Status of Belle II, first results and prospects

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MPP Project Review

15th December, 2020

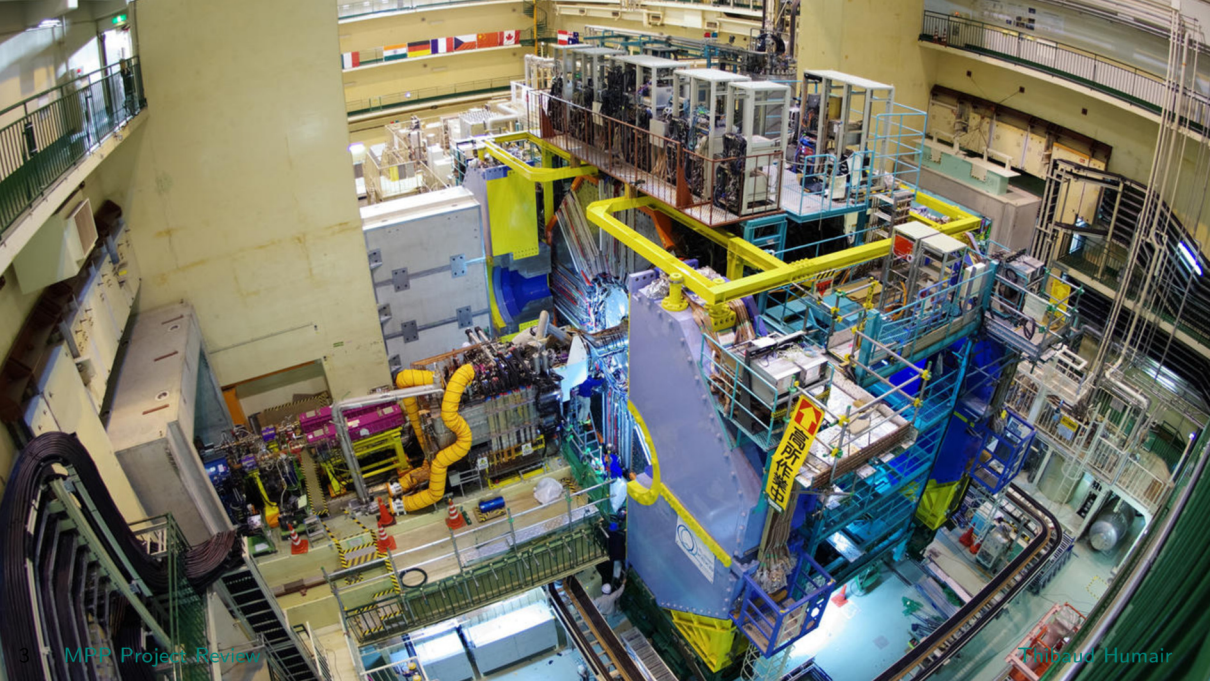
Belle II at SuperKEKB

Belle II probes the Standard Model looking at decays of heavy flavour particles B, D, τ...

It is a major upgrade from Belle (1999-2010), which ran at the same time as BaBar (1999-2008).

$\sim$ 1000 members, 123 institutes.

Look for New Physics using precision measurements, alternative way to direct searches at ATLAS/CMS.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Belle II main characteristics

- Belle II detects the products of e^+-e^- collisions;
- Accelerator operates at $\sqrt{s} = m(\Upsilon(4S)) = 10.6$ GeV;
- Beam energies are asymmetric: 4 & 7 GeV, boost $\beta\gamma = 0.28$;
- High luminosity goal:

$\Rightarrow$ $30\times$ Belle peak luminosity (6×10^{35} cm^{-2}s^{-1})

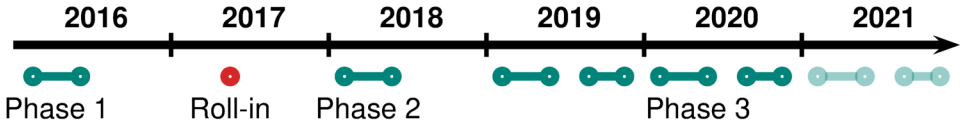
$\Rightarrow$ $50\times$ Belle integrated luminosity (50 ab^{-1})

- ... at the cost of higher background rate.

Clean and constrained environment: good complementarity with LHCb at CERN.

Must ensure $\geq$ performances than Belle despite higher beam backgrounds.
$\Rightarrow$ most parts of the detector were upgraded (more detail about the pixel detector later).

Data recorded so far



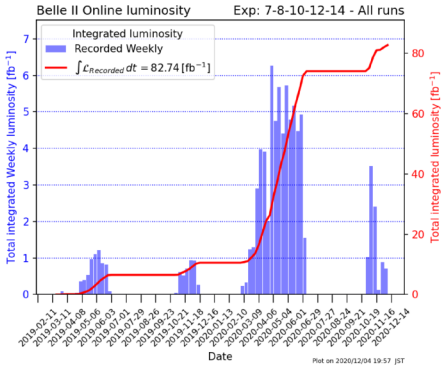
Phase 1 Accelerator tuning with single beam

Phase 2 Background studies w/o innermost detector

Phase 3 collision data with full detector!

So far achieved:

- World record peak luminosity (2.4×10^{34} cm^{-2}s^{-1})
- Integrated luminosity $\sim 1/10$ of Belle, ~ 80 mio $B\overline{B}$ pairs



Operating the detector in Covid times

Control Room @ KEK, June 2019

Control Room @ MPP, Nov. 2020

Boqun Wang mostly based at the experiment site in Japan.
$\Rightarrow$ participated in local shifts and hardware support.

Many shifts were done remotely.
$\Rightarrow$ Hendrik Windel set up a remote control room in one of our MPP offices.

MPP Team & responsabilities

Director: Allen Caldwell
Project Leader: Hans-Günther Moser
Staff: Frank Simon (Future Detectors)
MPI Fellow: Stephan Paul
Emeritus: Vladimir Chekelian, Christian Kiesling
Postdocs: Boqun Wang, Fabian Krinner (Stephan Paul), Thibaud Humair (FD)
PhD Students: **Philipp Leitl**, Felix Meggendorfer, **Sebastian Skambraks**, Benedikt Wach, Markus Reif, Hendrik Windel, Thomas Kraetzschmar (FD), Lukas Bierwirth (SP)
Master Students: Oskar Tittel, Marton Nemeth-Csoka, Caspar Schmitt, **Erwin Do**, Mansour Atalawi, Justin Skorupa (FD)
Technical Support: Ulrich Leis, **Karlheinz Ackermann**, Sven Vogt, Quirin Fischl, Enrico Töpper, Walter Kosmale, David Kittlinger, Andreas Wunderl, Janick Albrecht, Miriam Modjesch, Markus Fras, Stefan Horn, Carina Schlammer, Werner Haberer.

Technical responsabilities (more later):

- PXD: test & assembly
- IBBelle CO2 Cooling System
- Neural Net z-Trigger
- Computing

Management:

- PXD run coordination: Boqun Wang
- Speakers Committee: Hans-Günther Moser
- Regional shift coordinator: Frank Simon

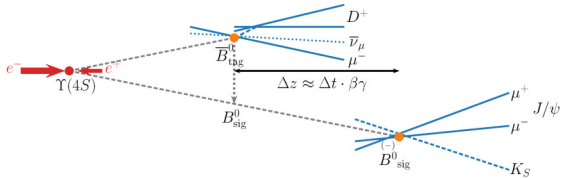
Rest of the talk: Contribution of MPP in the development and operation of the detector & some results using the first data collected.

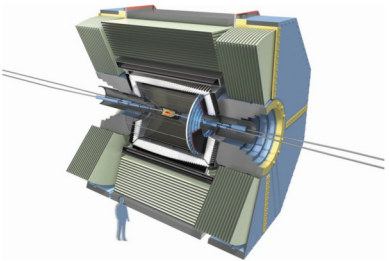
Belle II's pixed detector (PXD)

MPP Belle II is a key group in the development, production, commissioning of the PXD.

Difference Δt of decay time between B's fundamental.
Reduced boost, but recover Δt precision using pixel detector (PXD).

- 2 layer Si pixel detector, 2nd layer partially installed;
- DEPFET technology;
- 1.4 cm from beam;
- Sensor thickness: 75 µm.





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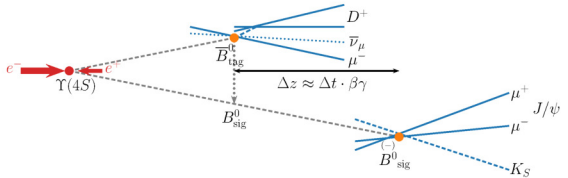
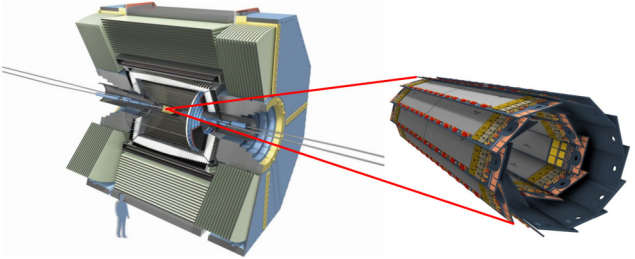




MPP Hardware contributions

Hardware activities:

- Module production (Kapton attachment);
- Characterisation and Tests;
- Ladder assembly and survey;
- Production of support and cooling structure;
- Assembly of Ladders on support;
- Installation of PXD at KEK;
- Services, patch panels;
- Power supply repairs;
- IBBelle cooling plant and cooling R&D.

Some highlights in the next slides...

Detector Production for PXD 2022

Due to problems in the ladder assembly only 2 out of 12 modules are installed in layer 2.
Also layer 1 suffered damage due to beam losses.
The PXD will be completely replaced in 2022

Module assembly:

- Soldering of Kapton tape to sensors
- Wire bonding
- Testing and characterisation

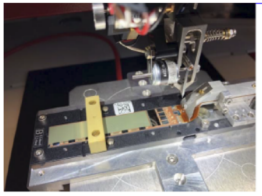
Assembly of two modules to a ladder

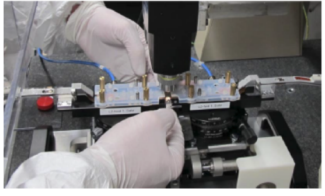
- Assembly procedure has been re-designed to avoid any touching of delicate sensor areas
- Since then, 19 ladders have been glued without loss

Mounting of ladders on support structure

- planned for 2021

Installation of new PXD early 2022

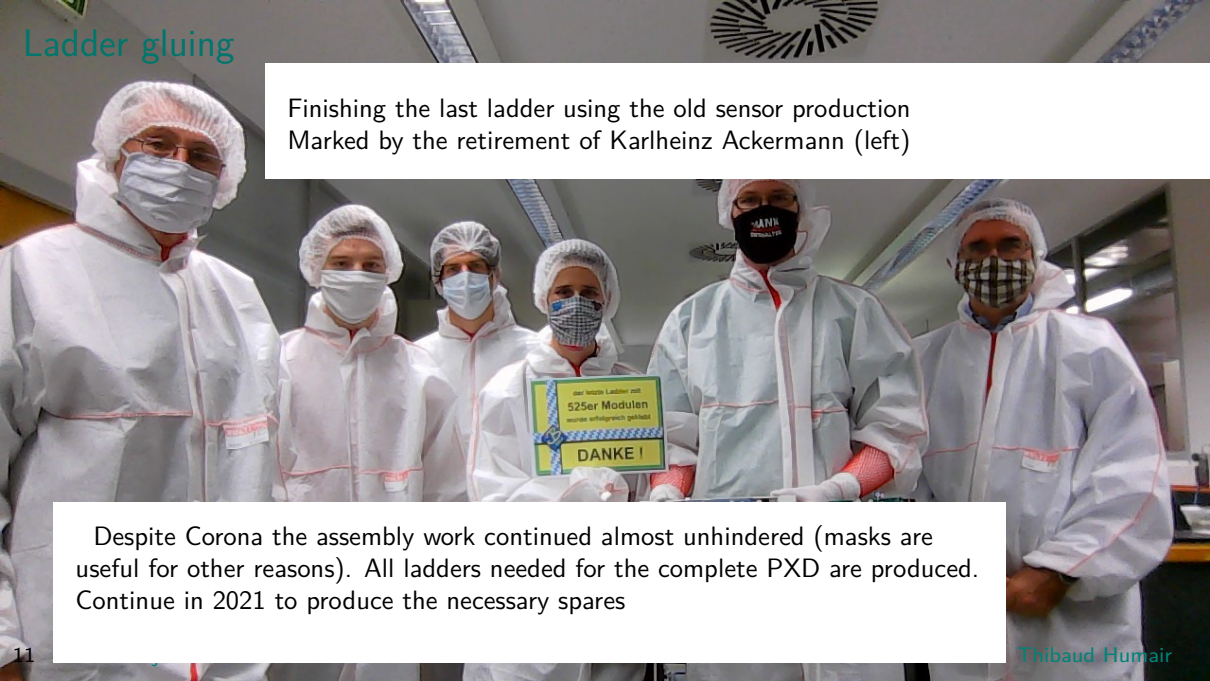




Ladder gluing

Ladder gluing

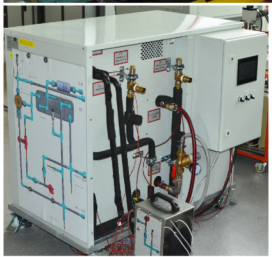
Finishing the last ladder using the old sensor production
Marked by the retirement of Karlheinz Ackermann (left)



Despite Corona the assembly work continued almost unhindered (masks are useful for other reasons). All ladders needed for the complete PXD are produced. Continue in 2021 to produce the necessary spares

CO_2 cooling

IBBelle CO_2 plant provides cooling for PXD and SVD.
MPP reponsible for operation and maintenance.
Worked smoothly during Phase 3 run.
$\sim$ 570 working days since Aug. 2018.

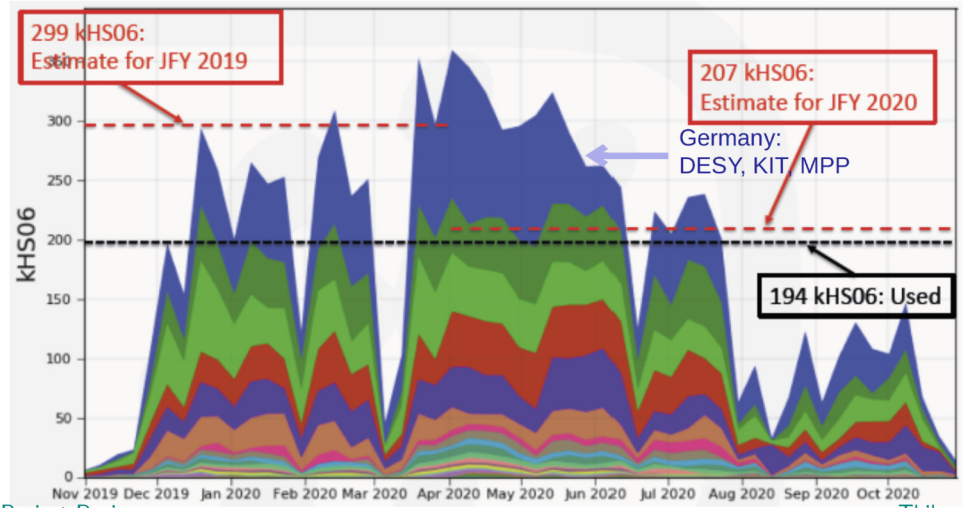


Mini Chiller: develop equivalent cooling plant using a commercial CO_2 chiller (not on the market when IBBelle was planned)

- $< 1/10$ of the costs;
- $\sim 1/20$ of volume and weight;
- Performance adequate.
- Backup
- commissionig of PXD22 (in parallel to physics run)
- Laboratory use

Computing

MPP (MPCDF in Garching) provided in 2020 19 kHEP-SPEC06 (9%) and 180 TB storage (2%) for Belle II MC production. Will be upgraded to keep up with increased demands.



First Physics Results
& ongoing analyses

CP violation and CKM matrix

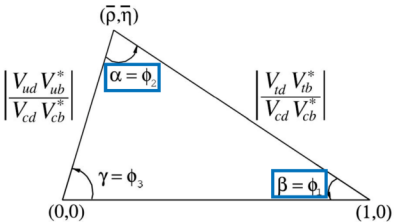
What is the origin of large matter/antimatter asymmetry in the universe?

$$\frac{n_B - n_{\overline{B}}}{n_\gamma} \sim 10^{-10} \quad \textbf{vs} \quad \text{SM expectation: } \sim 10^{-20}...$$

Is there extra CP violation (CPV) beyond the SM?

In SM, CPV occurs via a single complex phase in the CKM quark mixing matrix.

CPV in B decays give access to angles of CKM triangle.



High precision measurements of the CKM parameters is key in the Belle II physics program. We are very active on that in the MPP Belle II group.

Direct CP violation and ϕ_2

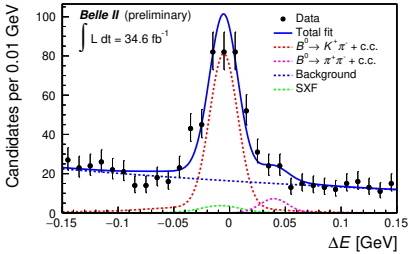
Markus Reif, Oskar Tittel, Benedikt Wach

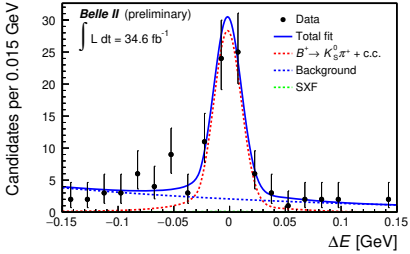
Direct CPV in charmless $b \to u, d, s$ transitions gives access to CKM angle ϕ_2.
QCD uncertainties: need to cleverly combine measurements of several decay modes to get ϕ_2.

Ten charmless modes observed at Belle 2, big contribution from MPP students shown at ICHEP 2020.
CPV not yet significant.

Planned update for Moriond 2021:

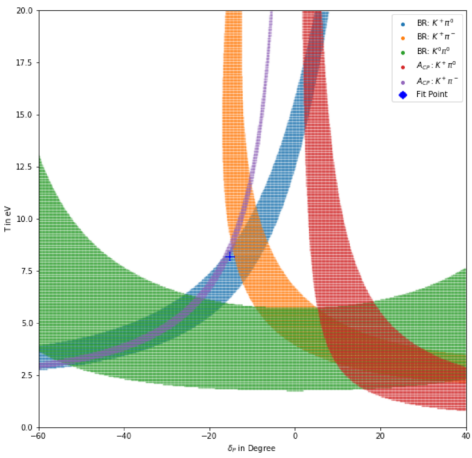
- refine analysis techniques;
- keep detection asym. under control.





Phenomenology project: $K\pi$ puzzle

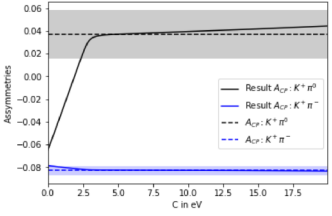
Hans-Günther Moser, Oskar Tittel



Use A_{CP} and $\mathcal{B}$ measurements + isospin
$\Rightarrow$ extract phases and amplitudes of several Feynman diagrams contributing to

$$B^+ \to K^+\pi^0,\ B^0 \to K^+\pi^-,\ B^0 \to K^0\pi^0.$$

Problem: inconsistencies seen when using present measurement: $K\pi$ puzzle.
Try to understand if tensions can be explained by contribution of sub-leading diagrams

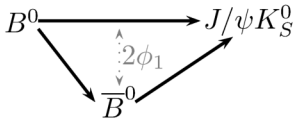


Example:
color-suppressed tree amplitude.

Future key measurement: $B^0 \to K_S\pi^0$

First Time-dependent CPV result

Vladimir Chekelian, Thibaud Humair, Caspar Schmitt, Justin Skorupa

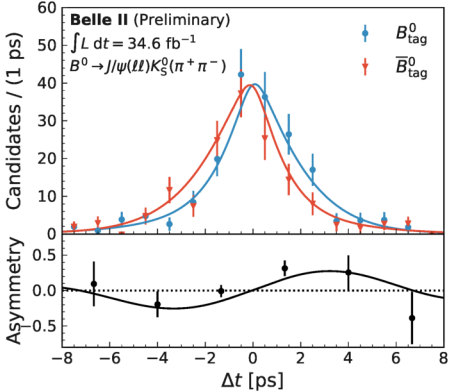


Using $B^0 \to J/\psi K^0_S$ events, see
2.7 σ hint for time-dependent CPV.

First time-dependent CPV measurement, presented at ICHEP 2020. MPP lead the analysis.

Now preparing for precision TD measurements:

- Improving understanding of backgrounds;
- Improving vertex fit algorithm;
- ...

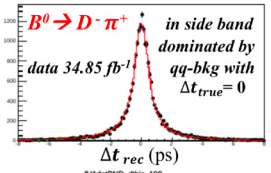


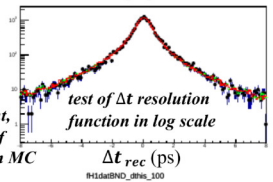
TDCPV: alternative MC-weighing technique

Vladimir Chekelian

idecay	*signal decay channel* **B-yields**	Data13 − 04 $34.58\ fb^{-1}$	expected MC13 − 04	Data/MC	diff. *in* σ
1	$B^0 \to J/\psi(\mu\mu)K^0_S$	238.7 ± 15.6	246.6 ± 4.1	0.968 ± 0.065	$-0.5\ \sigma$
2	$B^0 \to J/\psi(ee)K^0_S$	162.5 ± 14.0	154.7 ± 3.6	1.050 ± 0.094	$0.5\ \sigma$
3	$B^+ \to J/\psi(\mu\mu)K^+$	869.6 ± 29.5	976.2 ± 8.2	0.891 ± 0.031	$-3.5\ \sigma$
4	$B^+ \to J/\psi(ee)K^+$	539.4 ± 24.7	586.7 ± 6.8	0.919 ± 0.043	$-1.9\ \sigma$
10	$B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$	2867.0 ± 59.9	2769.8 ± 16.8	1.035 ± 0.023	$1.5\ \sigma$
12	$B^0 \to D^{*-}[D^0(K^-\pi^+)\pi^-]\pi^+$	776.0 ± 28.7	697.4 ± 7.3	1.113 ± 0.043	$2.6\ \sigma$
14	$B^0 \to D^{*-}[D^0(K^-\pi^+\pi^-\pi^+)\pi^-]\pi^+$	913.3 ± 32.1	1006.3 ± 9.3	0.908 ± 0.033	$-2.8\ \sigma$
16	$B^+ \to D^0(K^-\pi^+)\pi^+$	2327.1 ± 50.0	2498.0 ± 14.0	0.932 ± 0.021	$-3.2\ \sigma$
18	$B^+ \to D^0(K^-\pi^+\pi^-\pi^+)\pi^+$	3361.3 ± 67.4	4011.6 ± 20.6	0.838 ± 0.017	$-9.5\ \sigma$

→ ***B-yields are in agreement with expectations for all channels except*** $B^+ \to D^0(K3\pi)\pi^+$



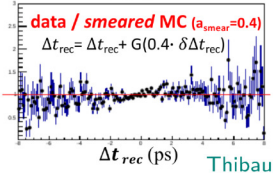


→ ***reasonable agreement, improved by smearing of resolution function from MC***

B-lifetimes

2019/2020 $34.58\ fb^{-1}$	9 *BB*, 9 *SB* 3 *param. fit*	9 *BB*, 9 *SB* 2 *param. fit*	9 *BB*, 9 *SB* 2 *param. fit*	9 *BB*, 9 *SB* 2 *param. fit*
$\tau_{B^0}(ps)$	1.483 ± 0.030	1.491 ± 0.030	1.477 ± 0.030	1.468 ± 0.030
$\tau_{B^\pm}(ps)$	1.574 ± 0.024	1.582 ± 0.024	1.570 ± 0.024	1.552 ± 0.024
α_{smear}	-0.31 ± 0.04	$-0.50\ (fixed)$	$0\ (fixed)$	$0.40\ (fixed)$

Spread of the B-lifetime results
-0.009 - +0.014
-0.018 - +0.012



→ ***The spread of the resulting B-lifetimes is smaller than half of statistical errors***

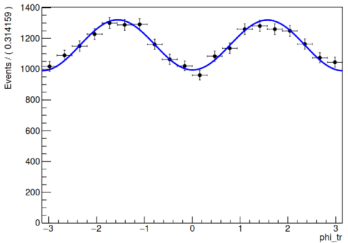
TDCPV: angular analysis

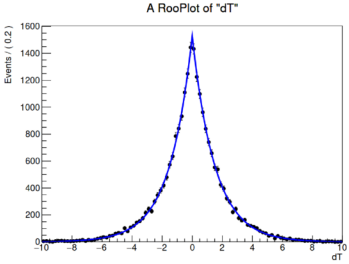
Boqun Wang

Other decay interesting to access CKM parameter:
$B^0 \to J/\psi K^{*0}(K_S\pi^0)$
contains a mixture of several CP-eigenstates

Fit angular observables to tell them apart
AND
fit decay time to extract TDCPV parameters.

Analysis in preparation.

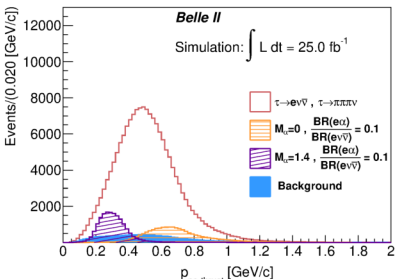




τ analyses

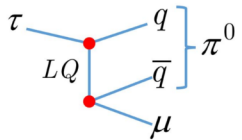
τ decays also a good laboratory to search for New Physics. Belle II produces as many τ pairs as B pairs and will be the leading τ experiment.

$\tau \to e +$ invisible:
Thomas Kraetzschmar



LFV decay with massive undetected boson.
Challenge: large $\tau \to e\nu\nu$ background.
$\Rightarrow$ developed new variables, BDT and fit method to tell signal apart!

$\tau \to \pi^0\mu$:
Christian Kiesling, Marton Nemeth-Csoka



Belle II sensitivity $\sim 5\times$ better than Belle, thanks to new neural network-based two track trigger decays with one-prong tag, *e.g.*:

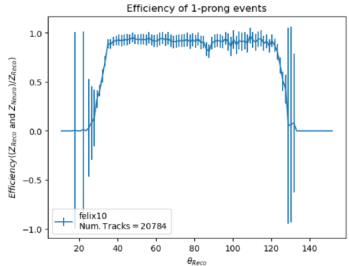
$$e^+e^- \to \tau^+(\pi^0\mu^+)\,\tau^-(\mu^-\nu\nu)$$

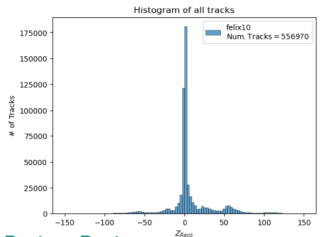
and also $\tau^- \to e^-\nu\nu$, $\pi^-\nu$, $\rho^-\nu$, $\pi^-\pi^0\pi^0\nu$.

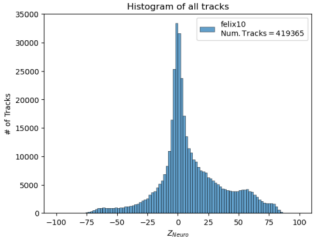
Neurotrigger

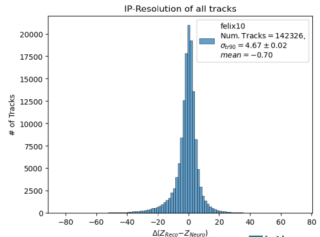
Christian Kiesling, Felix Meggendorfer, Sebastian Skambraks

- Level 1 Z-Vertex Track Trigger using a Neural Network for vertex estimation
- Network trained with real, reconstructed tracks
- Delta Z Resolution at the Beam IP: < 5cm
- Currently passive, will be used in next run phase
- Requires at least 1 track from within $|z|$ =40cm
- Efficiency for 1 Track from IP within CDC: $> 95\%$
- Reduces background by 35%









Charm physics & charm tagger

Lukas Bierwirth, Fabian Krinner, Stephan Paul

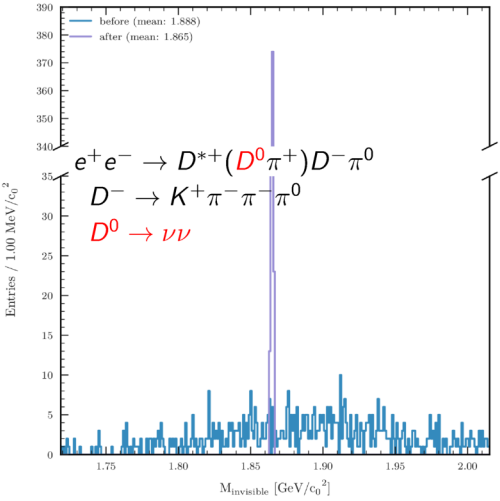
Developing charm tagger to reconstruct charmed meson decays to neutral or invisible particles

Use full $e^+e^- \to D\overline{D}X$ reconstruction and constraints from known beam energy.

Interesting for:

- Rare decay $D^+ \to \pi^+\nu\nu$;
- CPV in $D^+ \to \pi^+\pi^0$;
- V_{cd} with $D^+ \to \ell^+\nu$;
- ...

Now being tested using simulation.



Amplitude analyses

Fabian Krinner, Stephan Paul

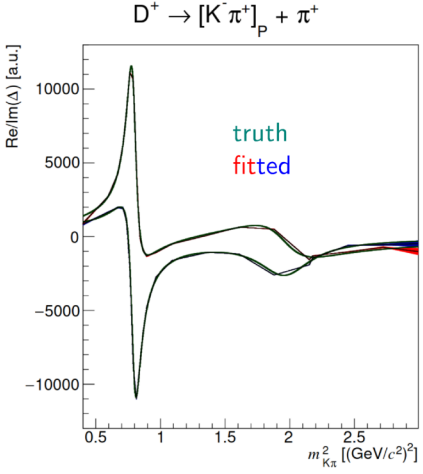
Amplitude analyses: find resonances that contribute to 3 body decays.

Useful for

- CPV analyses;
- Studies of QCD and search for new states;
- ...

Developing methods to solve mathematical ambiguities in model-independent amplitude analyses.

Performed simulation studies, going to move on to Belle II real data.



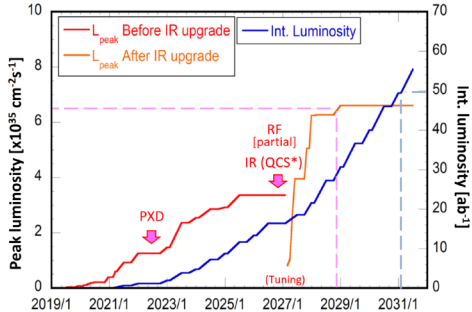
Conclusion

Future plan at Belle II:

→ 2022: accumulate dataset equivalent to Belle

2022: shutdown for upgrade. Replacement of PXD and TOP photocensors.

2023→2031: Keep increasing luminosity and accumulate data.



The MPP Belle II group was at the forefront of the analysis effort to produce the first physics with the first data

⇒ now a lot of work ongoing to prepare precision measurements!

There would be no result without a properly working detector and computing power.
Special thanks to the technical department for their support!