Konstruktion und Alignment des Belle II Pixel Vertex Detektors

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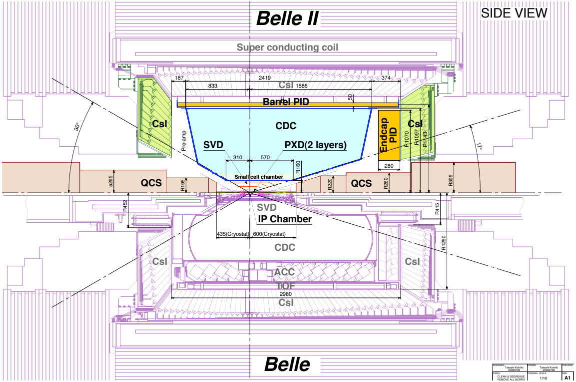
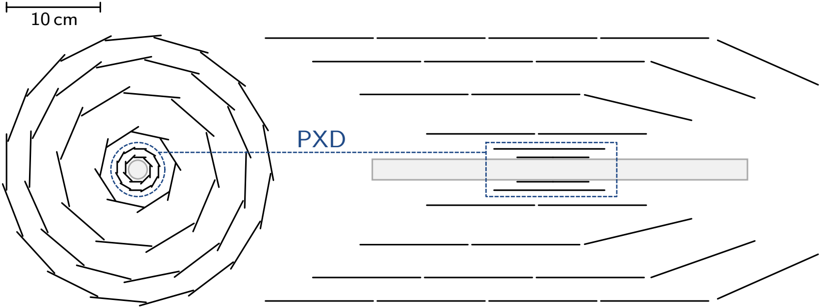
DEPFET
Active Pixel Detector

Belle/Belle II Experiment

- asymmetric e^+e^- experiment at the $\Upsilon(4S)$ resonance (10.58 GeV)
- KEKB peak luminosity of $2.11 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (world record)
- $1023\,\mathrm{fb}^{-1}$ integrated luminosity since 1999 (772 million $B\overline{B}$ pairs)
- upgrade to SuperKEKB/Belle II 2010-2013
  (target luminosity: $8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)



Belle II Vertex Detector



Will consist of two mechanically independent subdetectors:

Pixel Vertex Detector

- two layer DEPFET pixel detector
- very low material budget ($0.14\%\,X_0$ per layer)
- mounted on beampipe
- 40 sensor modules

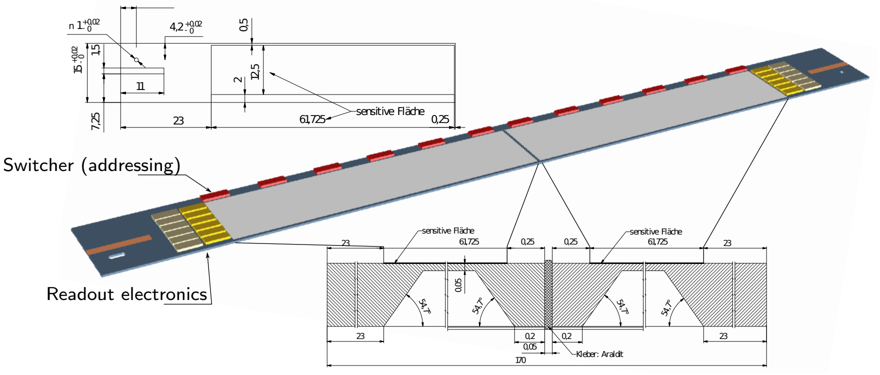
Strip Vertex Detector

- four layer double sided strip detector
- forward parts will be slanted
- attached to CDC
- 187 sensor modules

PXD Mechanical Design

Vertex resolution is the key to CP-Violation

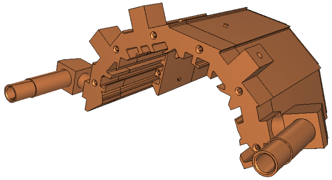
➡ low material budget required to minimize energy loss and multiple scattering

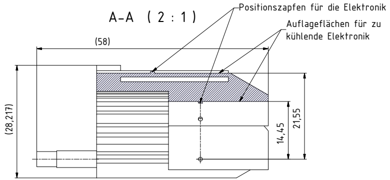


- sensitive area will be thinned down to 50 μm
- no support structures inside of the acceptance ($17^\circ < \theta < 150^\circ$)
- low material glueing between forward and backward half

Support and Cooling

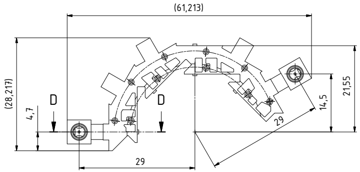
- space in forward/backward region is very limited
- electronics dissipate 9 W per module (180 W per side)
- 1 W power dissipation over active area





Integrated Support and Cooling Structure

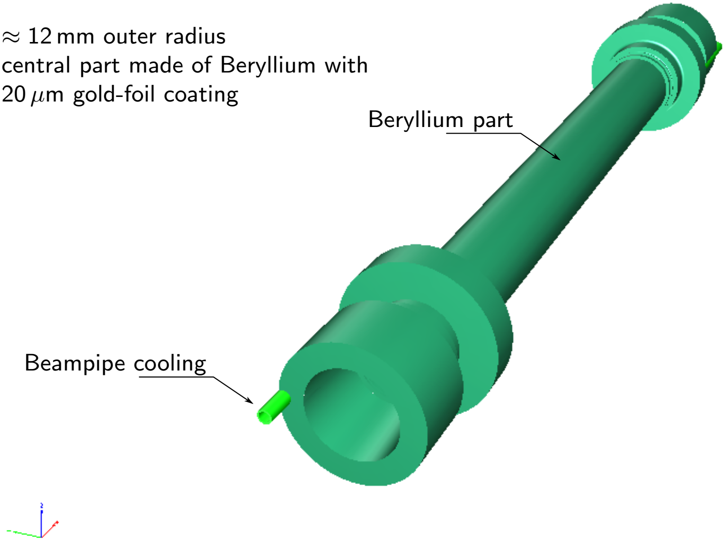
- copper/steel support structure
- integrated cooling channels
- airflow channels



Complete Design

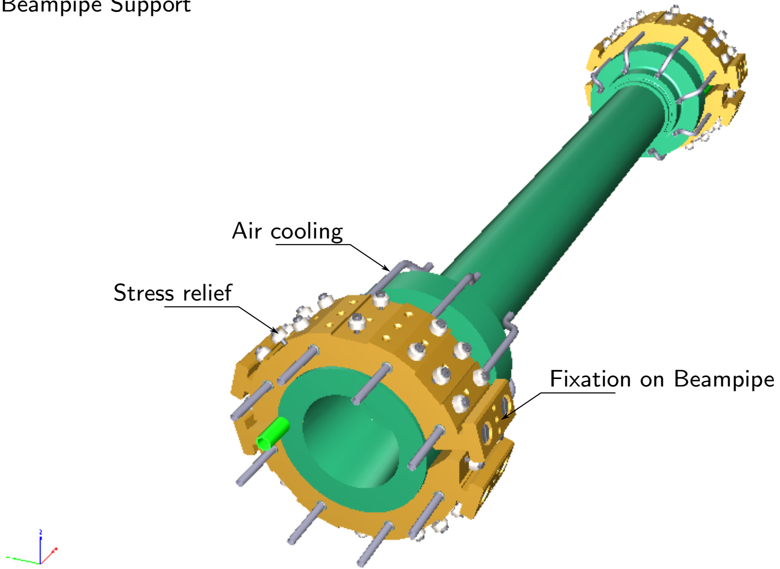
Beampipe

$\approx$ 12 mm outer radius
central part made of Beryllium with
20 μm gold-foil coating



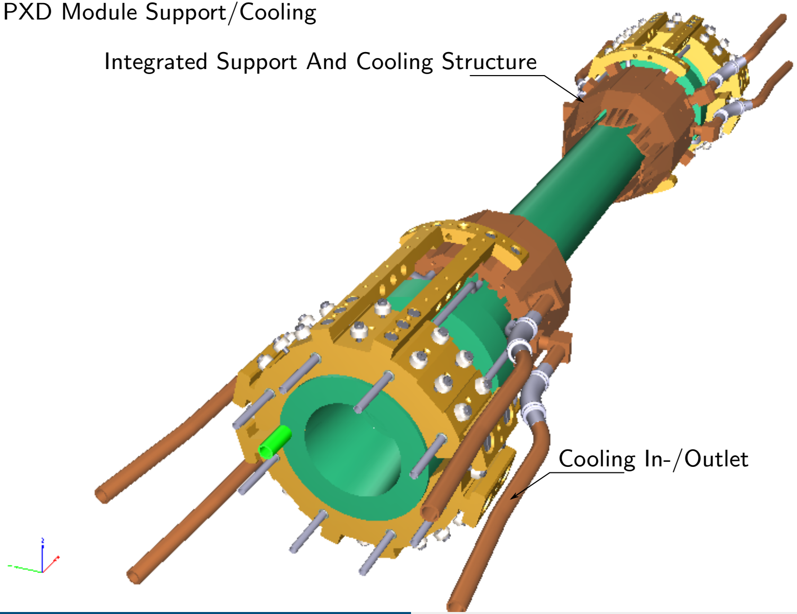
Complete Design

Beampipe Support



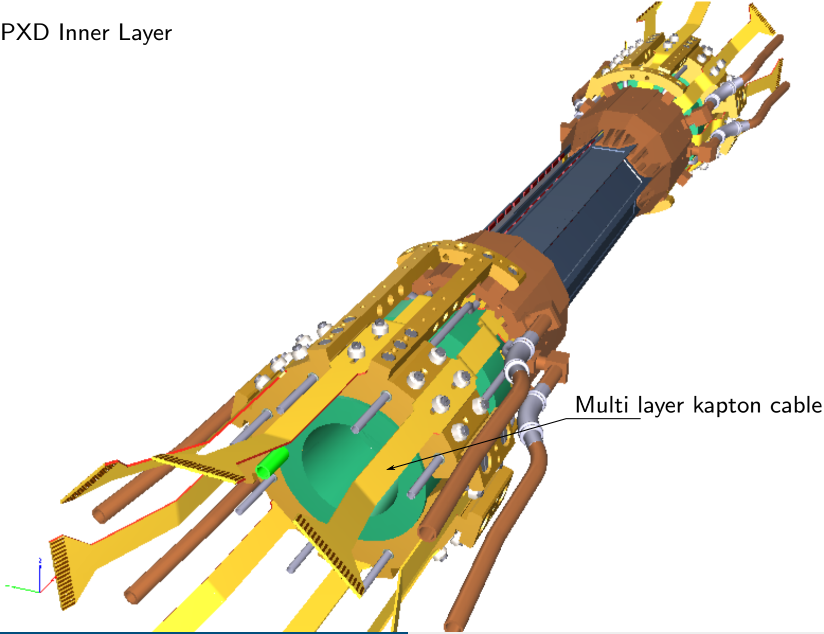
Complete Design

PXD Module Support/Cooling



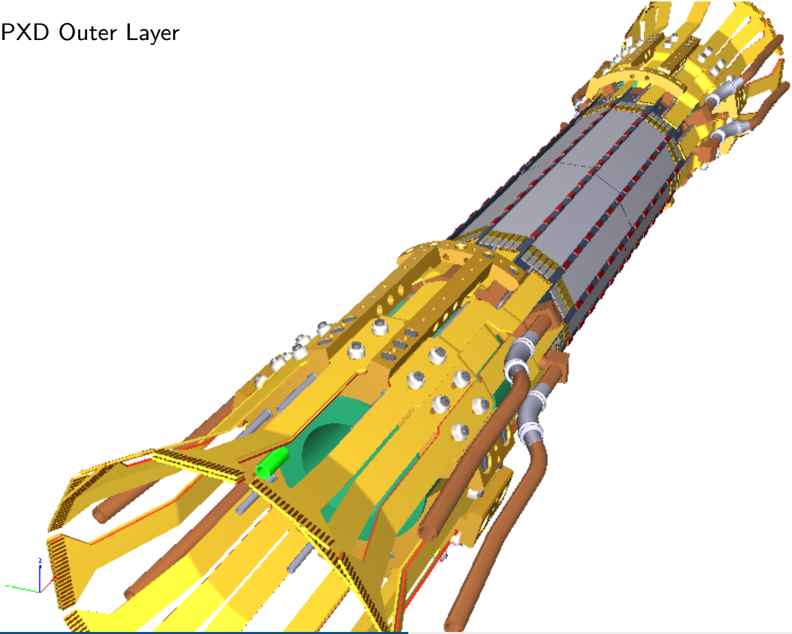
Complete Design

PXD Inner Layer

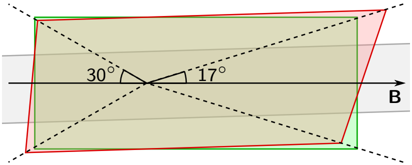


Complete Design

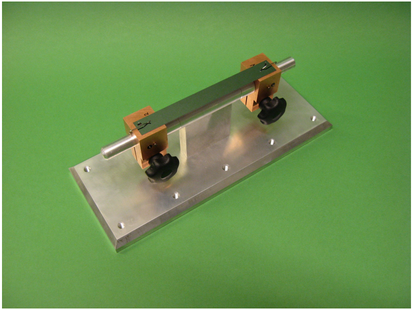
PXD Outer Layer

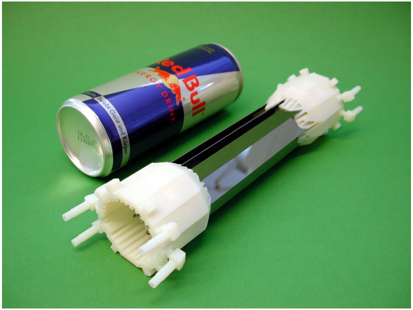


Open questions



- beampipe not yet fixed, might be rotated by max. 29.5 mrad, outer radius maybe not final.
- testing of temperature stability of current design
- glueing of modules has to be verified
- different cooling schemes under evaluation (Water, CO_2, C_3F_8)





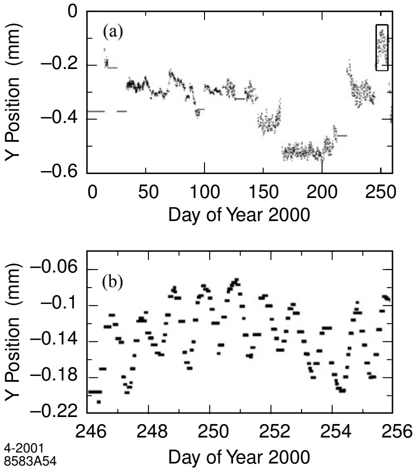
Alignment

Required spatial resolution: $\approx 10\,\mu m$

PXD + SVD

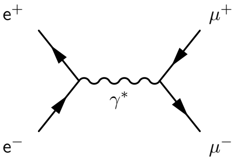
- pixel-detector mounted directly on the beampipe
- double-sided strip-detector attached to the CDC
- mechanically independent subsystems
- frequent and large relative movements possible

⇨ frequent, time-dependent alignment needed



Global alignment of the BABAR SVT

Alignment with $e^+e^- \to \mu^-\mu^+$



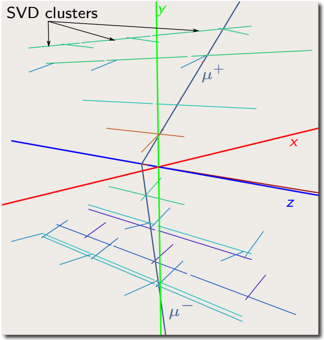
Goal

Implementation of a new alignment procedure for the Belle SVD2 using mainly muon pairs from e^+e^- annihilation as preparation for Belle II

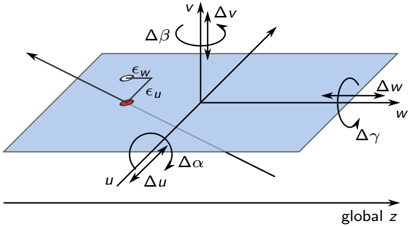
- high statistics

$$\sigma(e^+e^- \to \mu^+\mu^-) \approx 0.77\,\text{nb}$$
$$\sim 15\,\text{s}^{-1} \text{ @ } 2\times10^{34}\,\text{cm}^{-2}\text{s}^{-1}$$
$$\sim 600\,\text{s}^{-1} \text{ @ } 8\times10^{35}\,\text{cm}^{-2}\text{s}^{-1}$$

- large transverse momentum $p_t \gtrsim 2\,\text{GeV}$
- back to back in center of mass system
- not back to back in Lab system (asymmetric energies, crossing angle)



Track-based Alignment



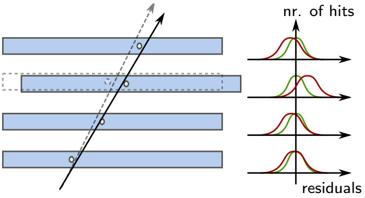
Residual ϵ: Distance hit ⇔ track

ideal: residuals normal distributed mean 0, width σ_r

but: real wafer position not known assembly precision $\sim 100\,\mu$m, no guaranteed time stability.

Necessary to determine absolute position of every detector module

- wrong positions will distort/degrade residual distribution
- minimize residuals by adjusting module position
- 6 degrees of freedom per module (3 translation + 3 rotation)

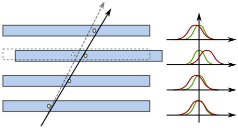


Track-based Alignment

- $\mathbf{a}$ = alignment parameters
- $\boldsymbol{\tau}$ = track parameters

$$\chi^2(\mathbf{a},\boldsymbol{\tau}) = \epsilon(\mathbf{a},\boldsymbol{\tau})^T V^{-1} \epsilon(\mathbf{a},\boldsymbol{\tau})$$

$$\chi^2(\mathbf{a},\boldsymbol{\tau}) = \sum_{i\in tracks}\sum_{j\in hits}\left(\frac{track(\mathbf{a},\boldsymbol{\tau}_i) - hit_j}{\sigma_j}\right)^2$$



Solution for linearized χ^2

$$\underbrace{\left(\mathbf{J}^T\mathbf{V}^{-1}\mathbf{J}\right)}_{\mathbf{C}}\begin{pmatrix}\Delta\mathbf{a}\\ \delta\boldsymbol{\tau}\end{pmatrix} = \underbrace{\left(\mathbf{J}^T\mathbf{V}^{-1}\epsilon(\mathbf{a}_0,\boldsymbol{\tau}_0)\right)}_{\mathbf{b}}$$

local alignment:

- neglect correlations between modules
- keep track parameters fixed
- χ^2-function per module
- small matrices (6×6)
- iteration needed to account for correlations

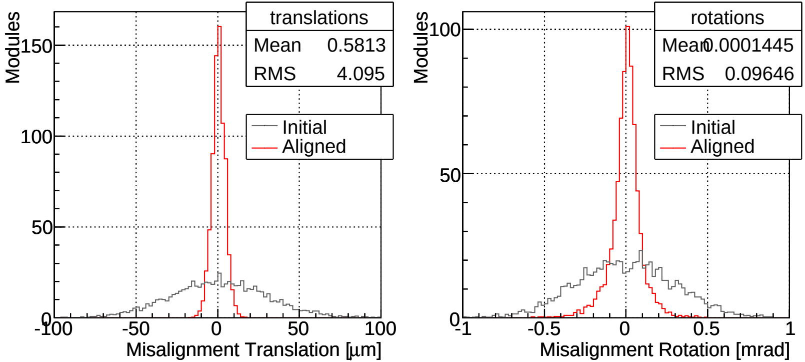
global alignment (Millepede):

- one global χ^2-function
- all correlations taken into account
- "large" set of equations (1476×1476 for Belle, similar for Belle II)

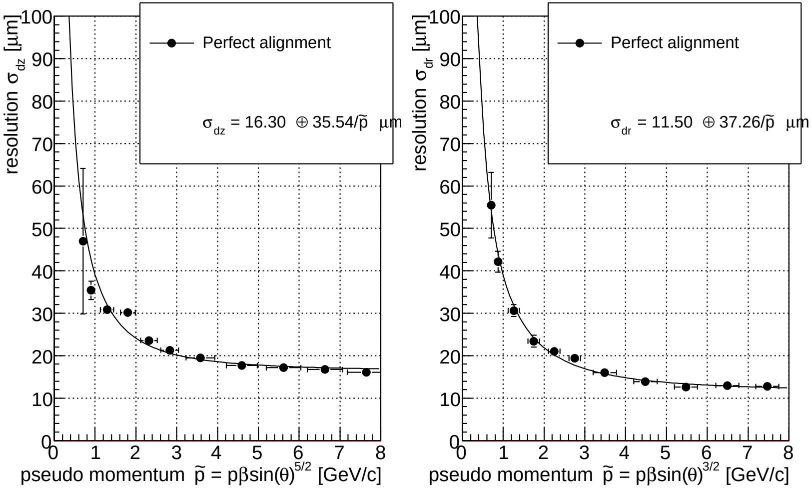
Internal SVD2 Alignment

Current Status

- internal alignment of all the 246 Belle SVD2 modules
- no alignment with respect to the CDC yet
- single tracks from muon 10^6 pair events
- simulated misalignment of 30 μm (0.3 mrad) for all modules.



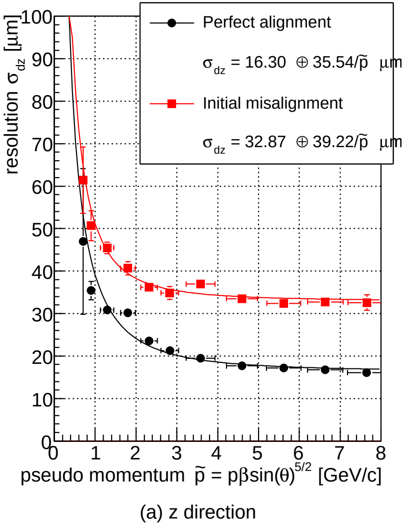
SVD2 Performance



(a) z direction (b) rϕ direction

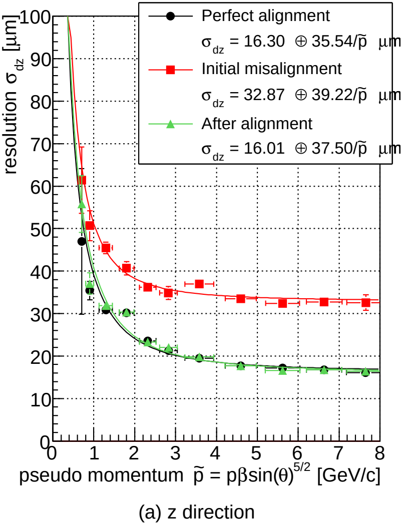
Impact parameters obtained from cosmic muons

SVD2 Performance



Impact parameters obtained from cosmic muons

SVD2 Performance



Impact parameters obtained from cosmic muons

Conclusions

PXD Mechanial Design

- low material PXD design well underway
- challenging spacial and material constraints: Sandwiched between beampipe and SVD
- details and cooling still under evaluation

Vertex Detector Alignment

- working prototype for the Belle SVD alignment
- global alignment to be implemented
- additional degrees of freedom/constraints needed

Thank you
for your attention

CP Violation

- CP violated in weak interactions
- represented by non-vanishing complex phase in the weak mixing matrix (CKM model, Nobel Prize 2008 for Kobayashi & Maskawa)

$$\begin{pmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{pmatrix} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{\mathbf{C}_{CKM}} \begin{pmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{pmatrix}$$

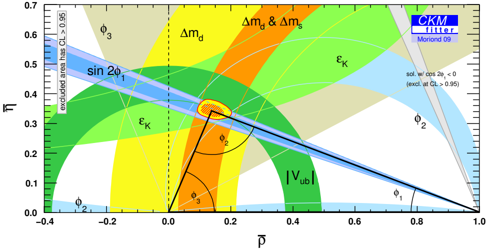
Precision Measurement of CP-Violation

- verification of the CKM model
- search for new sources of CP Violation ⇒ New Physics
- B mesons show large CP-Violation, well suited for CP measurements
- high statistics and precision needed to challenge SM

Unitarity Triangle

- unitarity of CKM matrix leads to column constraints $\sum_k V_{ik} V_{jk}^* = 0$
- triangles in complex space
- almost degenerate in Kaon system, large angles in B meson system

$$\underset{\mathcal{O}(\lambda^3)}{V_{ud} V_{ub}^*} + \underset{\mathcal{O}(\lambda^3)}{V_{cd} V_{cb}^*} + \underset{\mathcal{O}(\lambda^3)}{V_{td} V_{tb}^*} = 0$$



$$\bar{\rho} = \left(1 - \frac{\lambda^2}{2}\right)\rho \qquad \bar{\eta} = \left(1 - \frac{\lambda^2}{2}\right)\eta$$

$$\phi_1 = \arg\left(-\frac{V_{cd} V_{cb}^*}{V_{td} V_{tb}^*}\right) \qquad \phi_2 = \arg\left(-\frac{V_{td} V_{tb}^*}{V_{ud} V_{ub}^*}\right)$$

$$\phi_3 = \arg\left(-\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*}\right)$$

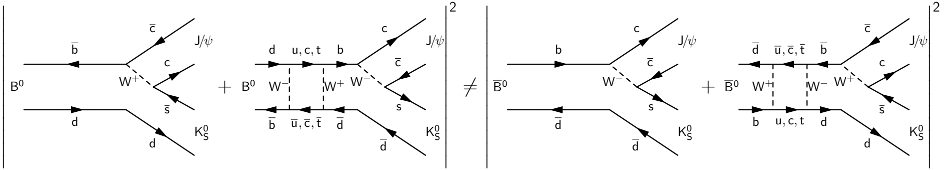
CP Observables

time dependent decay asymmetry

$$a_{CP}(t) = \frac{\Gamma\left(\overline{B}^0 \to f_{CP}; t\right) - \Gamma\left(B^0 \to f_{CP}; t\right)}{\Gamma\left(\overline{B}^0 \to f_{CP}; t\right) + \Gamma\left(B^0 \to f_{CP}; t\right)}$$

3 possible contributions

- CP-Violation in decay (direct)
- CP-Violation in mixing (indirect)
- CP-Violation by interference of mixing and decay (mixing induced)



For B mesons, contributions from indirect CP-Violation are negligible

Measurement of CP-Violation

time dependent decay asymmetry

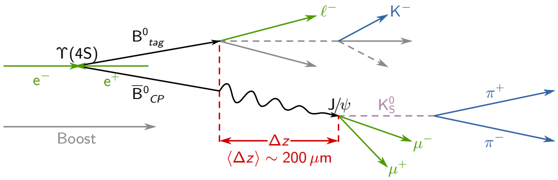
$$a_{CP}(t) = \frac{\Gamma\left(\overline{B}^0 \to f_{CP};t\right) - \Gamma\left(B^0 \to f_{CP};t\right)}{\Gamma\left(\overline{B}^0 \to f_{CP};t\right) + \Gamma\left(B^0 \to f_{CP};t\right)}$$

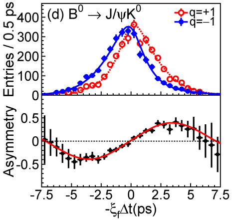
Experimental challenging

- lifetime of B mesons is 1.5 ps
- flavour of B meson has to be known

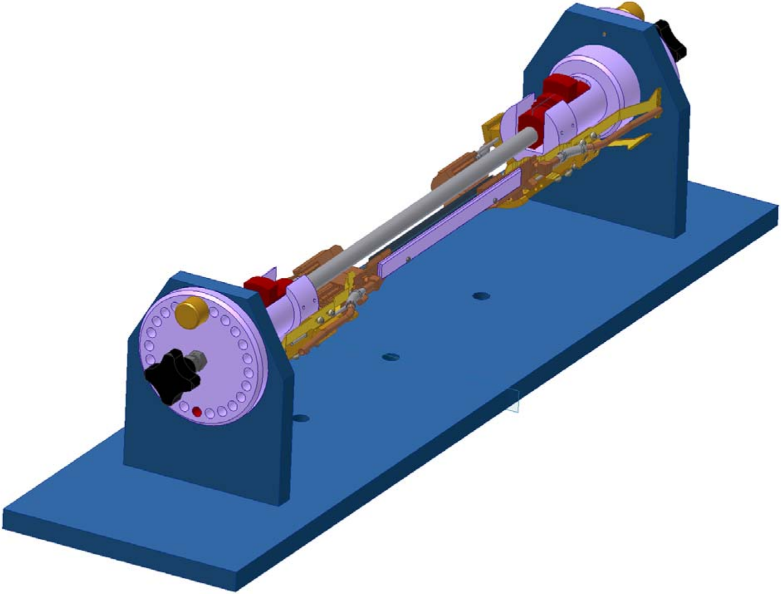
Solution

- $\Upsilon(4S)$: coherent B-meson pair production
- one B to determine flavour (tag side), other B for CP measurement (CP side)
- boost system using asymmetric beam energies
  $t \to \Delta t = \frac{\Delta z}{\langle \beta\gamma \rangle c}$





PXD Assembly



PXD Transport