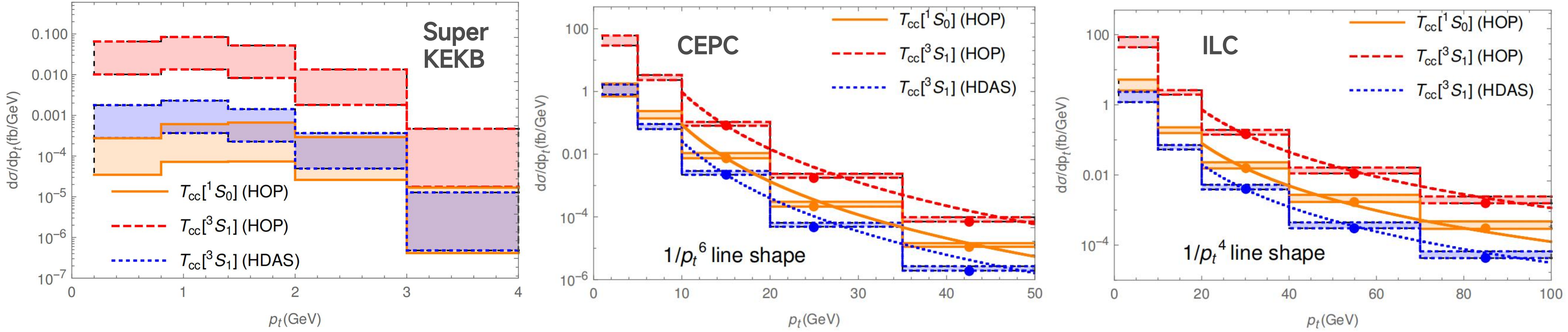
Results

Pt distribution

- CEPC data (small pt region) scales with $1/pt^6$ which implies double parton fragmentation dominates.
- ILC data (large pt region) scales with $1/pt^4$ which implies single parton fragmentation dominates.

Common Feature

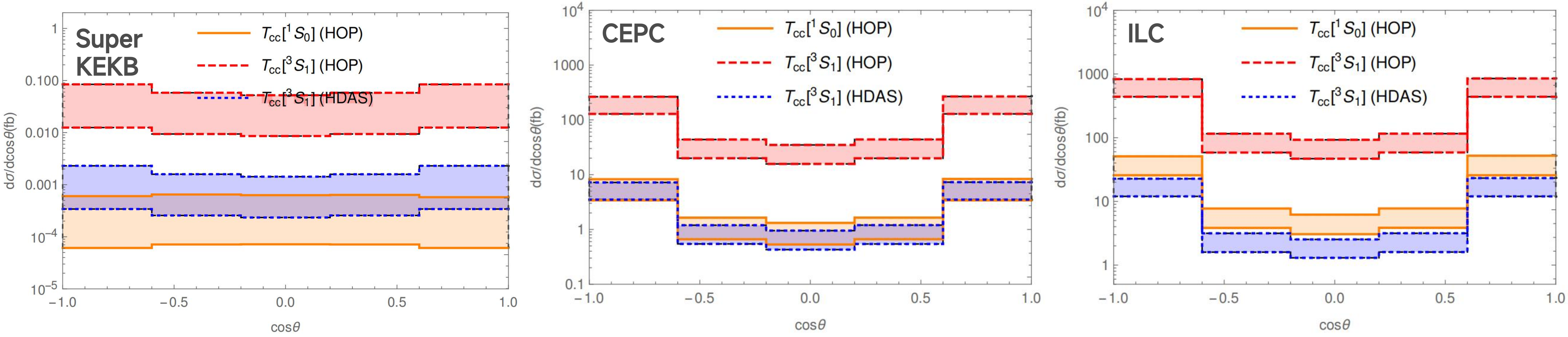
These are analogous to the charmonium production because of the diquark fragmentation model.

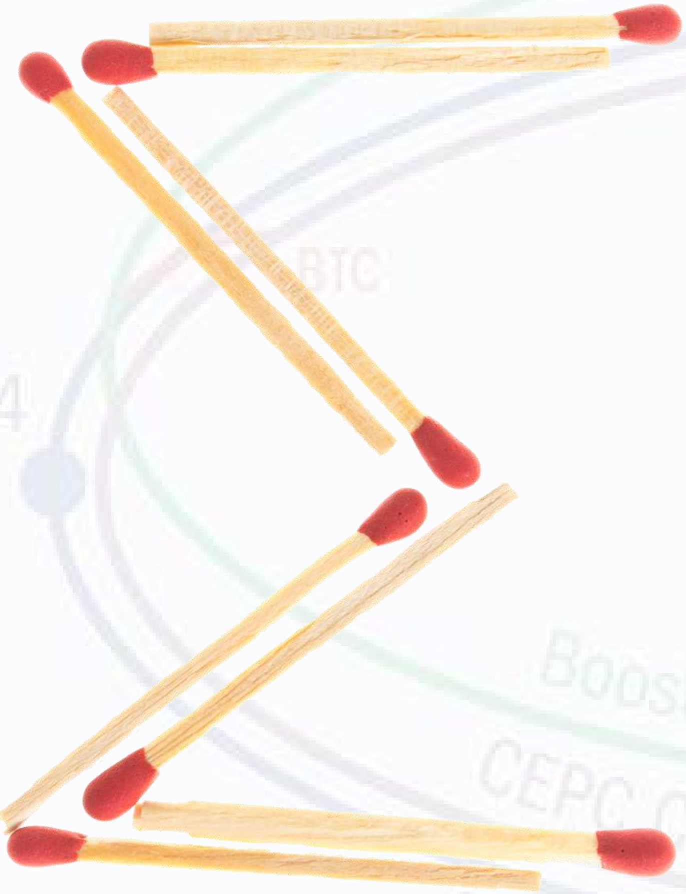


Results

Angle distribution

- SuperKEKB, CEPC and ILC have similar angle differential distributions.



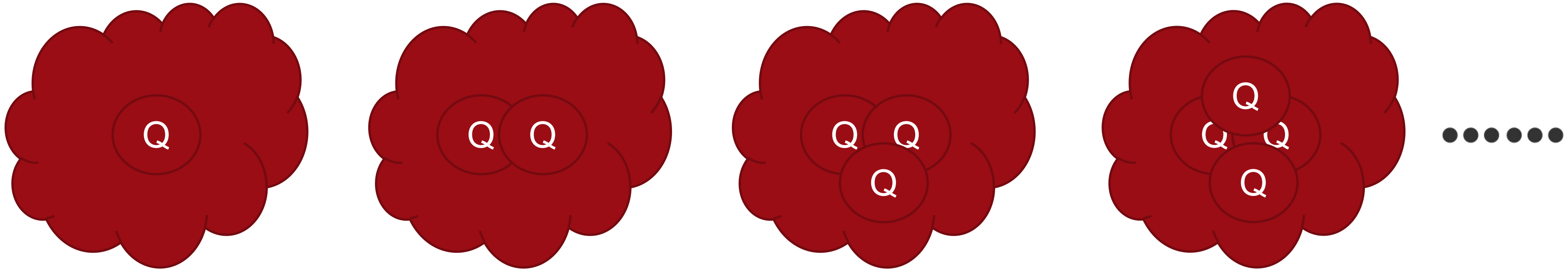


04 Summary

Summary

- Conclusion 1: It is promising to study the inclusive Tcc production at CEPC and ILC.
- Conclusion 2: The pt distribution of Tcc exhibit analogous behaviour as charmonium:
  scales as $1/pt^4$ at large pt while sacles as $1/pt^6$ at relative smaller pt.

- Outlook: Opportunities of studying multiquark exotic states at CEPC!



What is at the end of multiquark states?

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Thank You!

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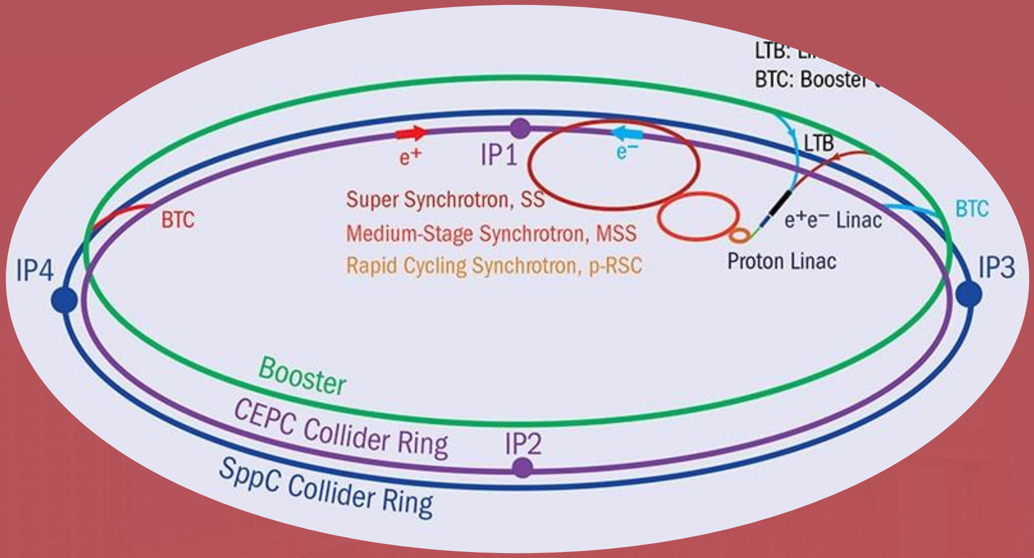

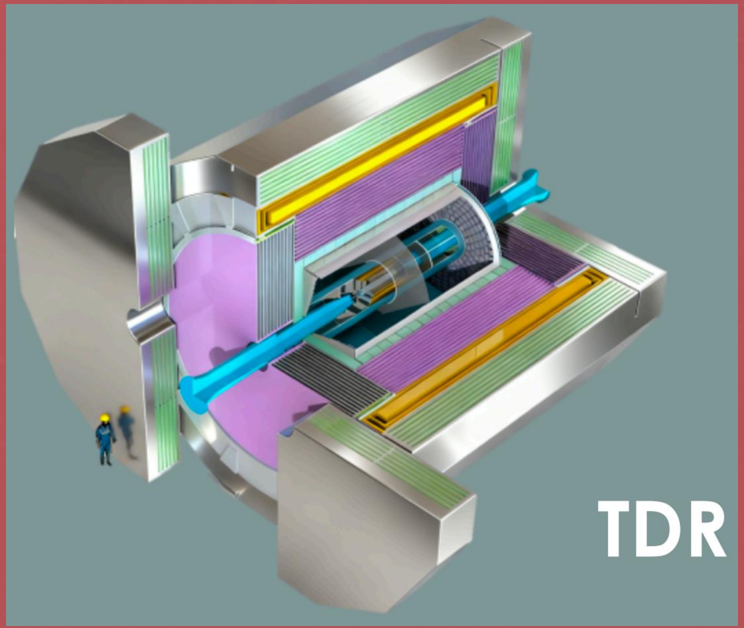

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