

# Alignment and tracking with Millepede II and GBL for the Belle II VXD test beam.

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for the Belle II Collaboration & the TB crew

Beam Telescopes and Testbeams for Detector R&D June 30 – July 2 @ DESY

## Overview

- Belle II Experiment
  Belle II Software Framework
  VXD Beam Test
- Fitting with General Broken LinesAlignment with Millepede II
- **D** Example Results

Conclusion

# Belle II Experiment @ SuperKEKB



# Belle II Vertex Detector (VXD)



## □ Pixel vertex detector (PXD)

- DEPFET technology (DEPleted Field Effect Transistor)
- 2 layers, 1<sup>st</sup> at 14mm from IP
- 8M pixels,  $50 \times (50 85) \mu m^2$
- Thickness  $75 \mu m$
- Large background, occupancy

□ Strip vertex detector (SVD)

 4 layers of double-sided silicon strip sensors

d, impact parameter resolution

Single particle µ

Belle I

Belle II

 $\chi^2$  / nd

Prob

 $\gamma^2 / nc$ 

Prot

16.31 / 19

0.0007619

15.27 ± 0.2353

13.6 ± 0.5338

Belle I

Belle II

96.963\*\*\*\*\*

 $p \times \beta \times sin(\theta)^{3/2}$  [GeV]

0.6363 21.74 ± 0.4334 26.41 ± 0.8107

- Pitch  $50 75 \mu m$  in  $R \varphi$ ,  $160 240 \mu m$  in Z
- Thickness 320µm

Data reduction (ROI)

# Belle II software framework (basf2)

## □ Belle 2 Analysis and Simulation Framework

- Modern Framework in C++ and Python being developed for Belle II
- Modular design, paralel and distributed computing
- Steering by python scripts
- Covers everything from MC to online reconstruction Data storage, geometry, simulation, digitization, reconstruction, DAQ, HLT, analysis ...

# Module chain Module Module Module #1 Module #3 Module #4 Path DataStore

## □ For fitting GENFIT 2 used

- Generic toolkit for track reconstruction for experiments in particle and nuclear physics
- Kalman filter and DAF as default fitting algorithms
- Interface to GBL for GENFIT 2 developed

http://sourceforge.net/projects/genfit/

☐ Millepede II for alignment (currently VXD only)

# Combined beam test @ DESY

## □ 1<sup>st</sup> combined beam test of PXD and SVD

- One section of Belle II vertex detector
  2 x PXD + 4 SVD layers
- 1st test of large PXD6 matrix in beam

#### DESY, Jan 2014

- Beamline 21, e<sup>-</sup>/e<sup>+</sup> beam 2-5 GeV/c
- 1 T superconducting magnet
- Only 1 PXD available  $\ensuremath{\mathfrak{S}}$
- 6 EUDET pixel telescopes

Crucial hardware and software test

- Sensors, readout, slow control
- PXD ROI selection/data reduction
- Test of DAQ, event building, DQM, ExpressReco and off-line software





# Combined VXD beam test in basf2

#### VXD testbeam package

- Allows full MC simulation and real data reconstruction of PXD+SVD
- Using most of common Belle II code
- EUDET telescopes fully supported in MC & offline reconstruction
- Special geometry (+magnetic field) and adapted track finder

Beam

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# Beam test simulation and reconstruction

## Geometry

- Created by special module from XML
- Materials, magnetic field (incl. measured field map), sensors & operation parameters
- Digitization
  - Converts energy deposit from Geant4 simulation to electronic signal
  - Simulation of drift and diffusion in electric field in silicon, incl. Lorentz force



## Clustering

- Search for connected fired pixels/strips
- Hit position reconstruction, measurement error estimation, Lorentz correction
- □ Track finding (by Jakob Lettenbichler)
  - Combination of cellular automaton and neural network (mainly for full VXD)
  - Supports EUDET telescopes

## TB raw data & reconstruction

 $\Box$  Sensors not fully optimized  $\rightarrow$  high noise, part of last SVD not useable, same to PXD

❑ Offline analysis after telescope merging: Lost of synchronization between EUTEL/VXD
 → only very small amount of telescope tracks for analysis



## GBL interface implementation

□ Multiple scattering between measurements described by *thick* scatterers

- Materials from extrapolation  $\rightarrow$  distribution of rad. length  $X_0(s)$  along trajectory
- Parameters of a thick scatterer

$$X_0 = \int X_0(s) \, \mathrm{d}s \,, \ \bar{s} = \frac{1}{X_0} \int s X_0(s) \, \mathrm{d}s \,, \ \Delta s^2 = \frac{1}{X_0} \int (s - \bar{s})^2 X_0(s) \, \mathrm{d}s$$

• Thick scatterer ( $\Delta\theta(X_0)$ ,  $\bar{s}$ ,  $\Delta s$ ) can be described by 2 *thin* scatterers ( $\Delta\theta_1$ ,  $s_1$ ), ( $\Delta\theta_2$ ,  $s_2$ )



 $\Box$  1<sup>st</sup> scatterer at detector plane  $s_1 = 0$ 

 $\Box$  Option to switch to thin scatterers at detector planes  $\theta_1 = \Delta \theta$ ,  $\theta_2 = 0$ 

# GBL / Millepede

- Continuing GBL integration into GENFIT 2
  - Fully independent fitter next to Kalman/DAF
  - Fitting with / without magnetic field (automatic switch)
  - Numerical Jacobians from extrapolation, inhomogeneous magnetic field supported
  - 1D/2D hits supported  $\rightarrow$  strip, pixel, wire
  - External iterations for GBL fitting incl. Jacobian recalculation supported
- Millepede II alignment
  - Using GBL interface to output Mille Binary
  - Automated MP2 running and update of alignment constants in xml
  - Telescopes: small track sample available (300 500) ... alignment still possible
    - Iterations with more strict cuts to remove fake tracks
    - Alignment used as starting point (very good) for alignment of VXD alone

## DESY TB Alignment

#### Before and after Millepede II alignment

## RUN 507 | Full tracks with 4 x 2 x 1D measurements B=1T E=4GeV

Combined alignment data: 500(4GeV)+607(0T)+508(5GeV) SVD3 fixed, SVD6 fixed shifts.

Normalized histograms (vertical axis in %) with results of GBL fit. Residuals in cm. Bending plane in v - coordinate



# TB alignment. Pulls

#### RUN 507 | Full tracks with 4 x 2 x 1D measurements B=1T E=4GeV

Combined alignment data: **500**(4GeV)+**607(0T)**+**508**(5GeV) SVD3 fixed, SVD6 fixed shifts. Shifts and in-plane rotations only.







Track Chi2/NDF

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## PXD residuals in *B* = OT after alignment



# Conclusion

□ 1st VXD TB successfull (except telescope merging)

## Developed features

- Interface to GBL  $\rightarrow$  allows GBL fit in GENFIT with thick scatterers
- Alignment package → allows alignment of VXD (full tracker / testbeam) with magnetic field off or on (inhomogeneous field supported)
- VXD testbeam package → allows full MC simulation and reconstruction using mostly common basf2 code. Full geometry developed. EUDET supported offline

#### □ Results (preliminary)

- Geometry and TB package worked fine during TB (with constant support for unexpected issues)
- Testbeam reconstruction and alignment of best runs (with telescopes available for initial alignment)
  - Precision/remaining misalignment: 3um, 0.5mrad



*PXD+SVD+CDC* 

# Belle 2 full VXD alignment

 $\Box$  > 100k muons from IP + > 100k cosmic muons (field off)

Generated average misalignment 100um in u, v; 1mrad in gamma

□ Plots for B=0 (cosmic muons)

Ideal geometry | misaligned | after alignment (using constraints)



# Belle 2 full VXD alignment

□ <u>Residuals in Z</u> in layer 2 (PXD) and layer 6 (SVD)

□ Plots for B=0T (cosmic muons)

Ideal geometry | misaligned | after alignment



## Backup: Belle 2 VXD alignment

#### □ Pulls per layer. Plots for B=0T

#### Ideal geometry | misaligned | after alignment

