τ_B AND $\bar{B}^0 - B^0$ MIXING RESULTS FROM EARLY BELLE II DATA

Flavour Physics and CP Violation
(FPCP 2019)

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ON BEHALF OF THE BELLE II COLLABORATION

Victoria, Canada, May 6-10

Outline

Introduction to τ_B and $\bar{B}^0 - B^0$ mixing measurements

Belle II and vertex detector

Importance of the detector alignment

Results from Commissioning run

Experiences using early data

Future analysis plans

Summary

Introduction to τ_B and $\bar{B}^0 - B^0$ mixing measurements

τ_B measurement

$$P(\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}$$

- Separated for $\tau_{B^0/\bar{B}^0}$ and $\tau_{B^\pm}$
- Ratio $\frac{\tau_{B^\pm}}{\tau_{\bar{B}^0/B^0}}$

$\bar{B}^0 - B^0$ mixing measurement

- Neglecting CP Violation:

$$P_{B^0\bar{B}^0 \to B^0\bar{B}^0}(\Delta t) = P_+(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + \cos\left(\Delta m_d \Delta t\right)\right]$$

$$P_{B^0\bar{B}^0 \to B^0B^0/\bar{B}^0\bar{B}^0}(\Delta t) = P_-(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 - \cos\left(\Delta m_d \Delta t\right)\right]$$

Belle-BaBar results

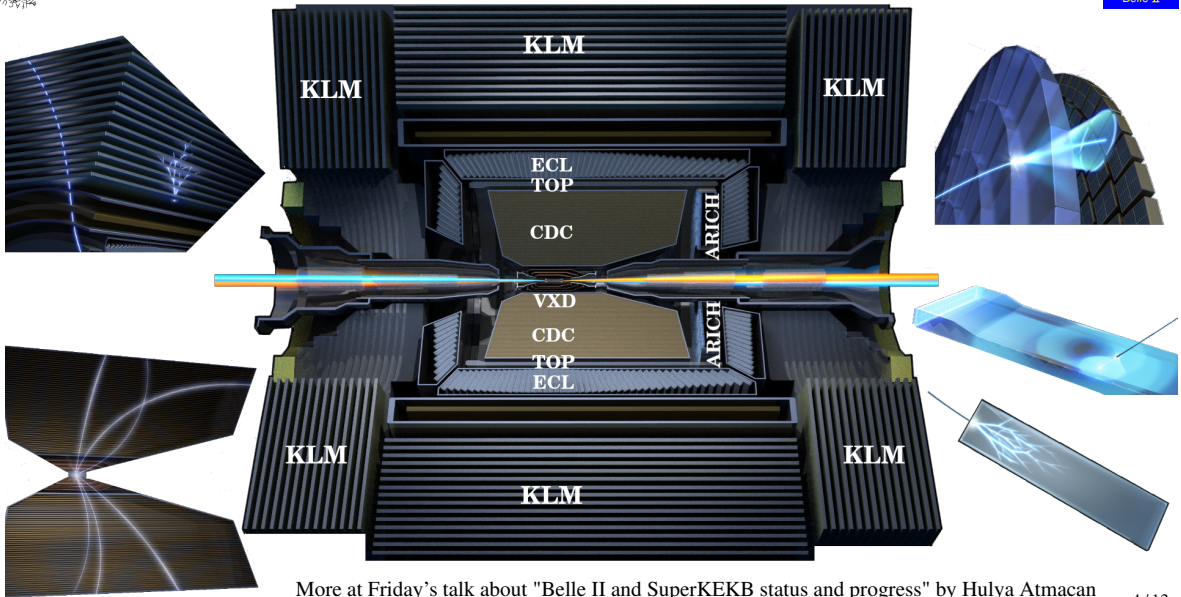
- $\tau_{B^0} = 1.530 \pm 0.005 \pm 0.009$ ps
- $\tau_{B^\pm} = 1.640 \pm 0.010 \pm 0.010$ ps
- $\tau_{B^\pm}/\tau_{B^0} = 1.068 \pm 0.009 \pm 0.007$
- $\Delta m_d = 0.508 \pm 0.003 \pm 0.003$ ps^{-1}
- First uncertainty is statistical.
- Second uncertainty is systematic.

Belle and Belle II comparison

$$\Delta t = \frac{\Delta z}{\langle\beta\gamma\rangle c}$$

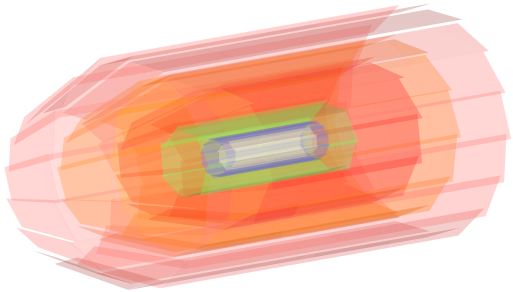
- Δz is distance between B_{tag} and B_{rec}
- $\langle\Delta z\rangle_{Belle} \sim 200\ \mu m$
- $\langle\Delta z\rangle_{Belle\ II} \sim 130\ \mu m$

BELLE II DETECTOR



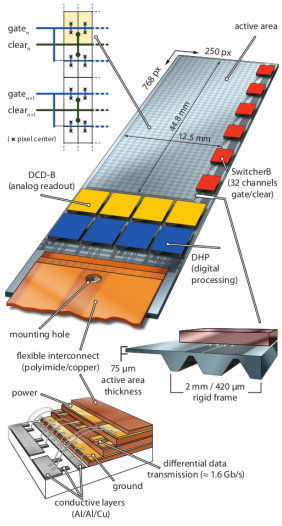
More at Friday's talk about "Belle II and SuperKEKB status and progress" by Hulya Atmacan

VERTEX DETECTOR (PIXEL & STRIP DETECTOR)



	Radius [mm]	*Thickness* [μm]	R/ϕ *pitch* [μm]	*Z pitch* [μm]	*Sensors*
PXD Layer 1	14	75	50	55 - 60	2×8
PXD Layer 2	22	75	50	70 - 85	$2 \times 2^*$
SVD Layer 3	39	300 - 320	50	169	2×7
SVD Layer 4	80	300 - 320	50	240	3×10
SVD Layer 5	104	300 - 320	50	240	4×12
SVD Layer 6	135	300 - 320	50	240	5×16

*PXD Layer 2 is not complete, but full pixel detector will be used after replacement in 2020.

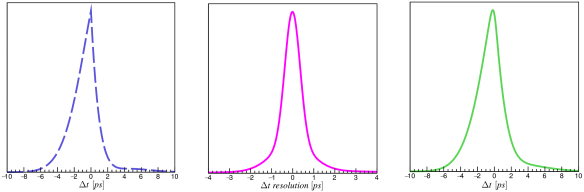


Schematic view of PXD sensor

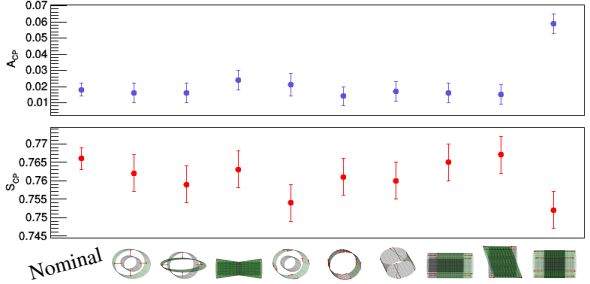
IMPORTANCE OF THE DETECTOR ALIGNMENT

- Alignment important for time-dependent analysis

Physical distribution $\otimes$ Detector resolution = Measured distribution



- Sensor displacements deform detector resolution distribution.



	Δr	$r\Delta\phi$	Δz
r	**Radial expansion** $\Delta r = c_{scale} \cdot r$	**Curl** $r\Delta\phi = c_{scale} \cdot r + c_0$	**Telescope** $\Delta z = c_{scale} \cdot r$
ϕ	**Elliptical expansion** $\Delta r = c_{scale} \cdot \cos(2\phi) \cdot r$	**Clamshell** $\Delta\phi = c_{scale} \cdot \cos(\phi)$	**Skew** $\Delta z = c_{scale} \cdot \cos(\phi)$
z	**Bowing** $\Delta r = c_{scale} \cdot \lvert z \rvert$	**Twist** $r\Delta\phi = c_{scale} \cdot z$	**Z expansion** $\Delta z = c_{scale} \cdot z$

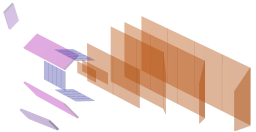
χ^2 invariant modes of minimization algorithm

ALIGNMENT AND CALIBRATION TASKS

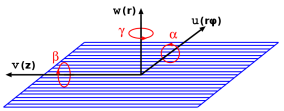
1) Precisely determine alignment and calibration constants.
2) Validate and monitor alignment constants and uncertainties.

ALIGNMENT RESULTS & VALIDATION @ COMMISSIONING RUN

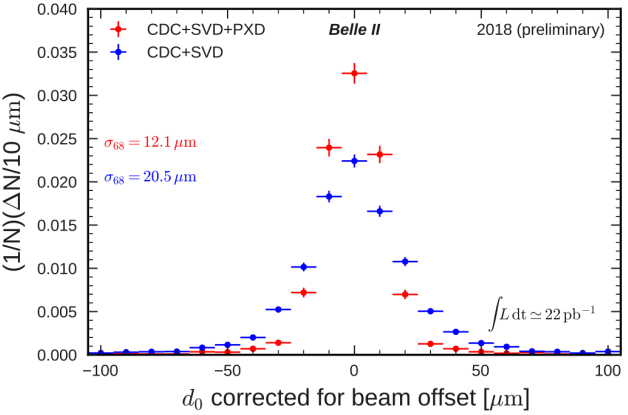
Layout of vertex detector



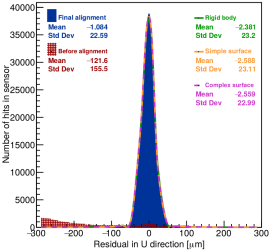
"Rigid" alignment parameters



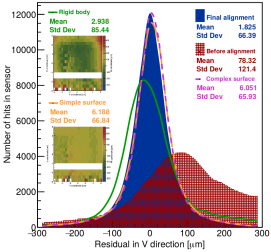
Transverse impact parameter resolution



Results for pixel sensor



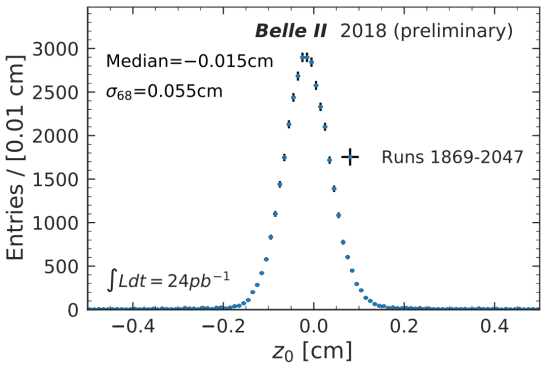
Result for strip sensor



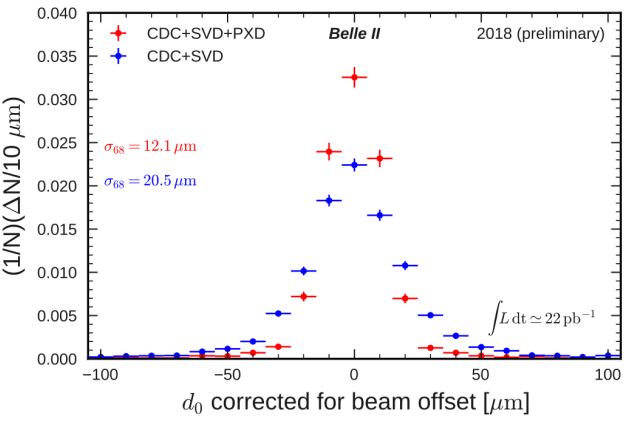
Time dependent VXD alignment validation

Alignment results & validation @ Commissioning run

Interaction region spread delivered by SuperKEKB

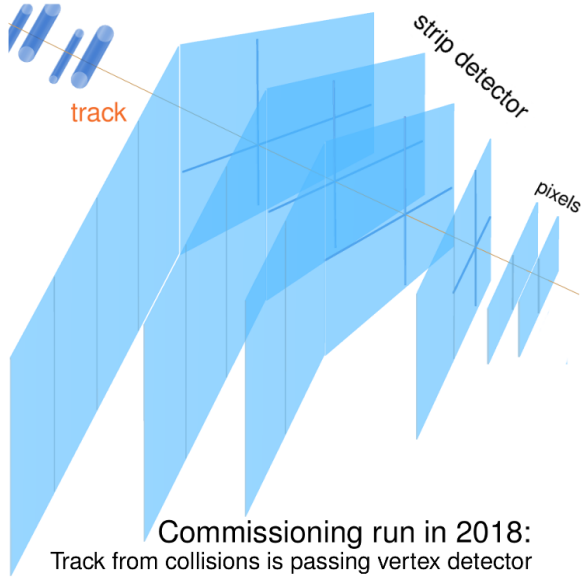


Transverse impact parameter resolution

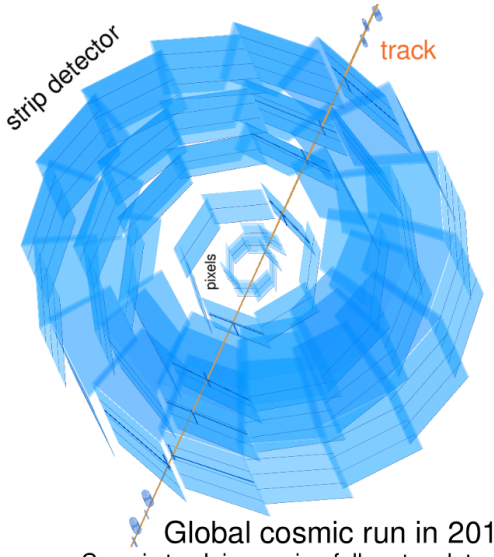


Time dependent VXD alignment validation

From Commissioning run to early data

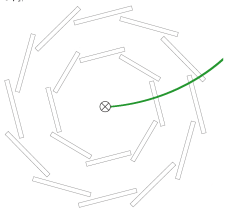


Commissioning run in 2018:
Track from collisions is passing vertex detector

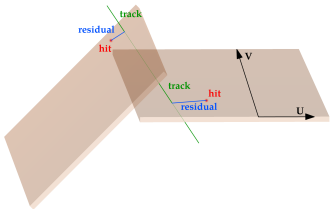


Global cosmic run in 2019:
Cosmic track is passing full vertex detector

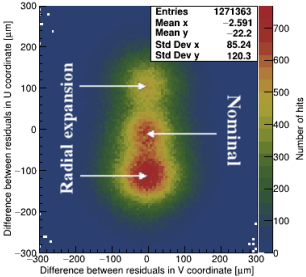
Experiences using early data



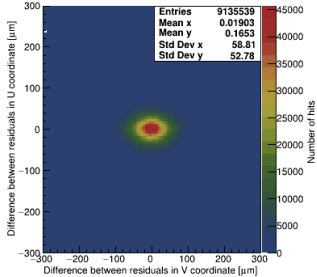
Schematic view



Overlapping sensors in layer in details



Result for data



Monte Carlo analysis

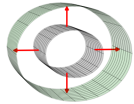
Monitor χ^2 invariant modes

- Tracks pass overlapping ladders in layers
- Residuals differences in u and v coordinates
- Possible to use cosmic, collision or background tracks
- Possibility to estimate systematic error

Example from data

- More than $4 \cdot 10^6$ cosmic tracks without magnetic field
- PXD and slanted SVD sensors are at nominal position.
- SVD barrel sensors are affected by radial expansion.

Systematic movements of SVD barrel sensors in radial direction about 100 μm.



$\Rightarrow$ Possibility to improve alignment procedure.

$\Rightarrow$ Possibility to update resolution function.

Future analysis plans: Semileptonic B decays

Fully inclusive (two leptons in event)

- \+ Highest statistics
- − No way to enrich the sample in B^+/B^0
- − Modelling of background might not be trivial

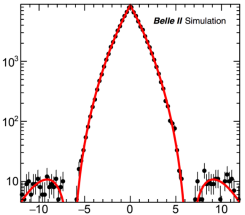
Full reconstruction of $B \to D^{(*)}\, l\, \nu$

- \+ Can separate B^+ from B^0
- \+ Better control of background
- − Significantly lower efficiencies

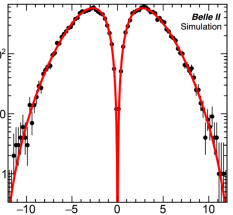
Partial reconstruction of $B \to D^{*-}(\to \bar{D}^0\, \pi^-_{soft})\, l^+\, \nu$

- \+ Better efficiency
- \+ D^* momentum is interred from π_{soft} momentum
- − Higher background

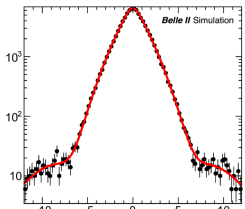
Monte Carlo studies



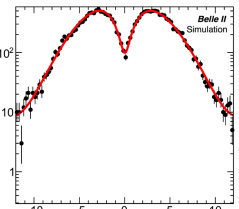
$P^{\,true}_{B^0\bar{B}^0 \to B^0\bar{B}^0}(\Delta t)$



$P^{\,true}_{B^0\bar{B}^0 \to B^0B^0/\bar{B}^0\bar{B}^0}(\Delta t)$



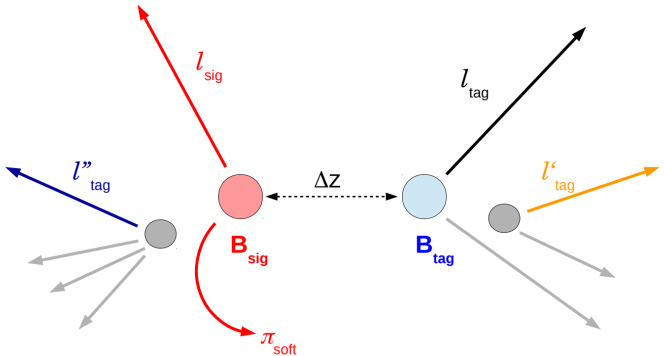
$P^{\,reco}_{B^0\bar{B}^0 \to B^0\bar{B}^0}(\Delta t)$



$P^{\,reco}_{B^0\bar{B}^0 \to B^0B^0/\bar{B}^0\bar{B}^0}(\Delta t)$

SUMMARY

- Belle II detector was commissioned.
- Partial vertex detector was successfully installed.
- Full vertex detector installation is planned in 2020.
- Sophisticated alignment procedure was applied.
- Alignment results are precise and stable.
- τ_B and $\bar{B}^0 - B^0$ mixing measurements will be performed on the dataset taken until this July



7/5 **Stefano Lacaprara**: First look at time-dependent CP violation using early Belle II data

7/5 **Niharika Rout**: Measurement of the CKM angle γ with Belle II

7/5 **Justin Tan**: Early physics prospects for radiative and electroweak penguin decays at Belle II

7/5 **David Perez**: Prospects for τ lepton physics at Belle II

8/5 **Markus Prim**: Semileptonic and leptonic B decay results from early Belle II data

9/5 **Chris Hearty**: Dark Sector Physics with Belle II

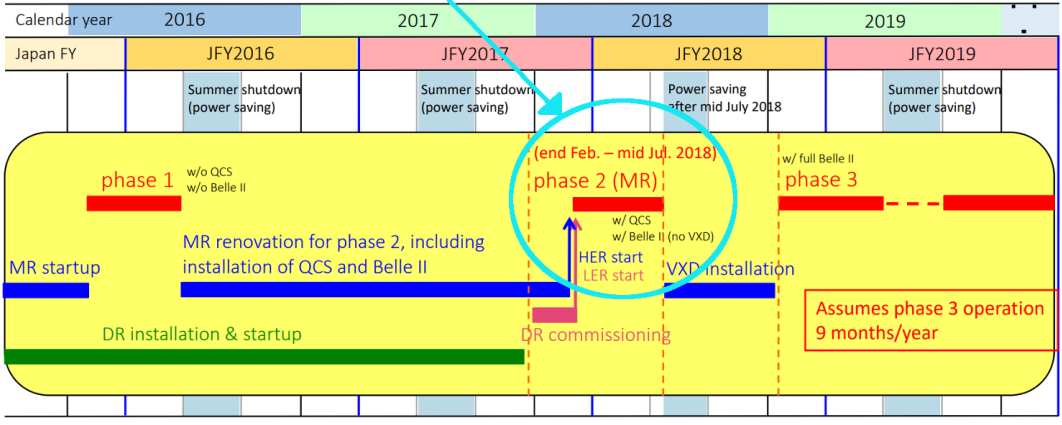
9/5 **Jake Bennett**: Exotic Quarkonium Physics Prospects at Belle II

9/5 **Hikari Hirata**: Sensitivity to X(3872) total width at the Belle II experiment

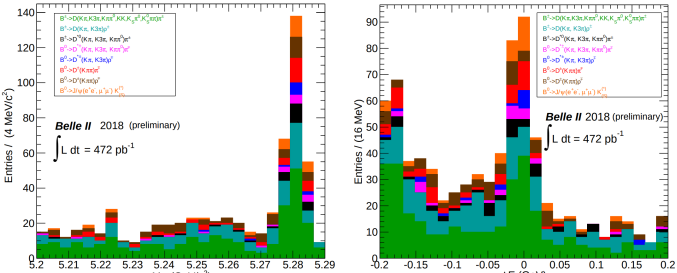
10/5 **Hulya Atmacan**: Belle II and SuperKEKB status and progress

BACKUP: COMMISSIONING RUN

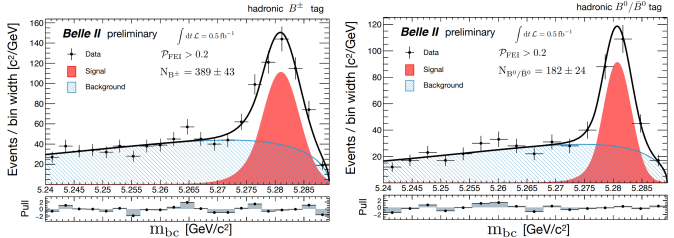
Belle II commissioning run means **Phase 2** in Belle II jargon. There was used full Belle II external detector with internal background detector (VXD samples shown in slide 4). Collisions were provided with full superconducting final focusing.



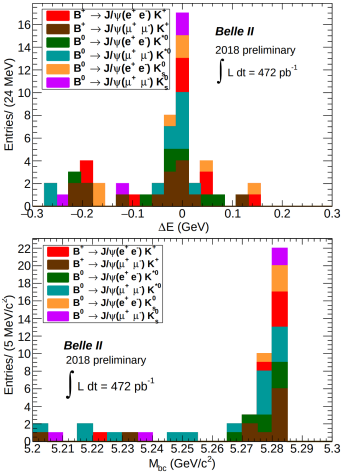
BACKUP: PHYSICS RESULTS @ COMMISSIONING RUN



Hadronic decay channels



Full event interpretation



Leptonic decay channels

We collect more than 500 B meson candidates in hadronic and leptonic decay channels at 500 pb^{-1}.

BACKUP: FUTURE ANALYSIS PLANS

- τ_B and $\bar{B}^0 - B^0$ mixing measurements using hadronic and semileptonic decays.

HADRONIC B DECAYS

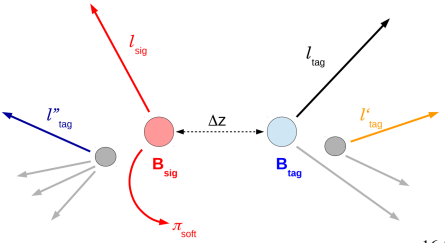
- Testing standard analysis technique with low statistics.
- Possibility to use full event interpretation machinery to select our samples.
- Tag Vertex reconstruction and Flavor Tagger can be performed (commissioned).

SEMILEPTONIC B DECAYS

- Analysis technique is not standard but simpler.
- High momentum leptons provides high purity and large branching fractions of B $\rightarrow$ X l ν for e, μ
- The B decay vertices can be found as intersection of lepton tracks with beamspot

SEVERAL APPROACHES

- Fully inclusive (two leptons in event)
- Reconstruction high momentum lepton + $B \rightarrow D^{(*)}\ l\ \nu$
- Reconstruction two $B \rightarrow D^{(*)}\ l\ \nu$



Analysis strategy is based on the signal side B candidate, the tag side of B and displaced open-charmed particles.

BACKUP: SOURCE OF SYSTEMATIC UNCERTAINTIES

- Based on "The Physics of the B Factories" [Eur. Phys. J. C (2014) 74:3026]

SYSTEMATIC UNCERTAINTY OF τ_B MEASUREMENT

- Δt resolution
- Δt background
- Vertex detector alignment
- Vertex reconstruction
- Low Monte Carlo statistics

SYSTEMATIC UNCERTAINTY OF $\bar{B}^0 - B^0$ MIXING MEASUREMENT

- τ_B measurement
- Δt resolution
- Δt background
- Vertex detector alignment
- Vertex reconstruction
- Low Monte Carlo statistics