Tracking at Belle II
and beam spot parameter measurement

Cyrille Praz
on behalf of the Tracking Group

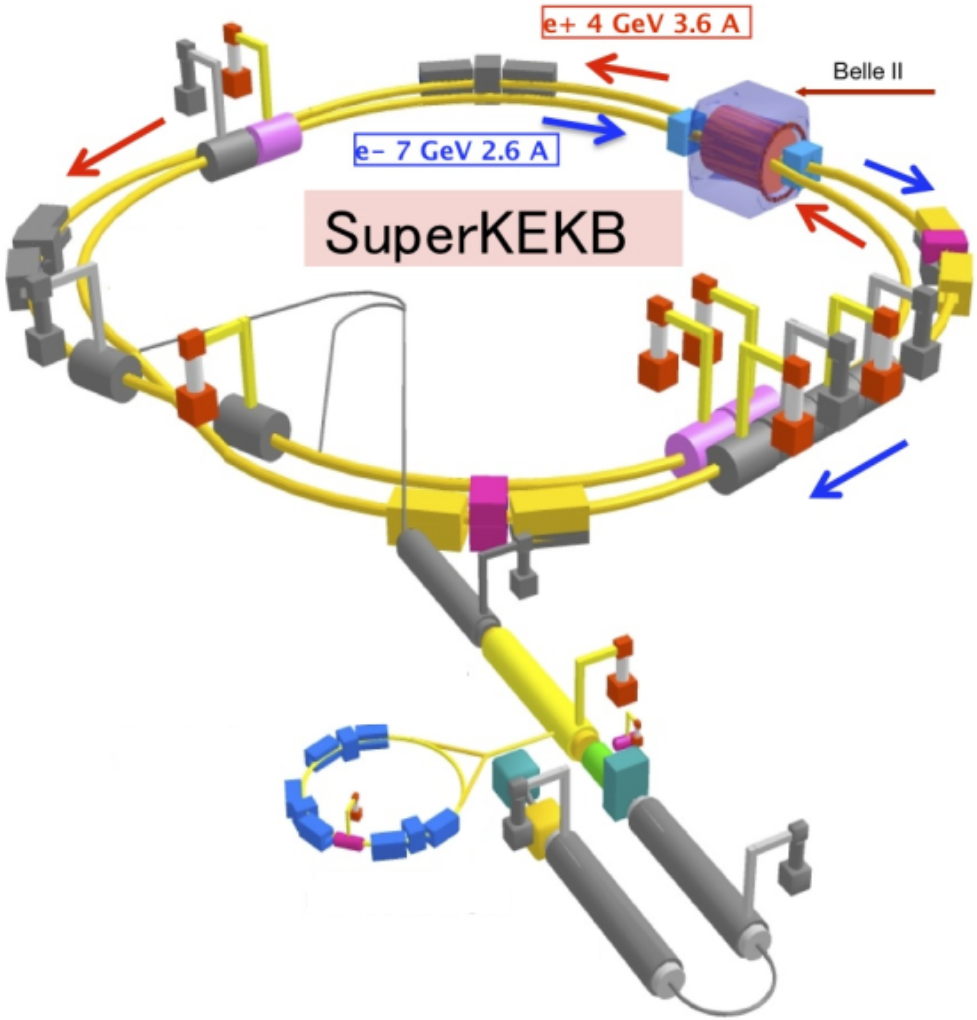
2019.11.01

Outline

1. Introduction
   - SuperKEKB and the nano-beam scheme
   - Belle II tracking
2. Transverse impact parameter resolution
3. Beam spot parameter determination
   - Selection and reconstruction
   - Demonstration: analysis with Jupyter Notebook + Pandas

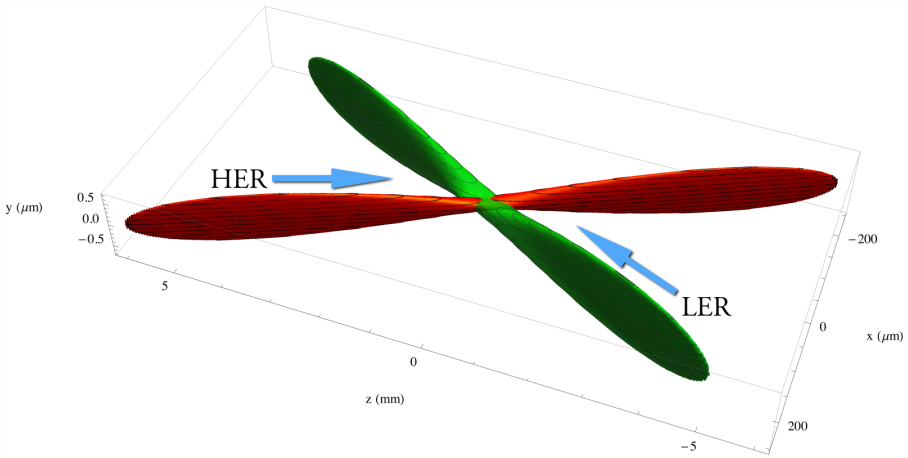
SuperKEKB

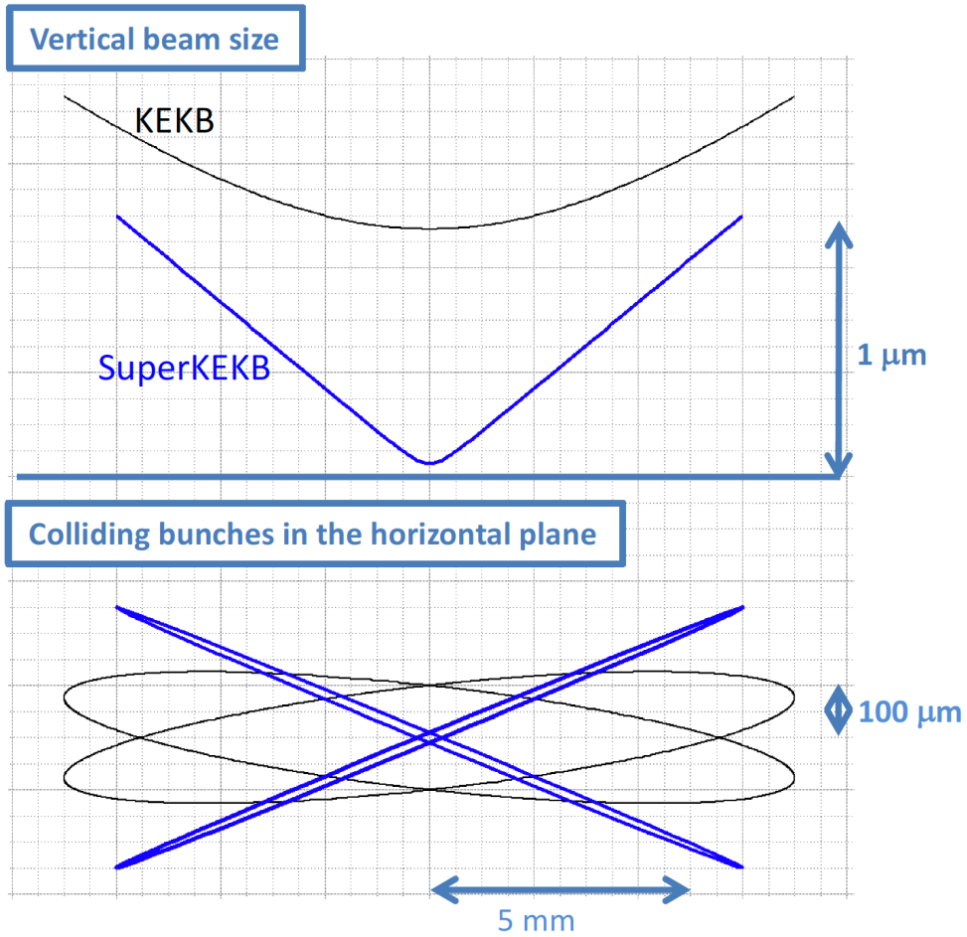
- e^+e^- collider.
- $\sqrt{s} = 10.6\,\mathrm{GeV} = \mathrm{m}(\Upsilon(4S))c^2$.
- $\mathrm{BR}(\Upsilon(4S) \to B\bar{B}) > 96\%$.
- Projection:
  - $\int_{2019}^{2027} L\,\mathrm{dt} \approx 50\,\mathrm{ab}^{-1}$.



Nano-beam scheme (idea from Pantaleo Raimondi)

- Half crossing angle:
  - $\phi_x \approx 40\,\mathrm{mrad}.$
- Nominal beam spot parameters:
  - $\sigma_x \approx 10\,\mu\mathrm{m}.$
  - $\sigma_z^{eff} = \frac{\sigma_x}{\sin\phi_x} \approx 0.25\,\mathrm{mm}.$
  - $\sigma_y \approx 50\,\mathrm{nm}.$

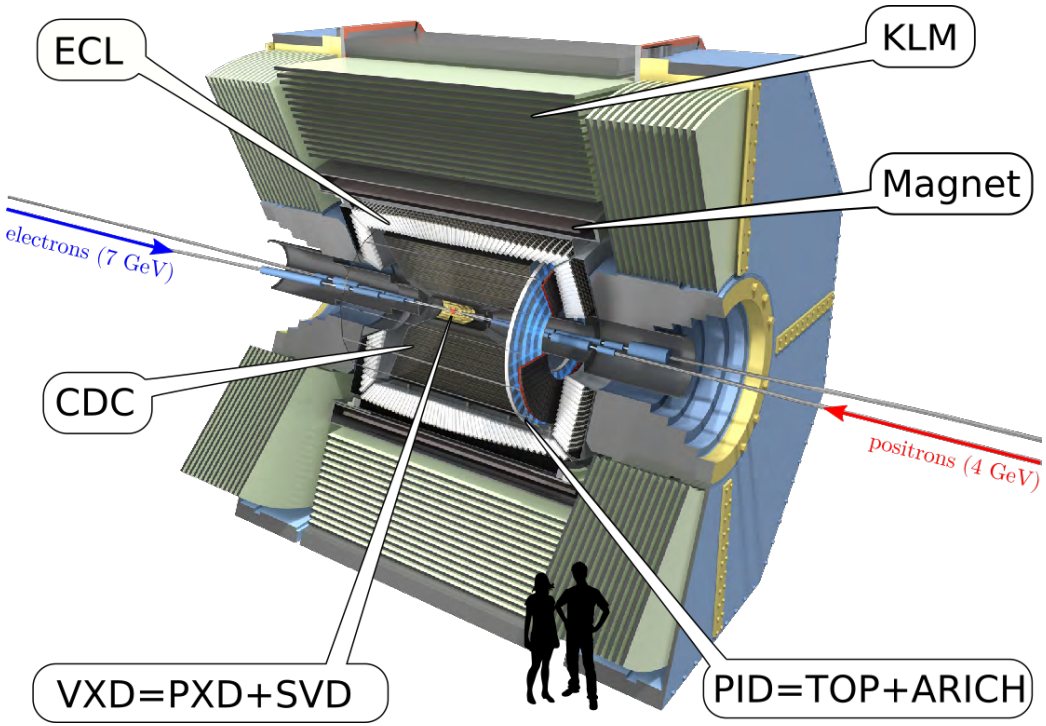




[BELLE2-TALK-CONF-2018-142]
[1809.01958]

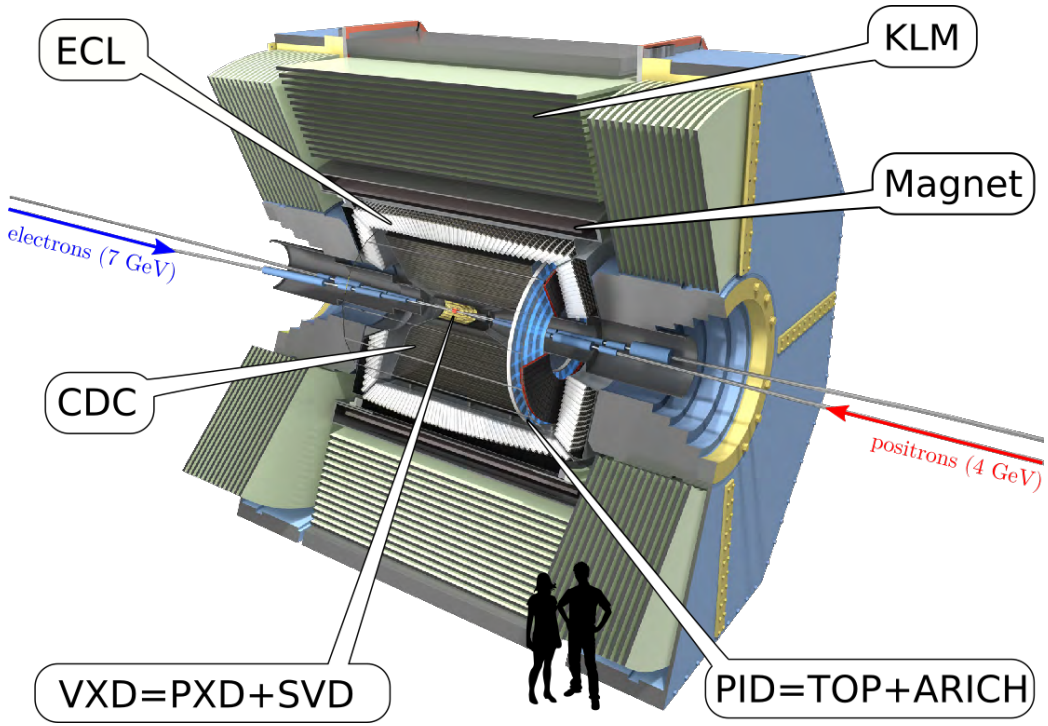
The Belle II detector

- Pixel detector (PXD).
- Silicon Vertex Detector (SVD).
- Central Drift Chamber (CDC).
- Calorimeter (ECL).
- Aerogel Ring-Imaging Cherenkov (ARICH).
- Time-Of-Propagation (TOP) counter.
- K_L^0 and μ detection (KLM).



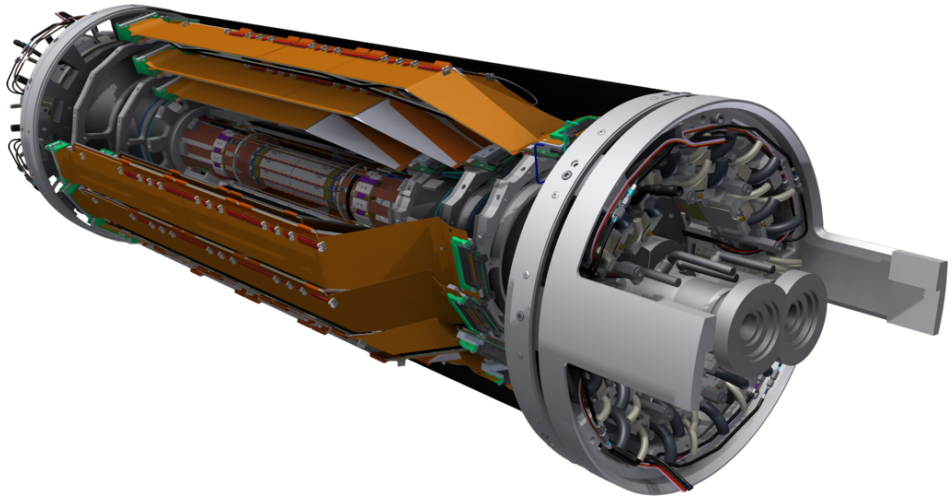
Tracking subdetectors

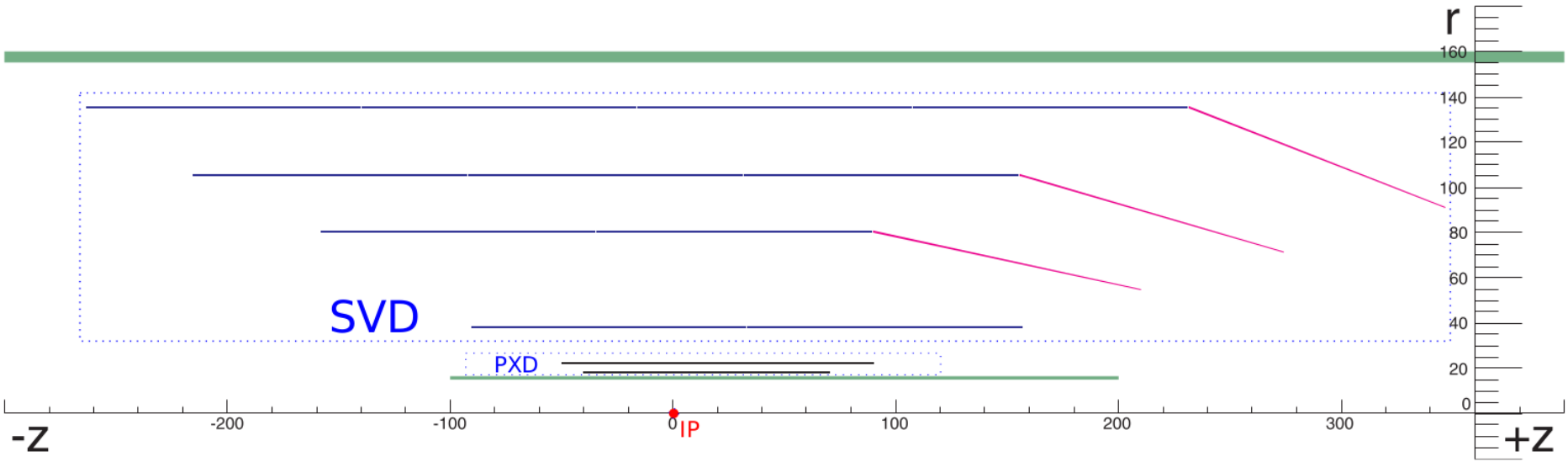
- Pixel detector (PXD).
- Silicon Vertex Detector (SVD).
- Central Drift Chamber (CDC).
- Calorimeter (ECL).
- Aerogel Ring-Imaging Cherenkov (ARICH).
- Time-Of-Propagation (TOP) counter.
- K_L^0 and μ detection (KLM).



VXD (=PXD+SVD)

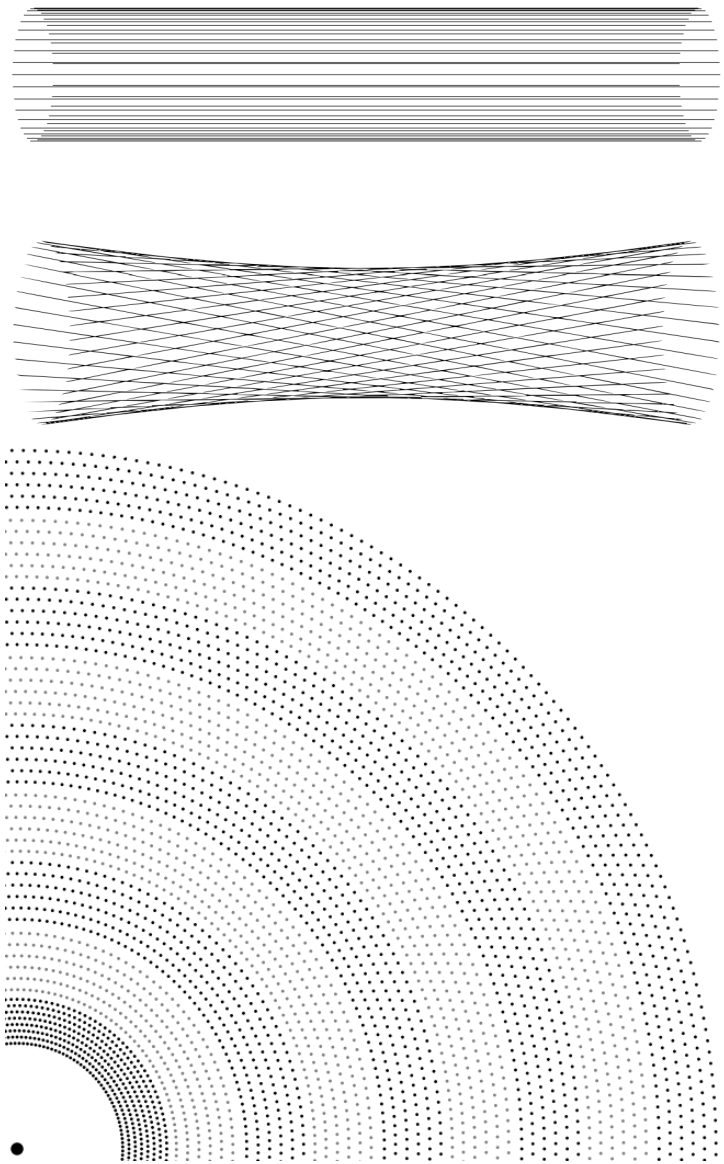
- PXD.
  - Pixel detector.
  - 2 layers.
  - Radii: 14, 22 mm.
- SVD.
  - Double-sided silicon strips.
  - 4 layers.
  - Radii: 39 to 135 mm.





CDC

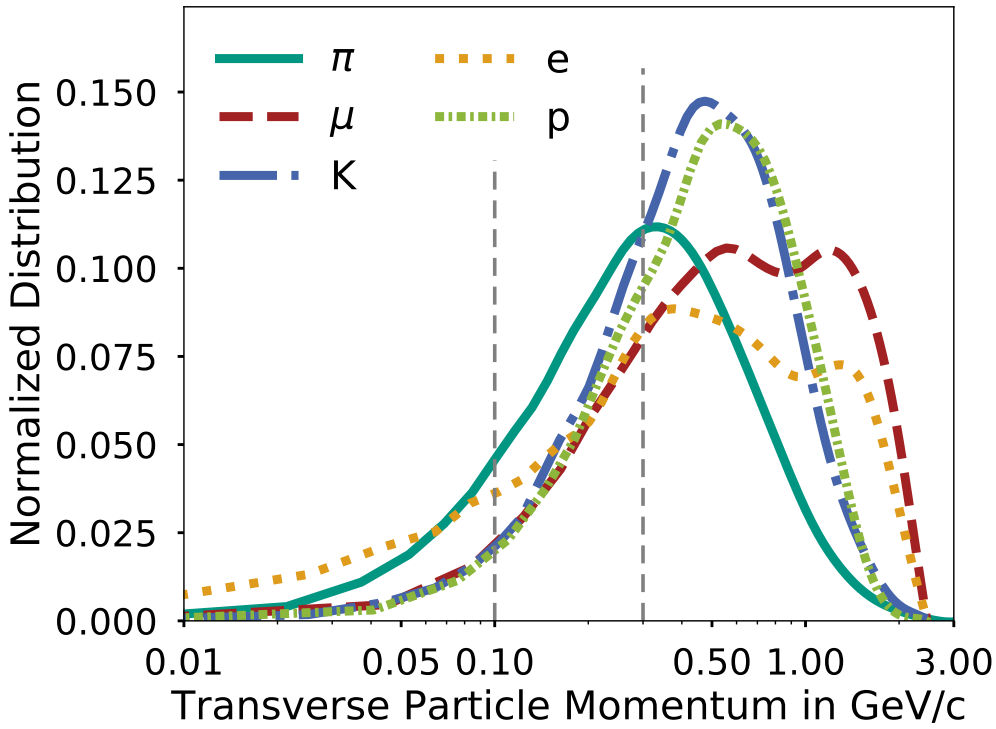
- Drift chamber.
- $\approx$ 50 000 wires.
- 56 layers.
  - Radii: 168 to 1111.4 mm.
- 9 superlayers.
  - axial orientation (A).
  - stereo orientation (U,V).
- Configuration:
  - AUAVAUAVA.



Charged particles from simulated $\Upsilon(4S)$ events

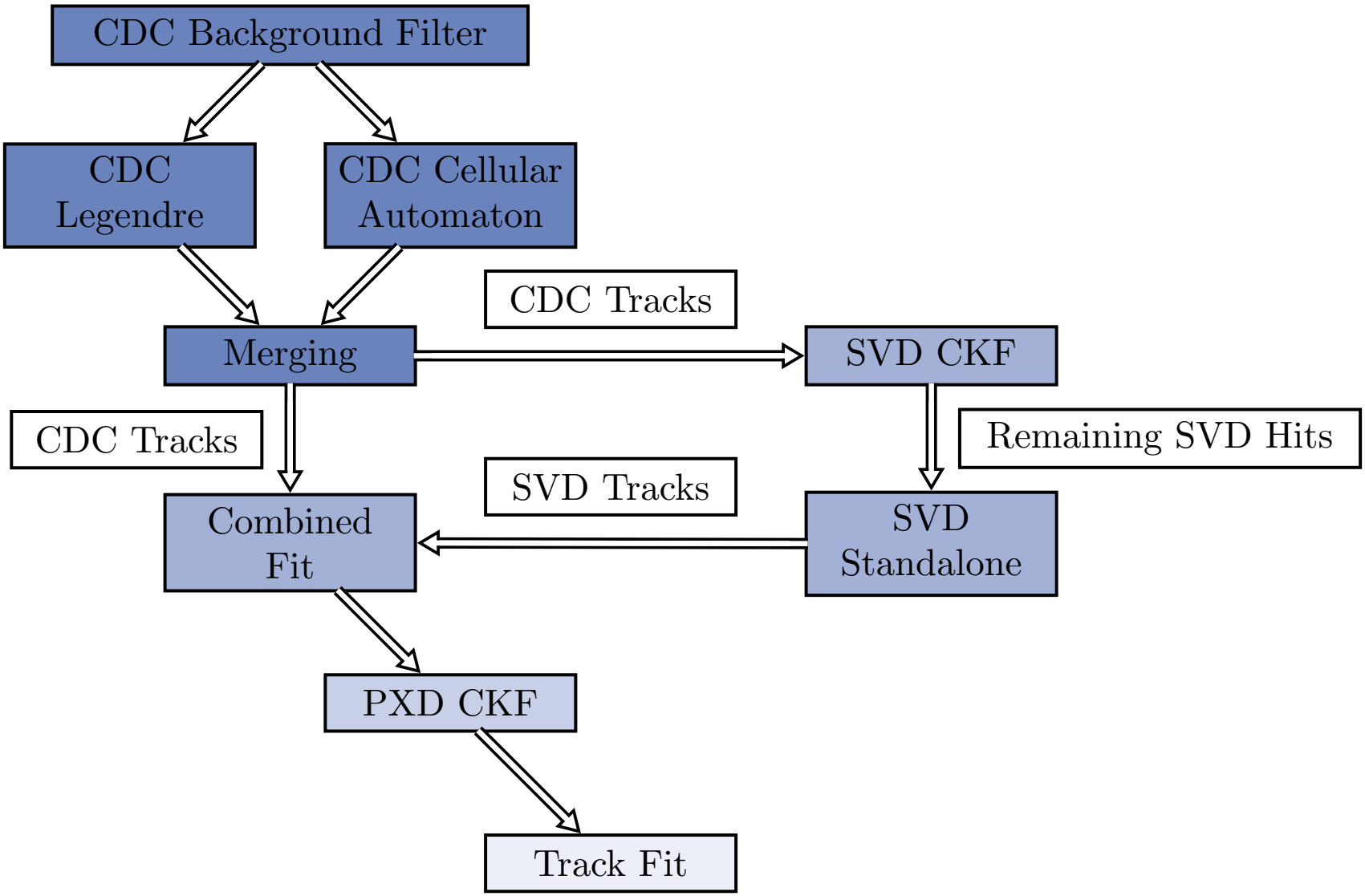
- $p_{\mathrm{T}} < 100\,\mathrm{MeV}/c$:
  - Track not seen by the CDC.
- $p_{\mathrm{T}} \in [100,\, 300]\,\mathrm{MeV}/c$:
  - Track can curl inside the CDC volume.

Particle type	Average fraction
$\pi^{\pm}$	72.8%
$K^{\pm}$	14.9%
$e^{\pm}$	5.8%
$\mu^{\pm}$	4.7%
$p^{\pm}$	1.8%



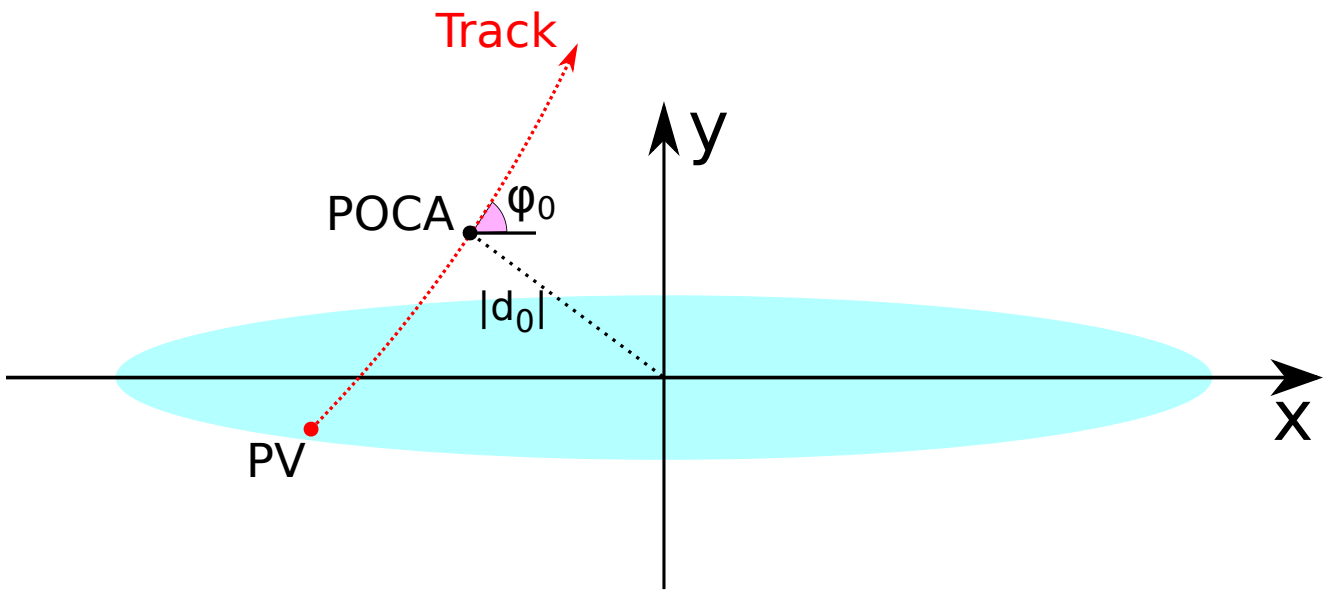
Track reconstruction steps

[BELLE2-PTHESIS-2019-002]



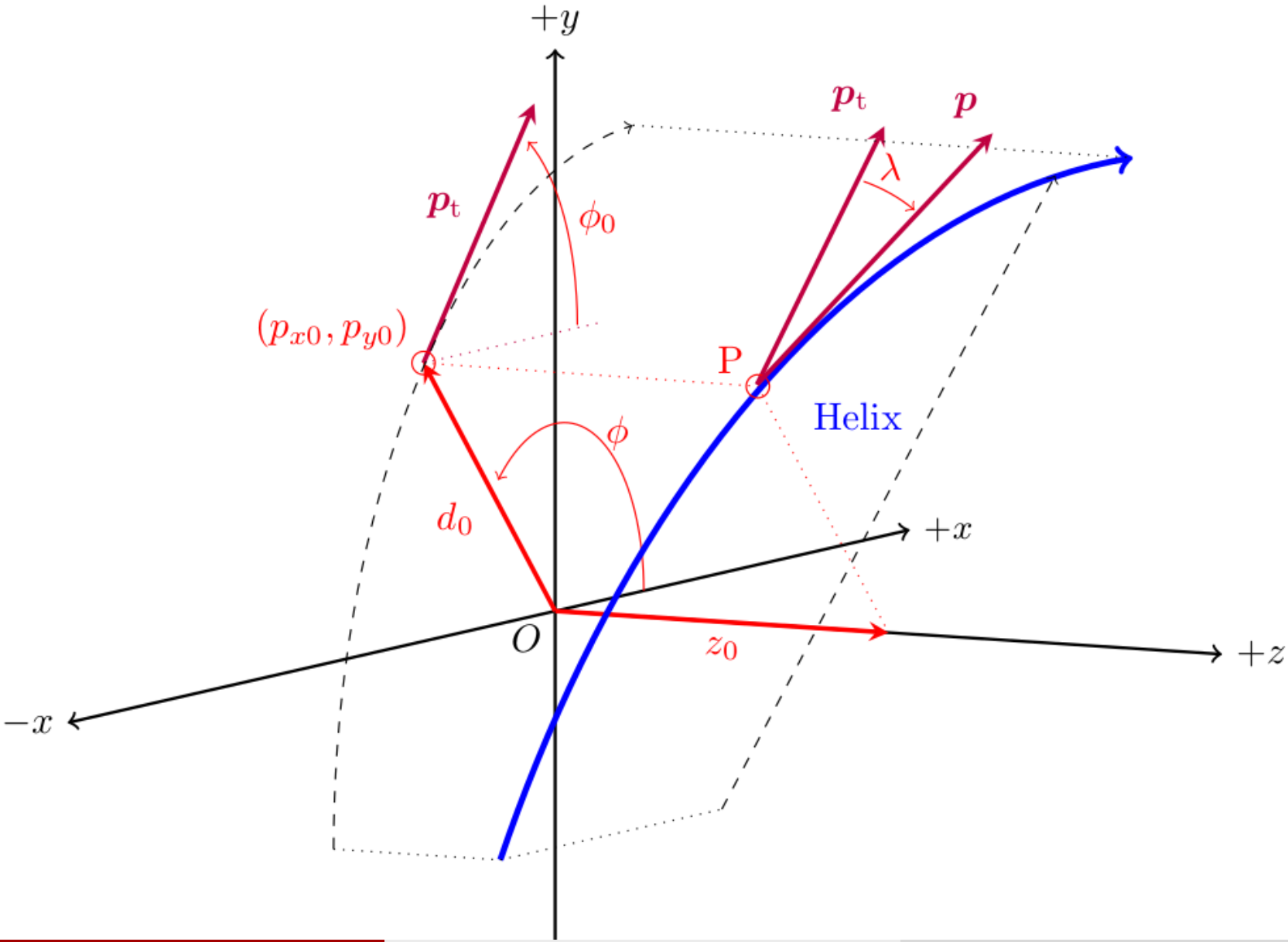
Track parametrisation: 2D picture

- Blue area[1]: high and low energy beams overlap.
- ϕ_0: azimutal angle at the point of closest approach (POCA).
- d_0: Transverse impact parameter at the POCA.



[1] In practice, the center of the overlap region is displaced with respect to the origin and d_0 needs to be corrected for this offset.

Track parametrisation: full picture [1901.11198], [github]

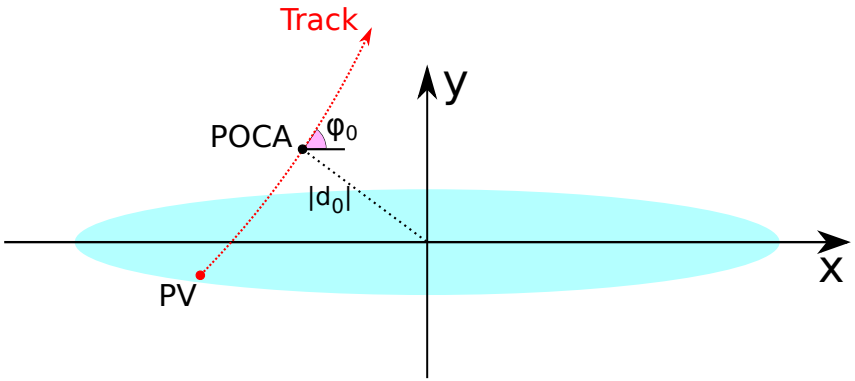


Transverse impact parameter resolution

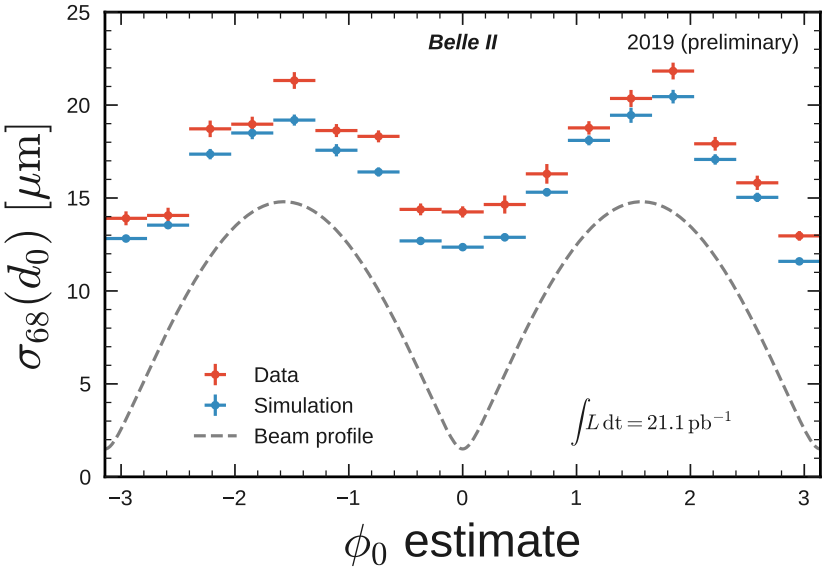
[BELLE2-NOTE-TE-2019-01]

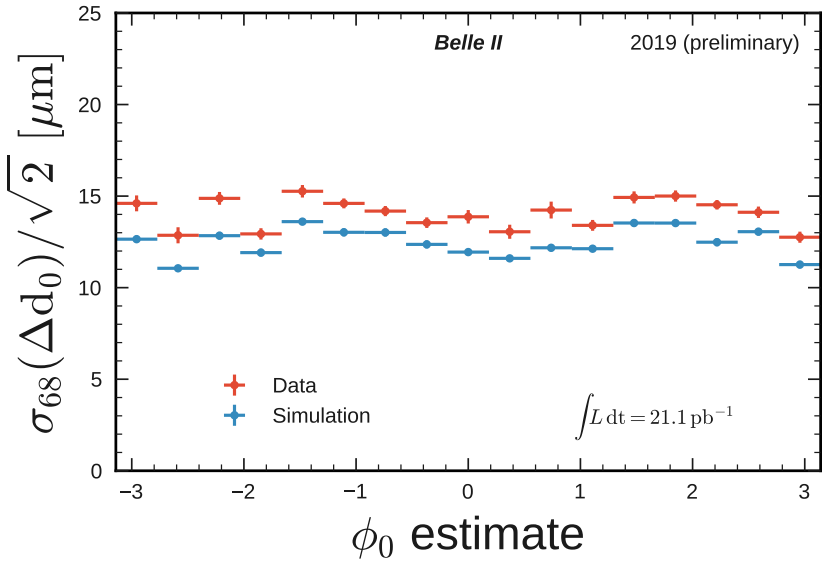
- Select tracks in 2 track events.

Variable	Requirement	Unit
$\lvert d_0 \rvert$	< 3	mm
$\lvert z_0 \rvert$	< 1	cm
# selected tracks in the event	$= 2$	
p_T	> 1	GeV/c
$\lvert \theta_0 - \pi/2 \rvert$	< 0.5	
$p\beta \sin(\theta_0)^{3/2}$	> 2	GeV/c
# PDX hits	≥ 1	
# SVD hits	≥ 8	
# CDC hits	> 20	
# selected tracks in the event	$= 2$	
product of the charges in the event	< 0	C^2



- $\sigma_{68}(.)$: half of the symmetric range around the median containing 68% of the distribution.





ϕ_0-dependence of $\sigma_{68}(d_0)$

- $\sigma_{68}(d_0)$ depends on the intrinsic detector resolution σ_i and the beam spot size:
  - $\sigma_{68}(d_0) = \sqrt{\sigma_i^2 + (\sigma_x \sin\phi_0)^2 + (\sigma_y \cos\phi_0)^2}$.
- The effect of the beam profile alone is given by the equation above when $\sigma_i = 0\,\mu\mathrm{m}$ (infinite detector resolution).

Beam spot parameter determination

1. Select tracks in dimuon events requiring:
   - $p > 1\,\mathrm{GeV}/c$.
   - $dr < 0.5\,\mathrm{cm}$ and $|dz| < 2\,\mathrm{cm}$.
   - #PXD hits ≥ 1 and #SVD hits ≥ 8 and #CDC hits ≥ 20.
2. Construct primary vertex candidates of 2 tracks satisfying:
   - $9.5 < M < 11.5\,\mathrm{GeV}/c^2$.
3. Exclude events with >1 candidates.
4. Extract the beam spot parameters from the distribution of the primary vertex position.

Demonstration

- Let's have a look at an example of analysis.
- Repository: https://stash.desy.de/users/prazcyri/repos/tutorials/browse/determination_of_the_beam_spot_parameters.