

Status of the CEPC Flavor Physics White Paper (Phase I)

1000,000,000,000+

Or Flavor Physics at Tera - 

Lingfeng Li Brown University

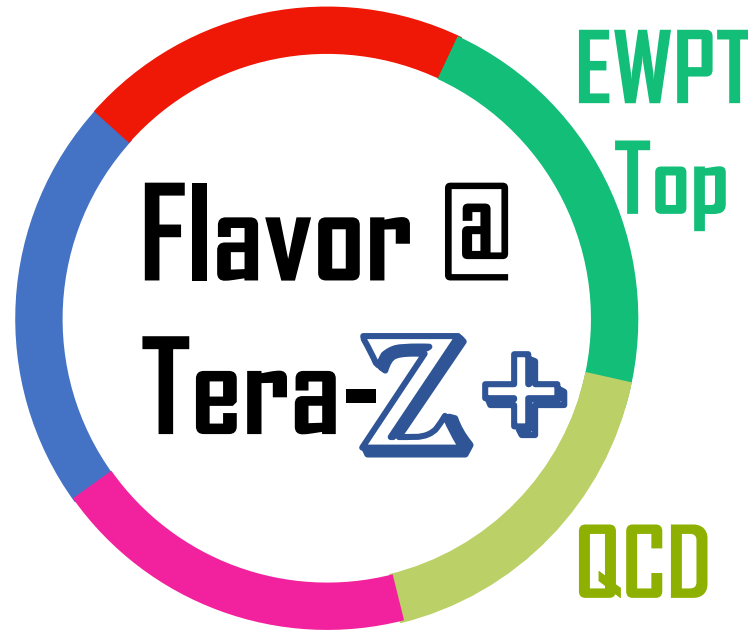
Jul. 4, 2023

The 2023 international workshop on the CEPC

Support the CEPC Project

- Origin of matter?
understand lepton and baryon numbers
- Light dark matter?
- Lepton Flavor Universality anomalies?

BSM



Hardware

- Origin of flavor hierarchy?
- CP violation phases from Yukawa?

- Flavor physics beyond the Tera-Z phase?
- Common need in τ phys.

- How does asymptotic freedom work with flavor?
- New formalism beyond the conventional meson-baryon picture?

- Use a plethora of data to improve hadronization

Most demanding field:
We need better tracker, E(H)CAL, electronics... everything!

Status and Timeline

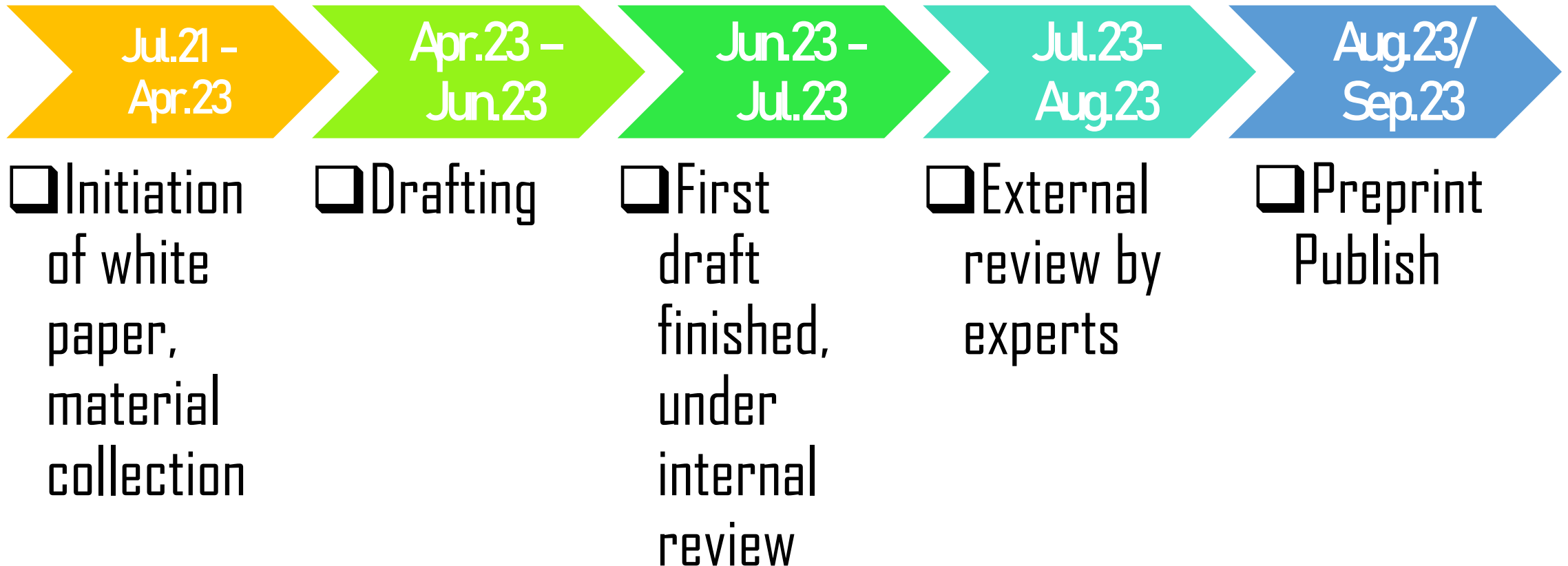


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➤ Includes >20 individual studies
and ~10 preliminary studies

The Purpose of the Flavor Physics White Paper (Phase I)

- To summarize the known results in an organized way
- To provide guidance and recommendation for studies in the next phase
- To resonate on relevant programs (e.g. flavor phys. @ FCC-ee)

Major Challenges

- Excessive statistics, data flow, and precision goals require **understanding and control** of experimental systematics (otherwise the projections will be very wrong)
- Recognize the **most valuable** analyses for CEPC, even overlooked ones
- Incorporate the appropriate **theory** (not always available)

The Primary Concern (Biased View)



CKM

CP Asy.

Spectroscopy

Hadronization

BNV

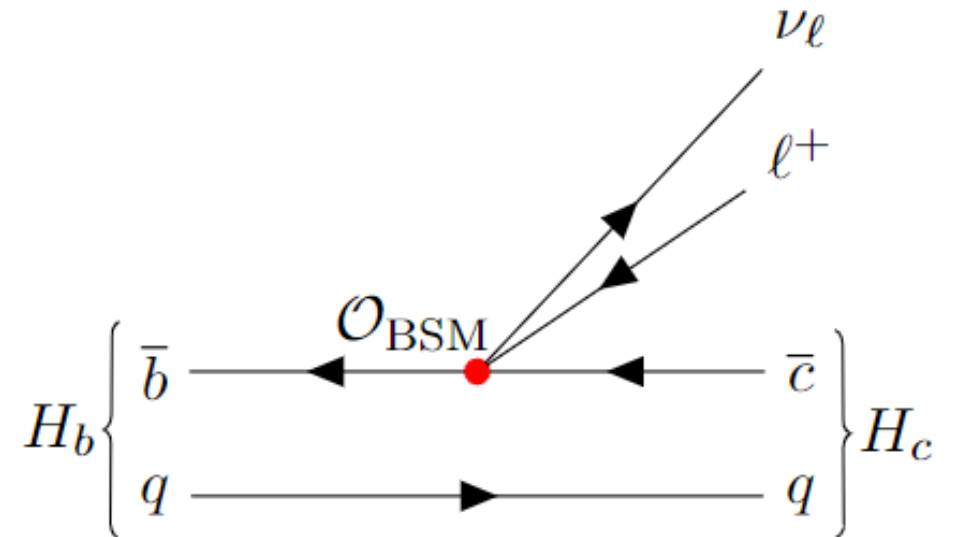
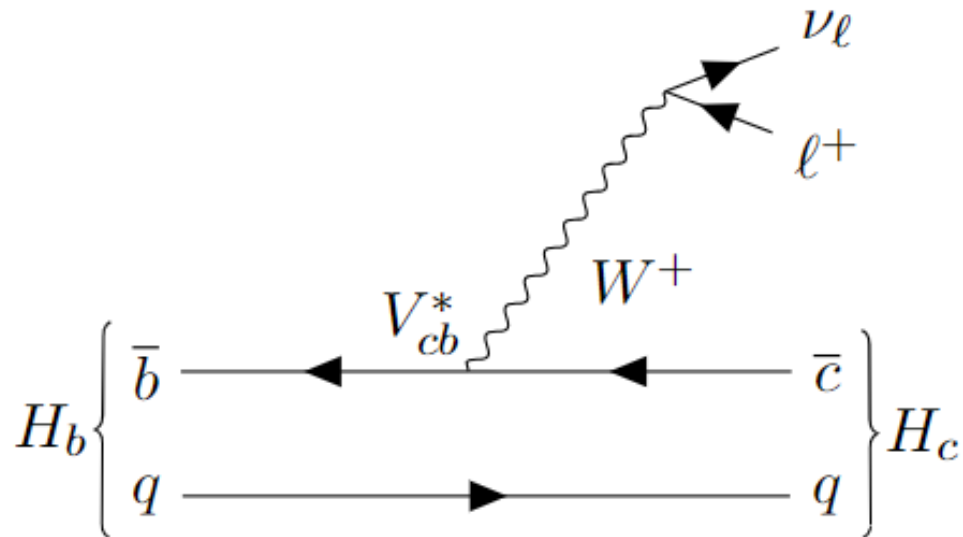
Charm.....

3 Charged Current Semileptonic and Leptonic b Decays

3.1 Theoretical Interpretation

3.2 Recent Progress and Directions to be Explored

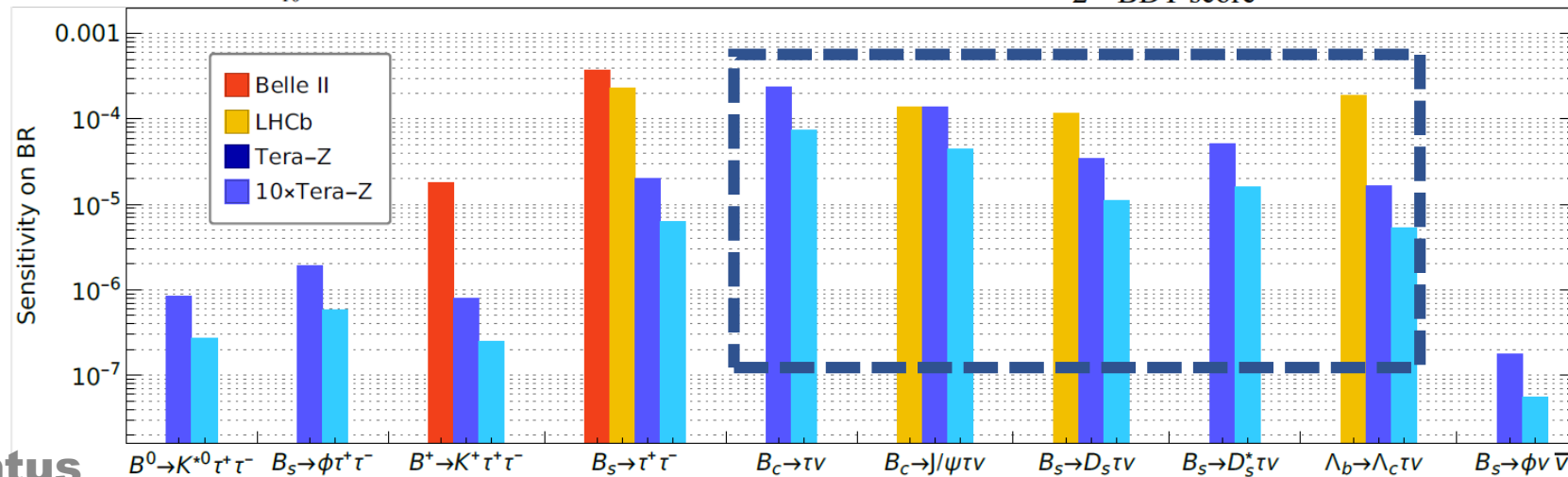
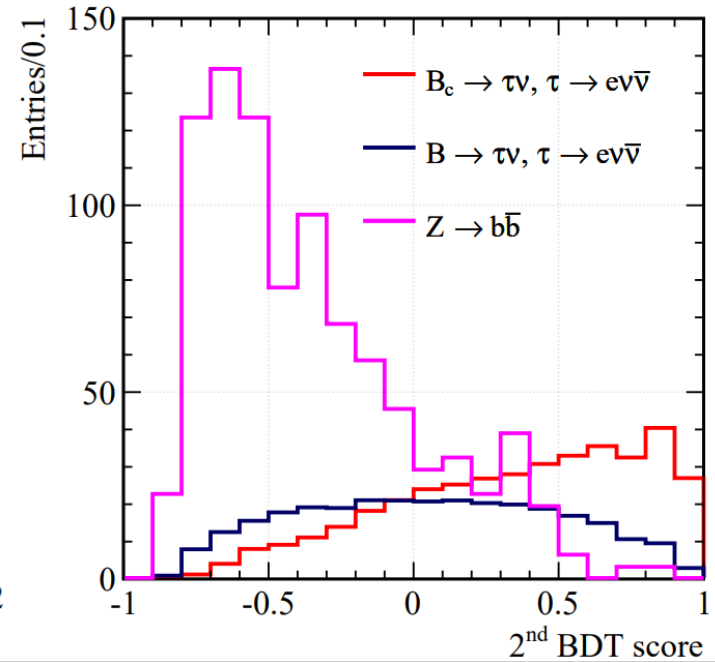
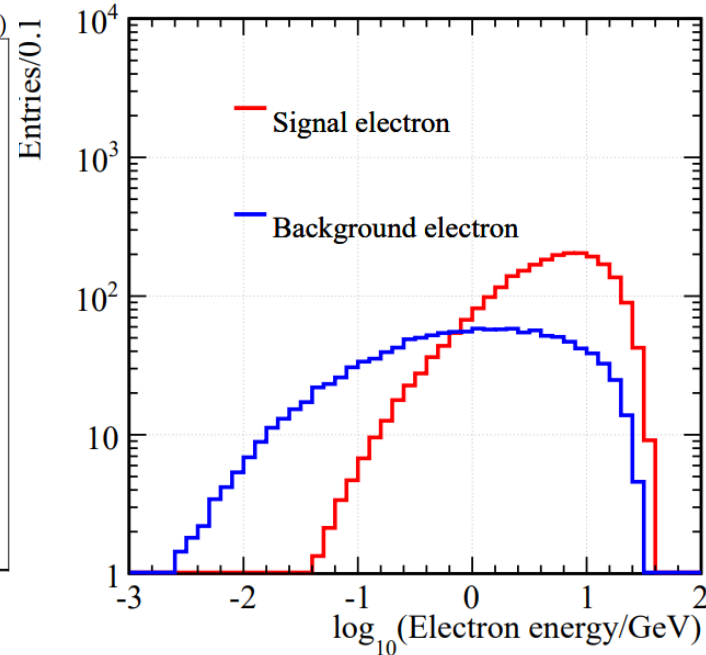
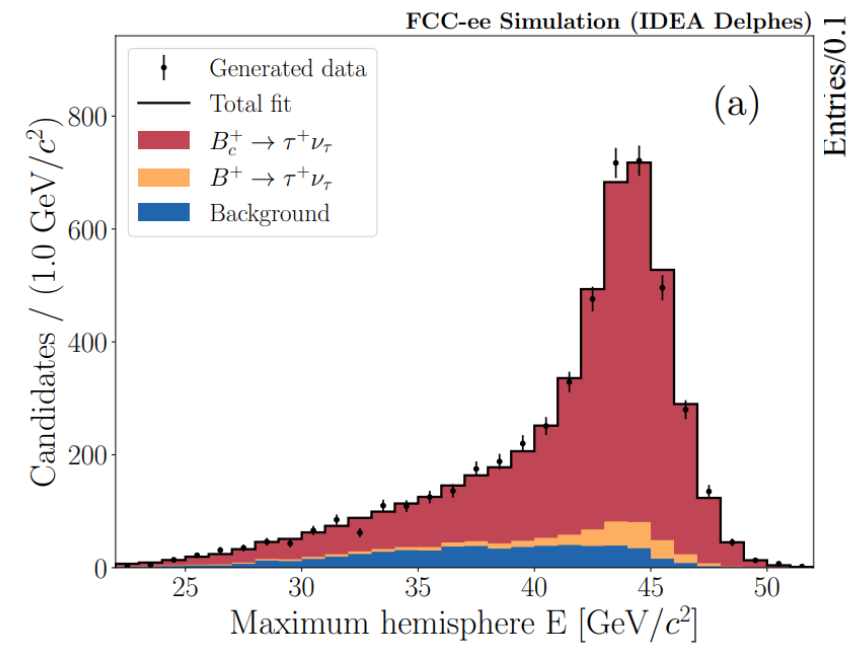
- Anomalies indicating lepton flavor universality violation
- Potential for $|V_{cb}|$ & $|V_{ub}|$ extraction
- CP asymmetries are clean
- Potentially probe higher scales of new physics



$B_c \rightarrow \tau\nu$ measurement, unique at CEPC

[Y. Amhis, M. Hartmann, C. Helsens, D. Hill, O. Sumensari](#)
[2105.13330](#)

[T. Zheng, J. Xu, L. Cao, D. Yu, W. Wang et al.](#)
[2007.08234](#)

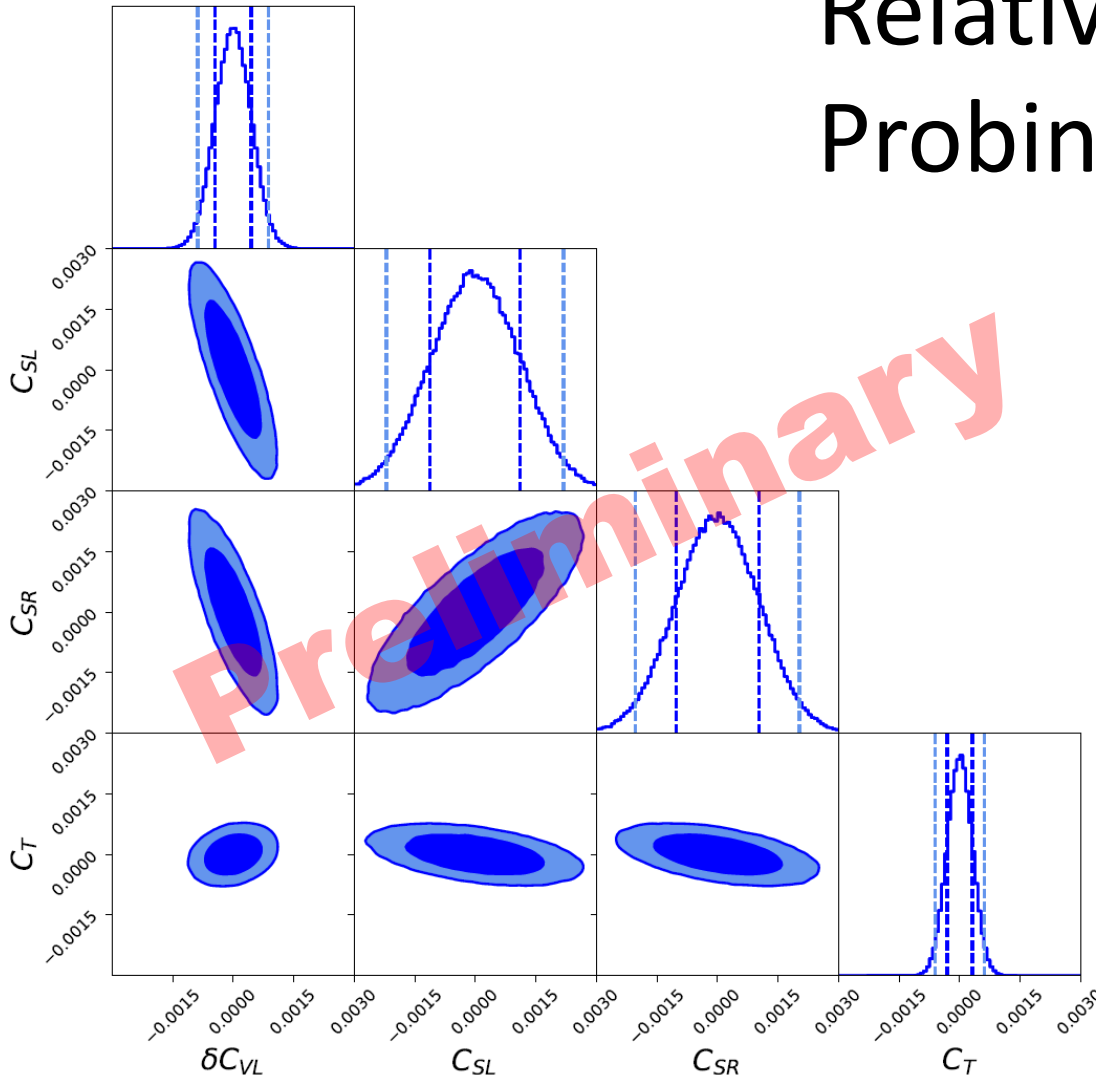


LFU tests with various transition types

See Anson Kwok's talk

Section Summary and Suggestions

Relative precisions $\lesssim O(1\%)$ achieved
Probing multi-TeV scales already



Recommended future steps:

- ❖ Differential measurements (polarimetry, asymmetry ...)
- ❖ Extend the search on more final states
- ❖ Evaluate electron modes with electron PID

4 Rare/Penguin and Forbidden b Decays

4.1 Theoretical Interpretation (preliminary)

4.2 Dileptonic Modes

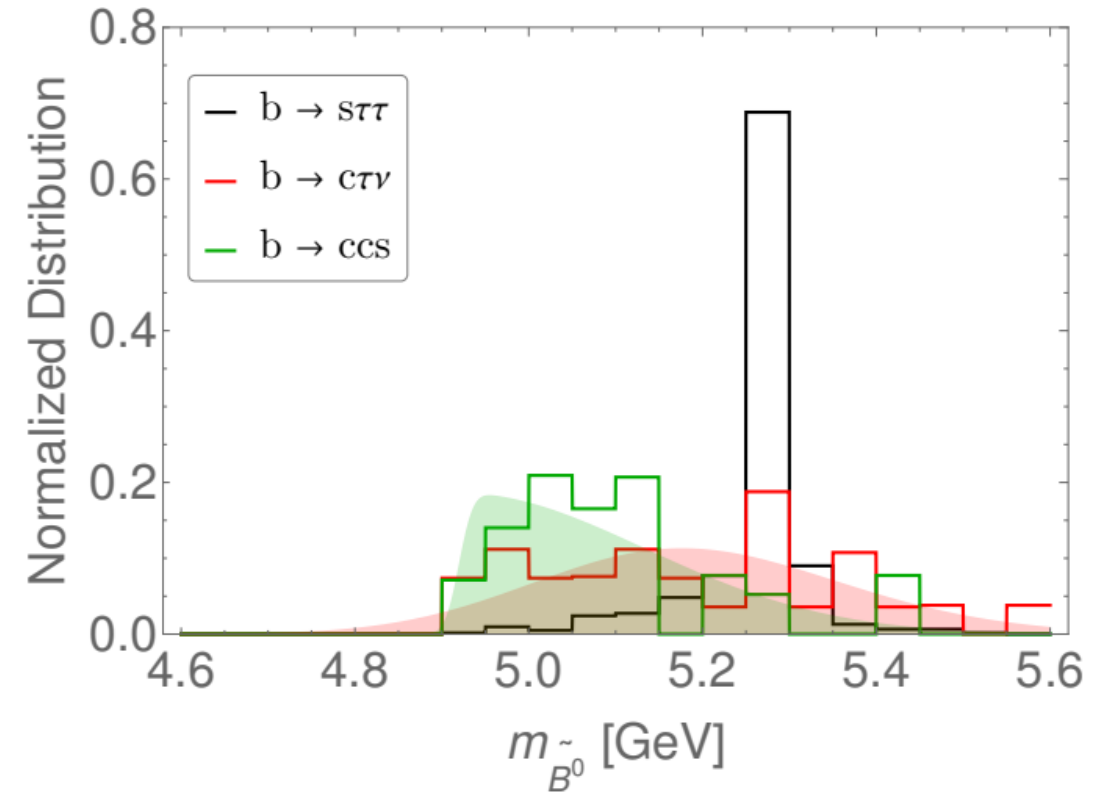
4.3 Neutrino Modes

4.4 Radiative Modes

[J. F. Kamenik, S. Monteil, A. Semkiv, L. V. Silva 1705. 11106](#)
[LL, T. Liu, 2012.00665](#)

- Partially motivated by B anomalies
- Rare decays, sensitive to BSM and probe multi-TeV

$$\Lambda_{\text{NP}} \simeq \left(\frac{\alpha}{4\pi} \frac{m_t^2}{m_W^2} G_F |V_{tb} V_{ts}^*| \delta_{\text{rare}} \right)^{-\frac{1}{2}} \simeq (30 \text{ TeV}) \times \delta_{\text{rare}}^{-\frac{1}{2}}$$

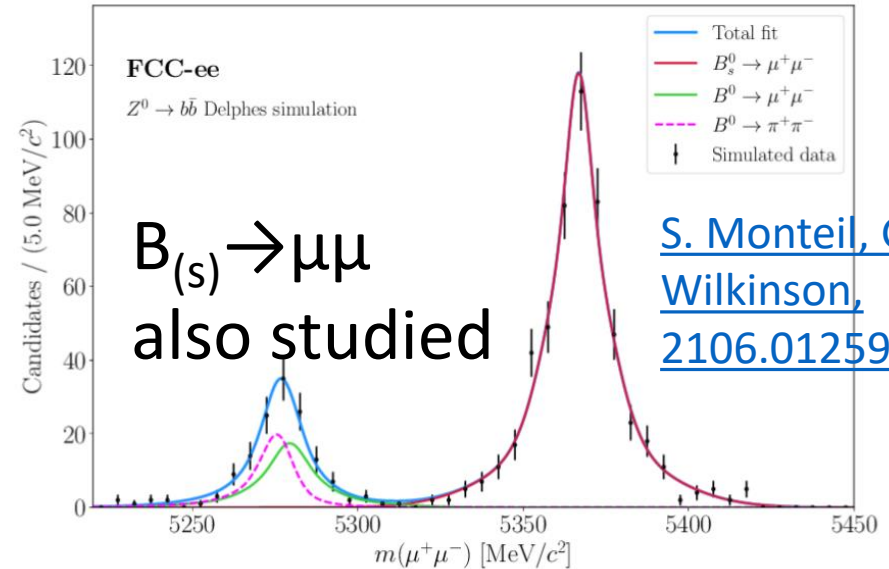
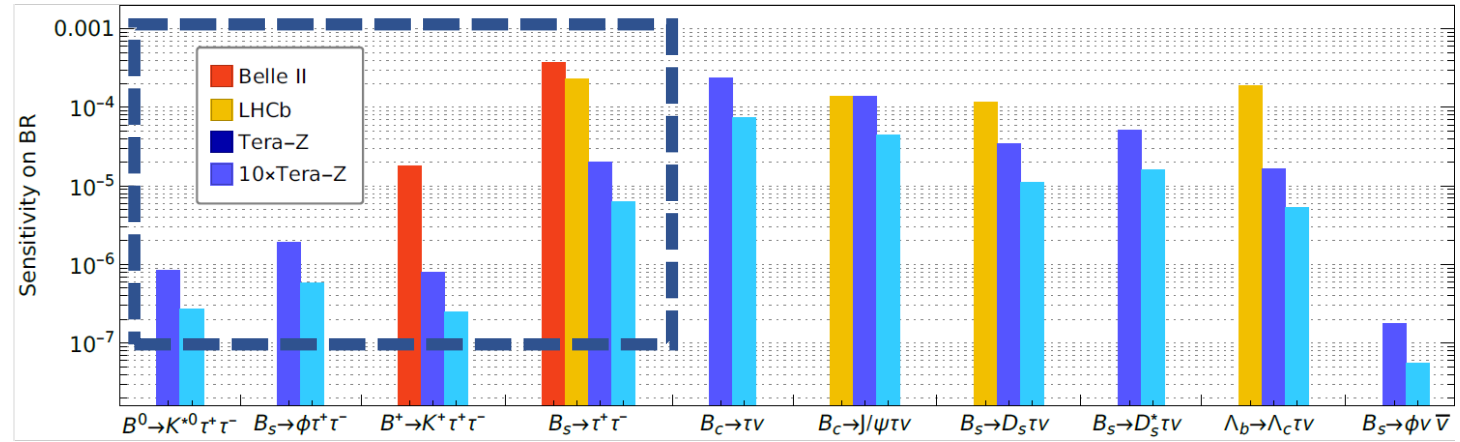
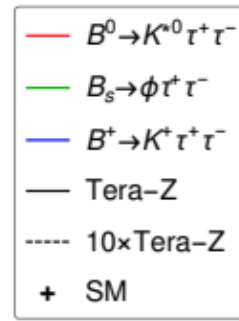
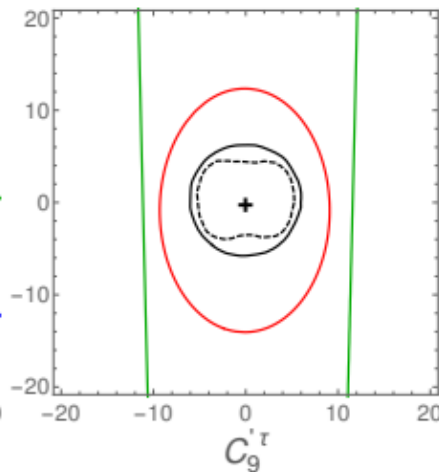
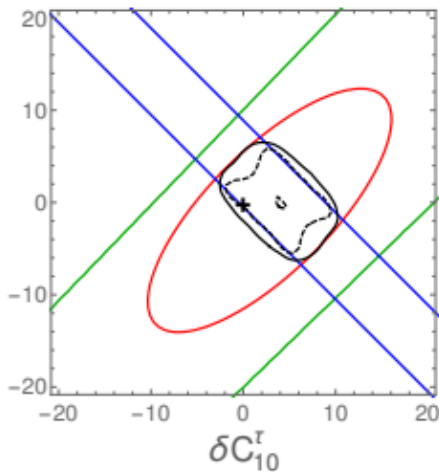
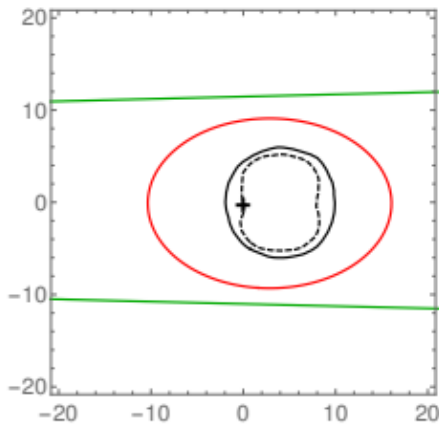
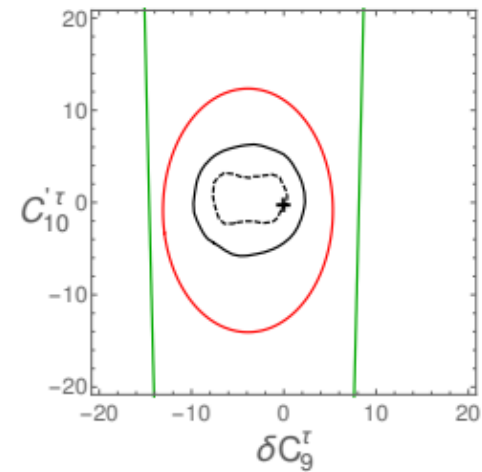
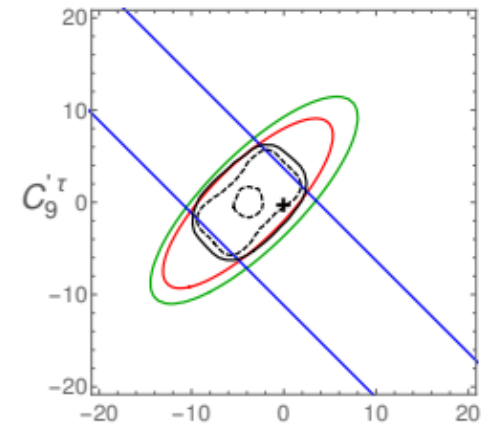
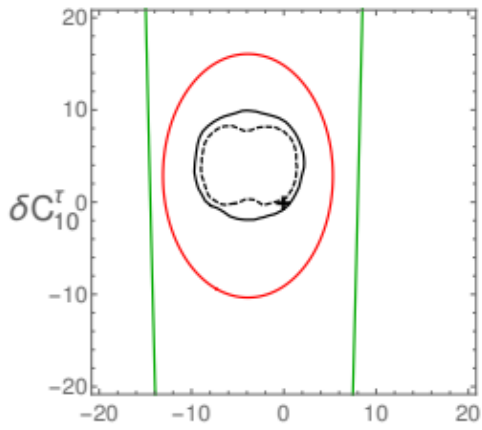


See also:

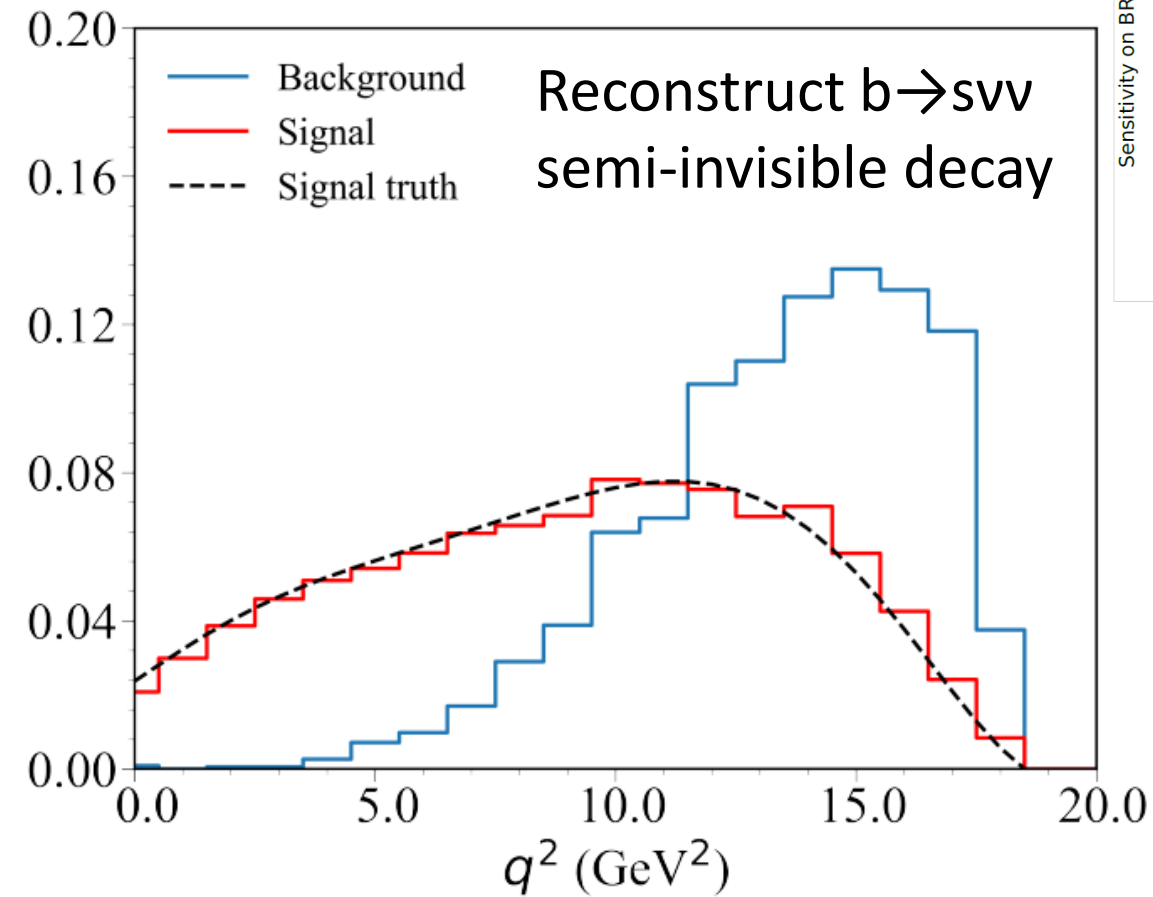
[S. Descotes-Genon, S. Fajfer, J. Kamenik, M. Novoa-Brunet 2208.10880](#)

➤ The LFU test via $b \rightarrow s \tau \tau$ rare decay are most studied

➤ Flagship channel for CEPC



4.3 Neutrino Modes

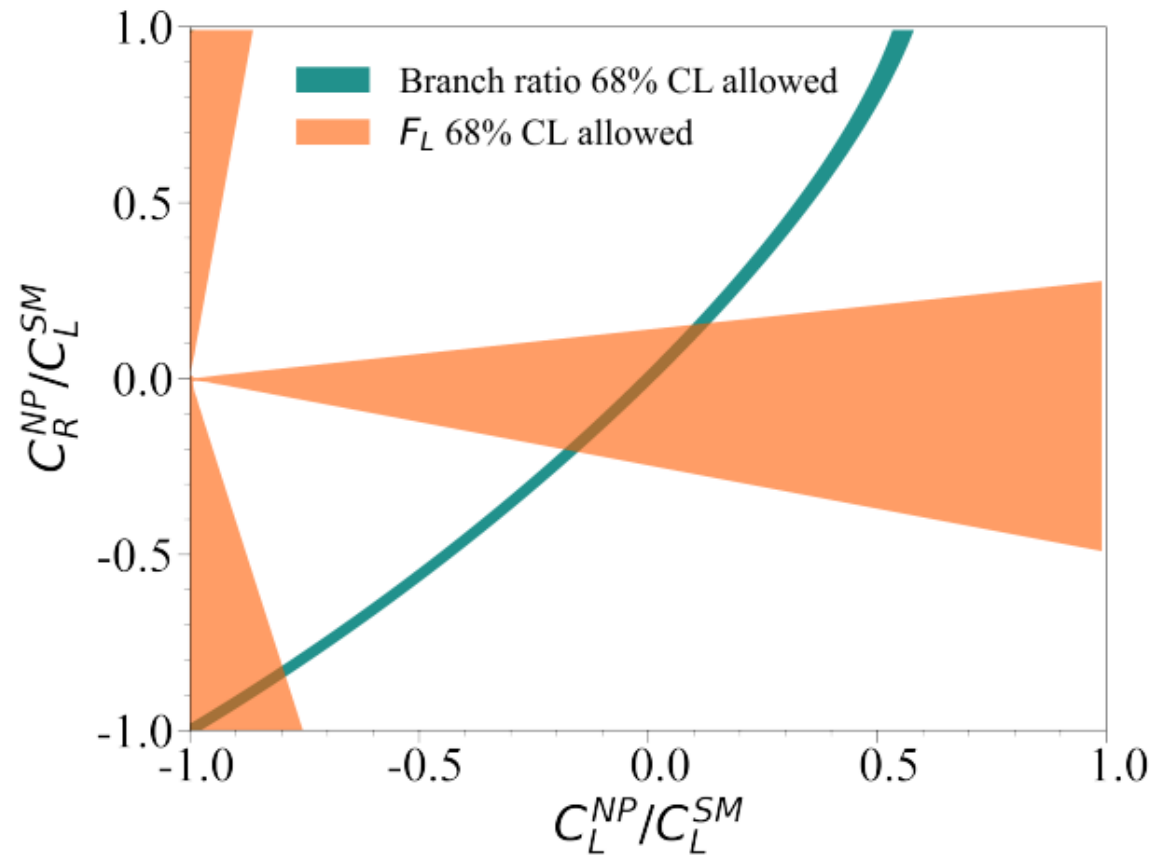
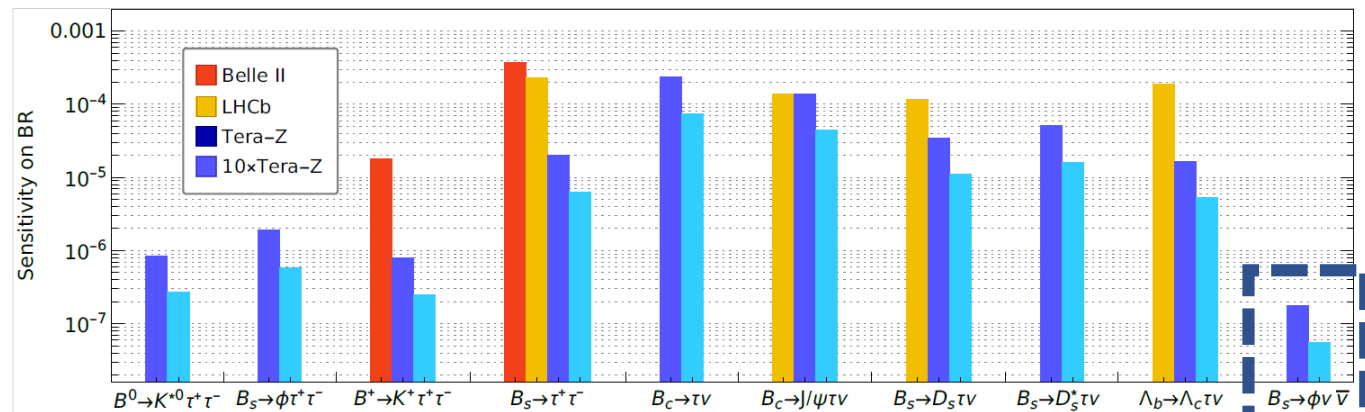


[LL, M. Ruan, Y. Wang, Y. Wang, 2201.07374](#)

See also:

[S. Descotes-Genon, S. Fajfer, J. Kamenik, M.](#)

[Novoa-Brunet 2208.10880](#)



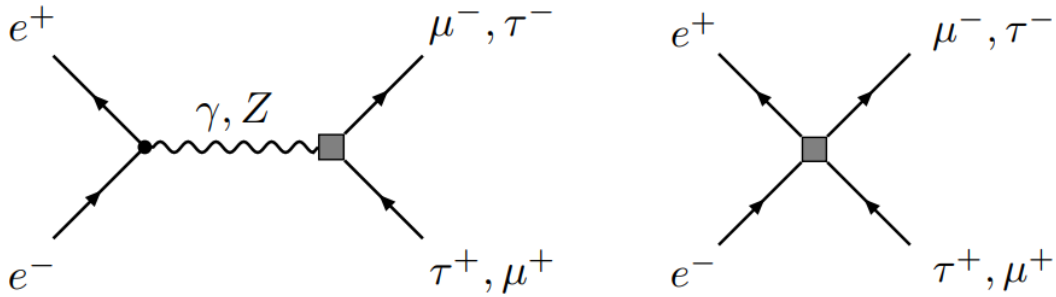
- Most decays are rare ($BR < 10^{-5}$).
- Relative precisions vary from $O(10^{-2} - 1)$ determined by final states, probing multi-TeV already
- Unique advantages at CEPC

Section Summary and Suggestions

- ❖ Benchmark studies for (double) radiative decays with proper ECAL simulations
- ❖ Modes of heavy hadrons like Λ_b
- ❖ Systematically dominated e vs. μ LFU tests

6 Testing SM Global Symmetry with Flavor

- lepton flavor, lepton number and baryon number are conserved in flavor physics
- Clear sign of new physics if violation observed



[W. Altmannshofer, P. Munbodh, T. Oh, 2305.03869](#)

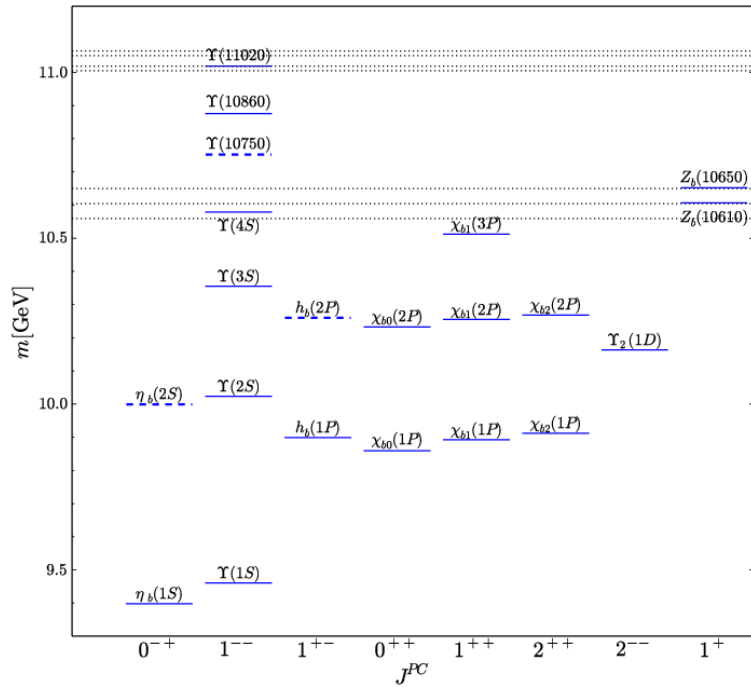
BR($Z \rightarrow \tau\mu$) limit down to 10^{-9}
 Also from runs of higher E_{cm}

\sqrt{s} [GeV]	\mathcal{L}_{int} [ab^{-1}]	$\frac{\delta\sqrt{s}}{\sqrt{s}}$ [10^{-3}]	$\frac{\delta p_T}{p_T}$ [10^{-3}]	$\epsilon_{\text{bkg}}^{x_c}$ [10^{-6}]	N_{bkg}	σ [ab]
91.2 (Z-pole)	50	0.92	1.35	1.53	6400 ± 80	55
87.7 (off-peak)	25	0.92	1.33	1.46	350 ± 20	27
93.9 (off-peak)	25	0.92	1.37	1.59	620 ± 25	35
160 (WW)	6	0.99	1.89	2.49	3 ± 2	17
240 (ZH)	20	1.20	2.60	4.42	7 ± 3	6.6
360 ($t\bar{t}$)	1	1.41	3.74	8.61	0.3 ± 0.5	72

Recommendations:

- ❖ Need studies on lepton and baryon number violation in the next phases

7 Spectroscopy and Exotics



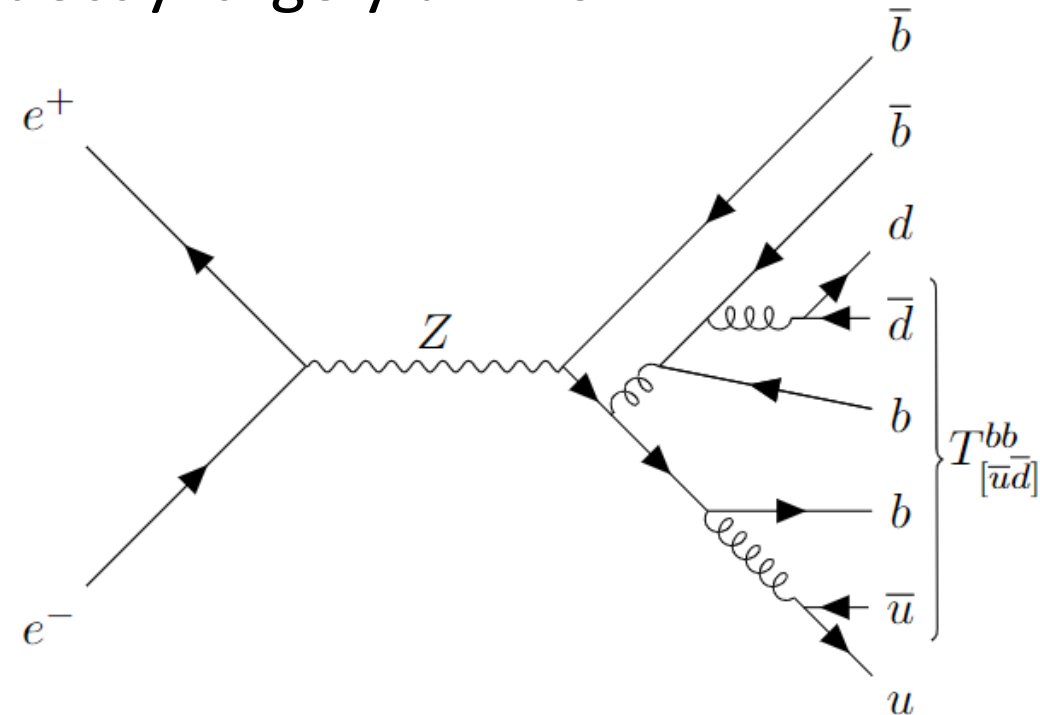
- A lot of states, guaranteed DISCOVERY at CEPC?
- $Z \rightarrow bbbb, bbcc, cccc$ processes may give rise to highly exotic species
- Production & decay largely unknown

Recent studies on production of tetraquarks & doubly-flavored baryons

[J. Niu, J. Li, H. Bi, H. Ma, 2305.15362](#) [A. Ali, A.Y. Parkhomenko, Q. Qin, W. Wang, 1805.02535](#)

Recommendations:

- ❖ More theory inputs for simulation
- ❖ Analysis framework to be developed



8 Charm and Strange Physics

$$\Gamma_9 \quad (u \bar{u} + c \bar{c})/2 \quad (11.6 \pm 0.6)\%$$

$$\Gamma_{10} \quad (d \bar{d} + s \bar{s} + b \bar{b})/3 \quad (15.6 \pm 0.4)\%$$

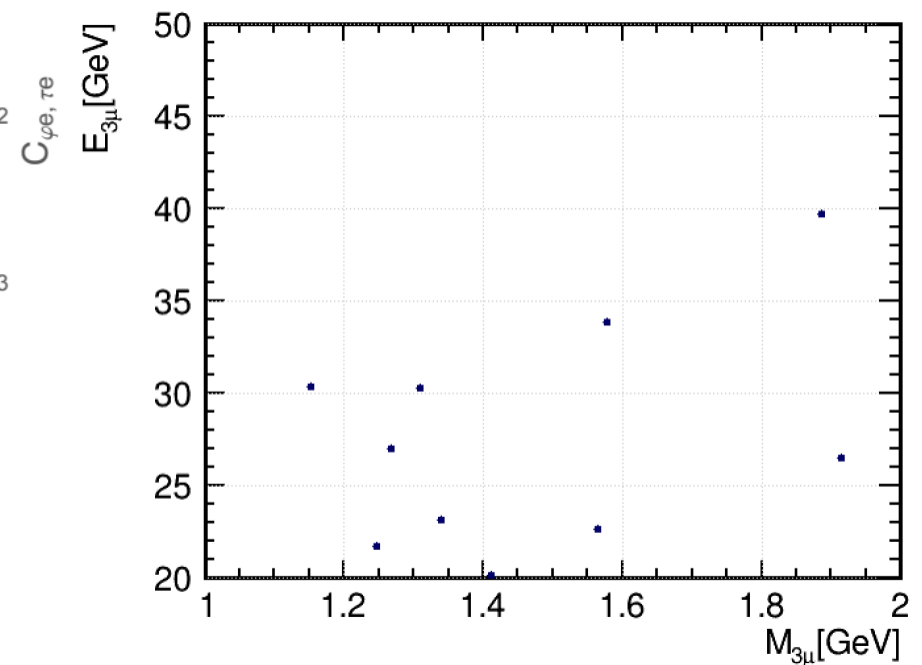
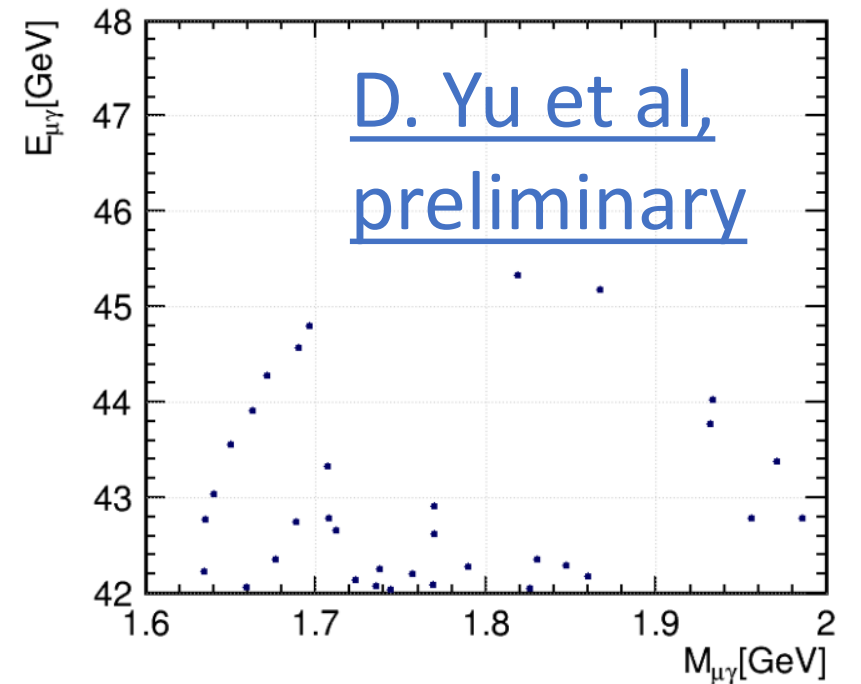
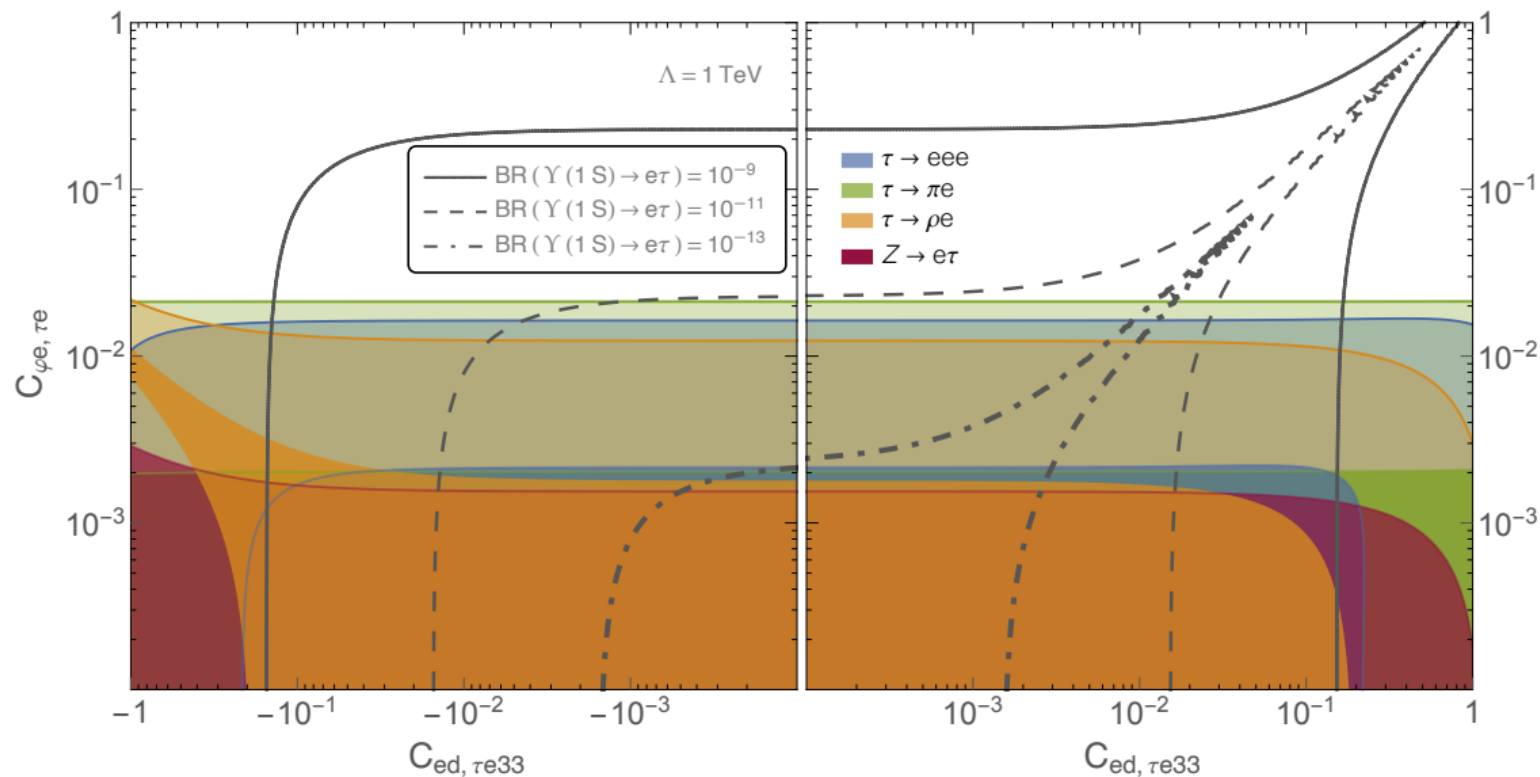
- Z decay also produces a lot of c and s quarks
- More s quarks ($K^{(*)}, \Lambda \dots$) produced by QCD
- Also building blocks of b physics

Recommendations:

- ❖ Have a charm physics program in parallel to bottom ones in the next phase
- ❖ Focus on K_S and Λ rare decays, e.g. $K_S \rightarrow \mu\mu(+\gamma)$, complementary to future kaon factories

9 τ Physics

- A most powerful tau machine
- Essential for EW and QCD in precision
- Most studies focus on exotic decays



[L. Calibbi, T. Li, X. Marcano, M.A. Schmidt, 2207.10913](#)

[L. Calibbi, X. Marcano, J. Roy, 2107.10273](#) [M. Dam, 2107.12832](#)

Section Summary and Suggestions

Measurement	Current [104]	FCC [102]	Tera-Z Prelim. [105]	Comments
Lifetime [sec]	$\pm 5 \times 10^{-16}$	$\pm 1 \times 10^{-18}$		from 3-prong decays, stat. limited
BR($\tau \rightarrow \ell \nu \bar{\nu}$)	$\pm 4 \times 10^{-4}$	$\pm 3 \times 10^{-5}$		0.1× the ALEPH systematics
m(τ) [MeV]	± 0.12	$\pm 0.004 \pm 0.1$		$\sigma(p_{\text{track}})$ limited
BR($\tau \rightarrow 3\mu$)	$< 2.1 \times 10^{-8}$	$\mathcal{O}(10^{-10})$	same	bkg free
BR($\tau \rightarrow 3e$)	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
BR($\tau \rightarrow e\mu\mu$)	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
BR($\tau \rightarrow \mu ee$)	$< 1.8 \times 10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
BR($\tau \rightarrow \mu\gamma$)	$< 4.4 \times 10^{-8}$	$\sim 2 \times 10^{-9}$	$\mathcal{O}(10^{-10})$	Z $\rightarrow \tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited
BR($\tau \rightarrow e\gamma$)	$< 3.3 \times 10^{-8}$	$\sim 2 \times 10^{-9}$		Z $\rightarrow \tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited

[M. Dam, 1811.09408](#)

- ❖ More exotic τ decay modes
- ❖ Hadronic τ decay for f_K , V_{us} , and $\alpha_s(m_\tau)$
- ❖ τ polarimetry/asymmetry at the Z pole for extracting EWPO

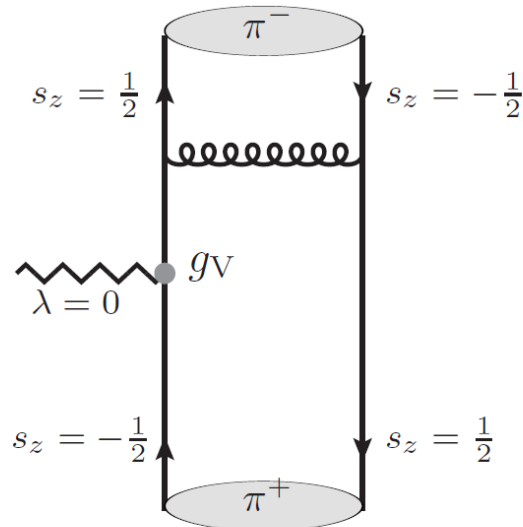
10 Flavor Physics at Higher Energies

10.1 Exclusive Hadronic Decays of Heavy SM Bosons

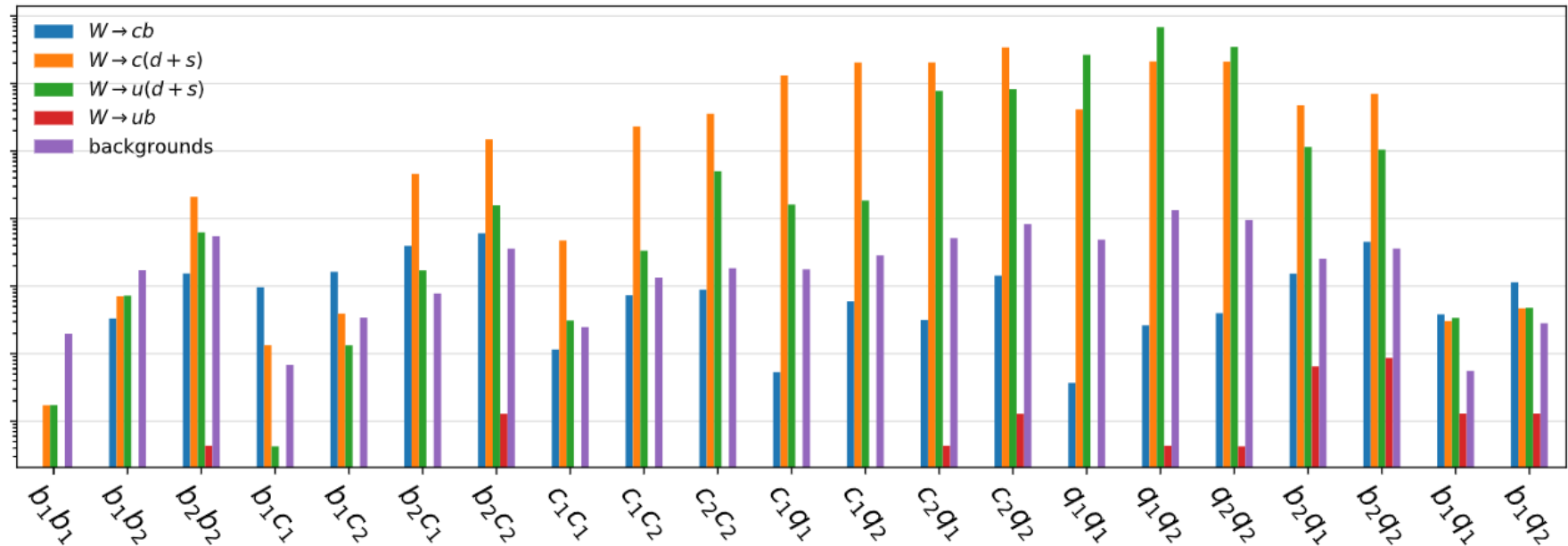
10.2 $|V_{cb}|$ measurement from on-shell W Decays

10.3 Other Possibilities

See Hao Liang's talk



(a) $Z \rightarrow \pi^+ \pi^-$



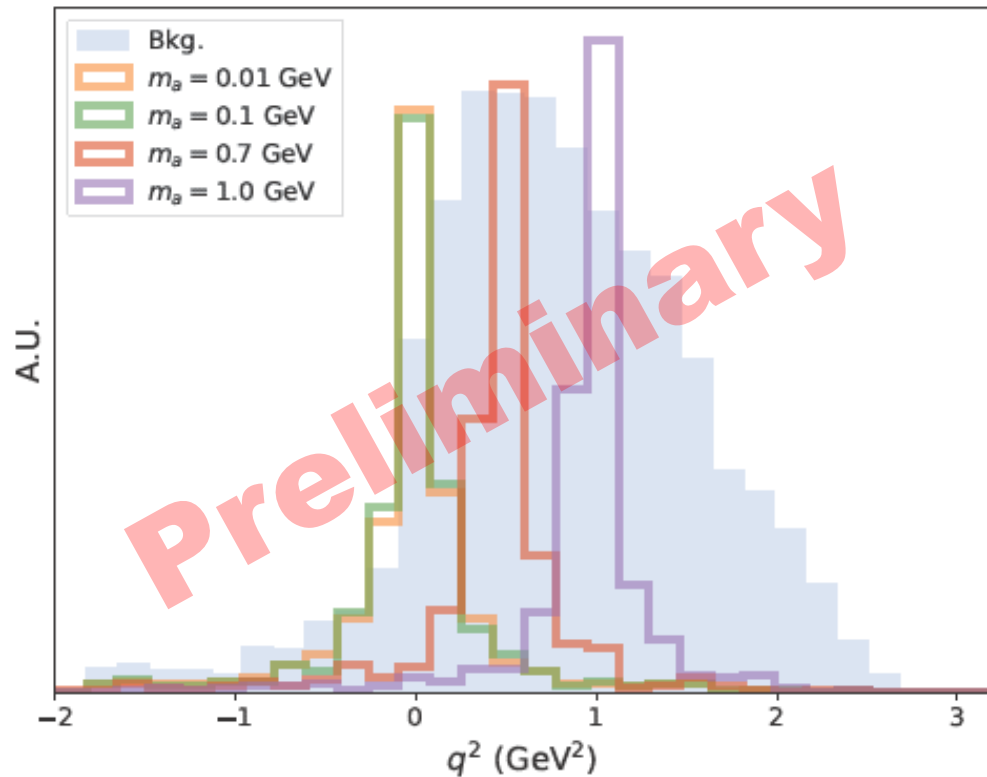
Current Recommendation:

❖ Flavored hadronization, also crucial for EW & Higgs

11 Production of BSM States from Heavy Flavor Decays

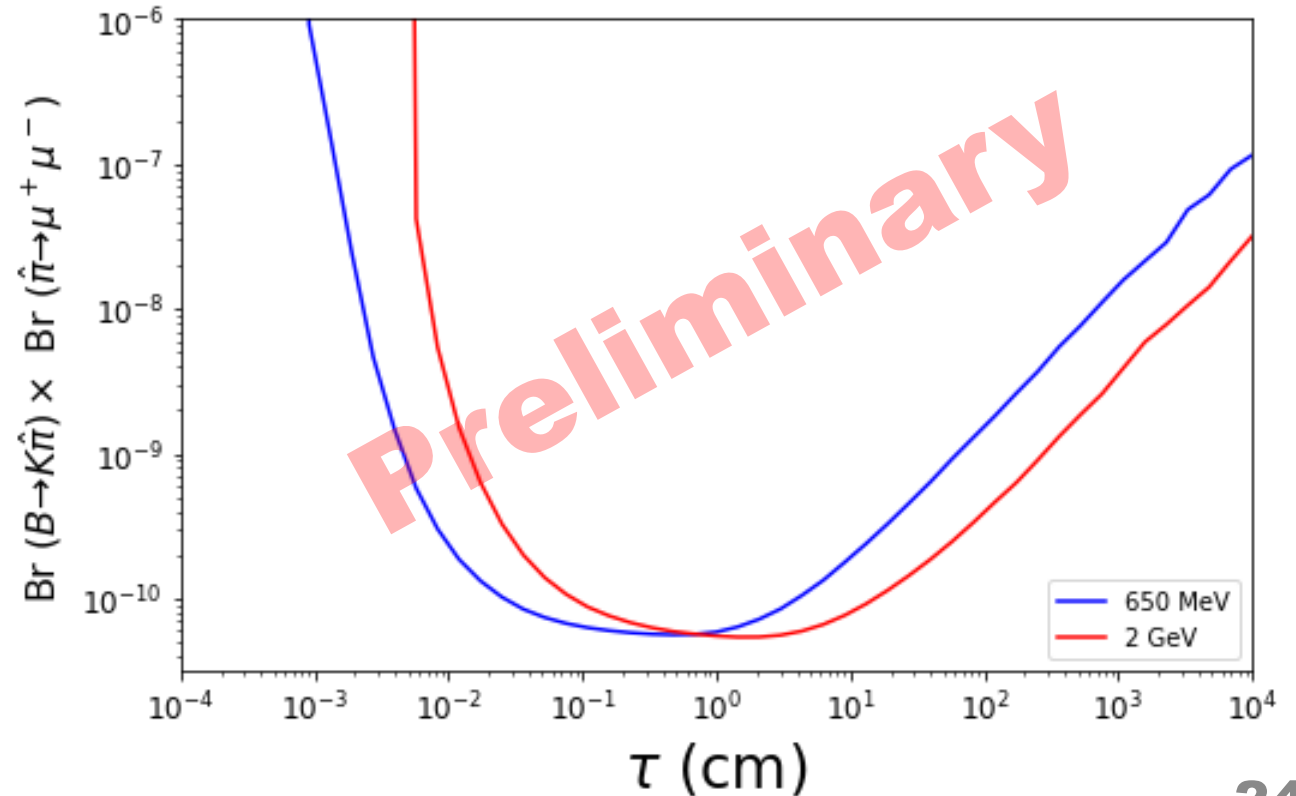
11.1 Light BSM states produced via their coupling with leptons

11.2 Light BSM states produced from FCNC quark decays



Dark sector from τ decays
Anson Kwok et al., in prep

Long lived particle from B FCNC rare decays Xuhui Jiang et al., in prep.



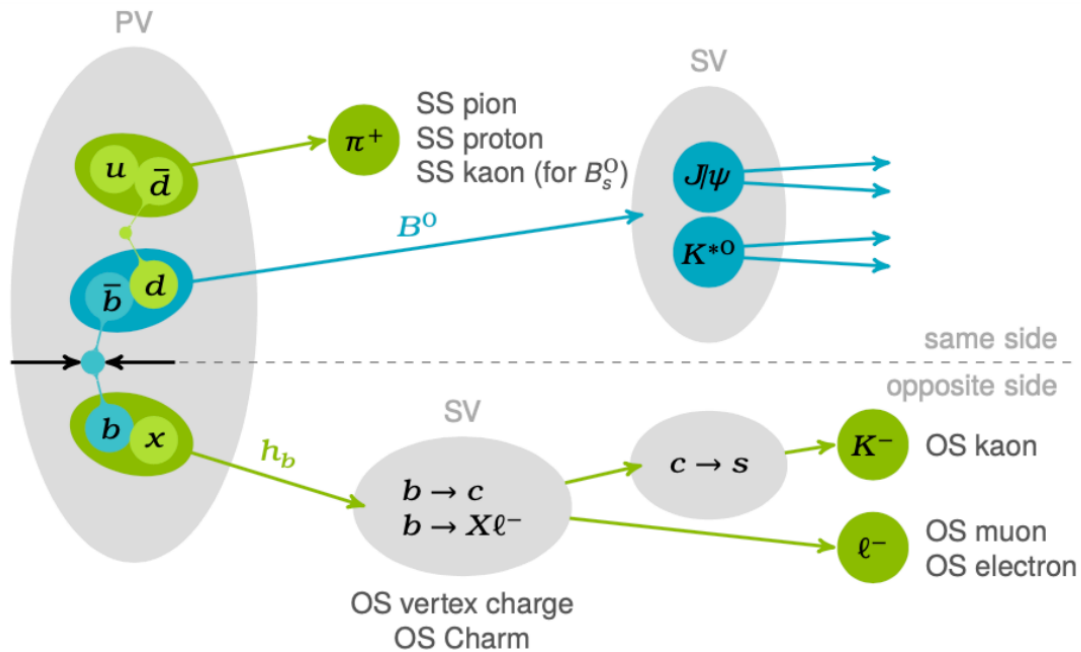
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5 Measuring CP Asymmetries

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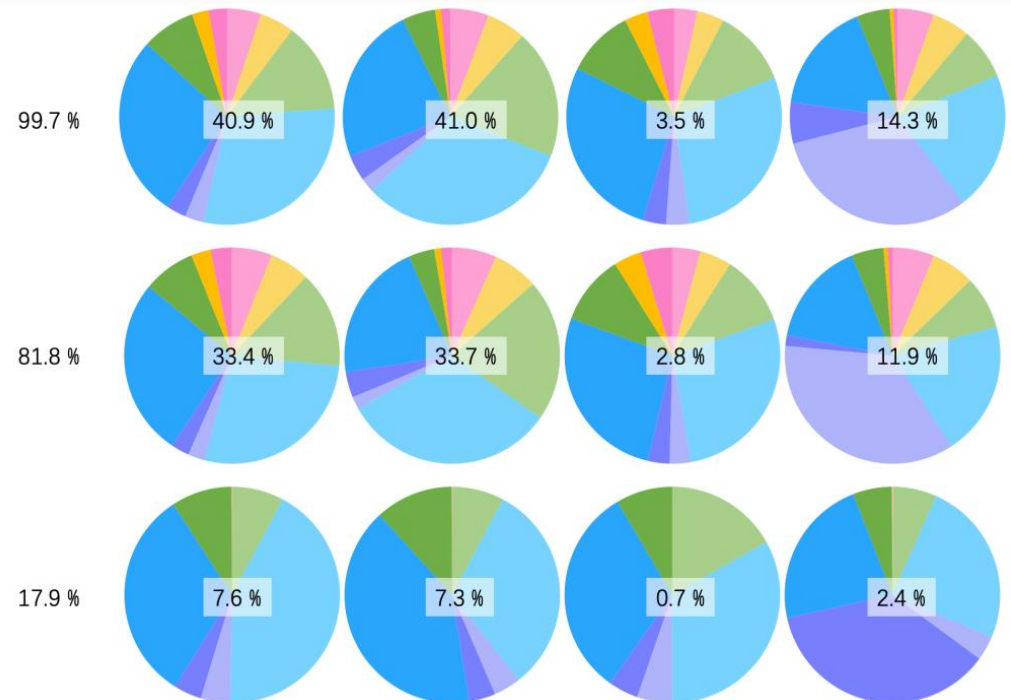
Flavor Tagging



Tagging strategies are similar to LEP and LHCb

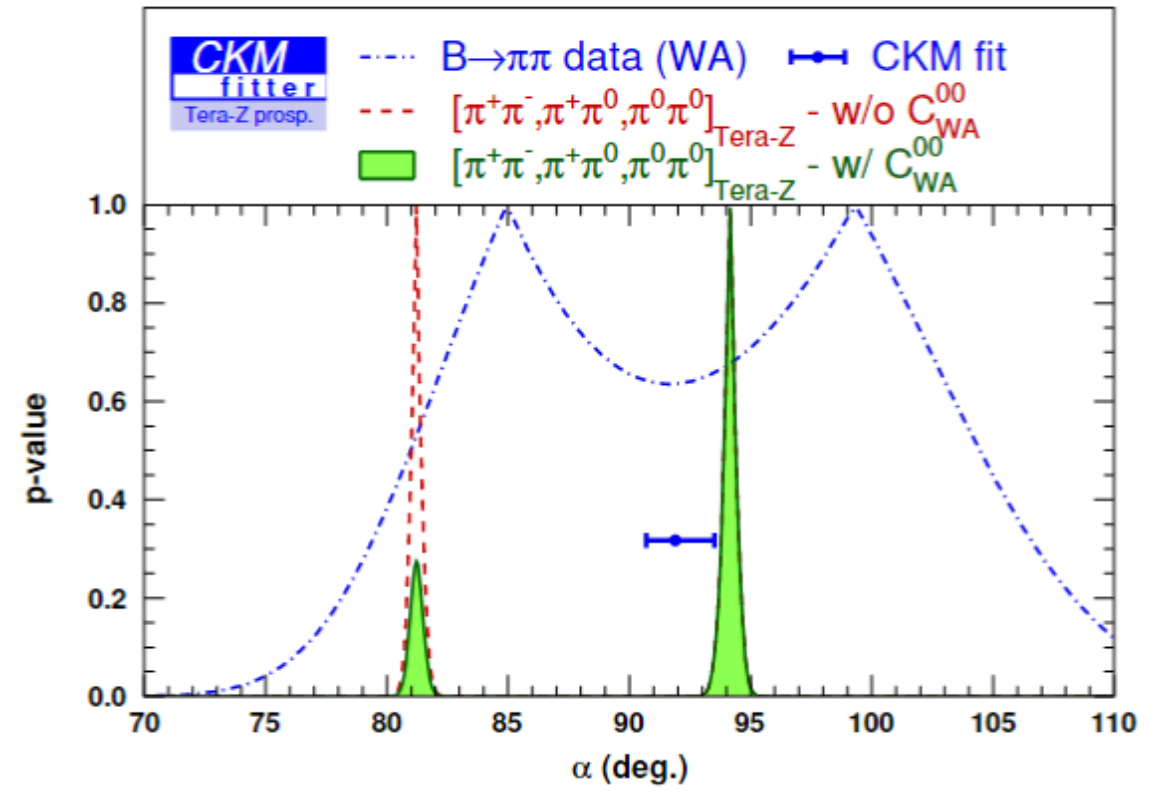
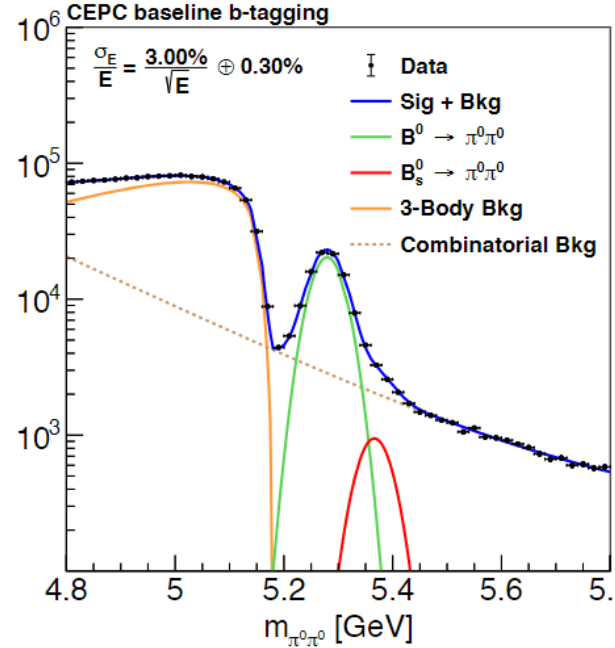
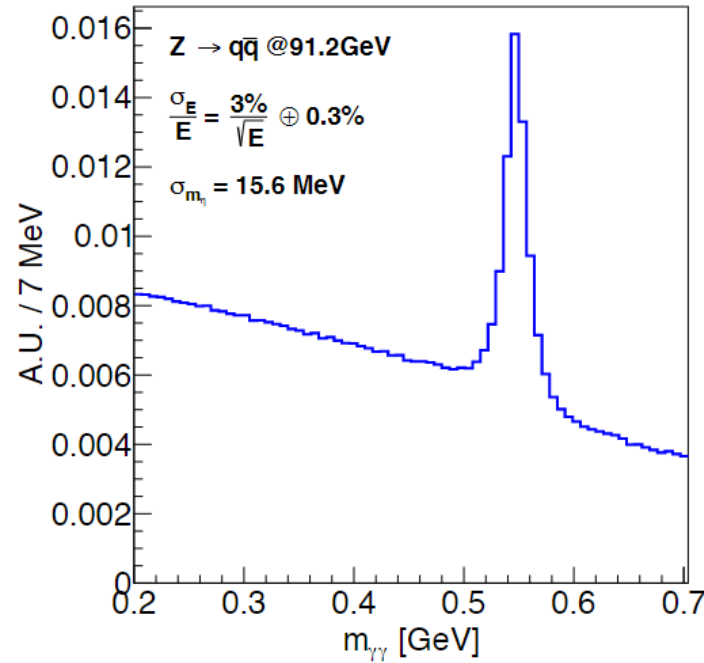
$$\epsilon_{\text{eff}} = \epsilon(1 - 2\omega_{\text{mistag}})^2$$

Effective tagging power @ LEP $\sim 20\%$, expected to improve further @ CEPC (vs. $\sim 5\%$ @LHCb & $\sim 35\%$ @ Belle II)



Preliminary study on going

Time-Integrated CP Asymmetry

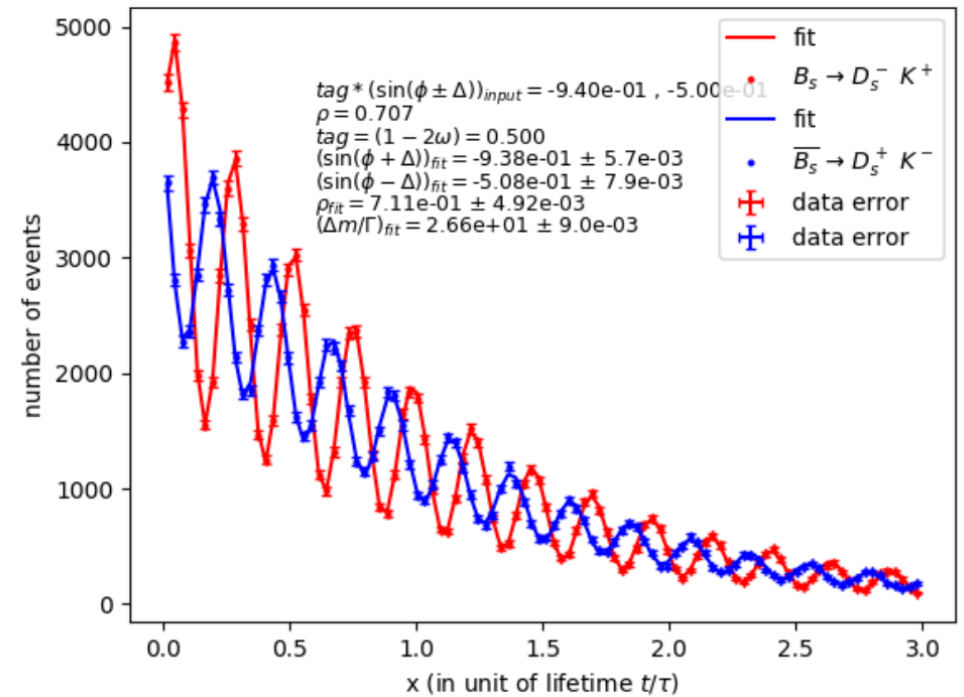
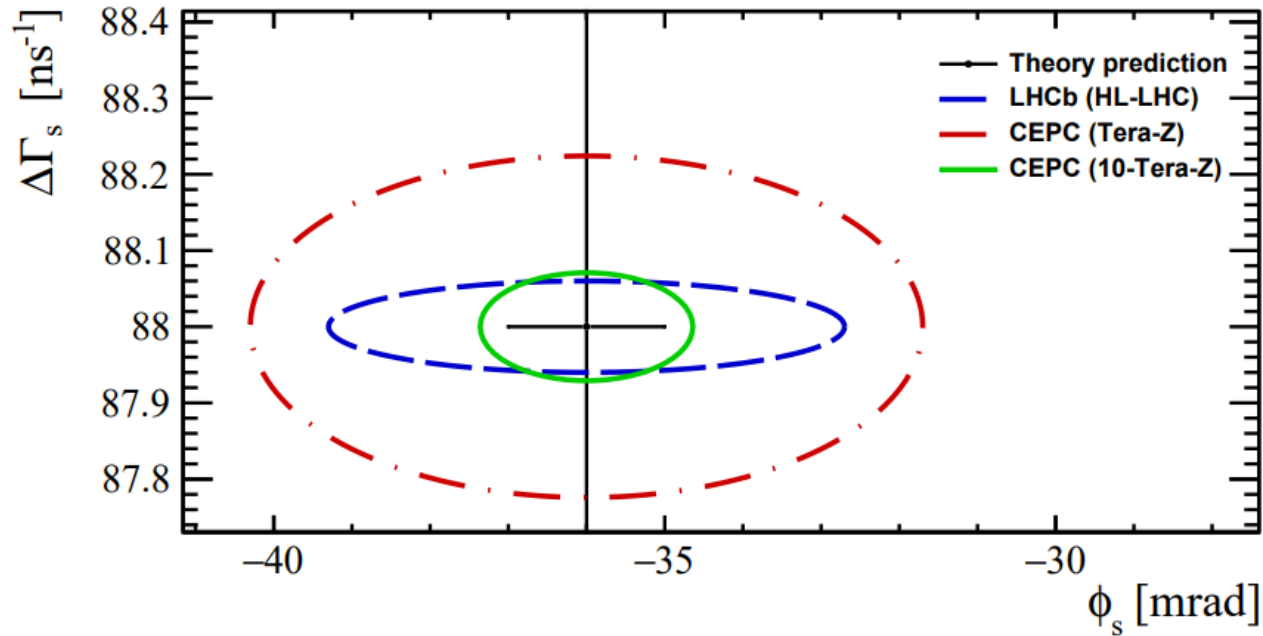


[Y. Wang, S. Descotes-Genon, O. Deschamps, LL, S. Chen, Y. Zhu, M. Ruan](#)

See also: [J. Charles, S. Descotes-Genon, Zoltan Ligeti, S. Monteil, M. Papucci, K. Trabelsi, L. Silva, 2006.04824](#)

Measure CKM α down to 0.4 deg by $B \rightarrow \pi^0\pi^0 \rightarrow 4\gamma$
 But only if ECAL is crystal

Time-Dependent CP Asymmetry



[X. Li, M Ruan, M. Zhao, 2205.10565](#)

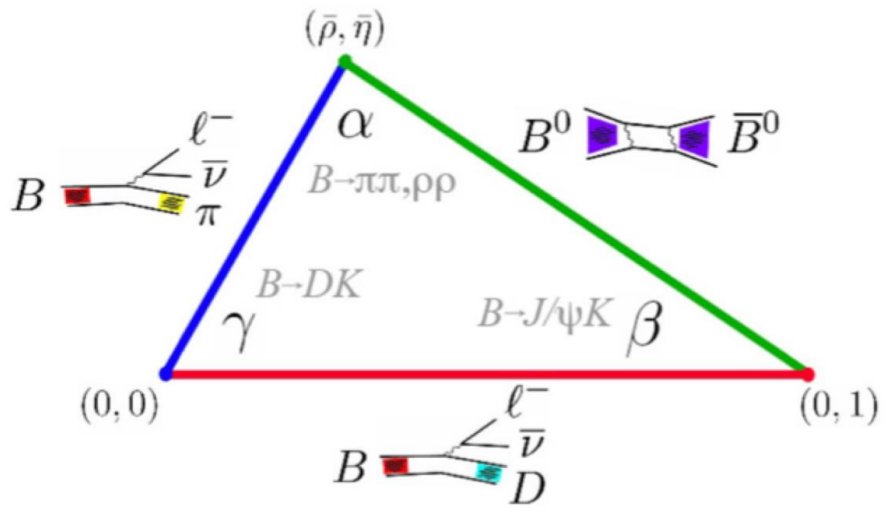
Angle β_s measurement by time-dependent $B_s \rightarrow J/\psi \phi \rightarrow \mu\mu KK$

See also [R. Aleksan, L. Oliver, 2205.07823](#)

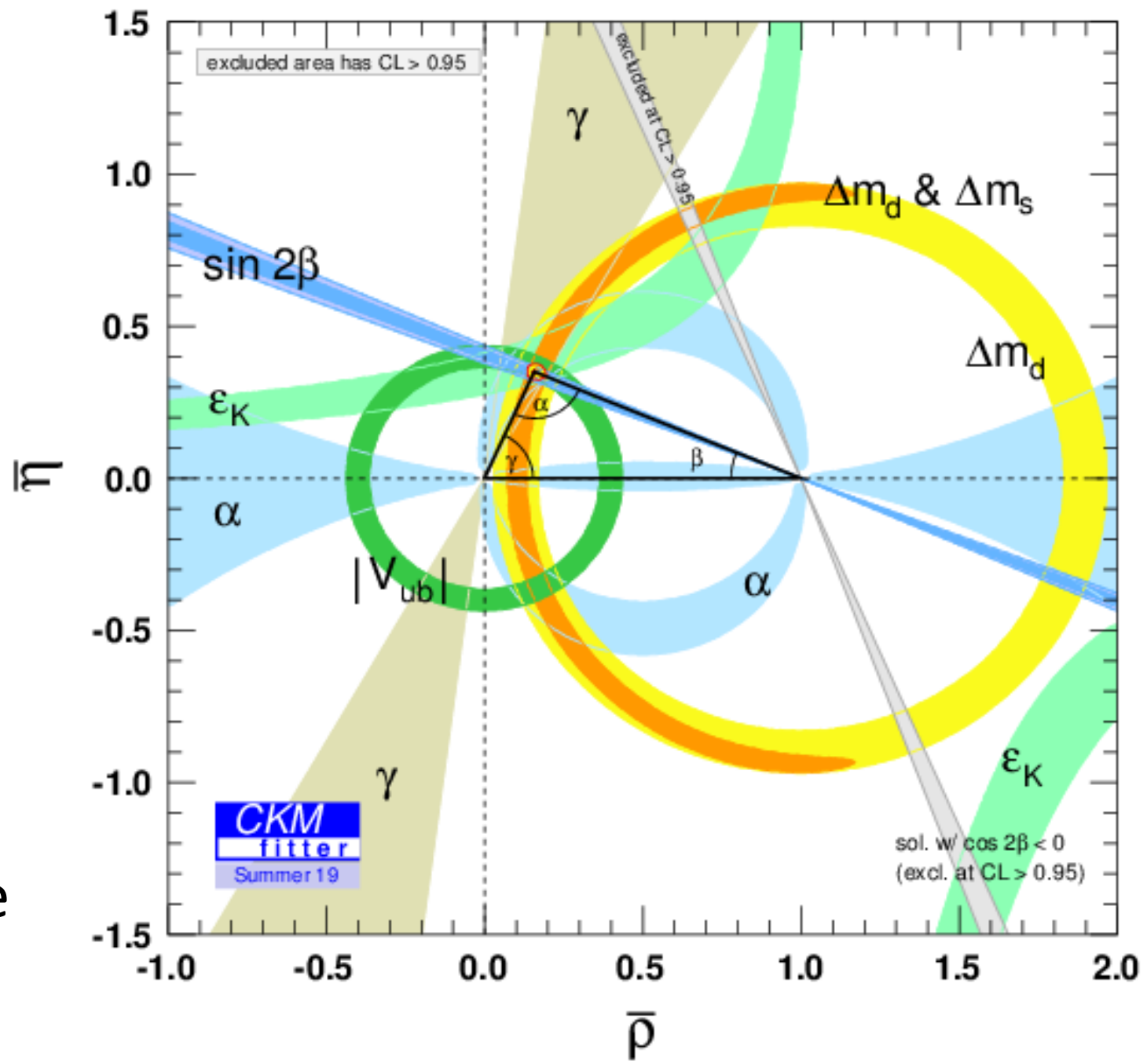
Time-dependent measurement of $B \rightarrow DK$ to give α_s and β_s , helpful to fix the value of angle γ

[R. Aleksan, L. Oliver, E. Perez, 2107.02002](#)

[R. Aleksan, L. Oliver, E. Perez, 2107.05311](#)



- ❖ We certainly want a CEPC version
- ❖ Need many more experiment and theory inputs
- ❖ Move on to the next phase



Summary

- ❖ Flavor program at CEPC is a healthy/urgent need
- ❖ Atypical layout for a flavor document due to inputs
- ❖ <https://www.overleaf.com/project/628f0728edf9ab937611359c>

“Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.”