March 5, 2018

Testing the Standard Model in rare decays of *B* mesons at the Belle experiment

Physic Seminar Centre CEA de Saclay

Presented by Simon Wehle

Deutsches Elektronen-Synchrotron

BELLE

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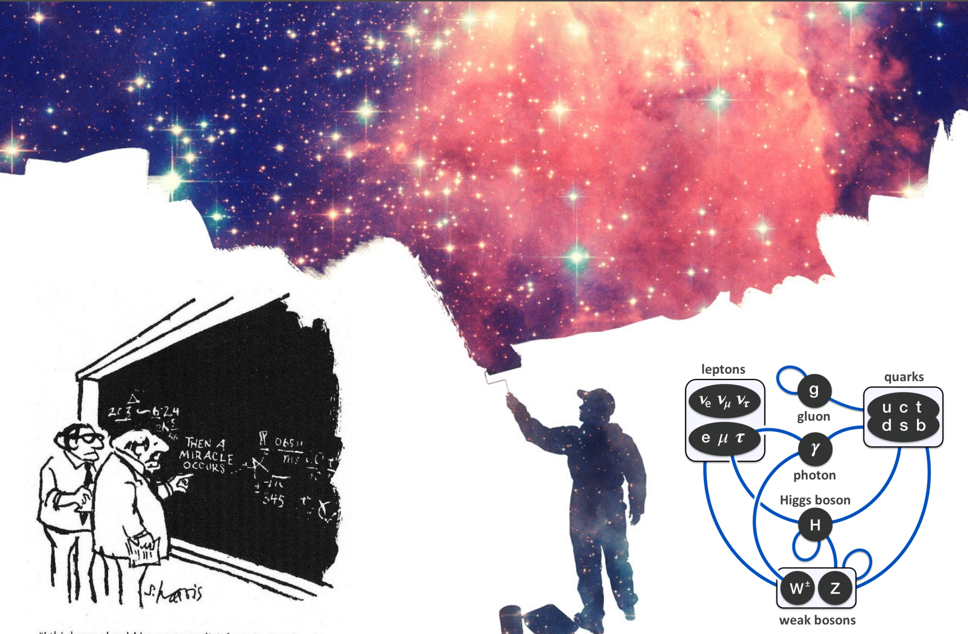
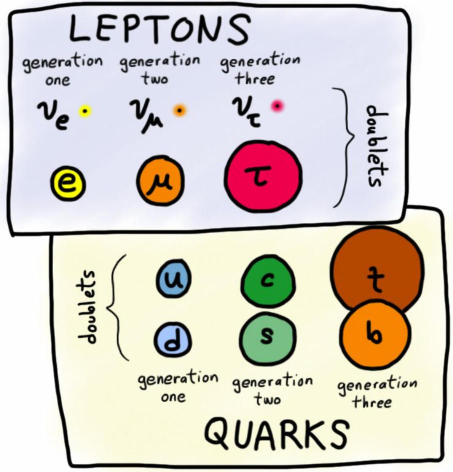


"I think you should be more explicit here in step two."

Design by Philipp Rietz

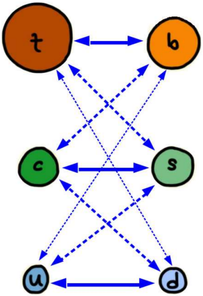
Particle Physics Today

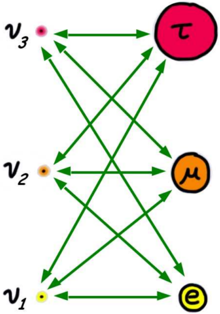
- The Standard Model leaves many questions
- Why do we have three generations of leptons and quarks?
- Hierarchy, masses, 22 free parameters



Credit: W. Altmannshofer, The Flavor Puzzle

Particle Physics Today

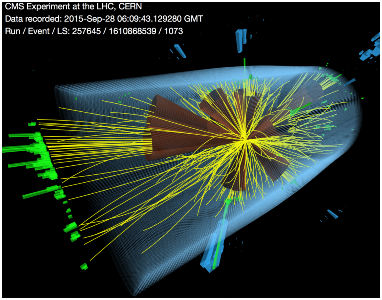


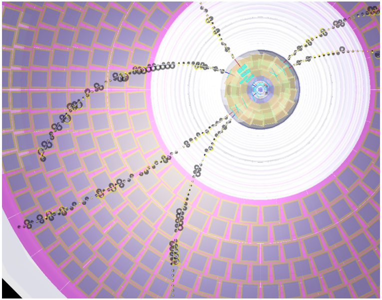


Credit: W. Altmannshofer, The Flavor Puzzle

- Can we find New Physics to understand the structure of the SM ?
- With flavor physics we soon might be a step closer..

Frontiers





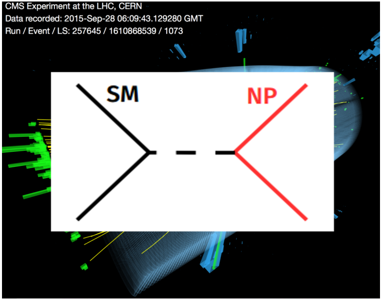
High Energy

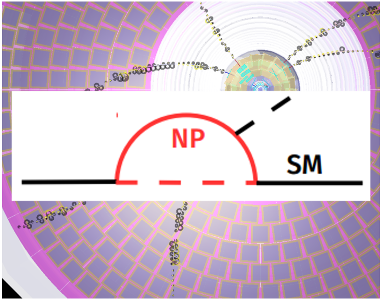
- Allows for the direct production of new particles
- Energy Scale $\sim$ 10 TeV
- No indication for NP

Precision Physics

- New "virtual" particles can occur in quantum loops
- Can test a higher mass scale of $\sim$ 100 TeV
  [A. Buras et al, JHEP1411(2014)121]
- There are many tensions in the flavor sector!

Frontiers





High Energy

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Precision Physics

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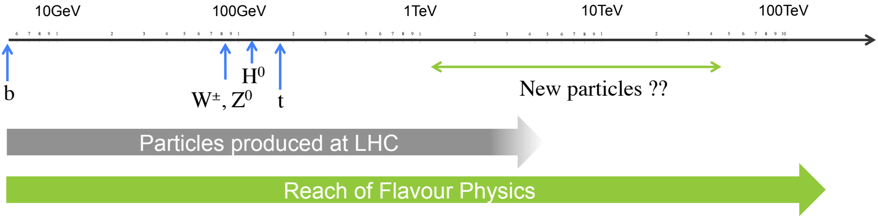
Complementary Pathways to New Physics



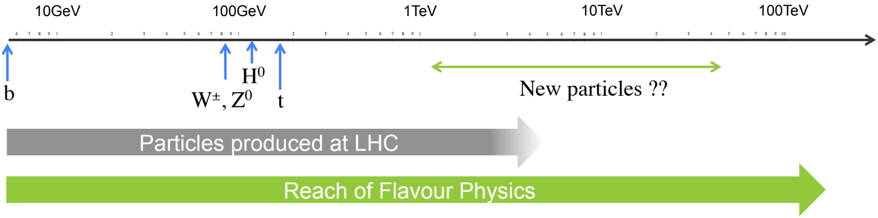
New particles ??

Particles produced at LHC

Reach of Flavour Physics

Credit: J. Albrecht, DESY Seminar 16

Complementary Pathways to New Physics

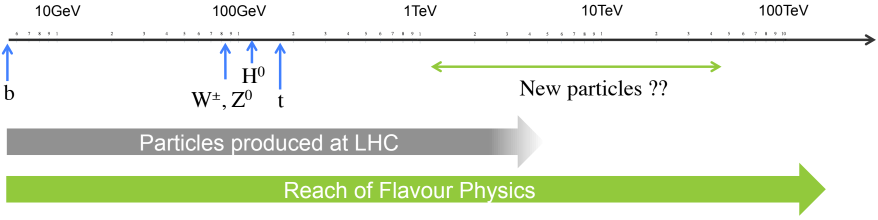


Credit: J. Albrecht, DESY Seminar 16

Past examples

- GIM Mechanism: *c* quark
- *B* oszillations $\rightarrow M_t > 50\ \mathrm{GeV}$

Complementary Pathways to New Physics



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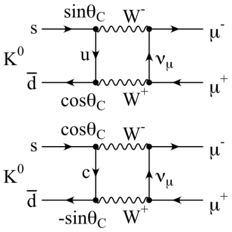

b Quark Decays

_b_ quark properties

- Third family, high mass
- must decay outside of third
- all decays CKM suppressed
- $\rightarrow$ long live-time

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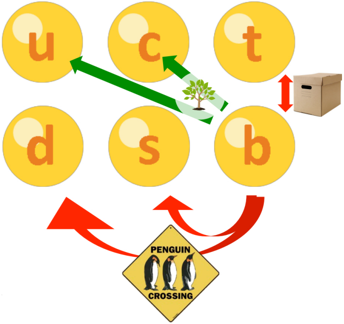

Credit: J. Albrecht, DESY Seminar 16

b Quark Decays

b quark properties

- Third family, high mass
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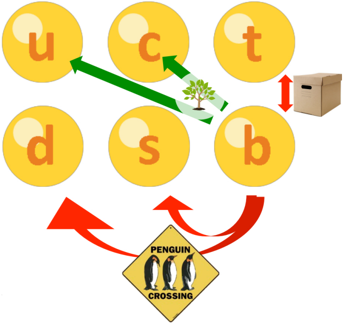
- All forces of the Standard Model involved in *B* meson decays



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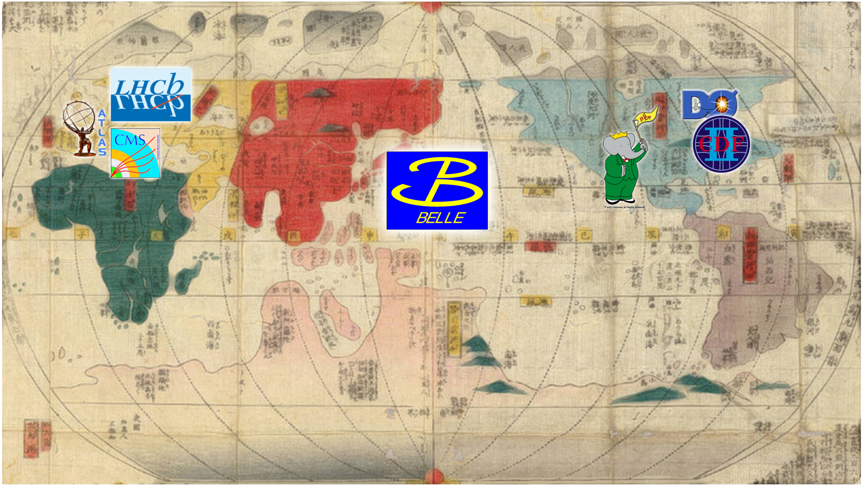
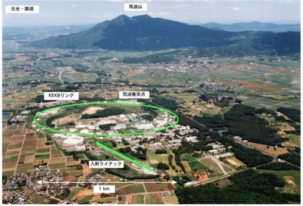
Flavor Physics around the World

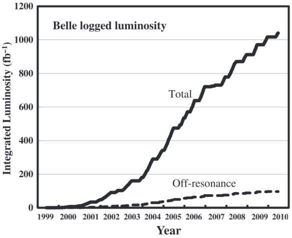


The Belle Experiment



- The Belle experiment is located at the KEKB accelerator in Tsukuba, Japan
- Data taking from 1999 to 2010
- It is designed as a “B factory”
- 772 million $B\bar{B}$ meson pairs

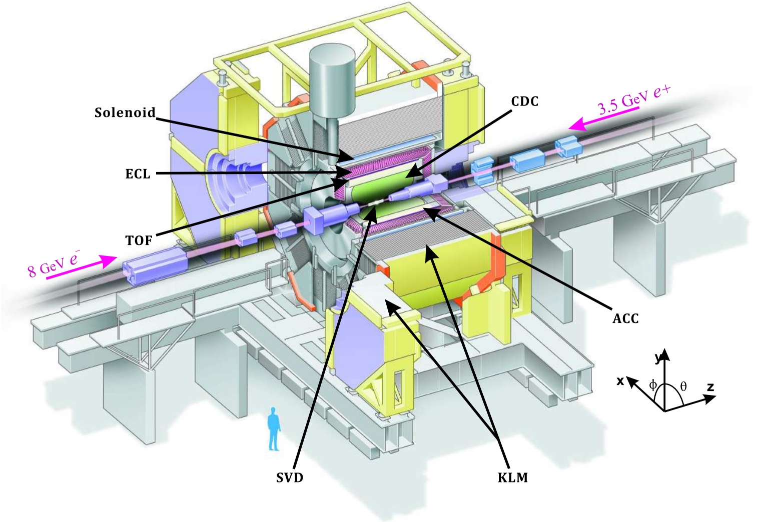
$$e^+e^- \to \Upsilon(4S) \to B\bar{B}$$



- World record for integrated luminosity

$$\int Ldt = 1\ \mathrm{ab}^{-1}$$

The Belle Detector



Flavor Anomalies

Flavor Anomalies

$> 3.5\sigma$	enhanced $B \to D^{(*)}\tau\nu$ rates
3.3σ	suppressed branching ratio of $B_s \to \phi\mu^+\mu^-$
$\sim 3\sigma$	tension between inclusive and exclusive determination of $\|V_{ub}\|$
$\sim 3\sigma$	tension between inclusive and exclusive determination of $\|V_{cb}\|$
$> 3\sigma$	anomalies in angular distributions of $B \to K^*\ell\ell$
2.6σ	lepton flavor non-universality in $B \to K^{(*)}\mu^+\mu^-$ vs. $B \to K^{(*)}e^+e^-$

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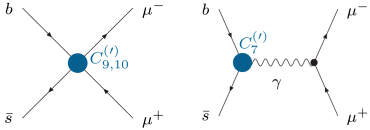
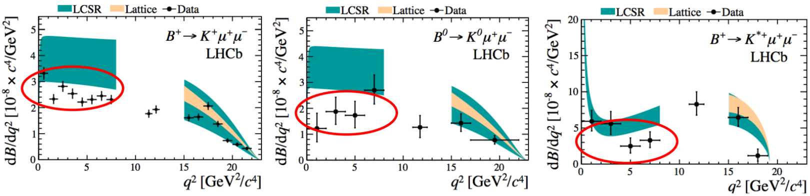
2.6σ lepton flavor non-universality in $B \to K^{(*)}\mu^+\mu^-$ vs. $B \to K^{(*)}e^+e^-$

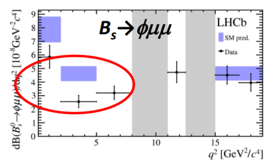


Same effective couplings
(Wilson Coefficients $\mathcal{C}_{7,9,10}$)

The Flavor Anomalies Overview - Branching Ratios



JHEP 06 (2014)133



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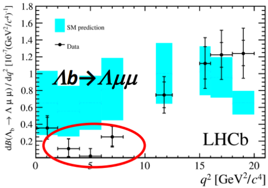

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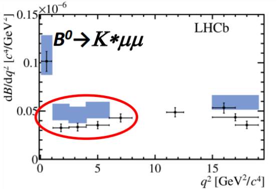
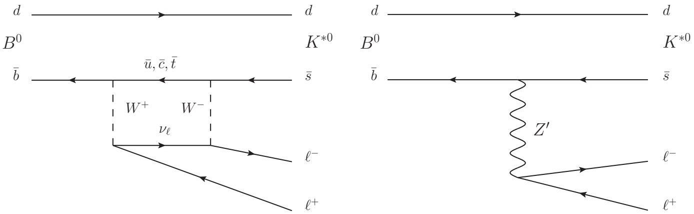


JHEP 11(2016)047
JHEP 04(2017)142

From Justine Serrano EPS2017

Flavor Changing Neutral Currents $b \to s\ell\ell$

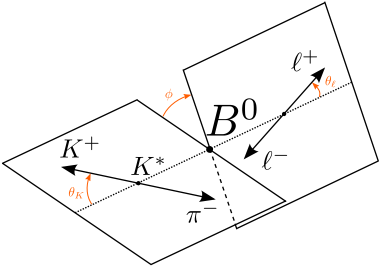


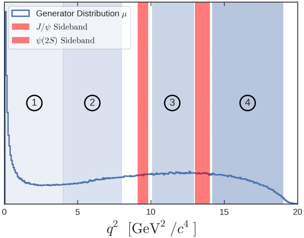
(b) SM example (c) NP example

- Branching ratios of $\mathcal{O}(1 \times 10^{-6})$
- In my thesis I analyzed $b \to s\ell\ell$ in the decay of $B \to K^{(*)}\ell^+\ell^-$
- In all three lepton modes:

e, μ An angular analysis of $B^0 \to K^*(892)^0\ell^+\ell^-$
τ Upper limit to $B^+ \to K^+\tau^+\tau^-$

Angular Analysis of $B \to K^*\ell\ell$





The observables are depended on $q^2 = M^2_{\ell^+\ell^-}$

The differential decay rate for $B \to K^*\ell^+\ell^-$ can be written as

$$
\begin{aligned}
\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_L\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Bigg[& \frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K \\
& + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_L \\
& - F_L\cos^2\theta_K\cos 2\theta_L + S_3\sin^2\theta_K\sin^2\theta_L\cos 2\phi \\
& + S_4\sin 2\theta_K\sin 2\theta_L\cos\phi + S_5\sin 2\theta_K\sin\theta_L\cos\phi \\
& + S_6\sin^2\theta_K\cos\theta_L + S_7\sin 2\theta_K\sin\theta_L\sin\phi \\
& + S_8\sin 2\theta_K\sin 2\theta_L\sin\phi + S_9\sin^2\theta_K\sin^2\theta_L\sin 2\phi\Bigg],
\end{aligned}
$$

Folding Procedure

$$P'_4, S_4: \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \phi \to \pi - \phi & \text{for } \theta_L > \pi/2 \\ \theta_L \to \pi - \theta_L & \text{for } \theta_L > \pi/2, \end{cases}$$

$$P'_5, S_5: \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_L \to \pi - \theta_L & \text{for } \theta_L > \pi/2, \end{cases}$$

Introduced by LHCb in Phys. Rev. Lett. 111, 191801.

- With a transformation of the angles, the dimension is reduced to three free parameters
- Each transformation remains three observables S_j, F_L and S_3
- The observables

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}},$$

are considered to be largely free from form-factor uncertainties (J. High Energy Phys. 05 (2013) 137).

- Transverse polarization asymmetry

$$A_T^{(2)} = \frac{2S_3}{(1-F_L)}$$

Reconstruction of $B \rightarrow K^*\ell^+\ell^-$

- Reconstructing **B^0 and B^+ modes**
- Using **muon** and **electron** modes
- K^* is reconstructed in (K^+, π^-), (K_S^0, π^+) and (K^+, π^0)

Electron Modes

- $B^0 \rightarrow K^*(892)^0 e^+ e^-$
- $B^+ \rightarrow K^*(892)^+ e^+ e^-$

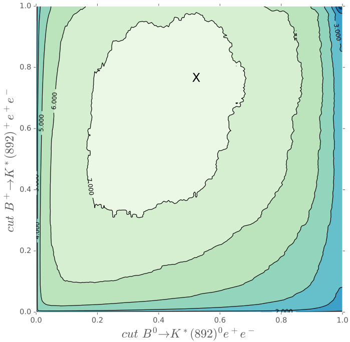
Muon Modes

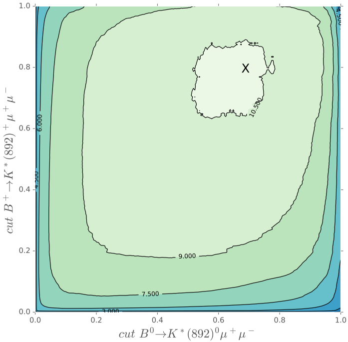
- $B^0 \rightarrow K^*(892)^0 \mu^+ \mu^-$
- $B^+ \rightarrow K^*(892)^+ \mu^+ \mu^-$

Signal selection:

- Neural network (NN) classifier for all particles in the decay chain
- Final signal selection on four B meson NN
- NN cut optimization on 2D figure of merit separate for the lepton flavor

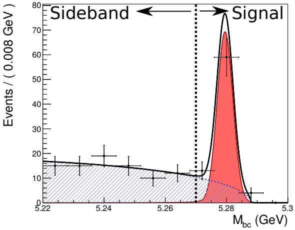
Cut Optimization





- Most stright forward strategy:
- Optimize a combined FOM for *ee* and $\mu\mu$ channels
- $FOM = N_s/\sqrt{(N_s + N_b)}$

Fit Procedure



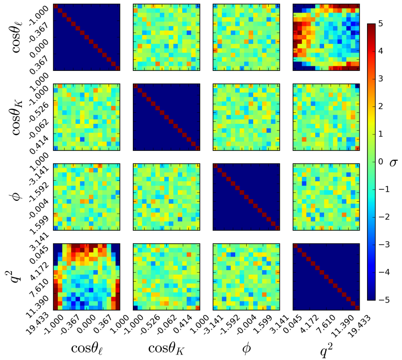
- Signal: Transformed differential decay rate
- Background: Kernel Density Estimation
- independent 3D unbinned maximum likelihood fit for:
  - q^2 bin: (1, 6), (0.1, 4), (4, 8), (10.09, 12.9), (14.18, 19)
  - P_4' and P_5'

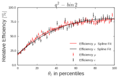
1. The data is split into bins of q^2
2. M_{bc} is fitted to determine the signal and background fractions
3. The data is split into a sideband and signal region
4. The shape of the background is determined and fixed in the sideband with smoothed histograms
5. The final fits are performed as 3D maximum likelihood fit in θ_L, θ_K and ϕ for $P_{4,5,6,8}$ each treated as an independent measurement

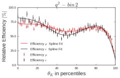
Efficiency/Acceptance is critical to understand(!)

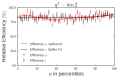
- We compare the generated distribution with the reconstructed
- The difference is fitted with a spline-fit

$$f_{eff}^{bin}(\cos\theta_\ell, \cos\theta_K, \phi, q^2) = f_{eff}^{fit}(\cos\theta_\ell) \otimes f_{eff}^{fit}(\cos\theta_K) \\ \otimes f_{eff}^{fit}(\phi) \otimes f_{eff}^{fit}(q^2),$$



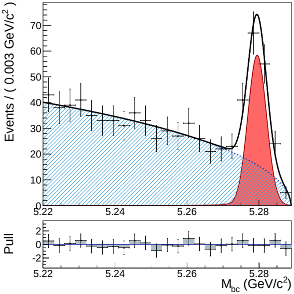




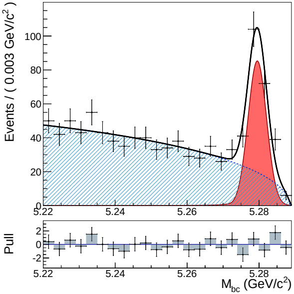


Signal Extraction $B \to K^*\ell^+\ell^-$

- Signal is extracted in Beam Constrained Mass: $M_{\mathrm{bc}} \equiv \sqrt{E^2_{\mathrm{Beam}} - |\vec{p}_B|^2}$
- Signal pdf: Crystal Ball shape, Background pdf: Argus shape

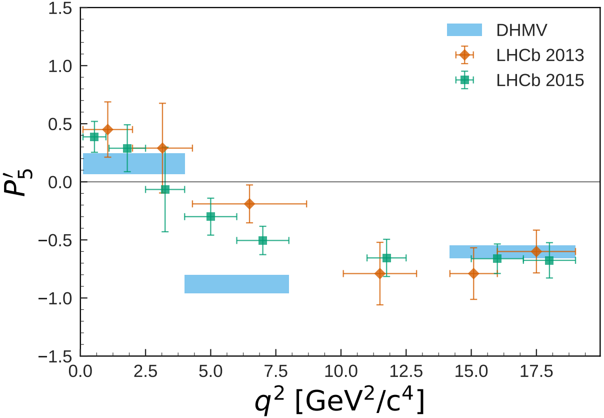


$B^0 \to K^*(892)^0 e^+ e^-$
$B^+ \to K^*(892)^+ e^+ e^-$
127 ± 15 signal candidates



$B^0 \to K^*(892)^0 \mu^+ \mu^-$
$B^+ \to K^*(892)^+ \mu^+ \mu^-$
185 ± 17 signal candidates

Result P_5' - Result



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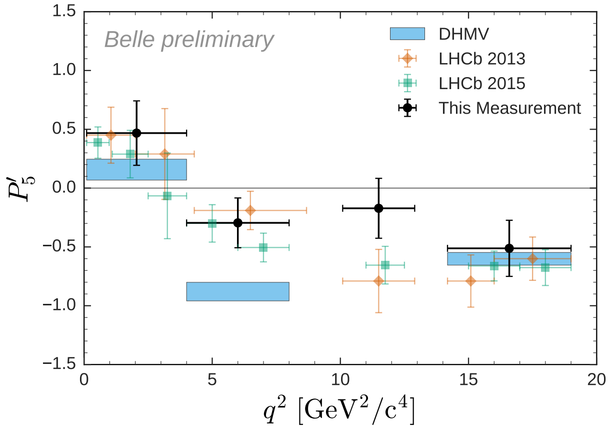
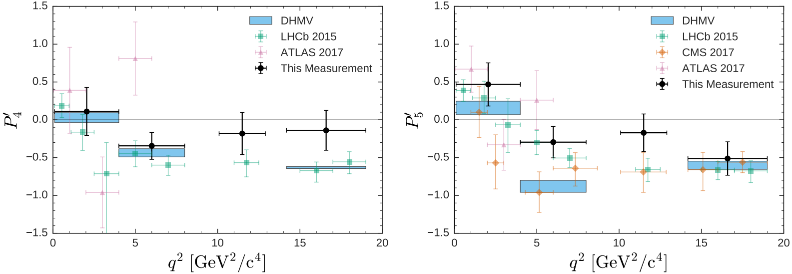


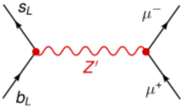
Result - Result for Combined Data



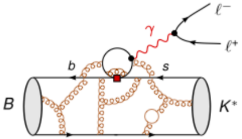
- Measurements are compatible with the SM
- Similar central values for the P_5' anomaly with 2.5σ tension

Complications - Doubts

Optimist's view point



Pessimist's view point



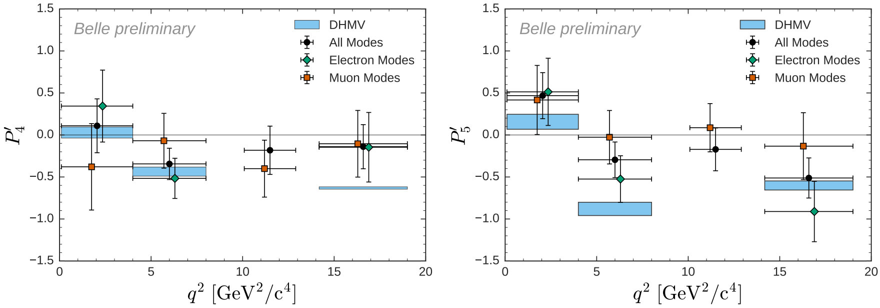
- Although, overall uncertainty on $b \to s\ell\ell$ form-factors decreased – significance of anomalies increased


e
μ
τ

Lepton Flavor Universality

- Fundamental in of the Standard Model
    - Very well tested
- Clean observables
- Only new particles can lead to LFU violation

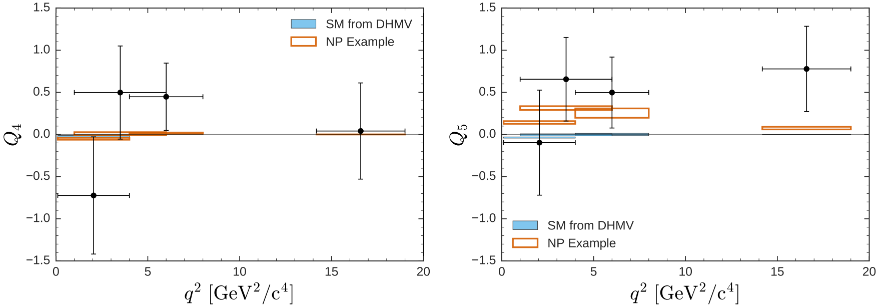
Result - Separate Lepton Flavor!



- The Largest deviation in the muon mode with 2.6σ
- Electron mode is deviating with 1.1σ
- Test on Lepton flavor universality

Lepton Flavor Universality in Angular Observables

- Test lepton flavor universality
- Observables $Q_i = P_i^\mu - P_i^e$, JHEP 10, 075 (2016)
- Deviation from zero very sensitive to NP

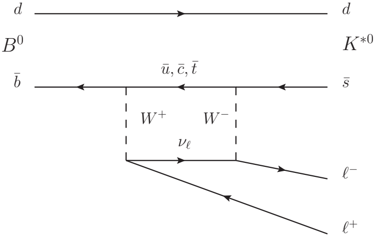


- Published recently in Phys. Rev. Lett. 118, 111801 (2017)

Simple Lepton Flavour Universality Tests

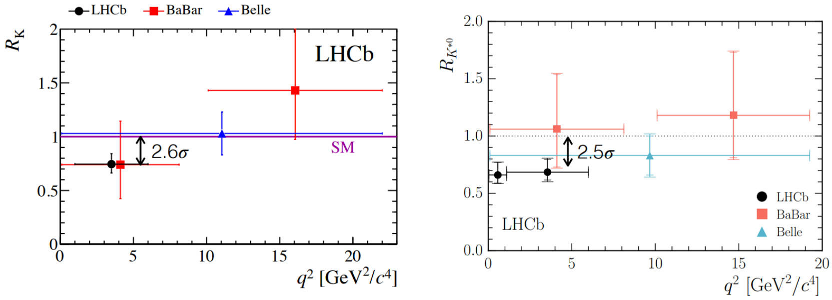
$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)}$$

$$R_K^* = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}$$



- Theoretically very clean
- Uncertainties from form factors cancel in the ratio
- Control mode $B \to J/\psi K^{(*)}$

Experimental Results for R_K



- Consistent experimental results
- Updated Belle result in preparation
  - Possible results for R_K^{*0} and R_K^{*+}
- 25% effect against SM for muons in electroweak penguins

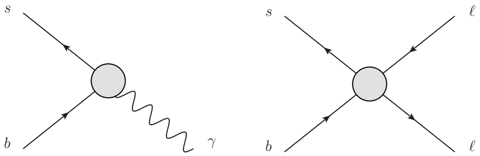
Effective Hamiltonian Approach

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_i (\underset{\substack{\uparrow \\ \text{left-handed part}}}{C_i\mathcal{O}_i} + \underset{\substack{\uparrow \\ \text{right-handed part} \\ \text{suppressed in SM}}}{C'_i\mathcal{O}'_i})$$

i=7 : photon
i=9 : vector current
i=10 : axial-vector current
i= S,P : scalar, pseudo scalar operators

- The $b \to s\ell\ell$ decay can be described by an effective field theory
- Model independent description:

$$\mathcal{H}_{eff} \propto \sum_i \left(C_i^{SM} + C_i^{NP}\right) \cdot O_i$$



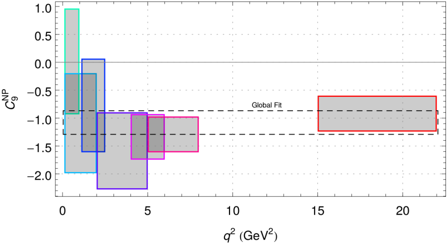
(a) $\mathcal{O}'_7$ (b) $\mathcal{O}'_9$ and $\mathcal{O}'_{10}$

Constraining Wilson Coefficients

- Look across all different measurements of $b \to s\ell\ell$
- Short distance effects can be described by Wilson Coefficients $\mathcal{C}_i$
- $\mathcal{C}_{7,9,10}$ important for $b \to s\ell\ell$ processes

- F_L from Atlas and LHCb
- A_{FB} from Atlas and LHCb
- R_K from BaBar and LHCb
- Branching ratios for $b \to s\ell\ell$
- P_5'...

→ constrain Wilson Coefficients $\mathcal{C}_i$ across measurements and experiments

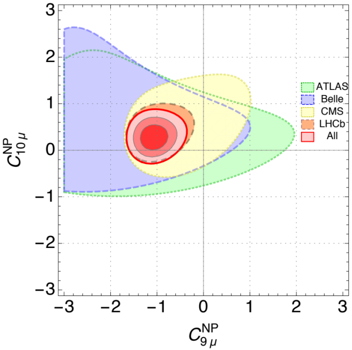


- Global fit
- Fit NP contribution

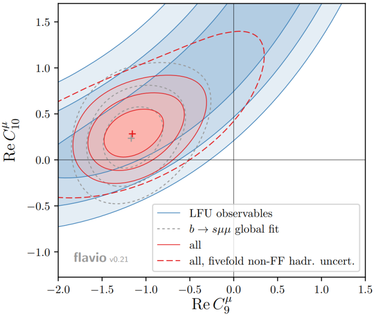
$$\mathcal{C}_9 = \mathcal{C}_9^{\mathrm{SM}} + \mathcal{C}_9^{NP}$$

- 4.5σ deviation in $\mathcal{C}_9$ from SM
  S. Descotes-Genon et al. arXiv:1605.06059v1

Fits for New Physics in Wilson Coefficients



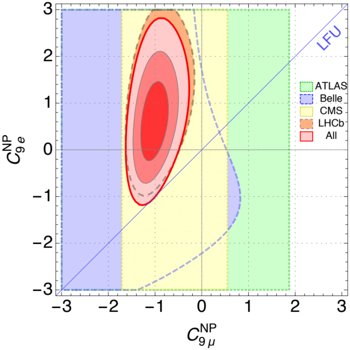
1704.05340



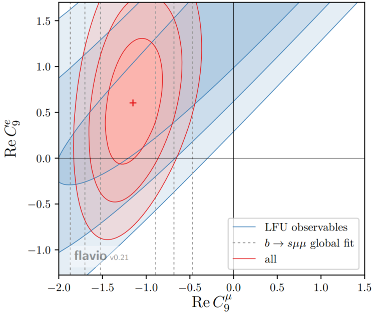
Phys. Rev. D 96, 055008 (2017)

- Many theorists perform global fits of $\mathcal{O}(150)$ measurements
- Pull for the SM at the level of 4.4-5 σ

Fits for Lepton Flavor Universality



1704.05340



Phys. Rev. D 96, 055008 (2017)

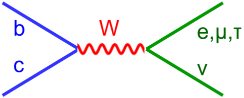
- Lepton Flavor Non Universality favored with $> 3\sigma$

Lepton Flavor Universality in $R_{D^{(*)}}$

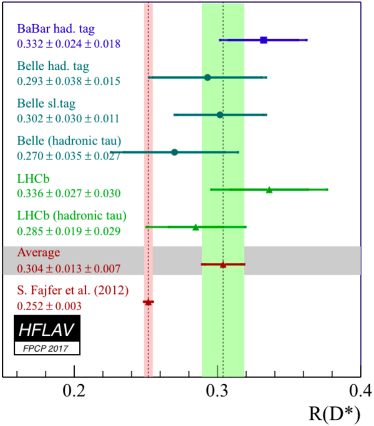
$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\mu\nu)}$$

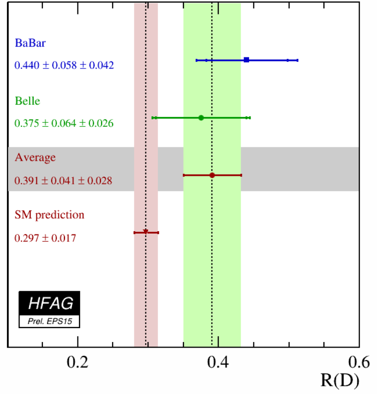
- Tree level decay
- Theoretically very clean observable
- Neutrinos in final state

SM:

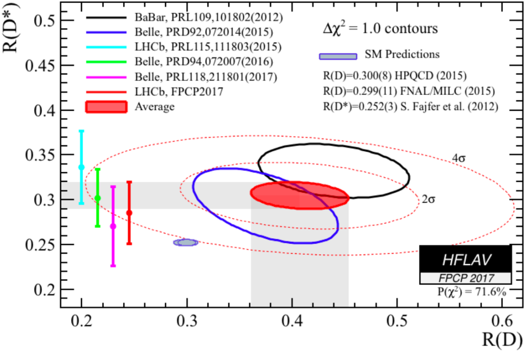


Lepton Flavor Universality in $R_D^{(*)}$





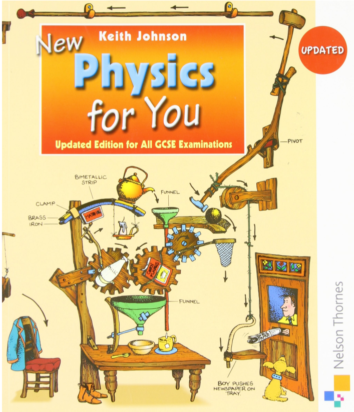
Lepton Flavor Universality in $R_{D^{(*)}}$



- Tension with SM $> 4\sigma$
- 30% effect against SM for taus in tree level decays

Did we find new Physics?

What does it mean?



Did we find new Physics?

- The anomalies are difficult to explain at once
- Two models are favored:

- Both cases may enhancement $b \to s\tau\tau$
- LQ: large enhancement of $b \to s\mu\tau$

Motivation for $b \longrightarrow s\tau\tau$ at Belle

Motivation

- New Physics may couple to mass of the τ
  $\rightarrow$ enhance sensitivity by $|m_\tau / m_\mu|^2 \simeq 286$
- Both Z' and leptoquark models predict large enhancements [1704.05340]

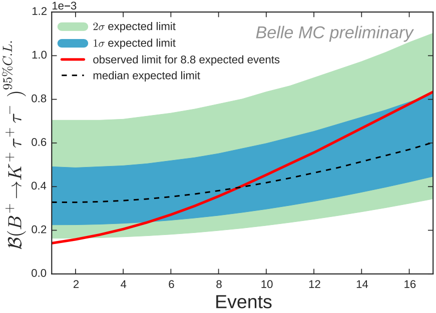
The $B^+ \longrightarrow K^+\tau^+\tau^-$ Decay

- $\mathcal{B}(B^+ \rightarrow K^+\tau\tau)^{SM} < 1.44(15) \times 10^{-7}$
- Some models may lead to a strong enhancement
- $\mathcal{B}(B \rightarrow K\tau^-\tau^+)^{MLFV} < 2 \times 10^{-4}$

  Alonso, R., Grinstein, B. & Camalich, J.M. J. High Energ. Phys. (2015) 2015
- Only experimental constraints by BaBar with $\mathcal{B}(B^+ \rightarrow K^+\tau^+\tau^-) < 2.25 \times 10^{-3}$ at 90% C.L..

Simulation for $B^+ \longrightarrow K^+\tau^+\tau^-$ at Belle

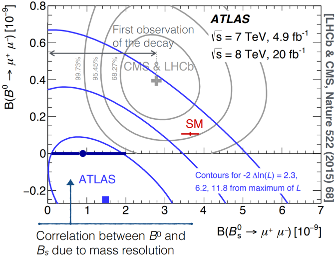
- Signal is Identified in calorimeter energy related observable E_{ECL}
- All systematic uncertainties are calculated
- Expected upper limit: $\mathcal{B}(B^+ \rightarrow K^+\tau^+\tau^-) < 3.17 \times 10^{-4}$ at 90% C.L. on MC



Important recent Measurements

$B_{d,s} \to \mu\mu$

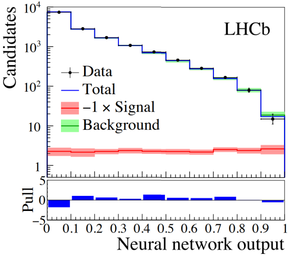
- Golden mode to study at LHC(b)
- LHCb: Single experiment observation of $B_s^0 \to \mu^+\mu^-$ with more than 7σ
- Powerful probe of models with enhanced (pseudo)scalar interactions



[ATLAS, EPJC 76 (2016) 513]
[LHCb & CMS, Nature 522 (2015) 68]

$B_{d,s} \to \tau\tau$

- LHCb measurement using $\tau \to \pi^-\pi^+\pi^-\nu_\tau$
- $\mathcal{B}(B_s^0 \to \tau^+\tau^-) < 6.8 \times 10^{-3}(95\%\mathrm{CL})$
- $\mathcal{B}(B_d^0 \to \tau^+\tau^-) < 2.1 \times 10^{-3}(95\%\mathrm{CL})$

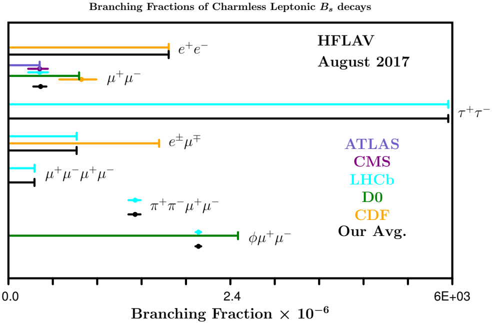


[LHCb, PRL 118 (2017) 251802]

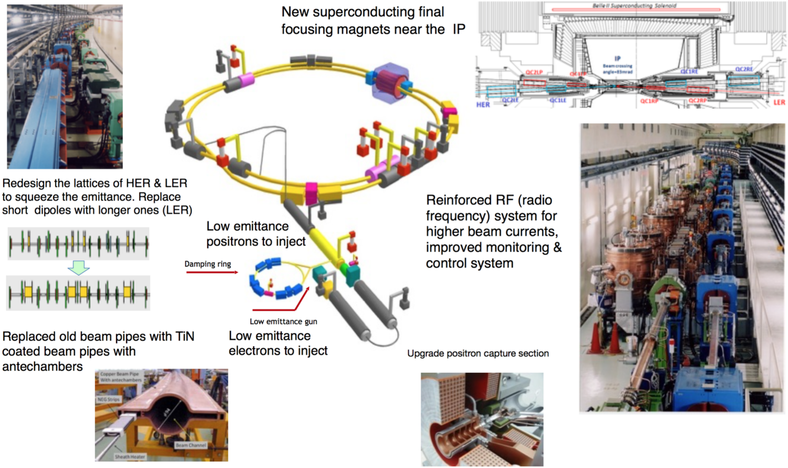
Important Measurements Wish-List

1. $B_s \to \phi e^+ e^-$
2. $B \to K^{(*)}\tau\tau$
3. $B \to K^{(*)}\mu\tau$
4. $B \to K^{(*)}\nu\nu$
5. $B_s \to \ell^+\ell^-$
6. $B_s \to \ell^{+\prime}\ell^-$
7. ...

B_s^0



Move Towards Belle 2



New superconducting final focusing magnets near the IP

Redesign the lattices of HER & LER to squeeze the emittance. Replace short dipoles with longer ones (LER)

Low emittance positrons to inject

Reinforced RF (radio frequency) system for higher beam currents, improved monitoring & control system

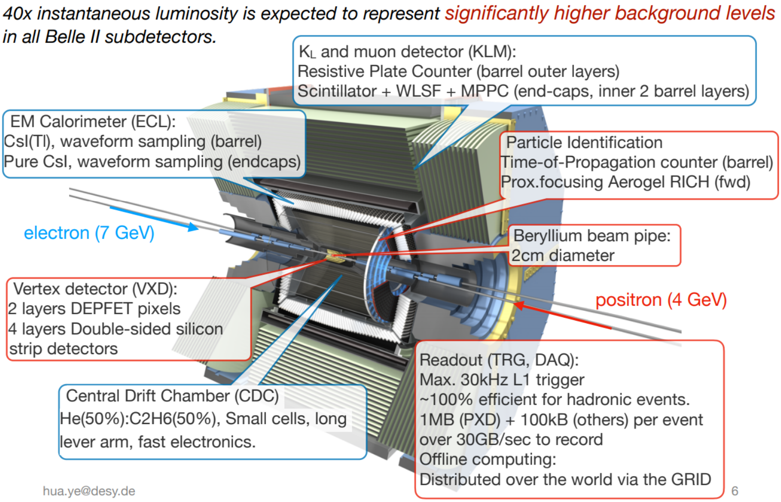
Replaced old beam pipes with TiN coated beam pipes with antechambers

Low emittance electrons to inject

Upgrade positron capture section

(Credit: F. Bernlocher)

Belle II Detector Upgrade



40x instantaneous luminosity is expected to represent significantly higher background levels in all Belle II subdetectors.

K_L and muon detector (KLM):
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

EM Calorimeter (ECL):
CsI(Tl), waveform sampling (barrel)
Pure CsI, waveform sampling (endcaps)

Particle Identification
Time-of-Propagation counter (barrel)
Prox.focusing Aerogel RICH (fwd)

electron (7 GeV)

Beryllium beam pipe:
2cm diameter

positron (4 GeV)

Vertex detector (VXD):
2 layers DEPFET pixels
4 layers Double-sided silicon strip detectors

Central Drift Chamber (CDC)
He(50%):C2H6(50%), Small cells, long lever arm, fast electronics.

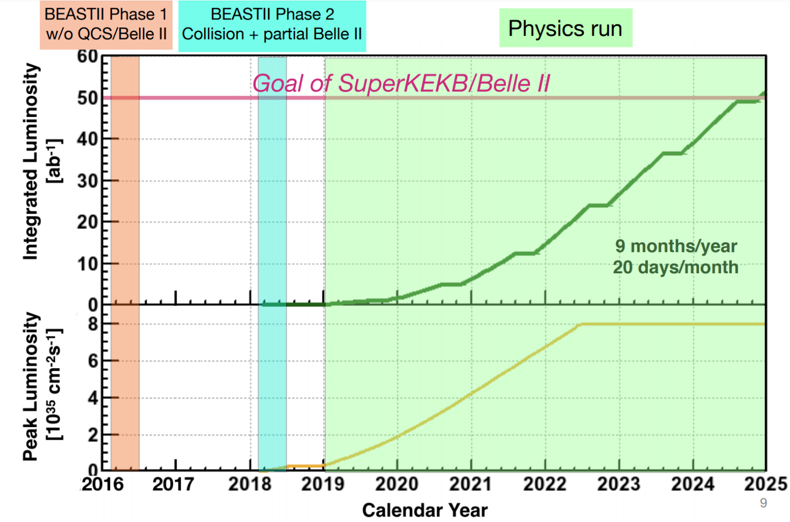
Readout (TRG, DAQ):
Max. 30kHz L1 trigger
~100% efficient for hadronic events.
1MB (PXD) + 100kB (others) per event
over 30GB/sec to record
Offline computing:
Distributed over the world via the GRID

hua.ye@desy.de

6

(Credit: F. Bernlocher)

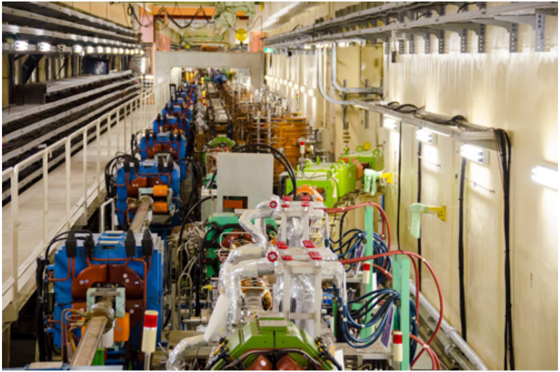
Super B Project - Highlights



(Credit: F. Bernlocher)

Phase I: SuperKEKB first turns 2016

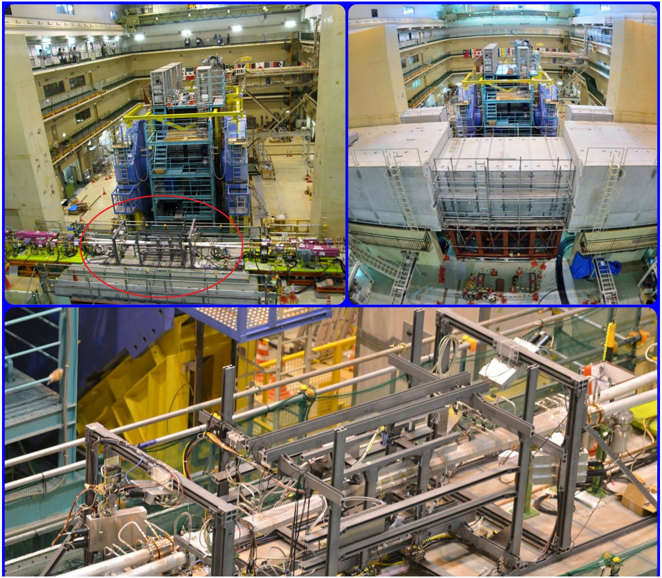
Feb 2016 News: First Turns at SuperKEKB (4 GeV e+'s and 7 GeV e-'s)



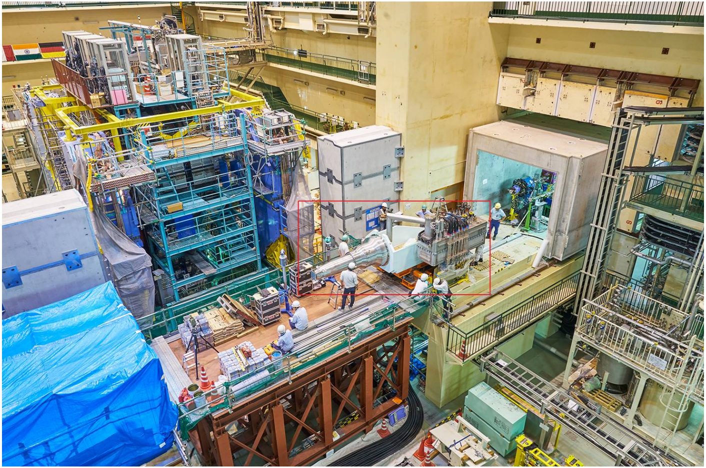
April 19, 2016 (LER beam current at 540 mA, HER at 480 mA)

(Credit: T. Browder)

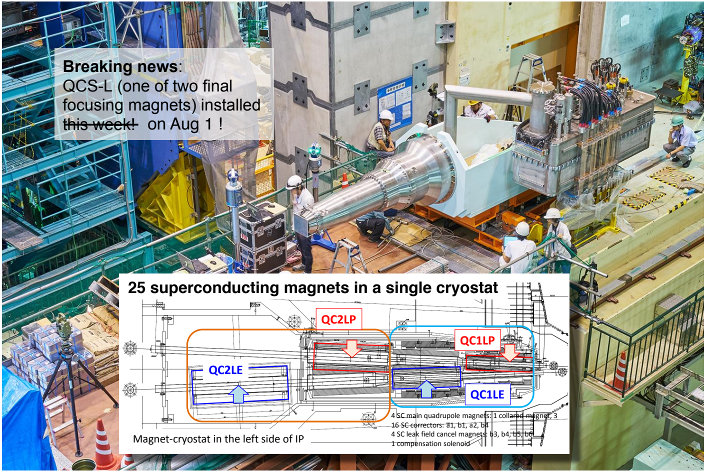
Phase I: The Beast



Phase II preparation: Final Focus Magnets Integration



Phase II preparation: Final Focus Magnets Integration



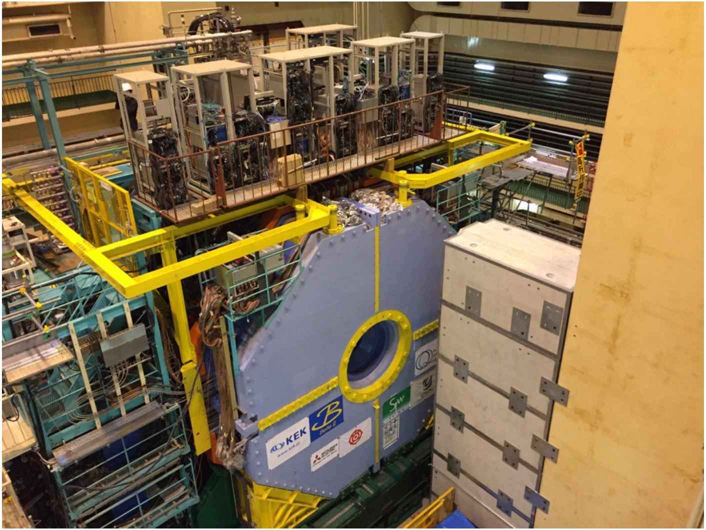
Breaking news:
QCS-L (one of two final focusing magnets) installed ~~this week!~~ on Aug 1 !

25 superconducting magnets in a single cryostat

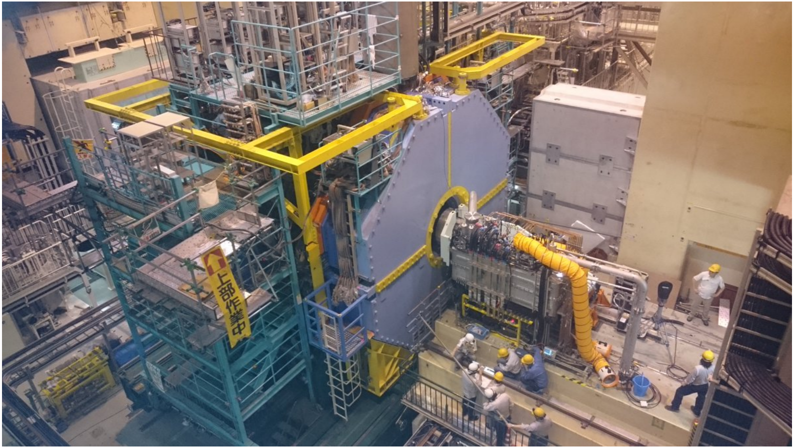
4 SC main quadrupole magnets: 1 collared magnet, 3
16 SC correctors: a1, b1, a2, b4
4 SC leak field cancel magnets: b3, b4, b5, b6
1 compensation solenoid

Magnet-cryostat in the left side of IP

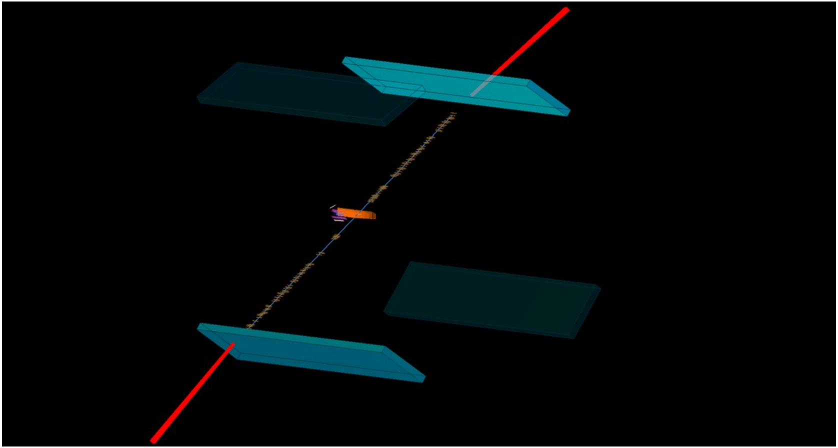
Phase II preparation: Detector Roll In



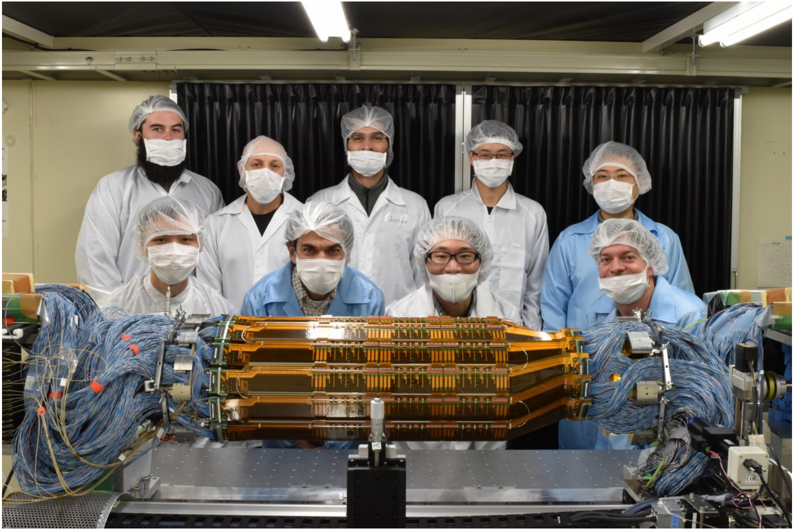
Phase II preparation: Detector Closed



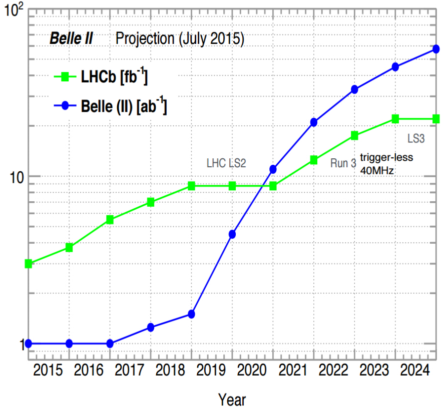
Phase II preparation: First Cosmic Events

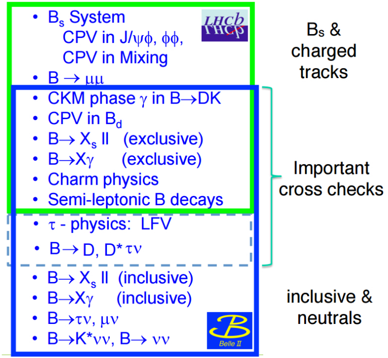


Phase III preparation: Vertex Detector Assembly



The next Generation of Flavor Factories





- B_s System
  CPV in $J/\psi\phi$, $\phi\phi$,
  CPV in Mixing
- $B \to \mu\mu$
- CKM phase γ in $B \to DK$
- CPV in B_d
- $B \to X_s ll$ (exclusive)
- $B \to X\gamma$ (exclusive)
- Charm physics
- Semi-leptonic B decays
- τ - physics: LFV
- $B \to D, D^* \tau\nu$
- $B \to X_s ll$ (inclusive)
- $B \to X\gamma$ (inclusive)
- $B \to \tau\nu, \mu\nu$
- $B \to K^*\nu\nu$, $B \to \nu\nu$

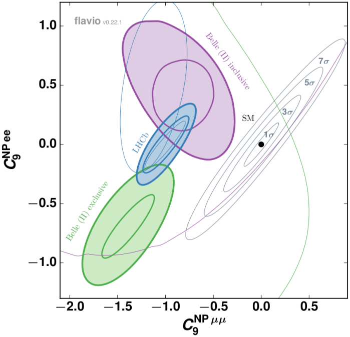
B_s & charged tracks

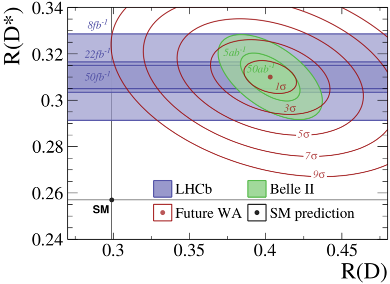
Important cross checks

inclusive & neutrals

Slide adapted from J.Albrecht, DESY Seminar 25.10.16

Belle 2 and LHCb Projections





J. Albrecht et al., Future prospects for exploring present day anomalies in flavour physics measurements with Belle II and LHCb

- Both Belle II and LHCb can individually verify the flavor anomalies

Next Generation of Experiments

- Both LHCb and Belle II have their strength and weaknesses
- We need to have a confirming experiment!

Conclusion

- We can find new physics
- In not too distant future

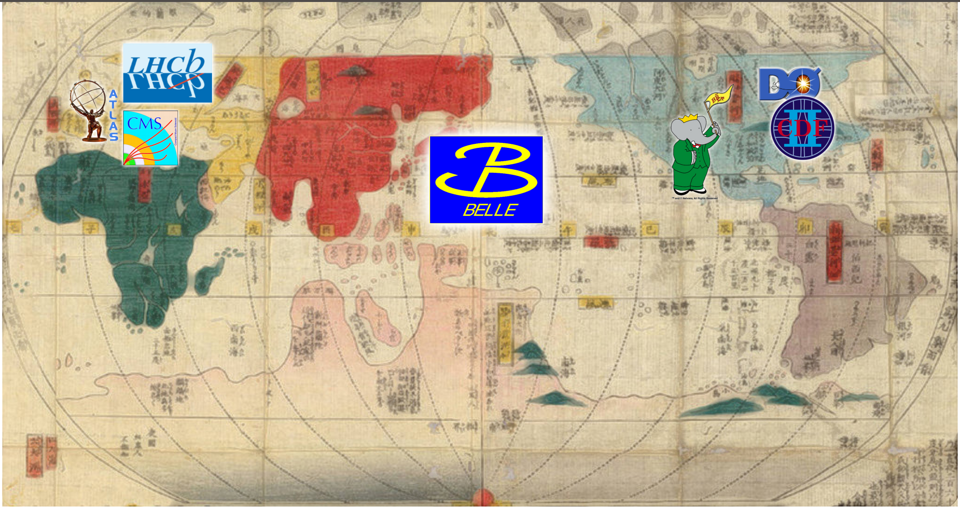
If there is new physics in the flavor sector, we will find it!

Next Generation of Experiments

- Both LHCb and Belle II have their strength and weaknesses
- We need to have a confirming experiment!

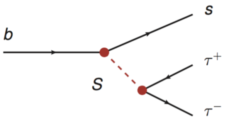
Conclusion

- We can find new physics
- In not too distant future



Thank you!

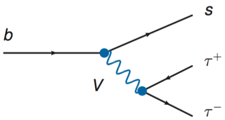
New Physics in $b \longrightarrow s\tau\tau$ Transitions



scalars (e.g. in 2HDMs)

if scalar couplings to leptons are prop. to the masses
$\Rightarrow B_s \to \mu^+\mu^-$ is the most important probe

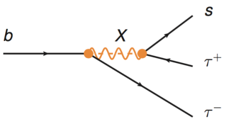
generic 2HDMs allow for much richer flavor structure
$\Rightarrow b \to s\tau^+\tau^-$ transitions can give important info



vectors

photon and Z are couple lepton flavor universaly
$\Rightarrow$ strong constraints from $b \to s\mu^+\mu^-$

Z' gauge bosons can violate lepton flavor universality
$\Rightarrow b \to s\tau^+\tau^-$ transitions are complementary probes



leptoquarks

generically no reason to expect
lepton flavor universality

(Credit: W. Altmannshofer)

Background Suppression - Best Variables

$\mathcal{NB}(B_{tag})$	is the NeuroBayes output of the B_{tag} candidate.
$M_{K^+\tau^-}$	invariant mass of the K^+ and τ^-.
$\hat{p}_{\tau^+}$	the momentum of the positively charged τ in the rest frame of the signal B candidate.
decayhash	Decay hash value corresponding to the six possibilities for the mass hypotheses of the children of the τ (ee, $e\mu$, $e\pi$, $\mu\mu$, $\mu\pi$ and $\pi\pi$).
$\mathcal{NB}(\tau^+ \times \tau^-)$	is the product of the NeuroBayes outputs of the children of both τ.
ΔE^{tag}	the beam constrained energy of the B_{tag} candidate.
...	

Background Suppression - Best Variables

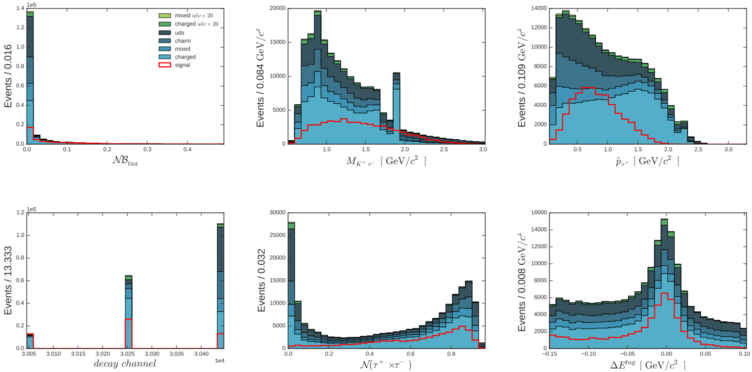
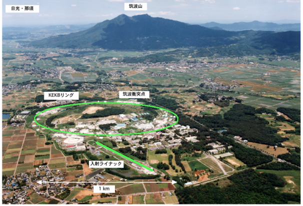
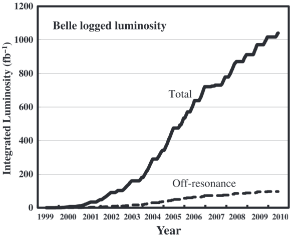


Figure: Some of the used input variables for the classifiers.

The Belle Experiment





- The Belle experiment is located at the KEKB accelerator in Tsukuba, Japan
- Data taking from 1999 to 2010
- It is designed as a “B factory”
- 772 million $B\bar{B}$ meson pairs

$$e^+e^- \to \Upsilon(4S) \to B\bar{B}$$

- World record for integrated luminosity

$$\int Ldt = 1\,\mathrm{ab}^{-1}$$

Reconstruction of $B \rightarrow K^* \ell^+ \ell^-$

- Reconstructing **$\mathbf{B^0}$ and $\mathbf{B^+}$ modes**
- Using **muon** and **electron** modes
- K^* is reconstructed in (K^+, π^-), (K^0_S, π^+) and (K^+, π^0)

Electron Modes

- $B^0 \rightarrow K^*(892)^0 e^+ e^-$
- $B^+ \rightarrow K^*(892)^+ e^+ e^-$

Muon Modes

- $B^0 \rightarrow K^*(892)^0 \mu^+ \mu^-$
- $B^+ \rightarrow K^*(892)^+ \mu^+ \mu^-$

Signal selection:

- Neural network (NN) classifier for all particles in the decay chain
- Final signal selection on four B meson NN
- NN cut optimization on 2D figure of merit separate for the lepton flavor