Belle II Update

Slavomira Stefkova on behalf of the DESY Belle II group

91st PRC meeting, 04.05.2021

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Belle II

SuperKEKB

@ Tsukuba, Japan

SuperKEKB is an energy asymmetric e^+e^- collider @ $\sqrt{s} = 10.58$ GeV:

- $\sqrt{s} = 10.58$ GeV $\leftrightarrow \Upsilon(4S)$ resonance $\rightarrow$
  $\Upsilon(4S) \rightarrow B\bar{B}$ + nothing else with $\mathcal{B} > 96\%$
  $\rightarrow$ clean B sample

SuperKEKB is not only *B*-factory:

- τ and c pairs have similar cross-sections @ $\sqrt{s} = 10.58$ GeV

With nanobeam scheme and upgraded rings SuperKEKB aims to reach $30\times$ higher $\mathcal{L}_{\text{inst}}$ than KEKB :

- x 1.5 currents
- x 1/20 β_y^*

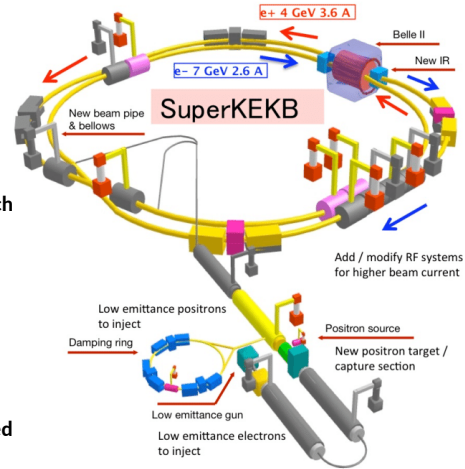
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm}{\beta_{y\pm}}\xi_{y\pm}\frac{R_L}{R_{\xi_y}}$$

beam current

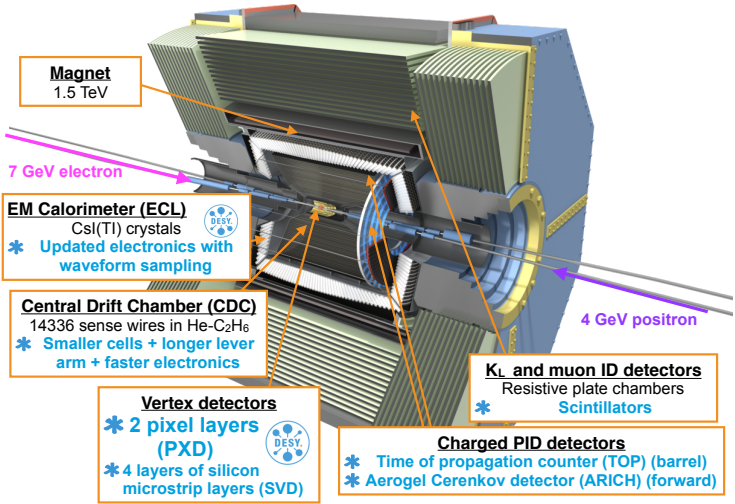
vertical beta function at IP

To keep current @ desired value $\rightarrow$ continuous injection scheme!

$\rightarrow$ In Belle II expect $\mathcal{O}(15)$ higher backgrounds @design luminosity compared to Belle



Detector

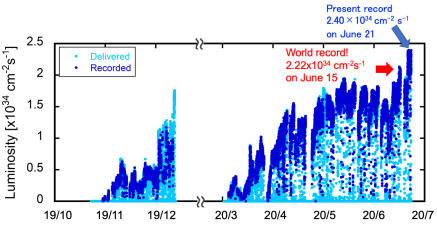


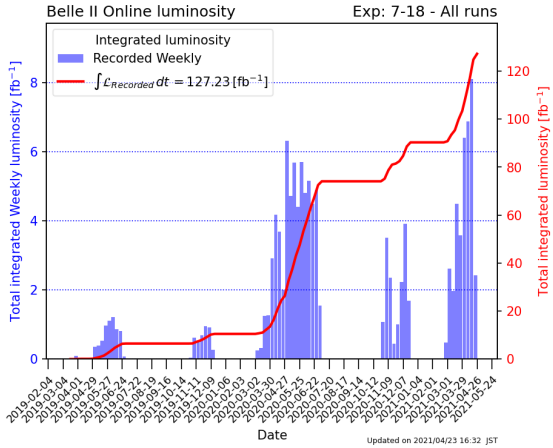
- Belle II detector was designed to give **similar or better performance** even under mentioned $\mathcal{O}(15)$ higher backgrounds
- **DAQ and trigger** systems were also upgraded!

Luminosity Status

Status:

- Regular data-taking with partially installed PXD from April 2019
- Despite Covid-19, collected **130 fb^{-1}** of on-resonance and **9 fb^{-1}** of off-resonance data
- Slower luminosity accumulation than initially planned → partly due to poor injection → challenging to squeeze beyond $\beta_y^* = 1.0$mm
- Running stably @ 90% data-taking efficiency





Milestone:

- **Record-breaking instantaneous luminosity** 2.4×10^{34} cm^{-2}s^{-1} was achieved for first time in June 2020, now running @ 2.6×10^{34} cm^{-2}s^{-1}

Luminosity Prospects

Short-term plan:

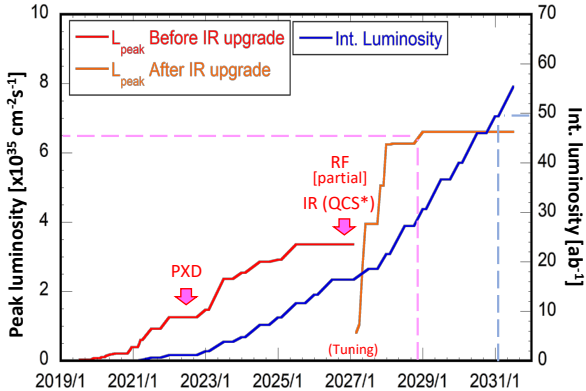
- **Summer 2022**: full new PXD **(PXD2) installation** $\rightarrow$ important to maintain good vertex resolution at high luminosity
- Extension of the current running period: additional operational money, Covid-19 restrictions, possibility to test aggressive machine parameters
- By summer 2022: $\mathcal{O}(0.5-1)$ ab^{-1} ($\sim$Belle dataset)

Long-term plan:

- $\geq$ 2026 : QCS/IR modification **necessary** to reach design luminosity
- Detailed proposals are currently under discussion, but no exact plan is established yet!
- By 2026: $\mathcal{O}(15)$ ab^{-1} ($\sim$ 20$\times$Belle dataset)

Presented short-term plan was agreed in February 2021

Goal is to collect 50 ab^{-1}

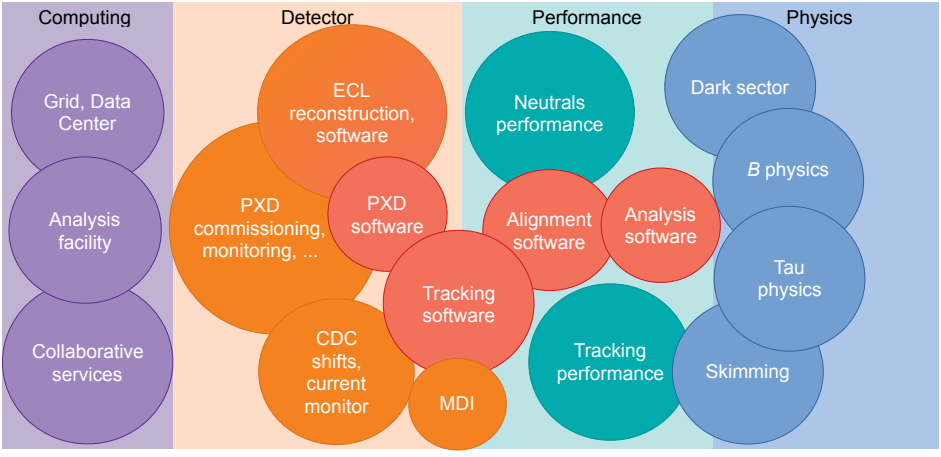


DESY Belle II Group Activities

Apart from group outings,

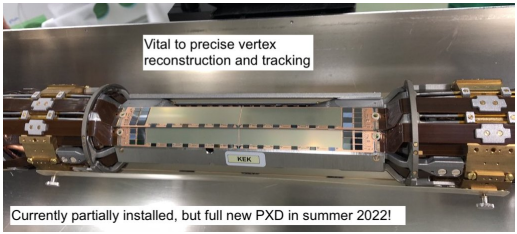
DESY Belle II Group Activities

we also contribute to many different aspects of Belle II project!



Pixel Detector (PXD)

PXD



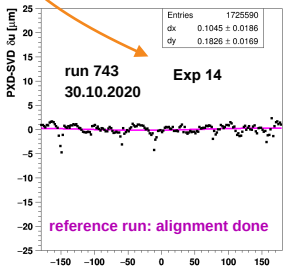
PXD @ r = 14 and 22 mm, consists of two half-shells
PXD operation is stable with occupancy 0.3%:

- Hit ϵ > 99% in regions without known defects
- Homogeneous SNR 40-50

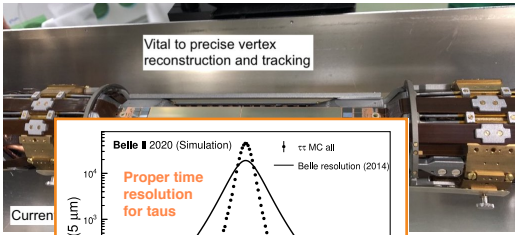
→Improvement of $\sigma(d_0)$ by 40% to ∼12 μm with PXD
→Factor 2 improvement in proper time resolution compared to Belle

Operational Improvements:

- Automatisation and Software Development: lab-framework, calibration
- Diagnostics : high-speed link drops and error diagnostics
- Offline Monitoring: independent hits-on-track performance studies (beam spot, alignment, resolution, efficiency) → fast-feedback, background studies
- Gated Mode Preparation: intensive tests with KEK modules → to counteract the effects of continuous injection



PXD



PXD @

PXD o

- H
- H

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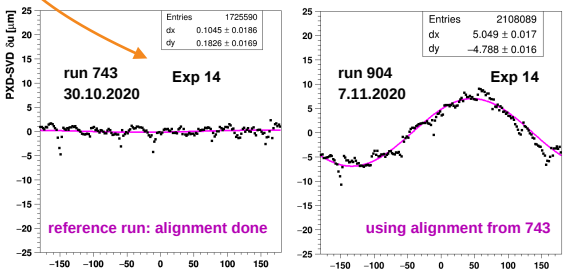


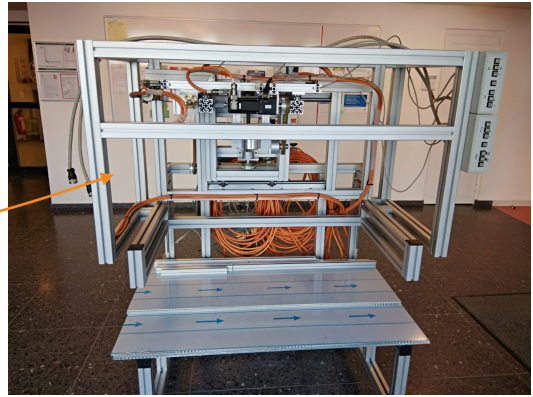
PXD2

PXD2 production status and plans:

- Module characterisation on-going @**DESY** and Bonn/HLL/MPP
- Further module and ladder assembly on-going, half-shell assembly to follow
- Half-shells will go through final tests @**DESY**: first half-shell expected in May 2021, second one after summer 2021
  - New setup for PXD2 including source scan to be installed in the clean room in HERA West

PXD2 installation schedule:

- Recent delays in the production of the new IP beam pipe → not ready for PXD2 before April 2022
- Transport of PXD2 and infrastructure to KEK in June 2022
- **Require** access to HERA West at least until start of LS1: summer 2022

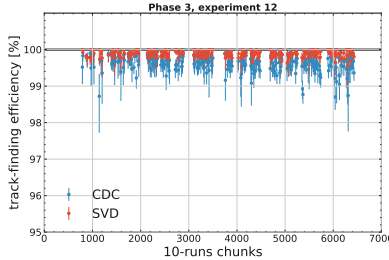


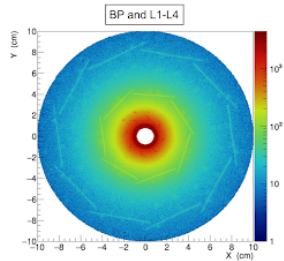
Tracking

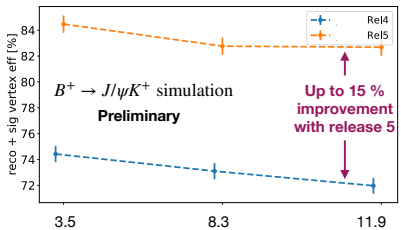
Tracking (Performance)

DESY is leading tracking efforts in Belle II:

- Low level performance: CDC wire efficiency, dead wire map
- High level performance: reconstruction of displaced vertices, tracking efficiency
  - Study of CDC track-finding efficiency with Bhabha-like events, using SVD standalone tracking as a reference (and vice-versa) → **high and stable track-finding efficiency**
  - Study of reconstruction of displaced vertices using K_S^0
  - Measurement of inner region characteristics (beampipe+VXD) from hadronic vertices
- Impact of increasing backgrounds
- Extensive work on software-side as well!





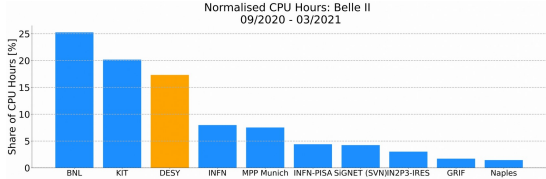


Collaborative Services and Computing

Collaborative Services and Computing

DESY is a vital player for computing @ Belle II:

- The **DESY Grid site** is a main contributor to Belle II Grid computing
- Since April 2021 **DESY** is one the Belle II **Raw Data Centers** :
  - 1st RAW data copy at KEK / 2nd copy outside KEK on tape
- This year **DESY** became one of the Belle II **Re-calibration Centers**
- **DESY analysis facility (NAF)** is used extensively in Belle II (>250 users):
  - NAF Jupyter Hub
- **DESY** utilizes professional state-of-the-art collaborative services for Belle II wherever suitable (e.g invenio)



2021 (revised)	2022	2023
0.20PB	0.32PB	0.74PB

RAW Data Center	Share after 2021
BNL	30%
CNAF	20%
UVIC	15%
IN2P3	15%
KIT	10%
DESY	10%

		2021	2022
disk	dcache	**300TB**	600TB
tape		600TB	1.5TB
CPU peak	NAF/BIRD	20kHS06	20kHS06
CPU total		50MkHS06	50MkHS06

B physics

Test of lepton universality in beauty-quark decays arXiv:2103.11769

LHCb collaboration: R. Aaij, C. Abellán Beteta, T. Ackernley, B. Adeva, M. Adinolfi, H. Afsharnia, C.A. Aidala, S.

$$R(K) = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)} = 0.846^{+0.044}_{-0.041} \quad \to 3.1\sigma$$

Open Access

Test of Lepton-Flavor Universality in $B \to K^*\ell^+\ell^-$ Decays at Belle

S. Wehle *et al.* (Belle Collaboration)
Phys. Rev. Lett. **126**, 161801 – Published 22 April 2021

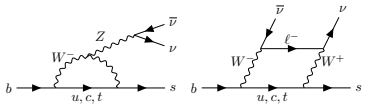
PRL 126 (2021) 16, 161801

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

→consistent with SM within errors

→largest deviation in the same kinematic region as LHCb

Search for $B^+ \to K^+ \nu\bar{\nu}$ NAF



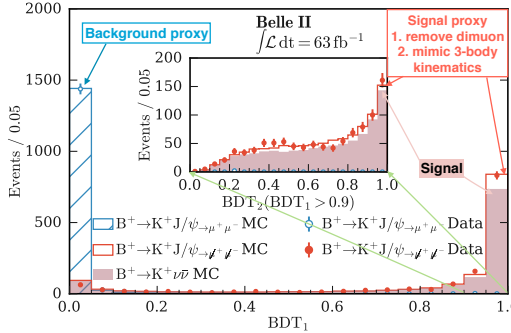
- $b \to sll$ transition with **clean SM computation** of $\mathcal{B} = (4.6 \pm 0.5) \times 10^{-6}$ [1606.00916]
- Not observed yet!
- Golden channel @ Belle II
- Sensitive to NP models that can explain $R(K)$ anomaly
- **Traditionally** searched with explicit B_{tag} reconstruction achieving maximum $\epsilon_{sig} = 0.2\%$ [1303.7465, 1702.03224]
- This **DESY-pioneered method** uses inclusive approach exploiting **very distinct signal kinematics**!

Strategy:

- Select signal = highest p_T track with as least 1 PXD hit in the event
- Identify discriminating variables : event topology, missing energy, vertex separation, signal kinematics
- Minimize the background contamination with BDTs
- **Validate analysis strategy with control channel:** $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$

This method yields higher $\epsilon_{sig}(\approx 4.0\%)$ but also higher backgrounds

- Statistical interpretation with `pyhf`



Search for $B^+ \to K^+ \nu\bar{\nu}$ NAF

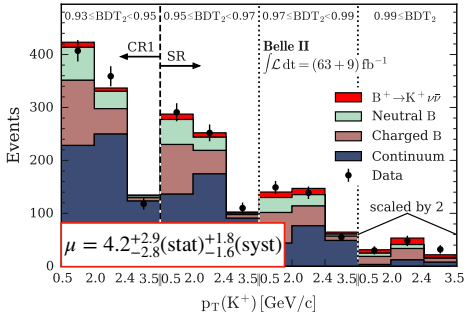
Results:

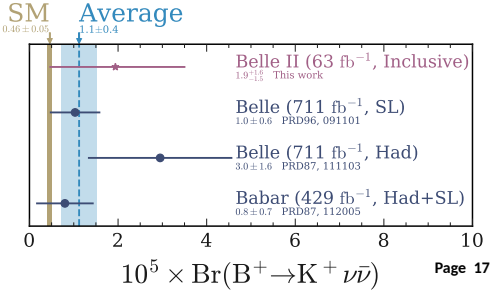
- Binned simultaneous ML fit to data to measure signal strength μ (1μ=SM BF= $(4.6 \pm 0.5) \times 10^{-6}$)
- As no significant signal is observed, set a limit of 4.1×10^{-5} @ 90 CL using CL_s method → competitive with only 63 fb^{-1}
- Comparison with other experiments shows at least matching performance

Prospects:

- This new method can be used in similar channels
- Leading systematics can be reduced
- Combined analysis of inclusive and exclusive tagged events → faster observation

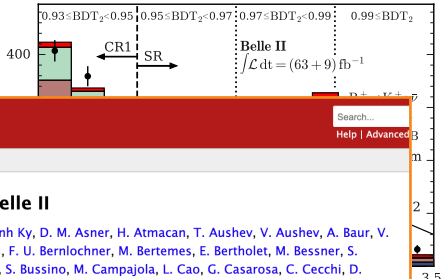
Experiment	Year	Observed limit on BR($B^+ \to K^+ \nu\bar{\nu}$)	Approach	Data [fb^{-1}]
BABAR	**2013**	$< 1.6 \times 10^{-5}$ [Phys.Rev.D87,112005]	**SL + Had tag**	429
Belle	**2013**	$< 5.5 \times 10^{-5}$ [Phys.Rev.D87,111103(R)]	**Had tag**	711
Belle	**2017**	$< 1.9 \times 10^{-5}$ [Phys.Rev.D96,091101(R)]	**SL tag**	711
Belle II	**2021**	$< 4.1 \times 10^{-5}$	**Inclusive tag**	63





Search for $B^+ \to K^+\nu\bar{\nu}$ NAF

Results:



High Energy Physics - Experiment

[Submitted on 26 Apr 2021]

Search for $B^+ \to K^+\nu\bar{\nu}$ decays using an inclusive tagging method at Belle II

Belle II Collaboration: F. Abudinén, I. Adachi, K. Adamczyk, P. Ahlburg, H. Aihara, N. Akopov, A. Aloisio, N. Anh Ky, D. M. Asner, H. Atmacan, T. Aushev, V. Aushev, A. Baur, V. Babu, S. Baehr, P. Bambade, Sw. Banerjee, S. Bansal, J. Baudot, J. Becker, P. K. Behera, J. V. Bennett, E. Bernieri, F. U. Bernlochner, M. Bertemes, E. Bertholet, M. Bessner, S. Bettarini, F. Bianchi, T. Bilka, D. Biswas, A. Bozek, M. Bračko, P. Branchini, N. Braun, T. E. Browder, A. Budano, S. Bussino, M. Campajola, L. Cao, G. Casarosa, C. Cecchi, D. Červenkov, P. Chang, R. Cheaib, V. Chekelian, C. Chen, Y.-T. Chen, B. G. Cheon, K. Chilikin, K. Chirapatpimol, K. Cho, S.-J. Cho, S. Choudhury, D. Cinabro, L. Corona, L. M. Cremaldi, S. Cunliffe, T. Czank, F. Dattola, E. De La Cruz-Burelo, G. de Marino, G. De Nardo, M. De Nuccio, G. De Pietro, R. de Sangro, M. Destefanis, S. Dey, A. De Yta-Hernandez, A. Di Canto, F. Di Capua, J. Dingfelder, Z. Doležal, I. Domínguez Jiménez, T. V. Dong, K. Dort, S. Dubey, S. Duell, G. Dujany, S. Eidelman, M. Eliachevitch, D. Epifanov, T. Ferber, D. Ferlewicz, T. Fillinger, G. Finocchiaro, S. Fiore, A. Fodor, F. Forti, A. Frey, B. G. Fulsom, N. Gabyshev, E. Ganiev, M. Garcia-Hernandez, A. Garmash, V. Gaur, A. Gaz, A. Gellrich, R. Giordano et al. (275 additional authors not shown)

A search for the flavor-changing neutral-current decay $B^+ \to K^+\nu\bar{\nu}$ is performed at the Belle II experiment at the SuperKEKB asymmetric energy electron-positron collider. The results are based on a data sample corresponding to an integrated luminosity of 63 fb^{-1} collected at the $\Upsilon(4S)$ resonance and a sample of 9 fb^{-1} collected at an energy 60 MeV below the resonance. A novel measurement method is employed, which exploits topological properties of the $B^+ \to K^+\nu\bar{\nu}$ decay that differ from both generic bottom-meson decays and light-quark pair production. This inclusive tagging approach offers a higher signal efficiency compared to previous searches. No significant signal is observed. An upper limit on the branching fraction of $B^+ \to K^+\nu\bar{\nu}$ of 4.1×10^{-5} is set at the 90% confidence level. This result is competitive with previous measurements, taking into account the smaller data sample.

Comments: 9 pages, 3 figures + supplemental material
Subjects: **High Energy Physics - Experiment (hep-ex)**
Report number: Belle II Preprint 2021-001, KEK Preprint 2020-45
Cite as: arXiv:2104.12624 **[hep-ex]**
(or arXiv:2104.12624v1 **[hep-ex]** for this version)

Submission history
From: Simon Kurz [view email]
[v1] Mon, 26 Apr 2021 14:51:18 UTC (173 KB)

First Belle II *B* physics paper about to be submitted to PRL, completed by **DESY** group!

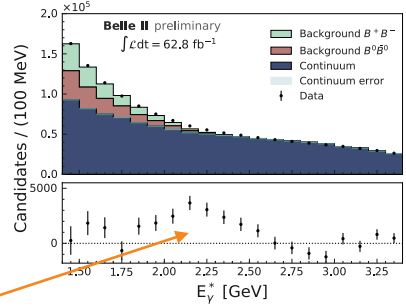
$10^5 \times \mathrm{Br}(\mathrm{B}^+ \to \mathrm{K}^+ \nu\bar{\nu})$

Inclusive *B*-meson Decays

NAF

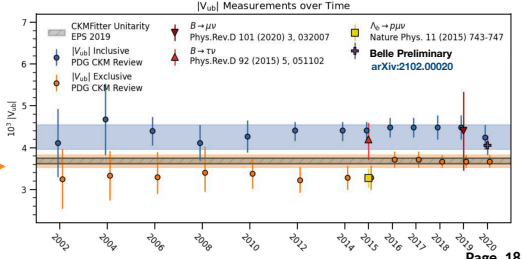
Inclusive $B \to X_s\gamma$:

- Decay rate and *CP* asymmetries sensitive to BSM physics via EW penguin loop
- Shape of photon energy spectrum sensitive to mass of *b* quark
- Ongoing DESY analyses with current data investigate several reconstruction approaches: hadronic tagging, semileptonic tagging, inclusive
- **Public plot for Moriond 2021 (inclusive) shows clear $B \to X_s\gamma$ signal**



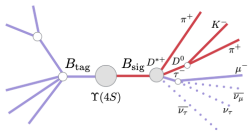
Plans for 500 fb^{-1} and beyond:

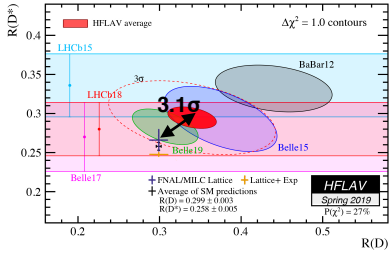
- Measurement of decay rates and kinematic spectra in inclusive $B \to X_s\gamma$ and $B \to X_u l\nu$ decays
- Measurement of $|V_{ub}|$ → least precisely determined CKM element
- $|V_{ub}|$ has long-standing discrepancy between inclusive and exclusive determinations



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

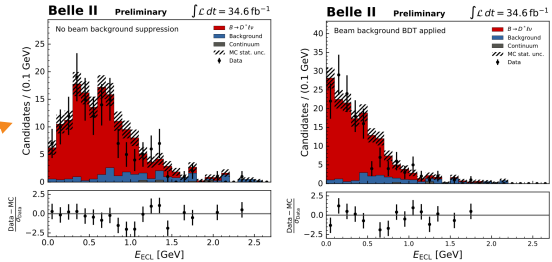
NAF





Test of lepton flavour universality (LFU) in $b \to c l \nu$ transitions:

- $R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)} l \nu)}{\mathcal{B}(B \to D^{(*)} \tau \nu)}$, where $l = \mu, e$
- New SM calculation of form factors has been released
  → slight decrease in tension
- **DESY**-led analysis uses hadronic tagging
- Developing tools to suppress beam background
  → improves separation in E_{ECL}; one of the fitting variables
- First measurement of R($D^{(*)}$) expected with $\mathcal{O}(500)$ fb^{-1}

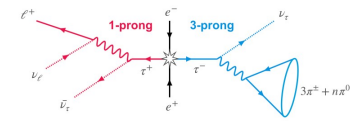


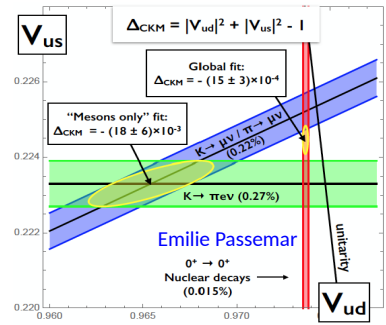
Tau physics

Tau Physics NAF

Published conference note on τ mass measurement last summer (DESY-based)
Plan to publish search for $\tau \to l\alpha$ soon!
Many searches for lepton flavour violating and lepton number violating channels, e.g $\tau \to \mu\mu\mu, \tau \to l\gamma, \tau \to l\rho^0, \tau \to hh(h = \pi, K)$, are in the pipeline and so is measurement of τ lepton EDM and MDM
New analyses led by DESY :

- LFU ($\frac{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}$) $[\mathcal{O}(100)\ \text{fb}^{-1}]$
  - Most precise measurement from BaBar [PRL 105 051602]
  - The $\mathcal{B}$ measurements dominated by systematic uncertainty
  - Use 3x1 and 1x1 (not used @BaBar) to improve the statistical precision
- V_{us} and V_{ud} $[\mathcal{O}(500)\ \text{fb}^{-1}]$
  - 4.8 σ tension with SM
  - Currently least precise determination from τ decays
  - Measure exclusively the $\mathcal{B}(\tau \to K\nu)$ (V_{us}) and $\mathcal{B}(\tau \to \pi\nu)$ (V_{ud})
  - Last publication by BaBar with leading systematics due to PID





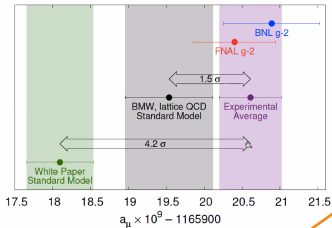
Dark Sector and Low Multiplicity

Dark Sector and Low Multiplicity NAF

DESY group has **leading role**
with series of active analyses:

- Dark Photon Search
- Inelastic Dark Matter
- $B \to K^+$ + Long Lived Scalar
- Updated Search for Axion-like Particle

DESY group plans to provide input
on two aspects of muon g-2 anomaly:

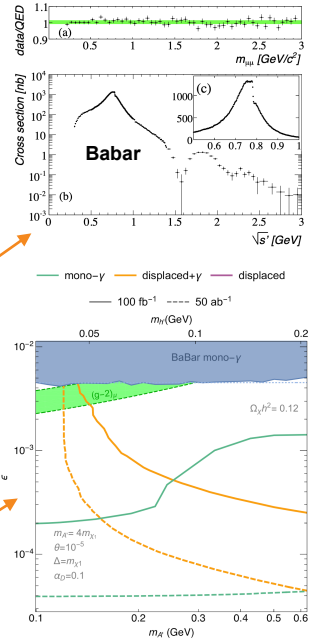


Measurement of $\sigma(e^+e^- \to \pi\pi(\gamma))$

- Key input to SM prediction (a_μ^{had})
- Dominated by BaBar [PhysRevD.86.032013] and KLOE
- Expect **world leading precision** @ Belle II with 10 ab^{-1}!

Search for mono-γ and displaced+γ signatures

- Possible NP explanation: light dark sector with inelastic dark matter
- Collaboration with **DESY** TH published [JHEP04(2021)146]



Summary

To conclude:

- Machine ramp-up is somewhat slower than expected but Belle II is stably accumulating data
- The timeline for the LS1 shutdown has been fixed in February 2021 $\rightarrow$ PXD2 is expected to be installed in summer 2022

DESY plays key role in many aspects of Belle II project such as:

- PXD detector and analysis
- tracking and ECL reconstruction
- performance studies
- computing

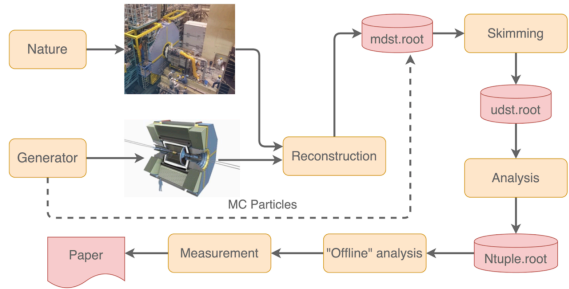
Many interesting measurements with B-decays, τ-decays and searches for dark matter are underway at **DESY**, just in time to address recent anomalies:

- First B physics paper just submitted to journal!
- Belle II has now 4 physics papers in total: 2 are fully **DESY**-based, 1 with **DESY**-participation!

Backup

Skimming

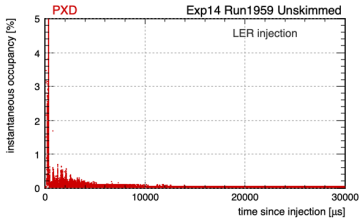
- Goal: to produce data and MC files that have been reduced from their original size, according to the analysis requirements of each physics working group
- Strategy: Python-based classes developed by 8 liaisons of Belle II physics working groups
- Output data format: micro-data summary table (uDST) Requirements:
  - Retention should be less than 10% of the mDST sample
  - Processing time for should be less than 500 ms per event
  - Maximum memory usage is 2GB
- Processing time and total memory for different sites are currently restricting the possibility to run all skims at once: maximum 10 uDST per input mDST

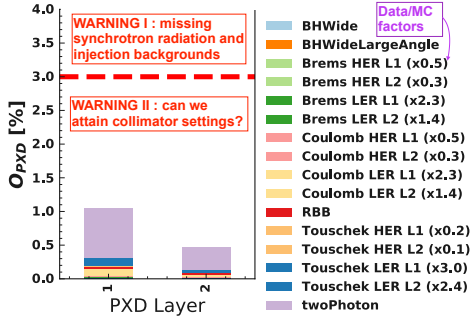


PXD

Operational challenges:

- Radiation damage from beam loss incidents → faster emergency shutdown implemented → no major incident since May 2020
- Several modules reached power supply current limit leading to cluster charge degradation → dedicated irradiation campaigns in Bonn reproduced observed behaviour → can be salvaged with intervention on PS
- Injection spikes cause already a significant data loss → increased the tolerance limits





PXD backgrounds are monitored:

- Data/MC agreement for occupancy is much improved
- Relatively stable for different optics

Background Extrapolations (@ old design luminosity optics):

- Total projected occupancy below 3% (tracking performance degradation, significant data loss)
- Projected integrated dose and fluence will not cause radiation damage