The Belle II Experiment

an introduction

Caspar Schmitt

LMU,MPP

May 9, 2022

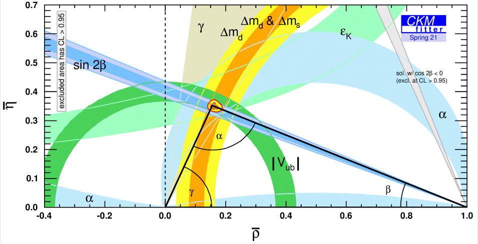
Overview

Open Questions

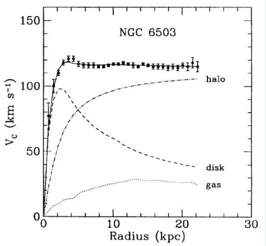
SM persists all experimental tests to date.

Still, it remains an incomplete phenomenological model that cannot answer many fundamental questions, e.g.

matter-antimatter asymmetry



dark matter



many more

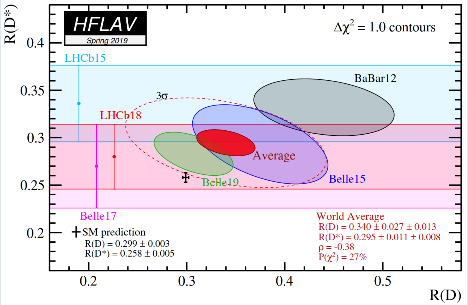
...

Flavor Physics

Search for violation of SM predictions: occurs only through NP in form of new particles or forces.

Flavour physics explores the three families of fundamental fermions in the SM. Anomalies hint towards lepton-non-universality (or even lepton flavor violation?).

$R(D^{(*)})$



$$R_{D^{(*)}\tau\nu_\tau/D^{(*)}l\nu_l} \equiv \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B\to D^{(*)}\tau\nu_\tau)}{dq^2}dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B\to D^{(*)}l\nu_l)}{dq^2}dq^2}$$

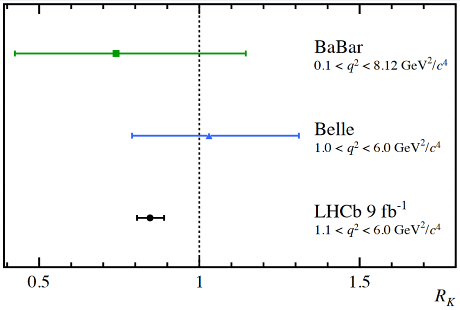
with $l \in (e, \mu)$

Flavor Physics

Search for violation of SM predictions: occurs only through NP in form of new particles or forces.

Flavour physics explores the three families of fundamental fermions in the SM. Anomalies hint towards lepton-non-universality (or even lepton flavor violation?).

$R(K)$ Moriand 2022



$$R_{K^{(*)}\mu\mu/K^{(*)}ee} \equiv \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B\to K^{(*)}\mu^+\mu^-)}{dq^2}\, dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B\to K^{(*)}e^+e^-)}{dq^2}\, dq^2}$$

Search for New Physics beyond Standard Model (NP)

There exist 2 complementary experimental approaches for search for NP

- **Direct Search:** Produce NP particles at high-energy collisions and observe their decays, e.g. LHC 14 TeV proton-proton.
- **Indirect Search:** Test precision measurements of suppressed reactions against SM predictions, e.g. B factories at 10.58 GeV electron-positron.

Indirect searches can test NP $\gg \sqrt{s}$

Due to lack of NP at LHC, efforts concentrate on indirect searches...

B factories

Produce heavy mesons and precisely measure their decay properties.

B meson production mechanism:

$$e^+e^- \xrightarrow{\sqrt{s}=m[\Upsilon(4S)]c^2} \Upsilon(4S) \xrightarrow{\mathcal{BR}>96\%} B\overline{B}$$

Advantages compared to hadron colliders

very low backgrounds, kinematically well-defined initial state, B meson pair in entangled coherent quantum state, can assess backgrounds at $\sqrt{s} < m[\Upsilon(4S)]c^2$, low multiplicity; easier to reconstruct neutral particles

Disadvantages compared to hadron colliders

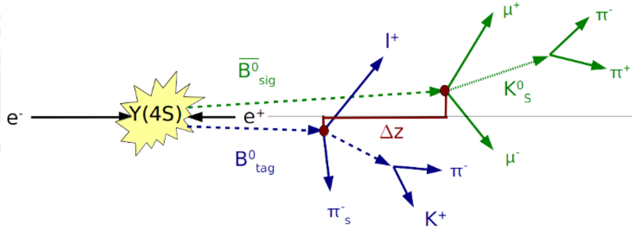
low B boost, B_s only at $\Upsilon(5S)$, low Υ production branching ratio; need high luminosity!

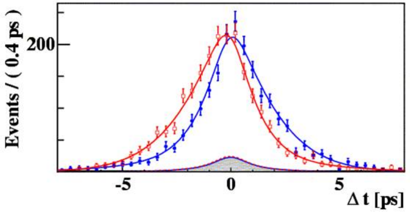
First Generation B Factories: Belle and BaBar

Belle (KEK collider) and BaBar (PEP-II) discover large CP violation in B meson system, confirm Kobayashi-Maskawa theory of quark mixing.

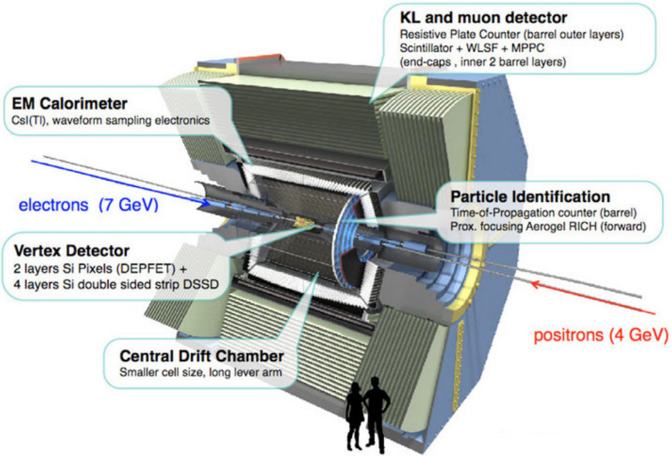
$$f_{\mathrm{flavor}} \longleftarrow B_{\mathrm{tag}} \longleftarrow \Upsilon(4S) \longrightarrow B_{\mathrm{sig}} \longrightarrow f_{\mathrm{CP}}$$

Flavor-tag one B meson in flavor-specific state and reconstruct the other in CP eigenstate. CP violation in interference of decay and mixing; need **decay-time dependent measurement**! Use **boosted CoM-frame in asymmetric collider!**





Second Generation B Factory: Belle II since 2019!

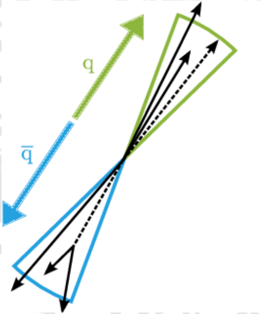


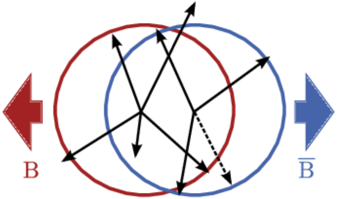
- SuperKEKB collider: record luminosity $3.8 \cdot 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in nano-beam scheme ($\sigma_y \approx 50\,\mathrm{nm}$)
- decreased beam asym., i.e. higher p_T
- close to 4π solid angle coverage
- Pixel Vertex Detector with $> 20\,\mathrm{\mu m}$ resolution

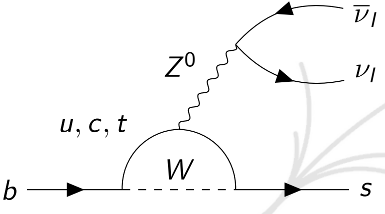
Missing Energy Channels at Belle II

B meson pair is produced exclusively with well-known CoM energy. Can use kinematic properties to identify **missing-energy decays** in hermetic detector.

$$\Delta E \equiv E^{*}_{\mathrm{beam}} - E^{*}_{\mathrm{B}}, \quad m_{\mathrm{bc}} \equiv \sqrt{E^{*2}_{\mathrm{beam}} - \vec{p}^{\,*2}_{\mathrm{B}}}, \quad p^2_{\mathrm{miss}} = p^2_{\mathrm{tag}} - p^2_{\mathrm{vis}}, \quad E^{\mathrm{res.}}_{\mathrm{ECL}}$$







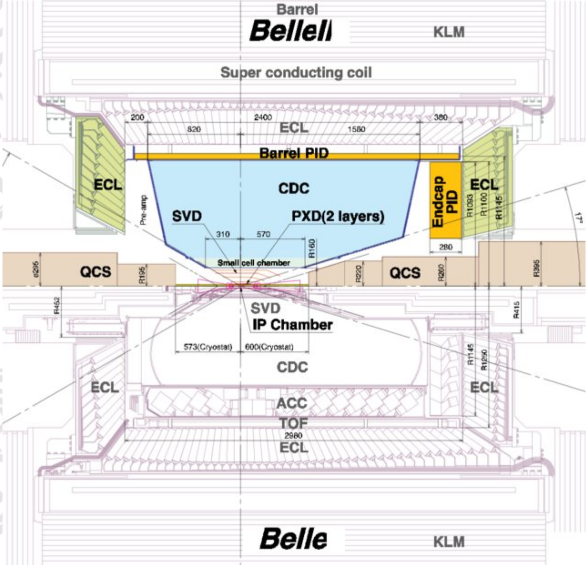
Event-shape variables

Conclusion and Belle II Prospects

Unique and complementary capabilities of Belle II, compared to hadron colliders.

- $\mathcal{L}_{\mathrm{int}} = 50\,\mathrm{ab}^{-1}$ by beginning of next decade
- precision CKM tests and serach for non-SM CP violation
- investigate anomalies in FCNC and semi-tauonic decays
- constraining hadronic vacuum polarization in muon $g-2$
- $e^+e^- \to \tau^+\tau^-$ factory
- ...

Belle vs. Belle II



References I

T. et al. Abe. Belle II Technical Design Report, 2010. URL https://arxiv.org/abs/1011.0352.

E Kou et al. The Belle II Physics Book. *Progress of Theoretical and Experimental Physics*, 2019(12), dec 2019. doi: 10.1093/ptep/ptz106. URL https://doi.org/10.1093%2Fptep%2Fptz106.

Francesco Forti. Snowmass Whitepaper: The Belle II Detector Upgrade Program, 2022. URL https://arxiv.org/abs/2203.11349.