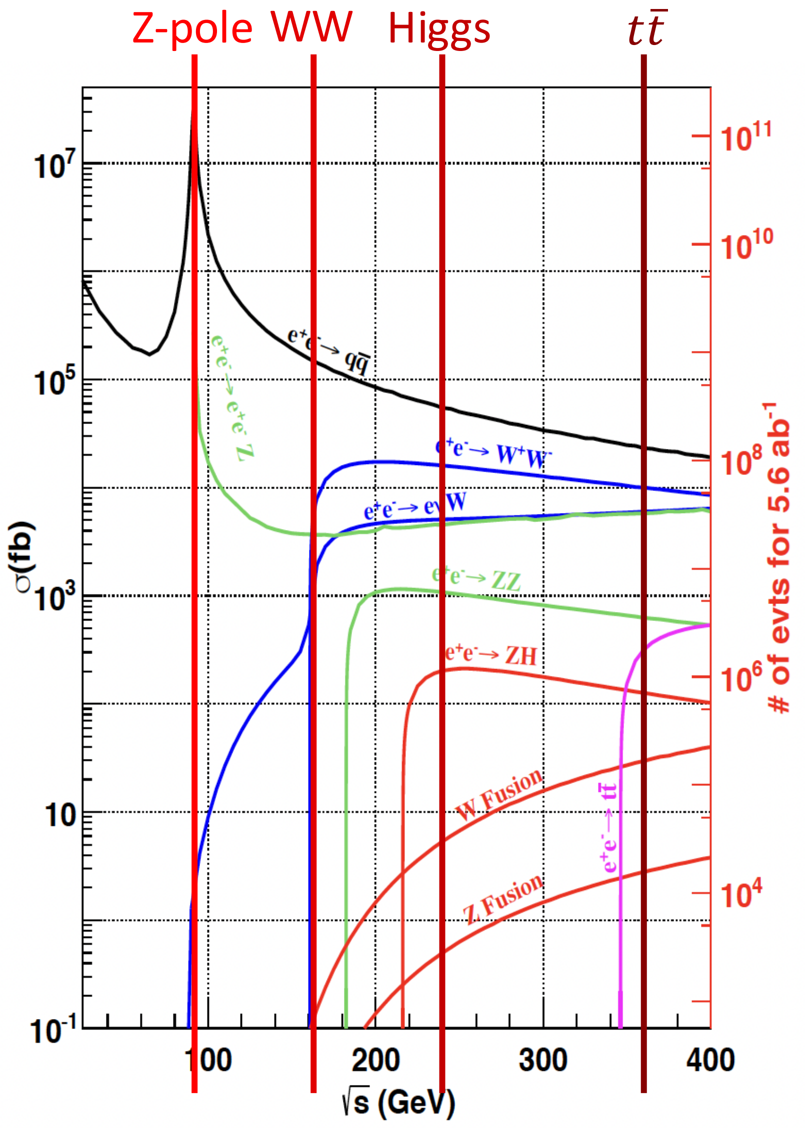
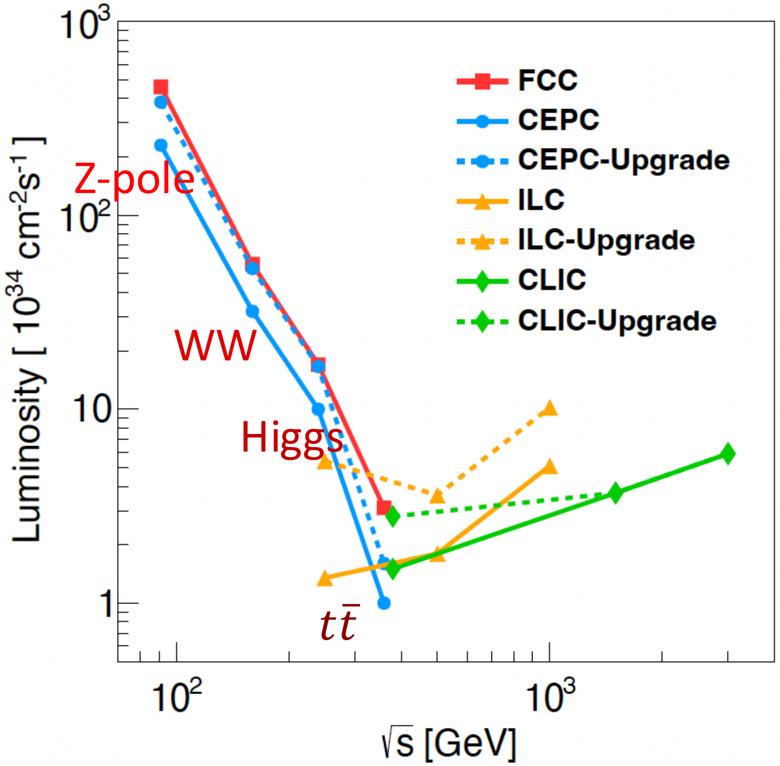
CEPC flavour physics Status

Shanzhen

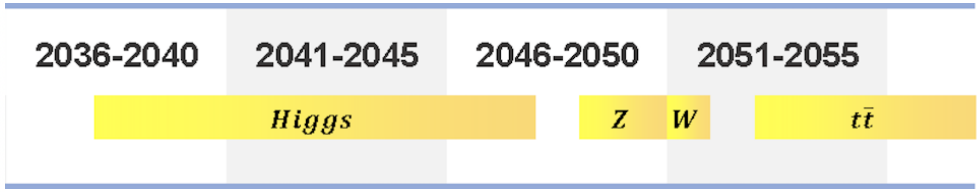
CEPC : a boson factory



- Yields ~ Xsec * Lumi * Time



- Higgs: 10 years
  ~ 4 Million Higgs
- Z: 2 years
  ~ 4 Tera Z
- WW: 1 year
  ~ 0.2 Giga WW
- Upgradable:
  Top factory
  (~ 0.6 Million $t\bar{t}$)



CEPC Tera-Z mode

- CEPC 50 MW scenario: 4 Tera Z. Z decay modes: $c\bar{c}$ (12.03 ±0.21) % ; $b\bar{b}$ (15.12 ±0.05) %
- Heavy flavour particle yields
  - One of the largest heavy flavour samples from e^+e^- collider

Particle	BESIII	Belle II (50 ab^{-1} on $\Upsilon(4S)$)	LHCb (300 fb^{-1})	CEPC (4×Tera-Z)
B^0, $\bar{B}^0$	-	5.4×10^{10}	3×10^{13}	4.8×10^{11}
$B^\pm$	-	5.7×10^{10}	3×10^{13}	4.8×10^{11}
B_s^0, $\bar{B}_s^0$	-	6.0×10^8 (5 ab^{-1} on $\Upsilon(5S)$)	1×10^{13}	1.2×10^{11}
$B_c^\pm$	-	-	1×10^{11}	7.2×10^8
Λ_b^0, $\bar{\Lambda}_b^0$	-	-	2×10^{13}	1×10^{11}
D^0, $\bar{D}^0$	1.2×10^8	4.8×10^{10}	1.4×10^{15}	8.3×10^{11}
$D^\pm$	1.2×10^8	4.8×10^{10}	6×10^{14}	4.9×10^{11}
$D_s^\pm$	1×10^7	1.6×10^{10}	2×10^{14}	1.8×10^{11}
$\Lambda_c^\pm$	0.3×10^7	1.6×10^{10}	2×10^{14}	6.2×10^{10}
$\tau^+\tau^-$	3.6×10^8	4.5×10^{10}		1.2×10^{11}

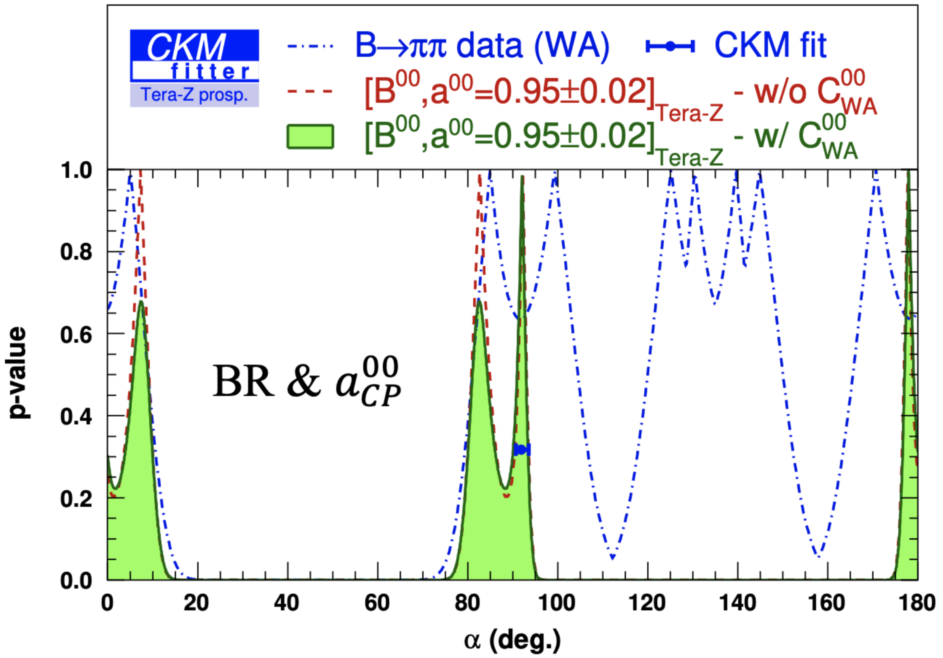
Physics Goal 1: Ultra-Precise Standard Model Tests

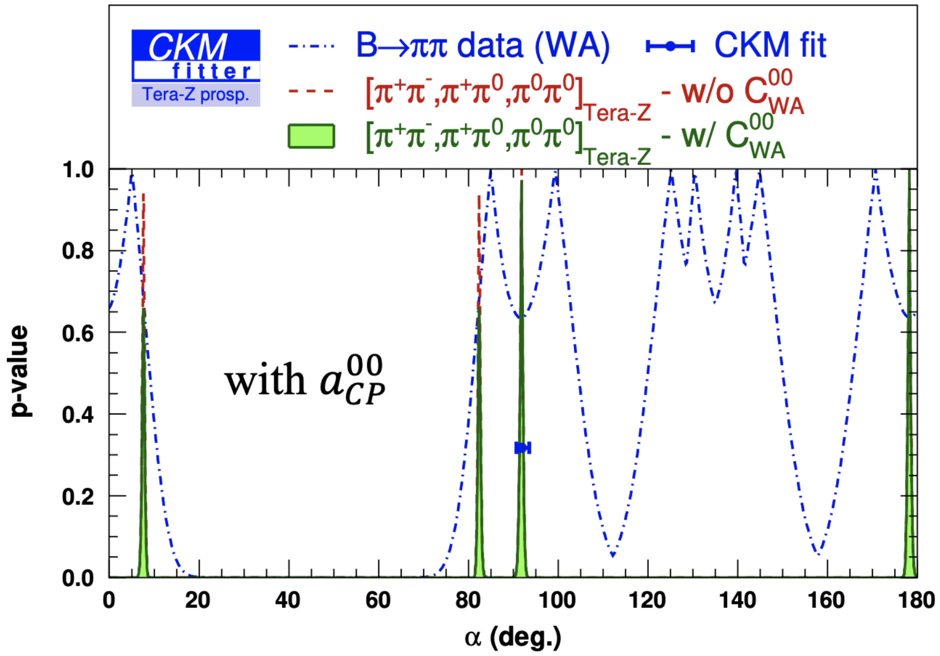
- CKM matrix elements measurements:
  - CKM matrix universality test by combining the measurements of CP violating phases.
- CP violation searches:
  - Direct / indirect CP violation searches with large statistics.
- Lepton universality:
  - Measure R($D^{(*)}$), R(J/ψ) ratios in B decays and $Z \to \ell\ell$ branching fractions to 10^{-4} precision, probing anomalies hinting at new physics.

α measurements with $B \to \pi\pi$

- Studied with $B \to \pi^0\pi^0$, $B_s \to \pi^0\pi^0$, $B \to \eta\eta$, $B_s \to \eta\eta$ samples
  - Only $B \to \pi^0\pi^0$ used in the estimation of CKM phase α
- Scenario 1, only use $B \to \pi^0\pi^0$

Scenario 2, projected to three $B \to \pi\,\pi$ modes





- precision of α: 2~3°

precision of α: 0.4°

Theoretical systematic uncertainties ~ 1-2° not considered

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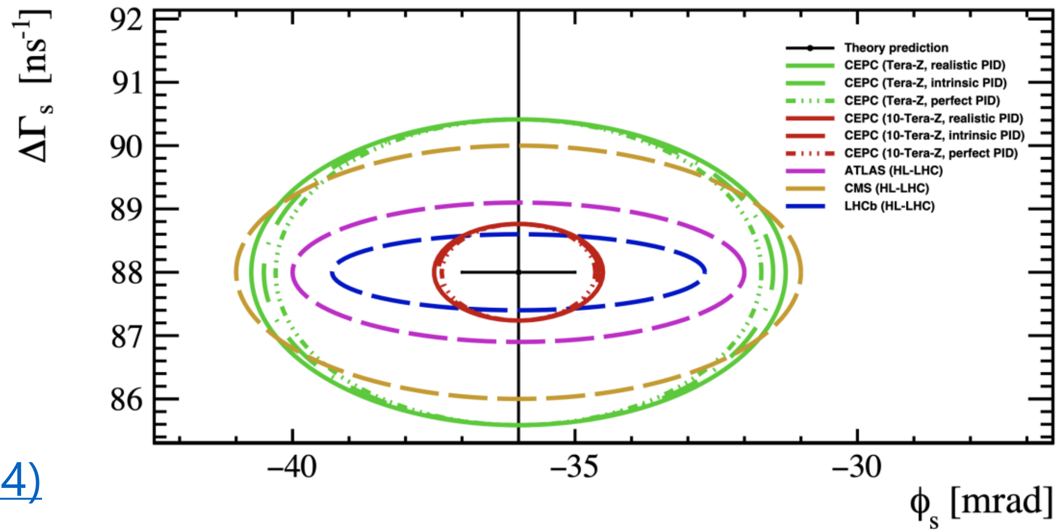
ϕ_s measurements with $B_s \to J/\psi\phi$

- Estimated resolution with 1 Tera Z
  - And comparison with LHCb 300 fb^{-1}

Table 1: Parameters table of factors to calculate the precision of ϕ_s, Γ_s and $\Delta\Gamma_s$. The terms with $*$ means that the factor is insensitive to the resolution of Γ_s and $\Delta\Gamma_s$.

	LHCb (HL-LHC)	CEPC (Tera-Z)	CEPC/LHCb
$b\bar{b}$ statics	43.2×10^{12}	0.152×10^{12}	1/284
Acceptance×efficiency	7%	75%	10.7
Br	6×10^{-6}	12×10^{-6}	2
Flavour tagging*	4.7%	17.3%	3.7
Time resolution* $(\exp(-\frac{1}{2}\Delta m_s^2\sigma_t^2)^2)$	0.52	1	1.92
σ_t(fs)	45	4.7	
scaling factor ξ	0.0015	0.0021	1.4
$\sigma(\phi_s)$	3.3 mrad	4.6 mrad	



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γ measurements with $B_s \to D_s K$

- Inputs: central values of current measurements / calculations:
- Outputs: fitted results with MC sample (preliminary)

Table 1. The latest results of parameters

Parameters	Value
$\tau(B_s^0) = 1/\Gamma_s$	1.520 ± 0.005 $[ps]$ [4]
$\Delta\Gamma_s$	$+0.084 \pm 0.005$ $[ps^{-1}]$ [4]
Δm_s	17.765 ± 0.006 $[ps^{-1}]$ [4]
β_s	$0.01882^{+0.00026}_{-0.00028}$ $[rad]$ [5]
γ	$(66.2^{+3.4}_{-3.6})^\circ$ [4]
δ	$(347.6^{+6.2}_{-6.1})^\circ$ [3]
r_{D_sK}	$0.318^{+0.035}_{-0.033}$ [3]

Fit results with 5.3% statistics

Fitted parameter	values
γ	$(66.43 \pm 3.01)^\circ$
δ	$(349.64 \pm 2.39)^\circ$
r_{D_sK}	0.314 ± 0.007

Projected to full statistics, all final states:
uncertainty of γ: 0.7°

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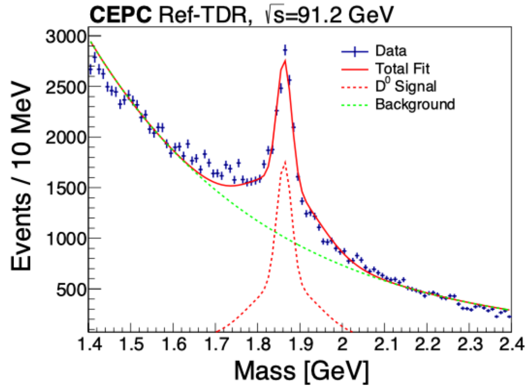
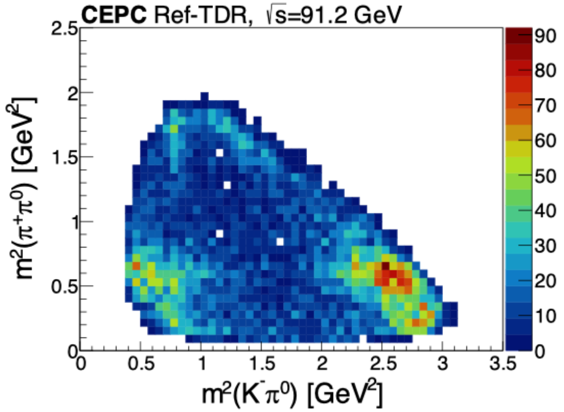
CPV searches with charm hadrons

- CEPC generally do not have advantages in statistics for charm hadrons compare to LHCb
- However, CEPC can have much higher efficiency with π^0s

Decays	LHCb (6 fb^{-1})	LHCb (300 fb^{-1})	CEPC (4 Tera Z)
D^{*+}	4.7×10^{12}	2.4×10^{14}	4.6×10^{11}
D^0 from D^{*+}	3.2×10^{12}	1.6×10^{14}	3.1×10^{11}
$D^{*+} \to (D^0 \to K^-K^+)\pi^+$	1.6×10^{10}	6.5×10^{11}	1.3×10^9
$D^{*+} \to (D^0 \to \pi^-\pi^+)\pi^+$	4.6×10^9	2.3×10^{11}	4.5×10^8
$D^{*+} \to (D^0 \to K^-\pi^+)\pi^+$	1.6×10^{11}	6.3×10^{12}	1.2×10^{10}
$D^{*+} \to (D^0 \to \pi^-\pi^+\pi^0)\pi^+$	4.8×10^{10}	2.4×10^{12}	4.6×10^9
$D^{*+} \to (D^0 \to K^-\pi^+\pi^0)\pi^+$	4.6×10^{11}	2.3×10^{13}	4.4×10^{10}
Reco. & Sel. $D^0 \to K^-K^+$	5.8×10^7 [147]	2.9×10^9	1.3×10^8
Reco. & Sel. $D^0 \to \pi^-\pi^+$	1.8×10^7 [147]	9×10^8	4.5×10^7
Reco. & Sel. $D^0 \to K^-\pi^+$	5.2×10^8 [147]	2.6×10^{10}	1.2×10^9
Reco. & Sel. $D^0 \to \pi^-\pi^+\pi^0$	2.5×10^6 [148]	1.2×10^8	4.6×10^8
Reco. & Sel. $D^0 \to K^-\pi^+\pi^0$	1.9×10^7 [148]	9.6×10^8	4.4×10^9

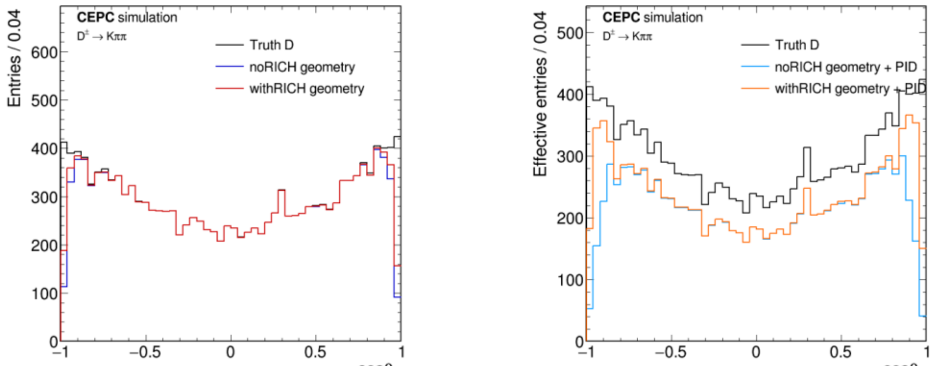




CPV searches with charm hadrons

- Current status: Using these channels for RICH studies

Acceptance vs. D Direction



Geometry acceptance　　Effective entries after PID

Selection	Yield	Fraction / efficiency	Gain vs. no RICH
with RICH geometry	14343	**95.93%**	+225 events
with RICH geometry + PID	11771.68	**78.73%**	+1034.69 events

The RICH geometry does introduce a relative improvement of about **9.6%**.

RICH Impact on Mis-identification Backgrounds

- The RICH detector provides additional particle-identification information in the small-angle region.
- Improved small-angle PID may reduce mis-ID backgrounds, such as π-to-K or K-to-π fake assignments.

Region	RICH role	Expected effect
Small angle	extra PID	lower fake rate
Central region	baseline PID	stable performance

Status

The study of RICH-assisted background suppression for $D^{\pm} \to KK\pi$ is ongoing.

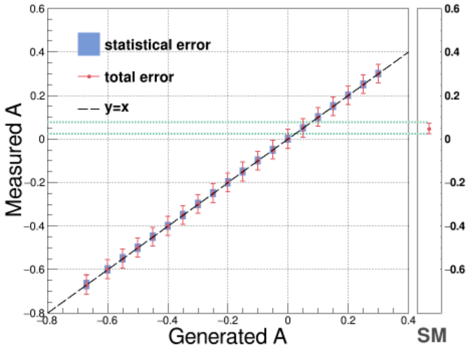
Physics Goal 2: Rare & Forbidden Decays

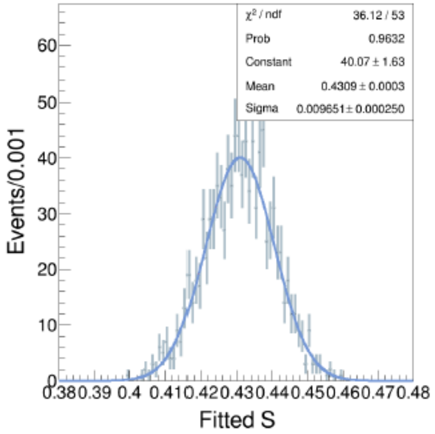
CEPC's clean environment and particle-flow detectors excel at reconstructing elusive processes:

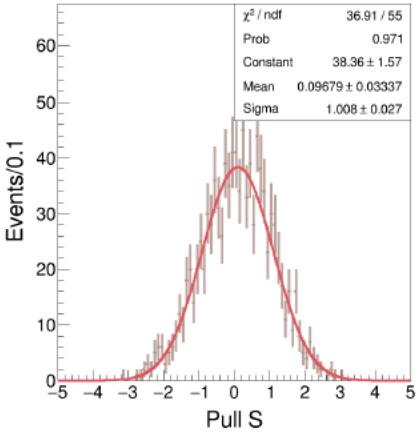
- Flavour-changing neutral currents (FCNC):
  - Search for $b \to s$ transitions suppressed in the Standard Model, e.g., $B_s \to \phi \nu\nu$ (aiming for 2% precision), $B \to K\tau\tau$, and $B_s \to \tau\tau$. Sensitivity to branching ratios as low as 10^{-7}.
- Lepton flavour violation (LFV):
  - Hunt for absolute forbidden decays like $\tau \to \mu\gamma$ (target: BR 10^{-10}), $Z \to e\mu$. These "smoking guns" for new physics are inaccessible at hadron colliders due to backgrounds.
- Baryon/lepton number violation:
  - Probe decays like $B^+ \to \pi^- \ell^+ \ell^+$ or $\Lambda_b \to \pi^- \ell^+$ that challenge fundamental symmetries.

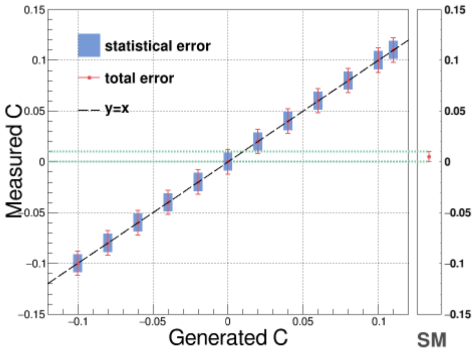
CPV parameter measurement with FCNC $B_s^0 \to \phi\gamma$ decays

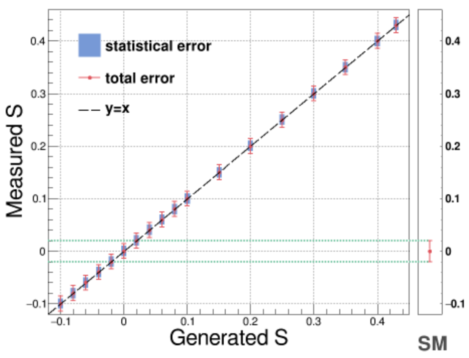
- A scan of CPV parameter as inputs, uncertainty obtained from pseudo-experiments
- Obtained expected sensitivity to new physics increased by 1 order of magnitude comapare to current LHCb











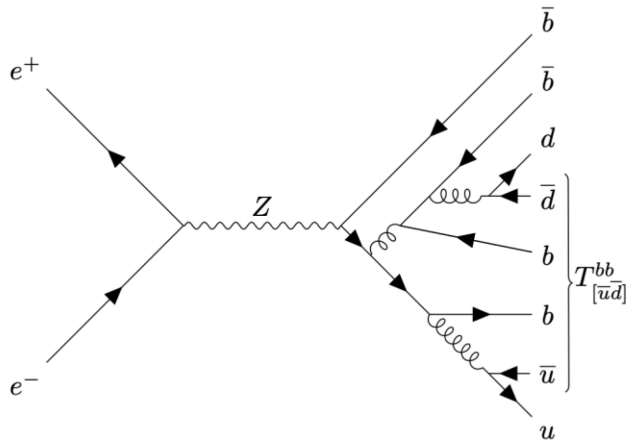
Physics Goal 3: Exotic Hadrons & Spectroscopy

With 10^{11} b-hadrons and charm particles, CEPC will map the "heavy-flavour zoo":

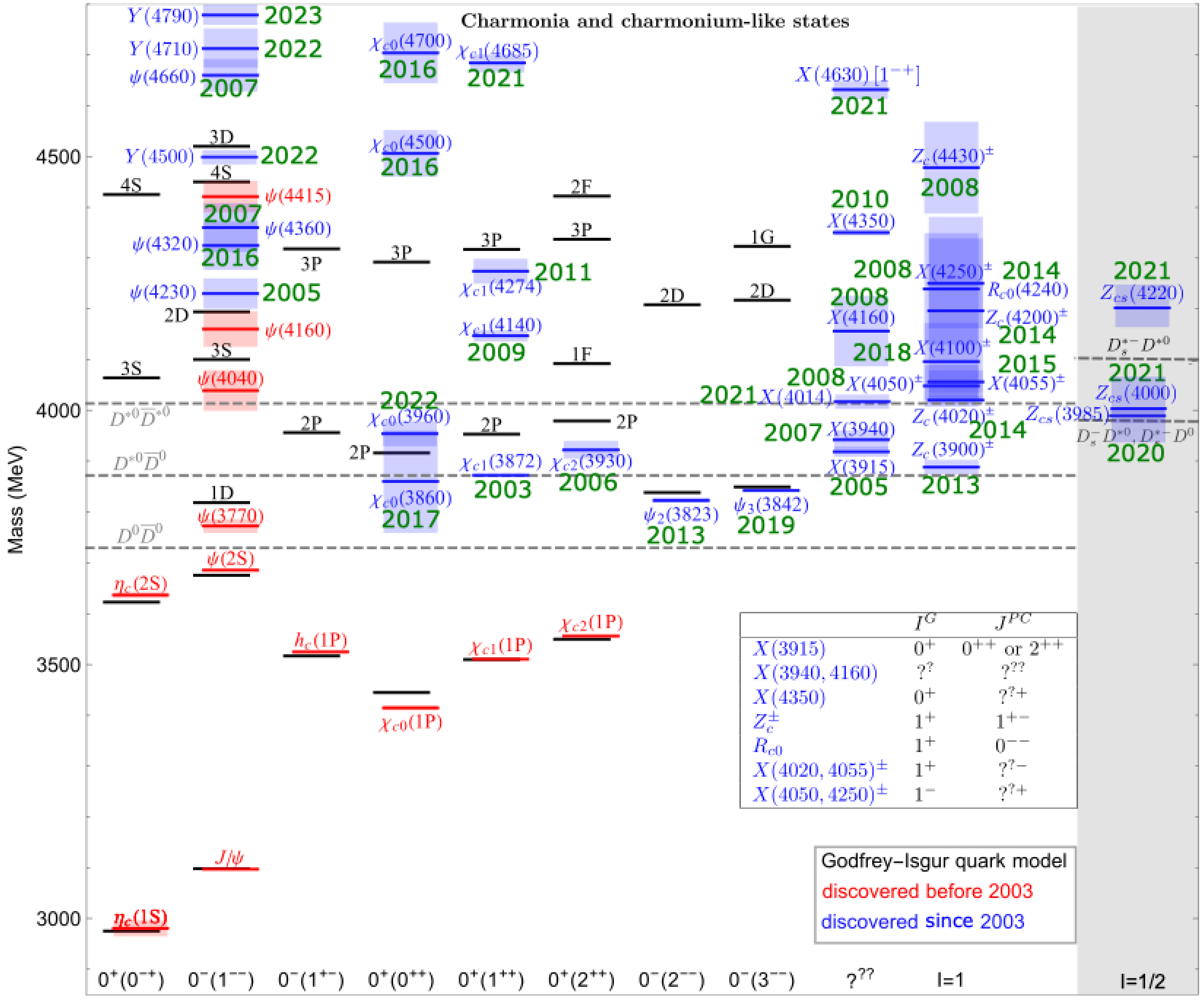
- Discover tetraquarks (T_{cc}, T_{bb}) pentaquarks (P_c), and doubly heavy baryons (Ξ_{cc}, Ξ_{bb}), predicted by QCD but rarely observed.
- Study production mechanisms of charmonium-like states (e.g., *X(3872)*) via $Z \rightarrow qq$ or B-decay chains.
- Precision spectroscopy of conventional b/c-mesons and baryons (e.g., Λ_b, B_c), including excited states.

Spectroscopy and Exotics - prospects

- A lot of states, guaranteed discovery at CEPC?
- *Z→bbbb*, *bbcc*, *cccc* processes may give rise to highly exotic species



- Need more theory inputs for simulation



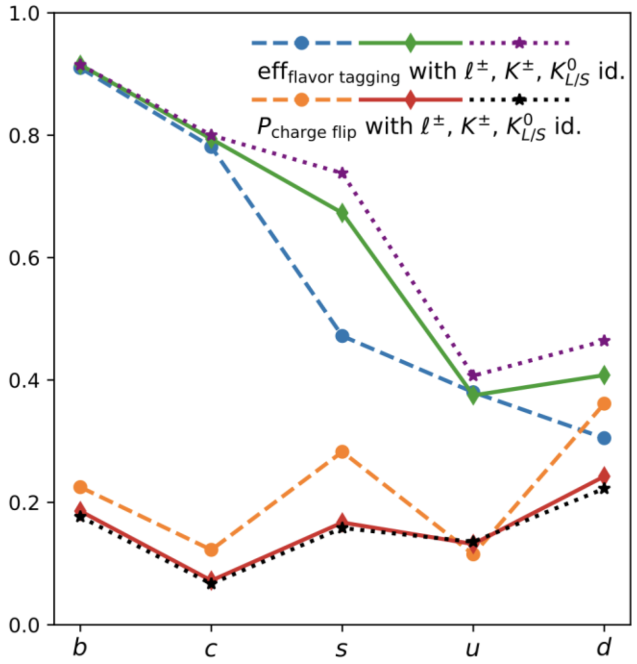
Physics Goal 4: WW & Higgs & Top Quark Flavour Physics

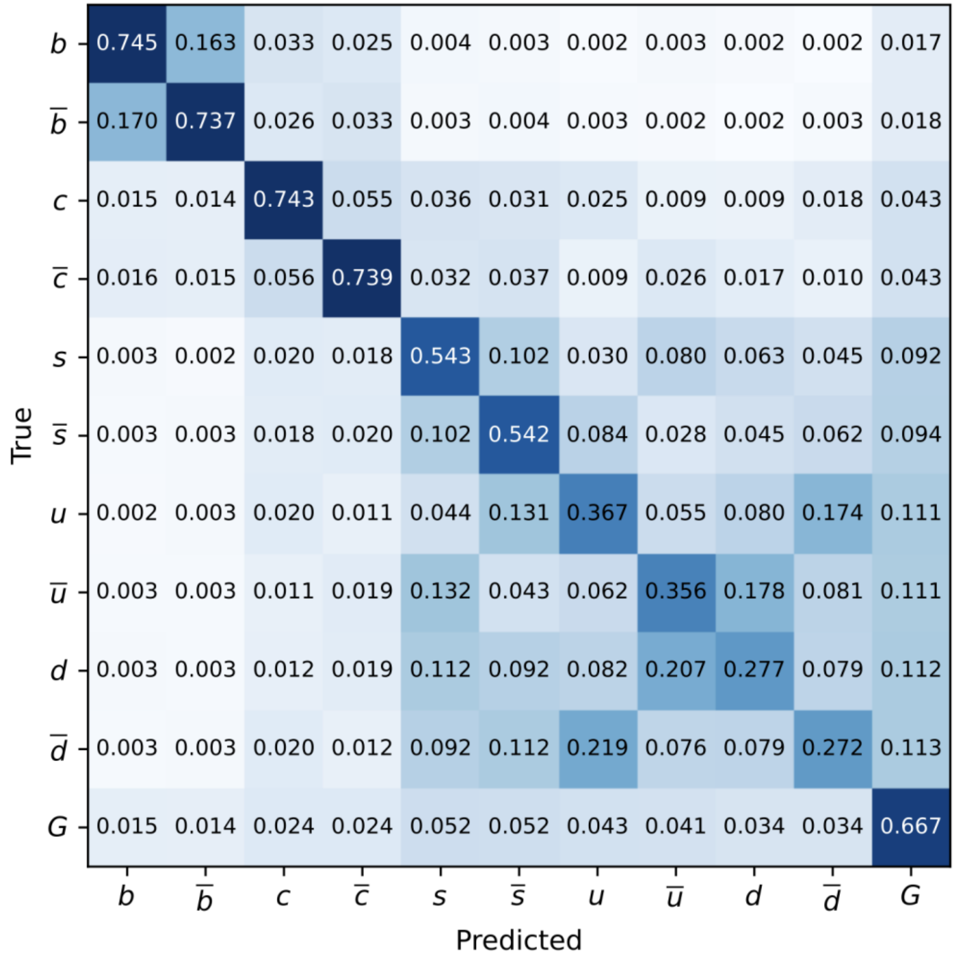
Higher-energy CEPC runs extend flavour studies:

- Higgs flavour violation:
  - Search for $H \to b\bar{s}$, $H \to c\bar{u}$, or $H \to \tau\mu$ decays at the Higgs factory (240 GeV). Jet-origin identification via ML could constrain branching ratios to 10^{-3}.
- Top quark FCNC:
  - At the $t\bar{t}$ threshold (360 GeV), probe anomalous $t \to cZ$ or $t \to cH$ decays, sensitive to new physics in top-Higgs couplings.
- CKM elements from WW threshold:
  - Resolve long-standing tensions in CKM matrix elements (e.g., $|V_{cb}|$, $|V_{ub}|$) by combining data from B/D meson decays and on-shell W boson decays at the WW threshold. Target precision for $|V_{cb}|$ reaches 0.1–0.4%.

Jet origin identification

- Full Simulated vvH, Higgs to two jets sample at CEPC baseline configuration, reconstructed with deep learning techniques
- Jets identified as the category with highest likelihood
- 5 quarks+antiquarks + gluon





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Flavour violating Higgs decay & Top FCNC

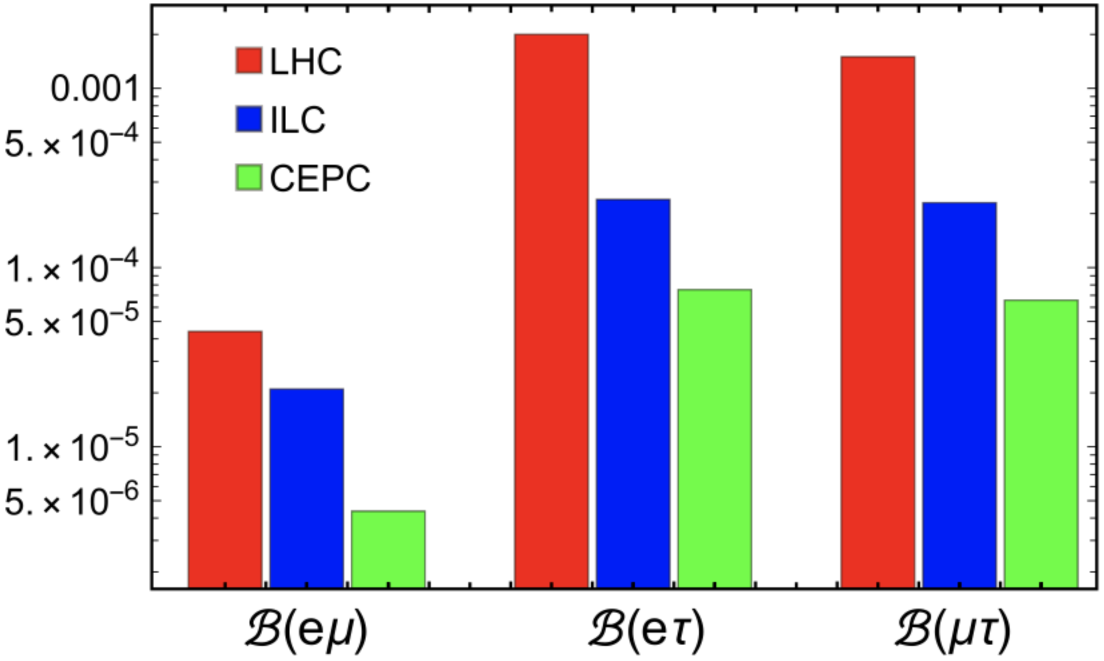
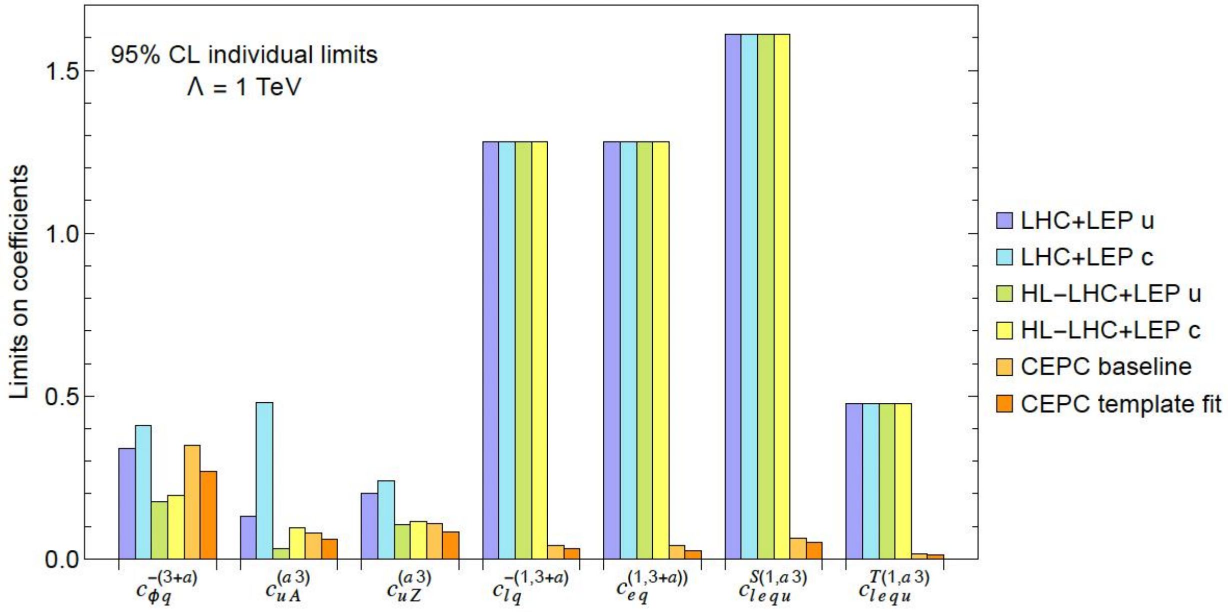


Fig. 34. (color online) Projected upper limits on the LFV Higgs decays at the LHC, ILC and CEPC. The figure is updated from [255].



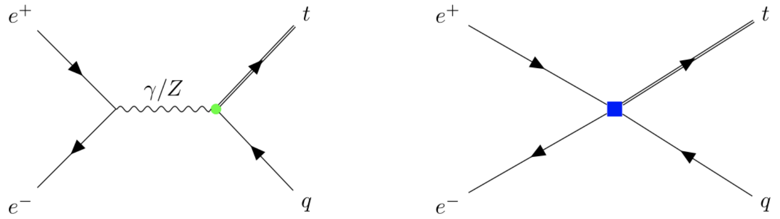


Fig. 35. (color online) Illustrative Feynman diagrams for the FCNC single top production $e^-e^+ \to t(\bar{t})j$. The green dot and blue square represent two-fermion FCNC and four-fermion (two-lepton two-quark) contact operators, respectively.

Conclusion

- A few results shown, with efforts made in the past few years
- For flavour physics, current TDR-based detector software (CEPCSW) does not make good vertex in PFO, therefore current analysis uses truth information with expected performance parameters
- A few analysis ongoing