

## Alignment with Millepede II using General Broken Lines for the Belle II Vertex Detector



Tadeáš Bilka Charles University in Prague DESY Summer Student Session, 5 September 2013





## Outline

- > Belle II Experiment
- Track Based Alignment
- > Millepede II
- > General Broken Lines
- Software Implementation
- > Results
- Conclusion



#### **Belle & Belle II Experiment**

- Succesfull Belle detector & KEKB accelerator
  - Finished 2010, World record in luminosity
     data > 1ab<sup>-1</sup>
  - Study of CP-violation, exotic particles, precision measurements of B, D,  $\tau$  ...
- Located in Japan, KEK research facility
- > Belle / KEK  $\rightarrow$  Belle II / SuperKEKB ...  $\mathcal{L} \times 40$  ... Physics from 2016



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## **Belle II Experiment**

- Precission experiment
  - High statistics + low sys. Errors
- **B**-Factory
  - Assymptric e<sup>+</sup>e<sup>-</sup> collider:  $E_{CM} = m_{\Upsilon(4S)}$
  - Belle: 13  $B\overline{B}/s$ , 770M  $B\overline{B}$  pairs collected
- Typical CP-violation measurement:
  - $B^0$  or  $\overline{B}^0$ ? Identify B's
  - Measure  $\Delta z$



... and particle identification, charge reconstruction, energy resolution ...

PDG:

Mode

ΒB



T(45) DECAY MODES

 $\Upsilon = b\overline{b}$ 

## **Belle II Experiment: The Detector**



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## **Track Based Alignment: Formulation**

- > Construction precision + e.g. laser measurements  $\sim$  100  $\mu$ m
- Intristic resolutions ~ 14 μm (PXD)
- > Better estimation of detectors' positions required  $\rightarrow$  track based alignment
  - Particles from IP + cosmics ... large sample + different angles, origin ...



## **Track Based Alignment: Solution?**

> Minimum of  $\chi^2$  formaly

$$\frac{\partial}{\partial \boldsymbol{g}}\chi^2 = 0$$

- Expand  $\chi^2$  to first order in  $g_l$
- Rewrite as matrix and <u>invert</u> it to get solution
- But: The size of matrix to be inverted proportional to number of tracks
- Example: CMS full tracker alignment ... ~ 4 milions of tracks
- We have to invert 4 000 000 × 4 000 000 matrix!
  - 16 TB of memory to just store this matrix
  - Time to invert of  $n \times n$  matrix ~  $n^3$
  - On my notebook: Inversion of  $1\,000 \times 1\,000$  matrix takes ~ 4s
  - To align CMS tracker on my machine with this approach: > 200 years !

Is there a clever way to do this??? YES!





## **Millepede II**

- Algorithm for solving certain  $\chi^2$  optimization problems
- Key assumption: two kinds of parameters
  - Local ... related only to small subsets of data (parameters of individual tracks)
  - Global ... appear in many measurements (alignment parameters)
- tracks hits Minimization of  $\chi^{2}(\boldsymbol{g},\boldsymbol{l}) = \sum_{i}^{n} \sum_{j}^{n} \frac{1}{\sigma_{ij}^{2}} \left(\boldsymbol{m}_{ij} - \boldsymbol{p}_{ij}(\boldsymbol{g}_{0},\boldsymbol{l}_{0}) - \frac{\partial \boldsymbol{p}_{ij}}{\partial \boldsymbol{g}} \Delta \boldsymbol{g} - \frac{\partial \boldsymbol{p}_{ij}}{\partial \boldsymbol{l}_{j}} \Delta \boldsymbol{l}_{j}\right)^{2}$
- Global / local parameters  $\rightarrow$  special structure of matrix
- > Application of block matrix theorems:
  - Update of "Global block" with information from locals
  - Matrix size reduced to # alignment parameters
  - No approximations
- Solution of reduced problem





PHYSIC



## **General Broken Lines**

- Track model with proper describtion of multiple scattering
- Track constructed from measurement and scattering points kink interpolation

User has to provide at each point:

- Residuals, measurement errors, projections from track  $\rightarrow$  measurement
- Propagation Jacobians
- Scattering errors at scatterers; derivatives of residuals w.r.t. align. params (for MP2)
- Track described by change of curvature and kinks at scattering points

$$x = (\Delta q/p, u_1, ..., u_{\# \text{ of scatterers}})$$
Frack fit by minimization of:  

$$\chi^2(x) = \sum_{i=1}^{n_{\# \text{ meas}}} (H_{m,i}x - m_i)^T V_{m,i}^{-1} (H_{m,i}x - m_i)^{\not L}$$
from kinks
from kinks
$$+ \sum_{i=2}^{n_{\# \text{ scat}}} (H_{k,i}x)^T V_{k,i}^{-1} (H_{k,i}x)^{\not L}$$





## **Software Implementation**

- Interface between GBL and Belle II Simulation and Analysis Framework (basf2) using GENFIT 2 reconstruction toolkit
  - Developed in C++



- > GENFIT 2 development & basf2 integration in progress
  - Nontrivial compilation
  - Some features still missing → several workarounds
- > Aproximated Jacobian for track propagation in limit  $q/p \rightarrow 0$



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## **Results: General Broken Lines Fitting**



## **Results: Test of Millepede II Alignment**



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## Conclusion

- First integration of GBL & basf2 succesfully developed
- Promissing results despite some approximations
- First test of MP2 alignment succesfull
- Experience from development will lead to addition of GBL features
- Further GENFIT 2 development will allow more straightforward integration



# Thank you!

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