Tracking and Vertexing in BELLE II

Vertex2018

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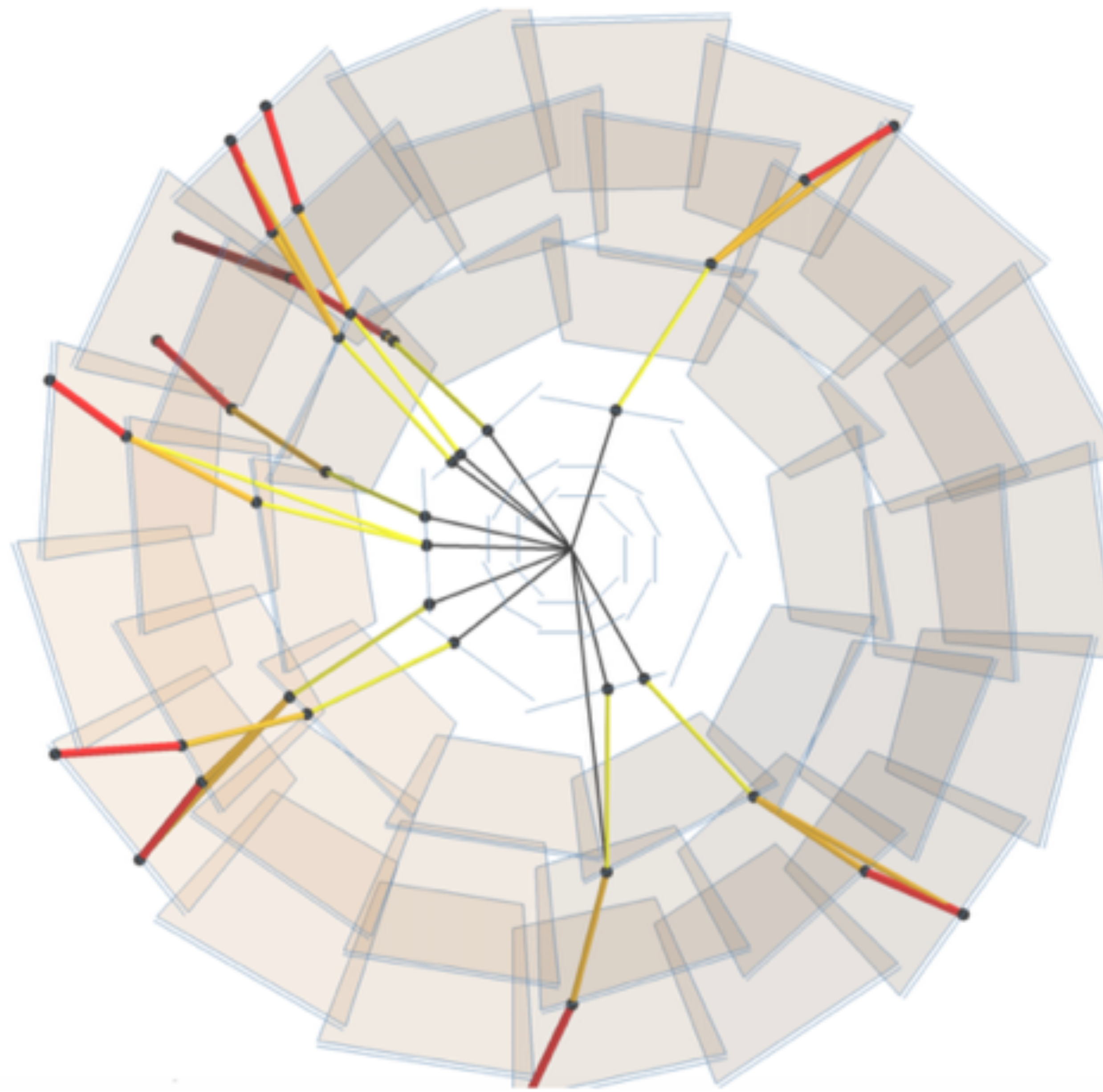
Outlook

- The challenges of tracking at Belle II
- Track Finding
- Track Fitting
- Vertexing
- Performances



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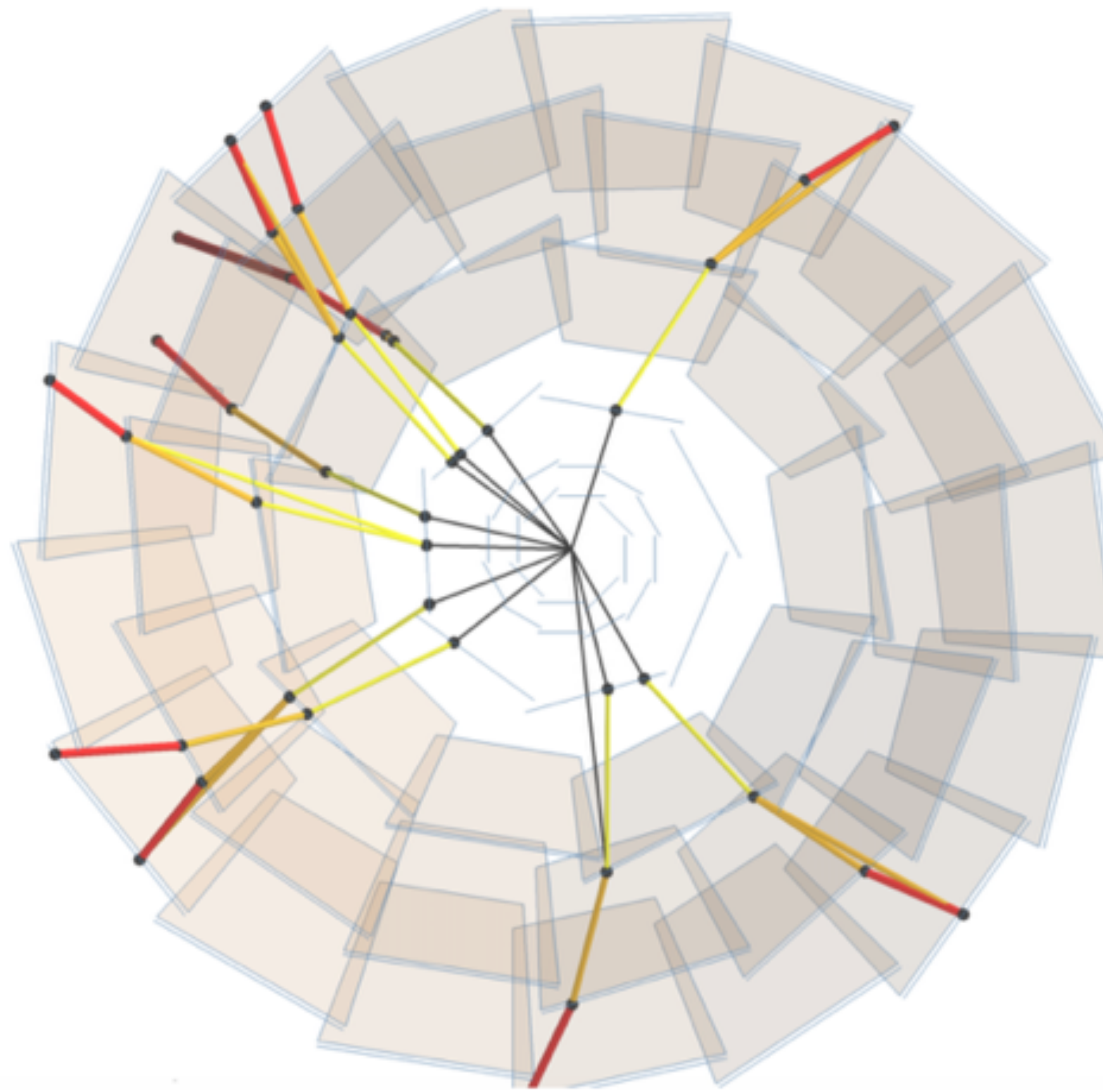
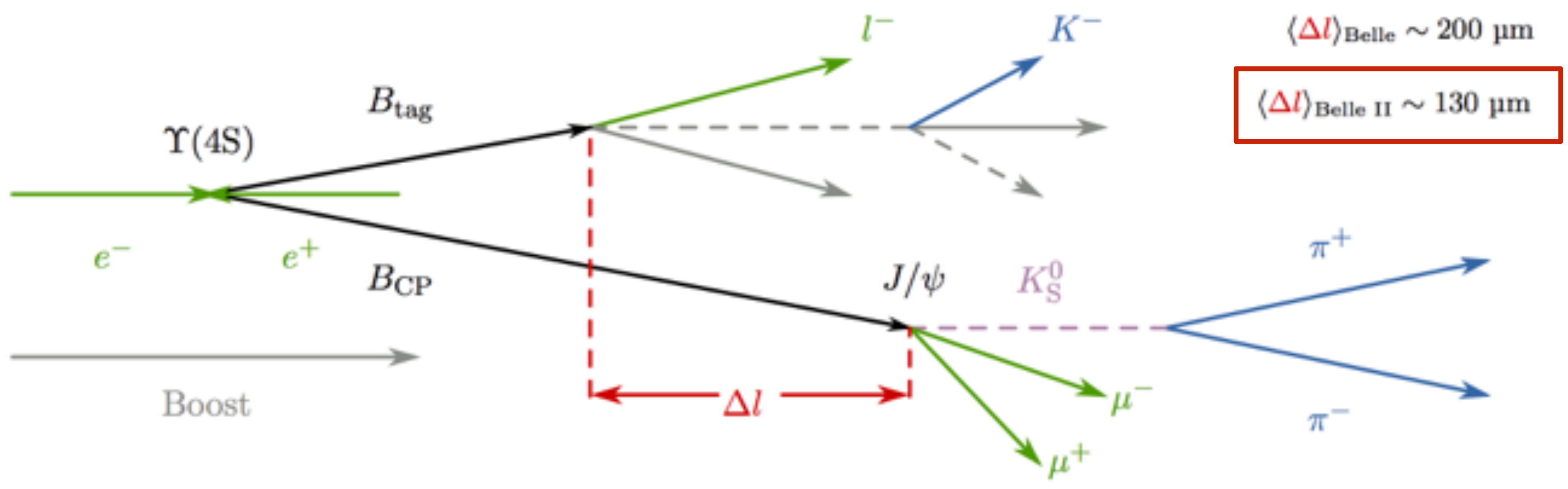


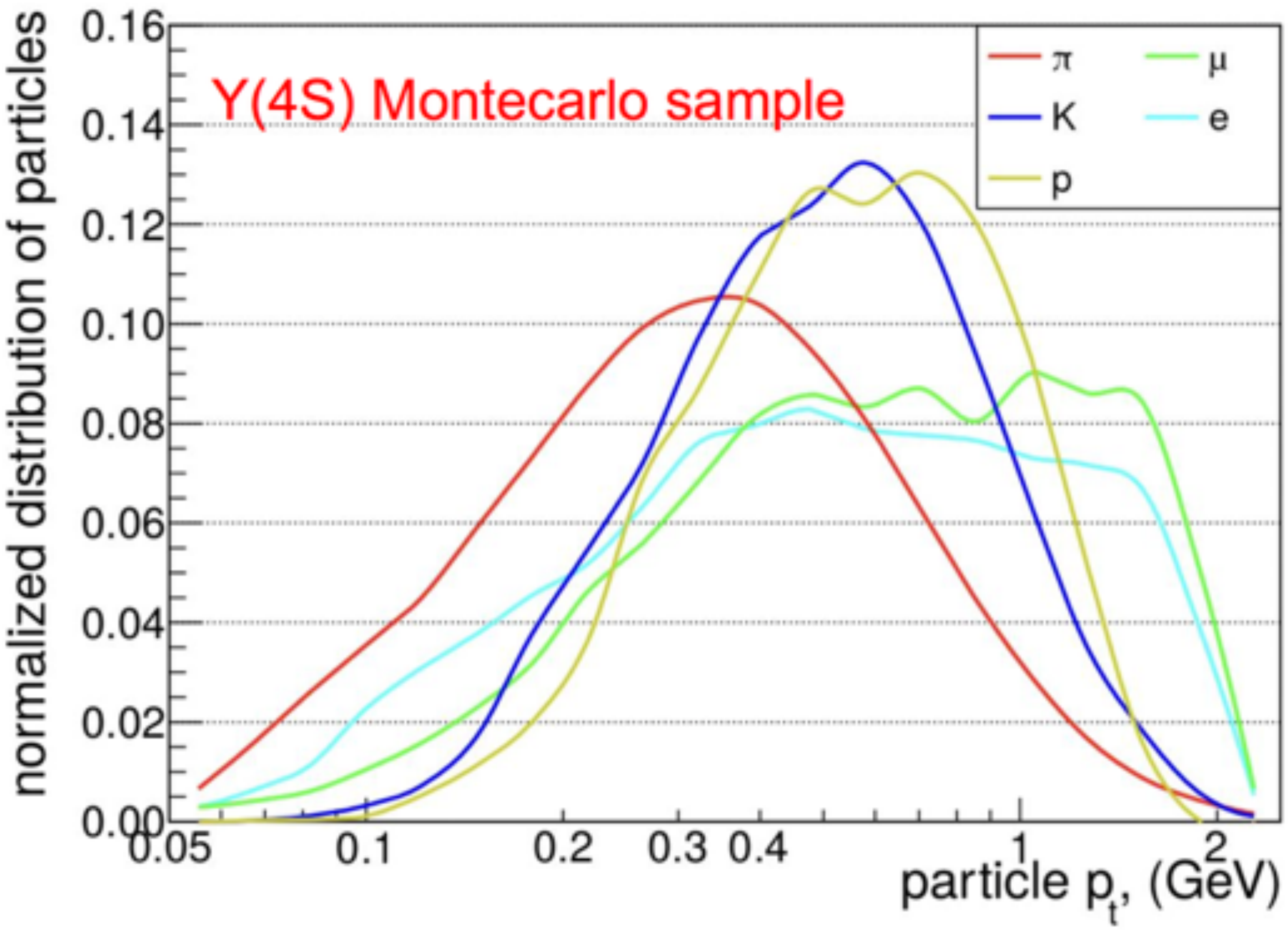
The challenges of tracking at Belle II

- Belle II is a multipurpose detector operated at the SuperKEKB asymmetric collider
- e^+ and e^- collide at $\sqrt{s}$ = 10.58 GeV / c^2, corresponding to $m_{Y(4S)}$
- High spatial resolution required to resolve the two B mesons coming from the Y(4S)



The challenges of tracking at Belle II

- On average 11 tracks in a Y(4S) event



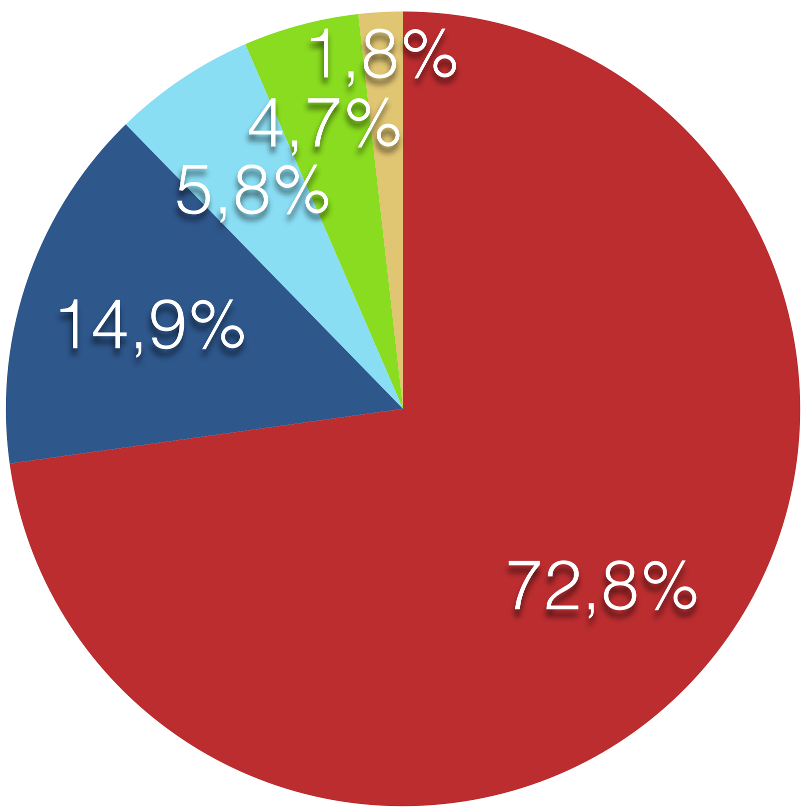


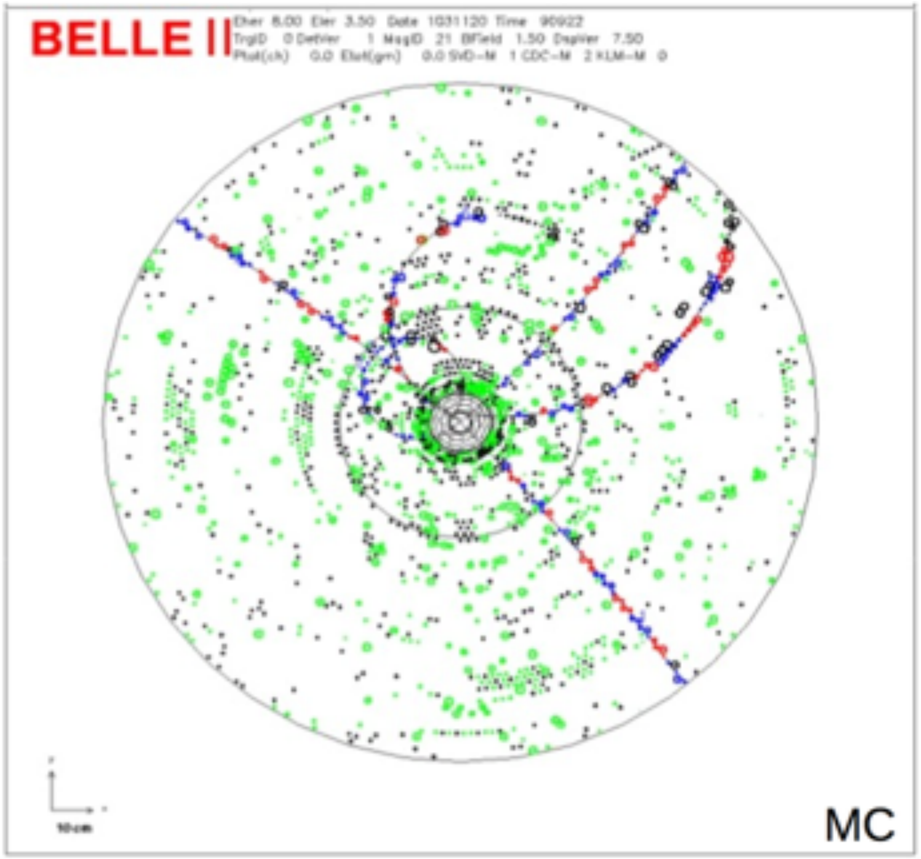
Fig: Average fraction of particles produced according to the type

- Large fraction of π
- Mostly particles with p_t below 1 GeV

The challenges of tracking at Belle II

- SuperKEKB will deliver a peak luminosity of 8×10^{35} cm^{-2} s^{-1}

➡ High occupancy of the beam-induced background
  - 11 tracks → 10^2 signal hits
    10^4 background hits



- Touscheck effect
- Beam-gas scattering
- Synchrotron radiation
- Radiative Bhabha process
- Two photons process
- Beam beam background

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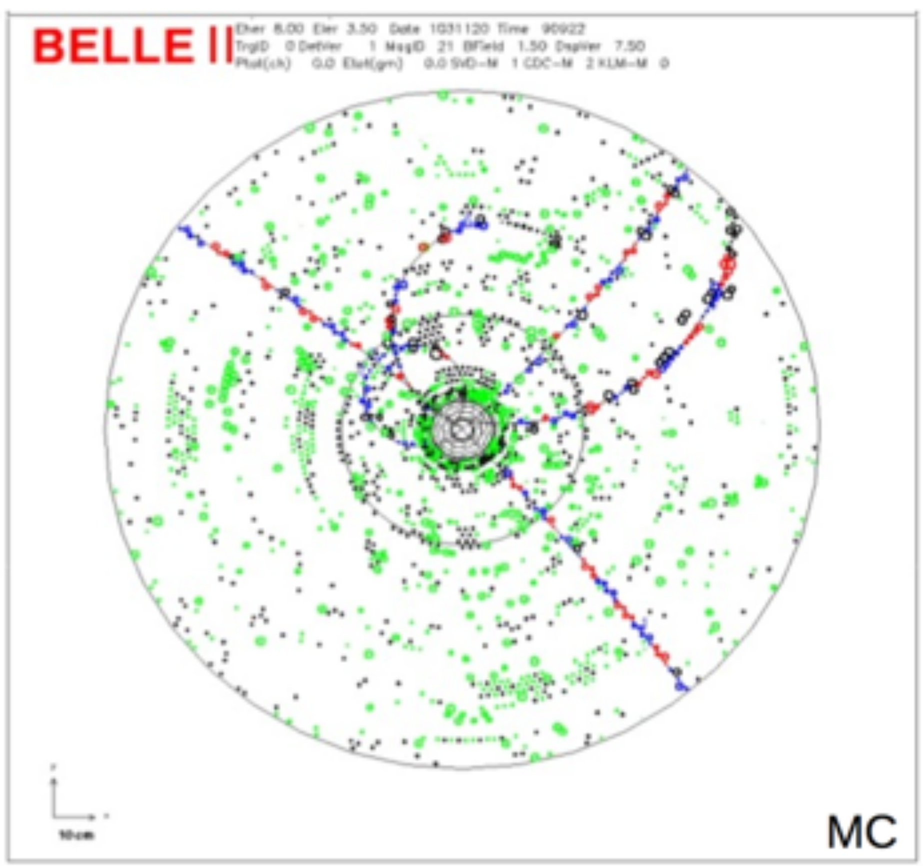
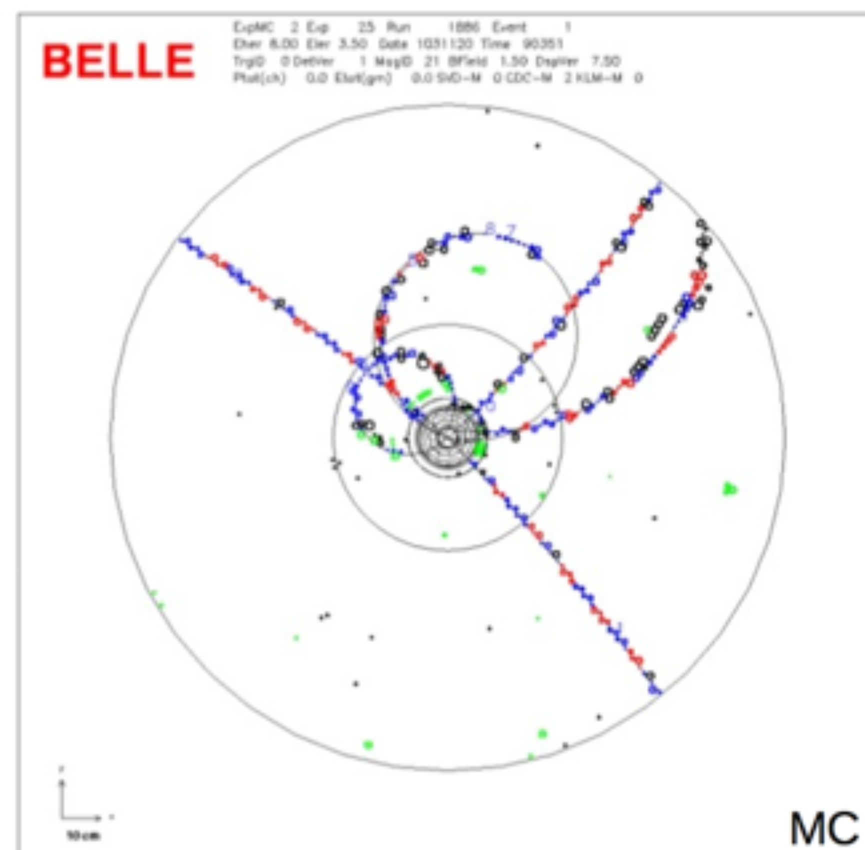
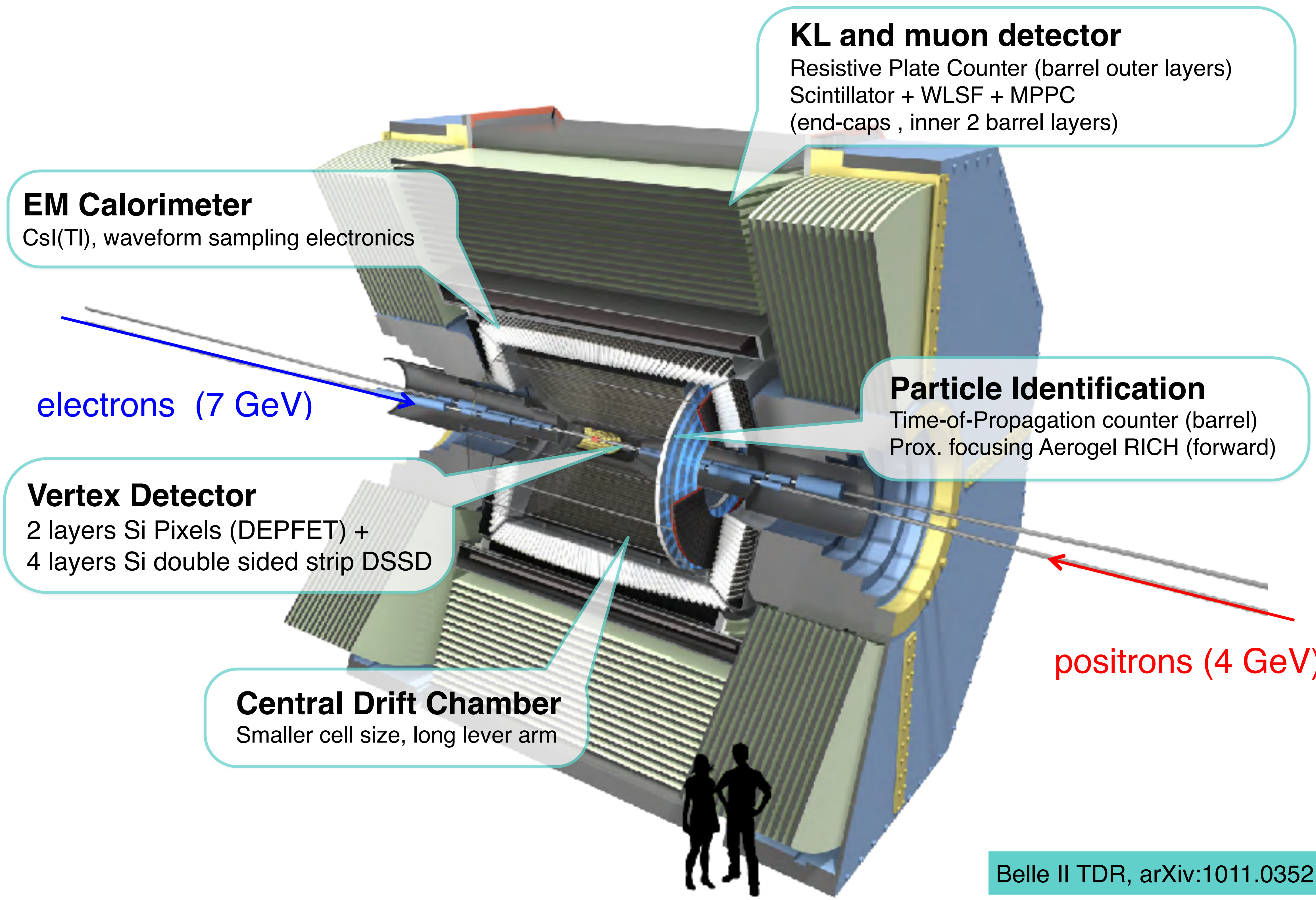




The Belle II detector



Belle II TDR, arXiv:1011.0352

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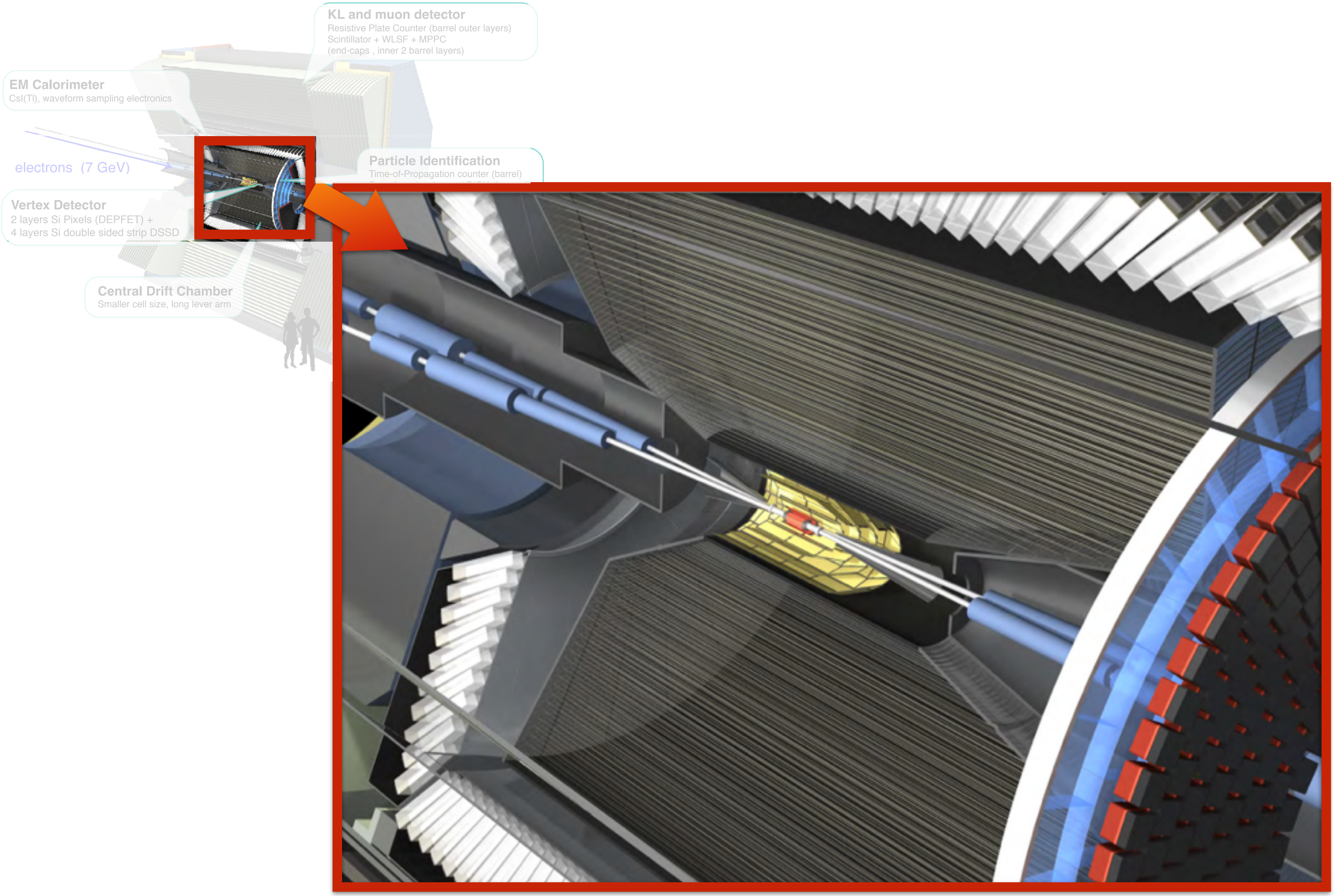

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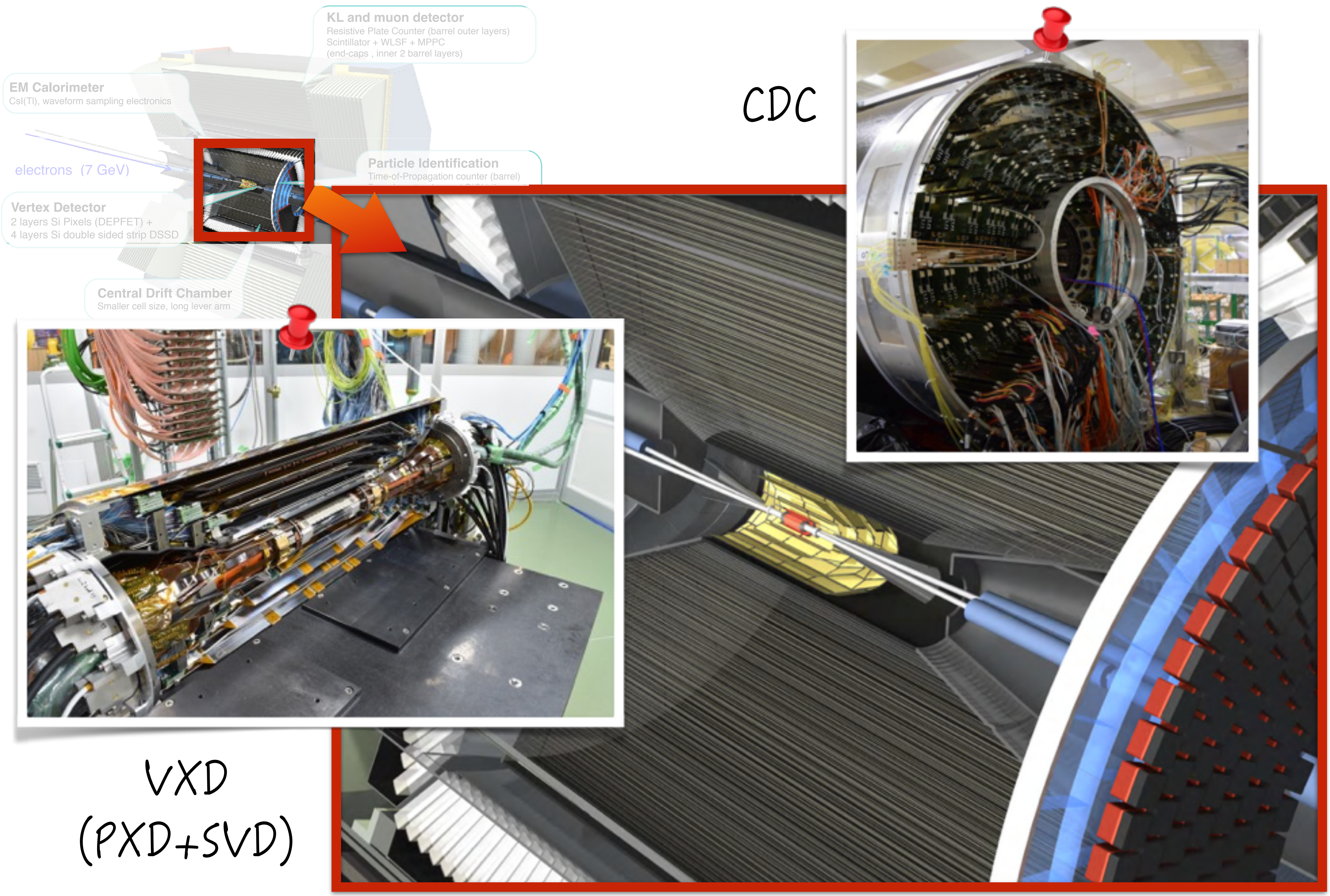
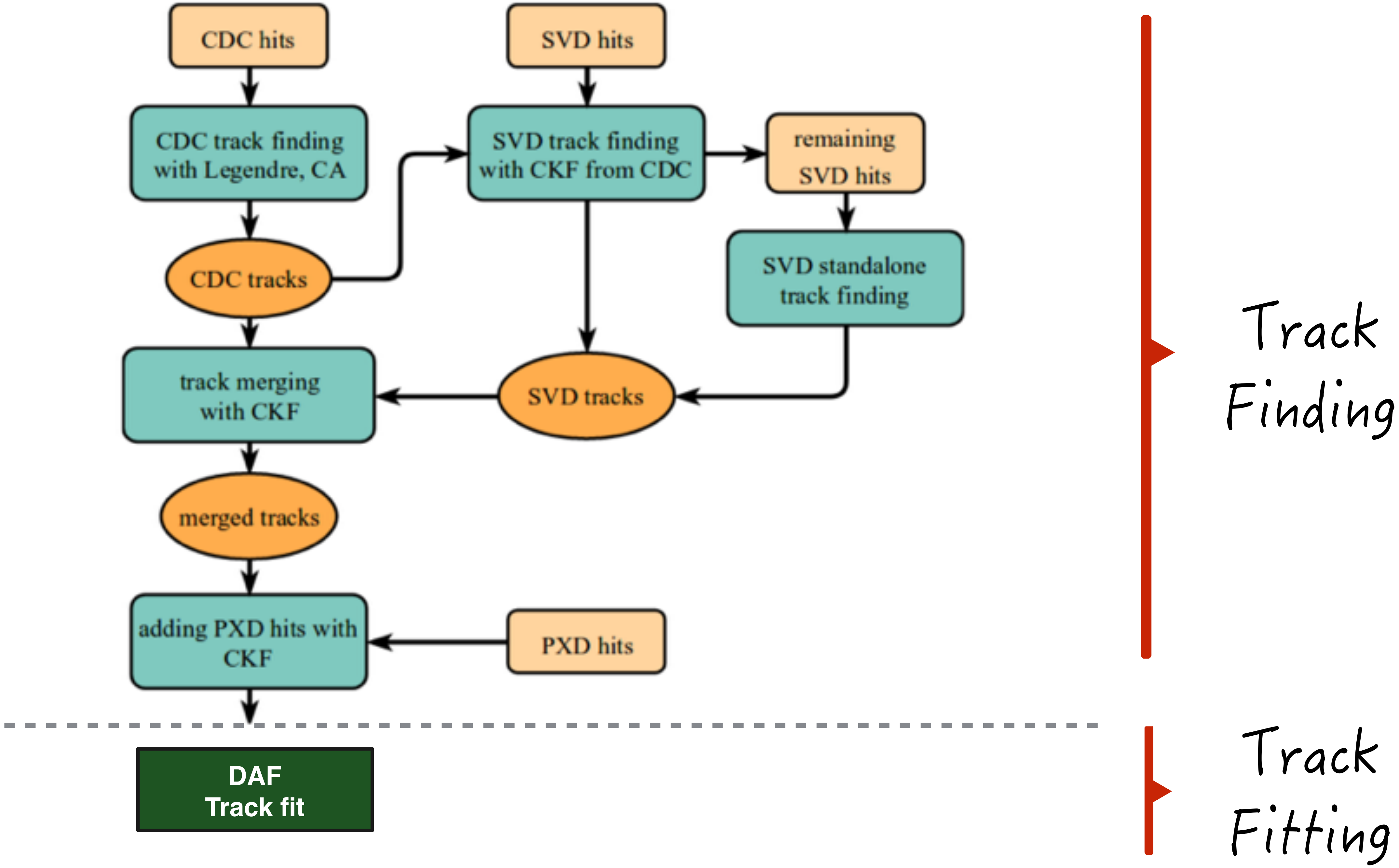


Tracking design



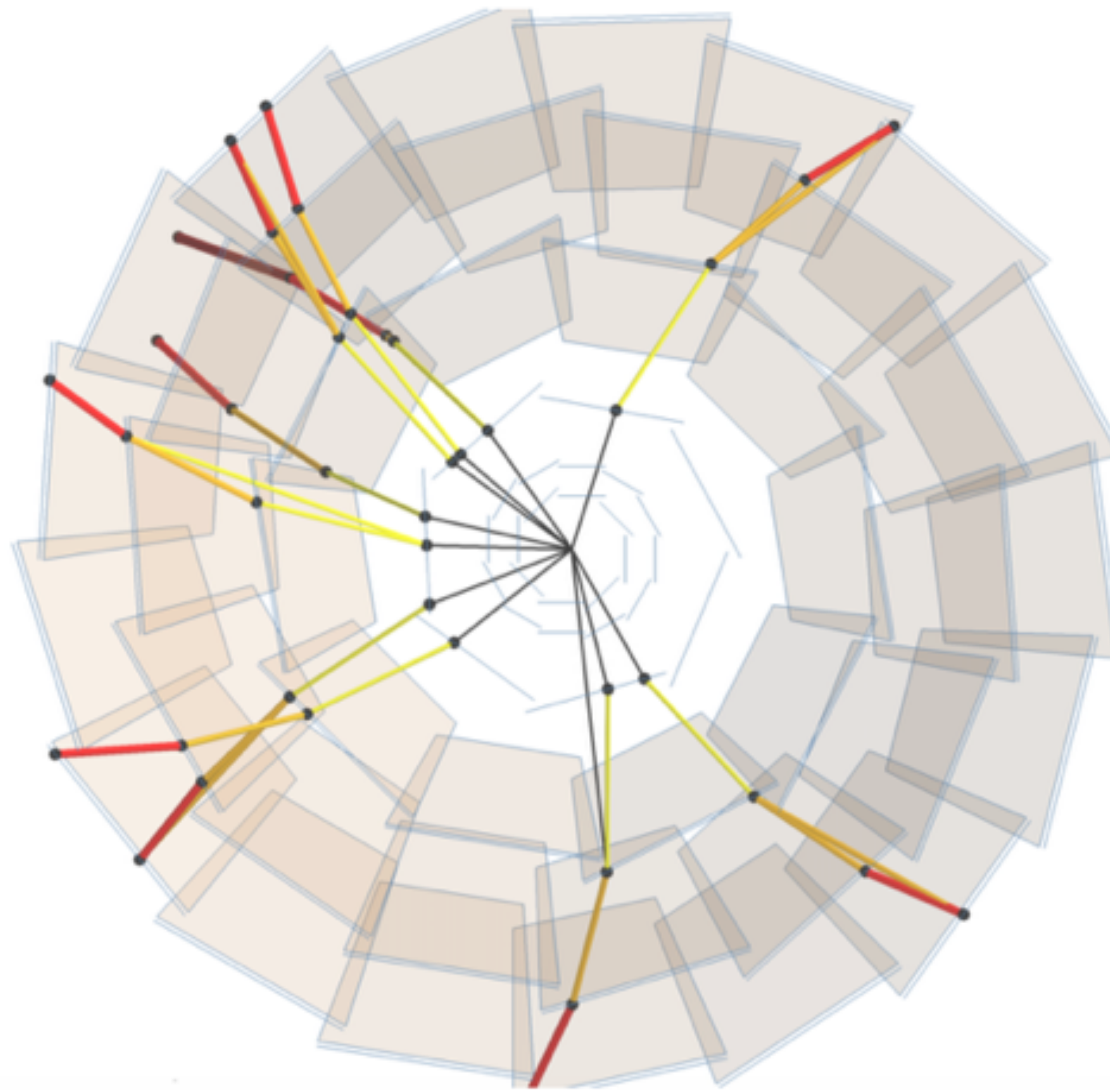
The challenges of tracking at Belle II

Track Finding

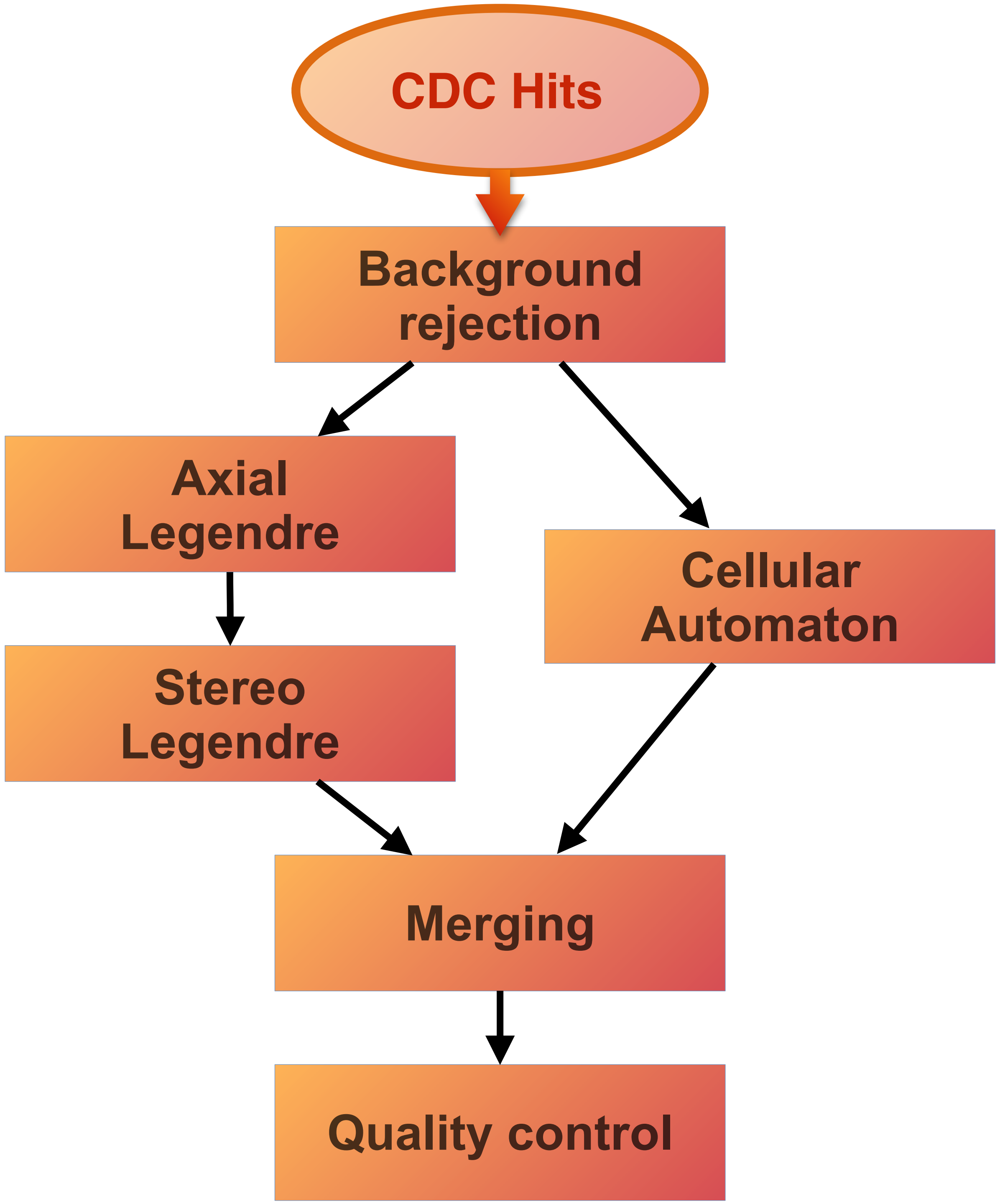
Track Fitting

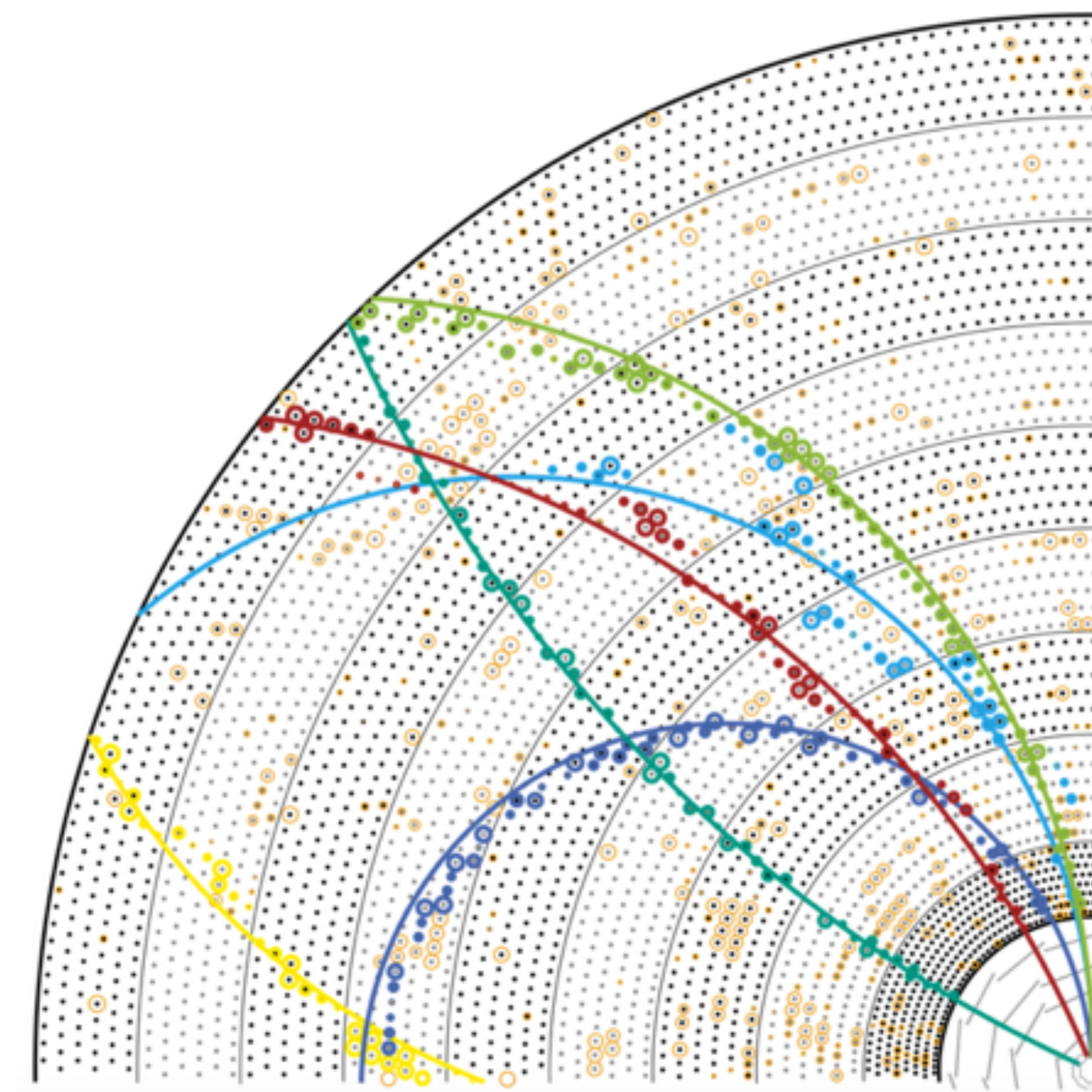
Vertexing

Performances

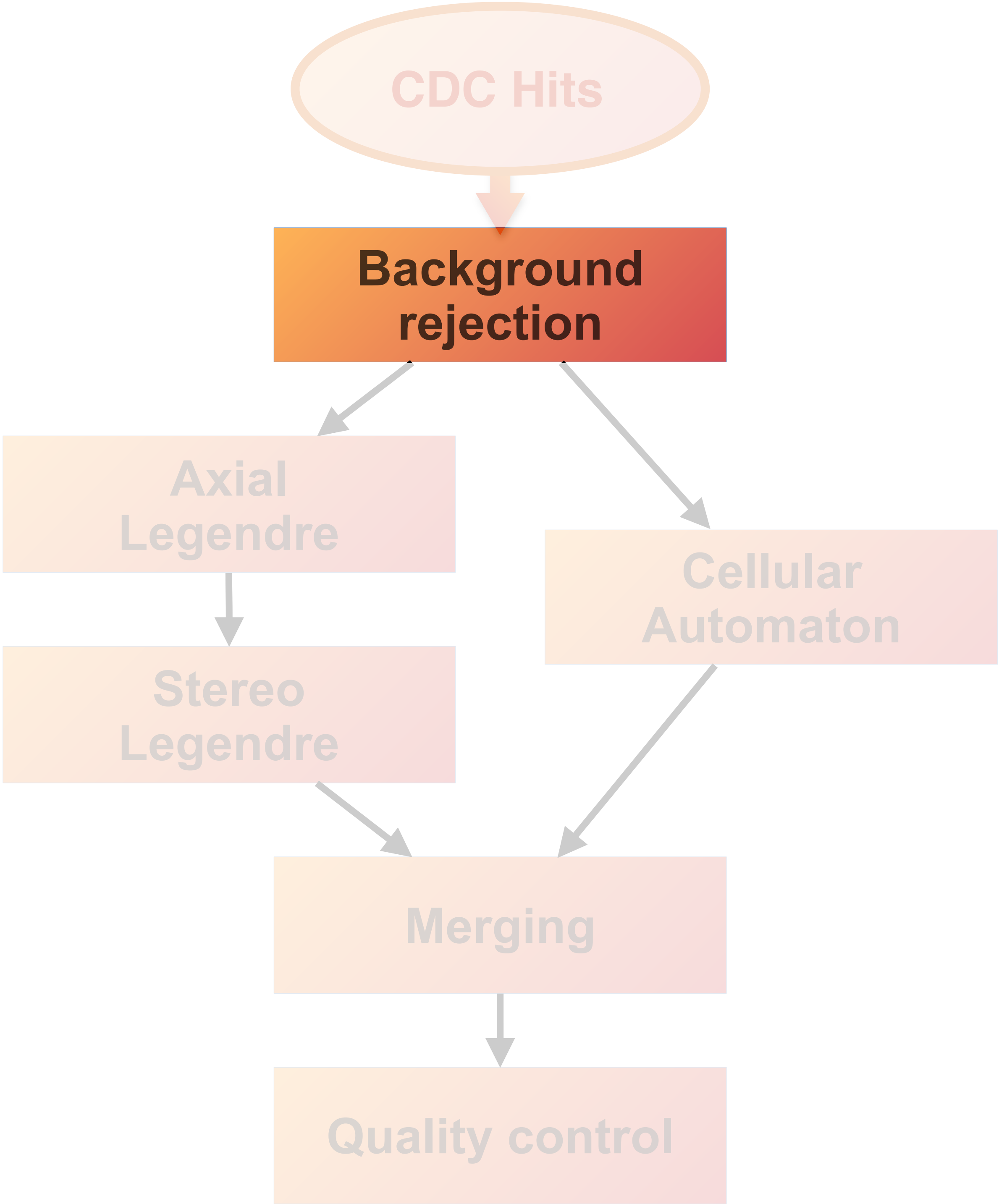


CDC track finding

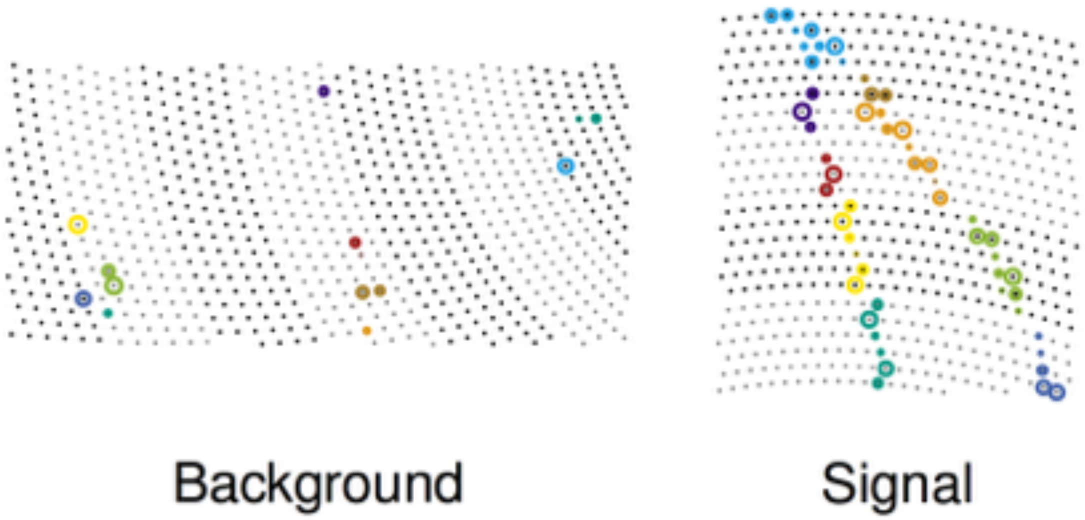




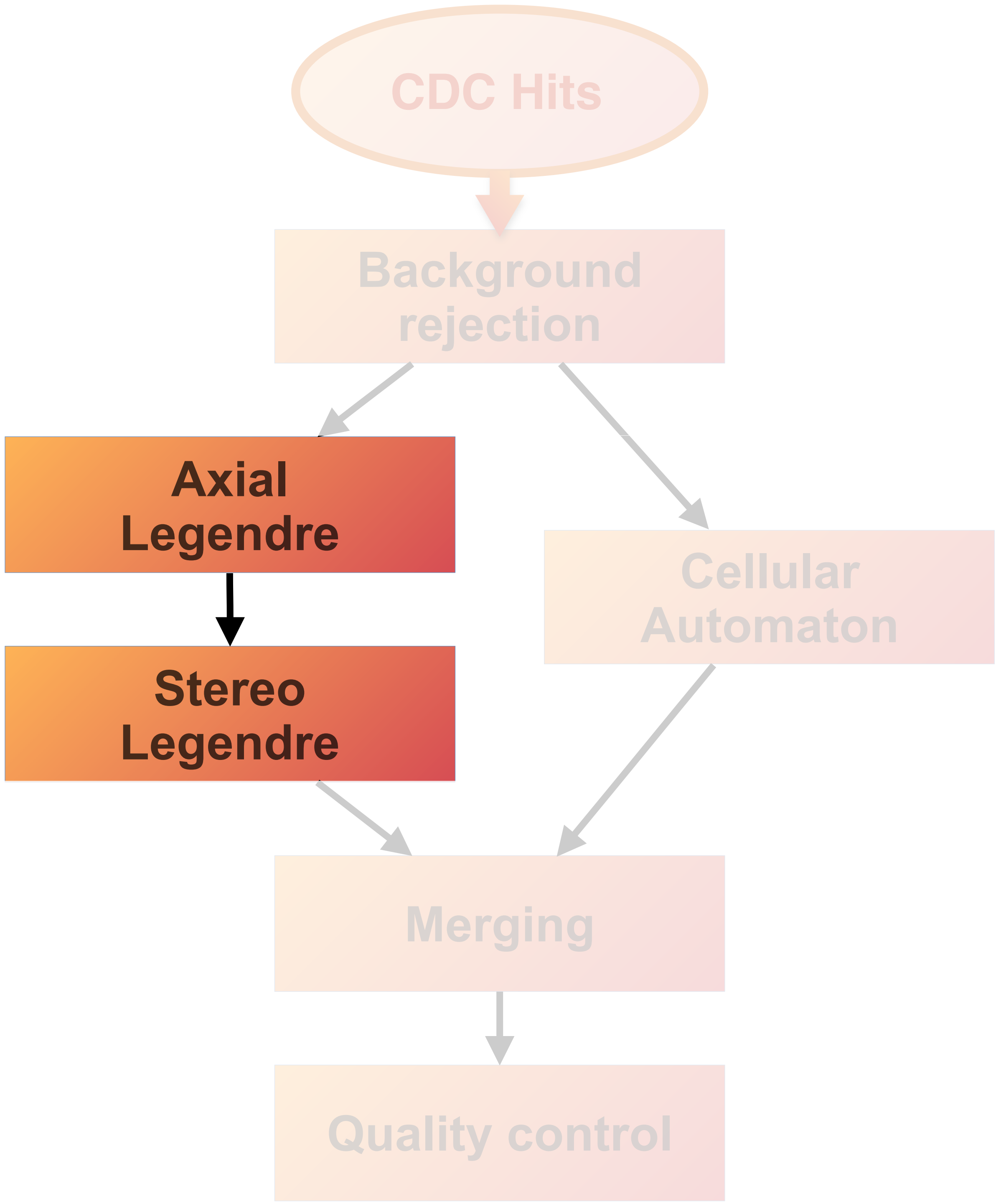
Background filter



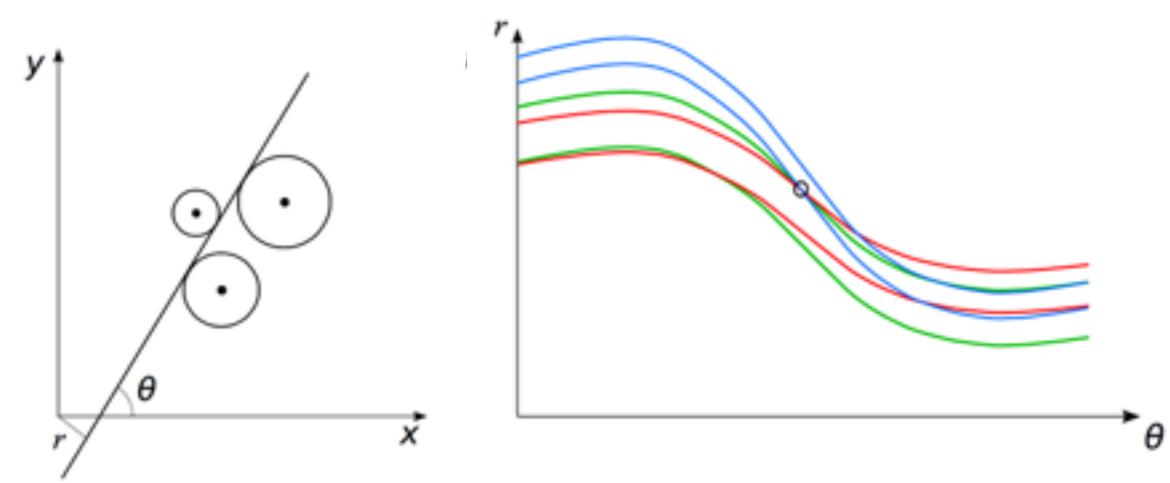
- Background filter implemented with a MVA (FastBDT)
- Based on variables from clustered hits
- Will be tuned with background only data



Global Legendre Algorithm



- Hits in the CDC be can geometrically represented as circles
  - Center: fired sense wire
  - Radius: hit drift length

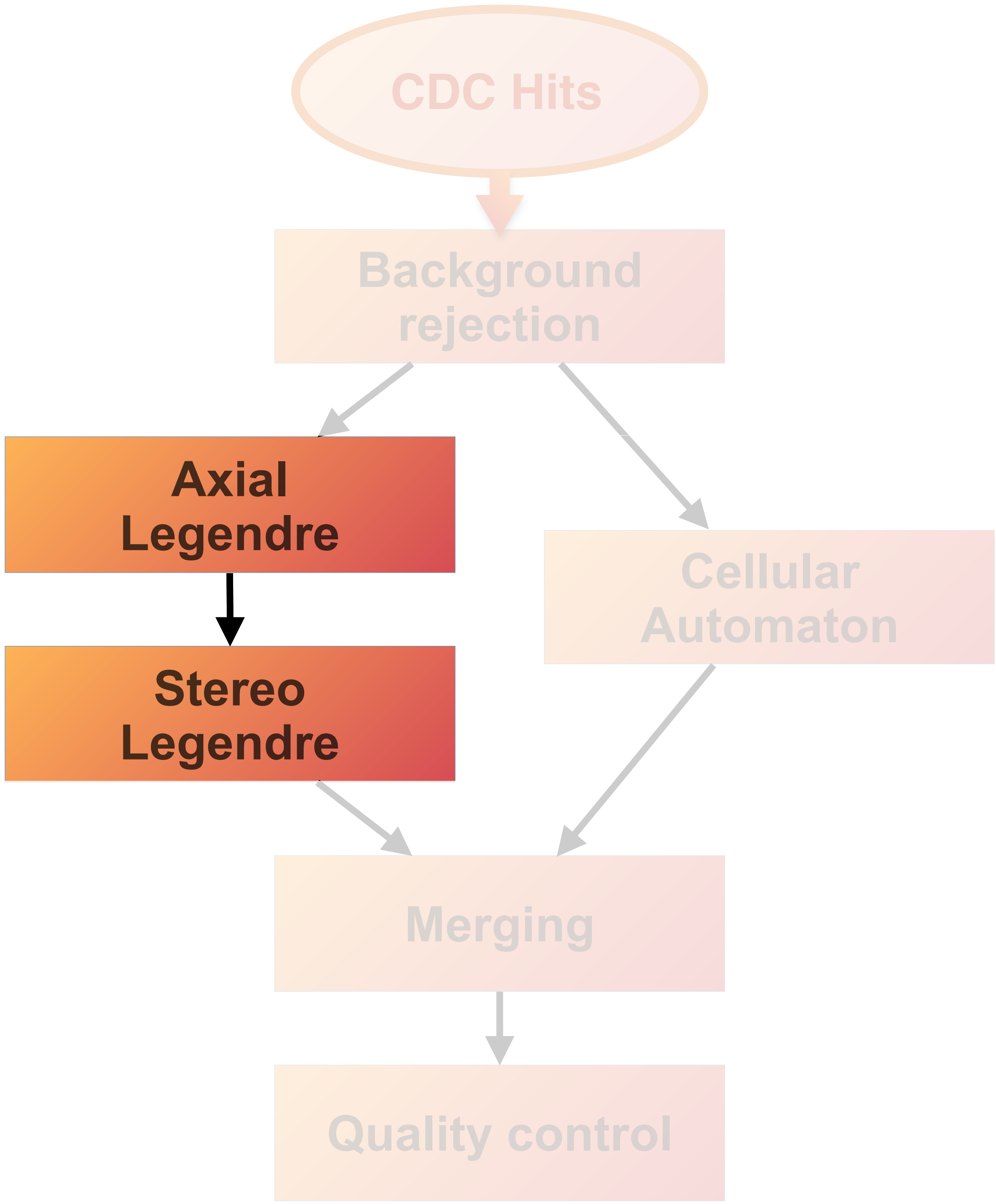


(a) Drift circles, sharing a common tangent (b) Representation of a common tangent in the Legendre space

$$r = x_0 \cos\theta + y_0 \sin\theta \pm R_{dr}$$

the equation of a tangent to a drift circle in the Legendre space

Global Legendre Algorithm



- 2-dimensional binary search toward the possible track candidate

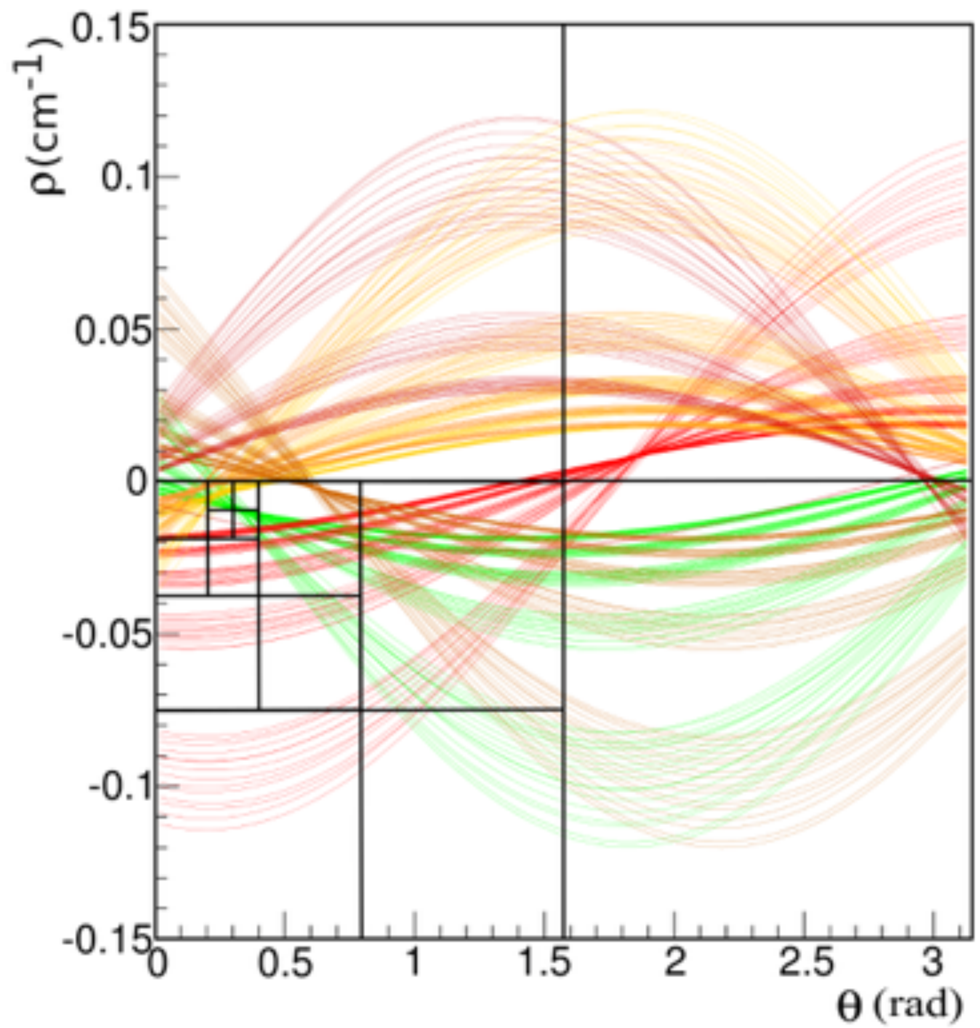
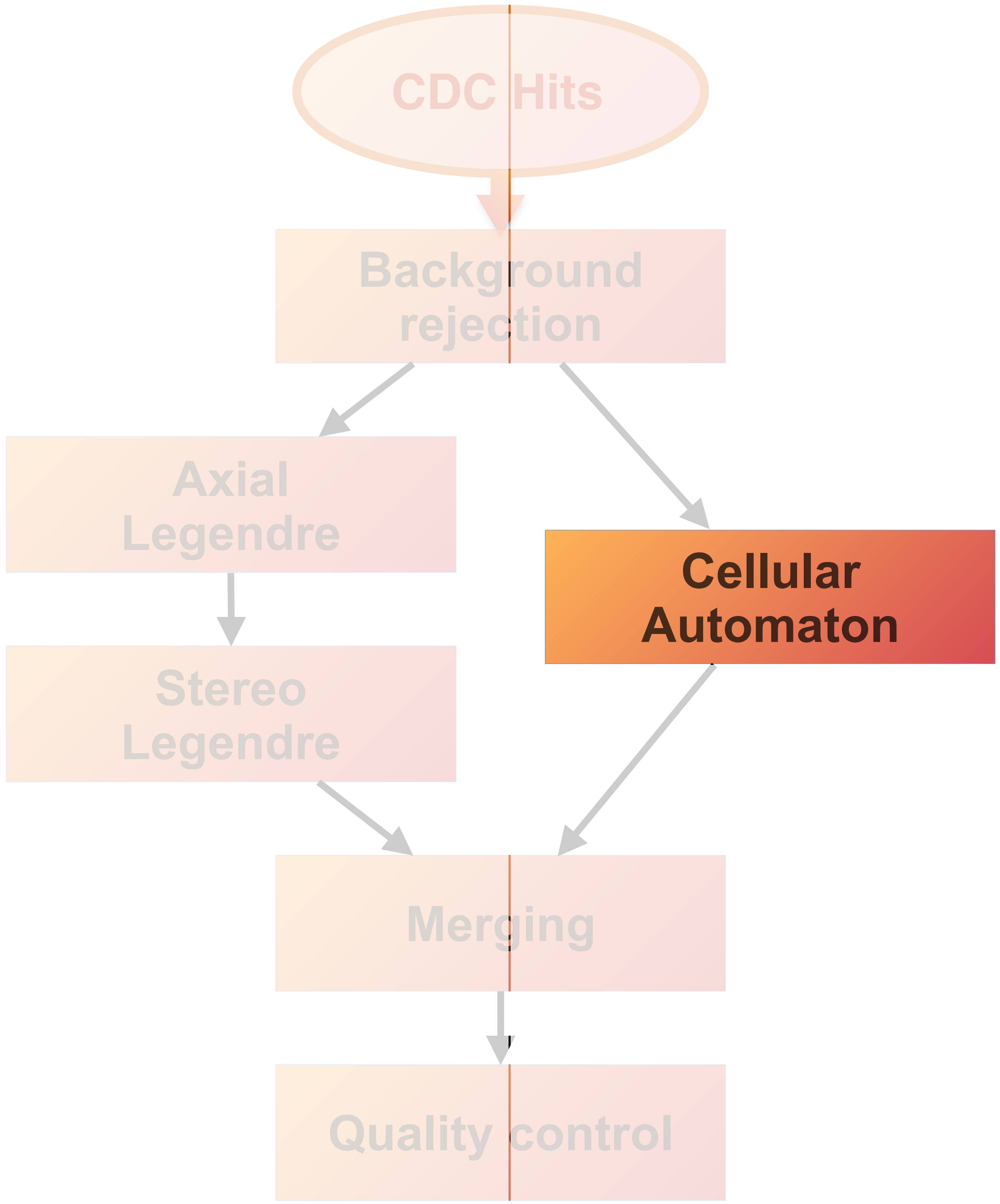
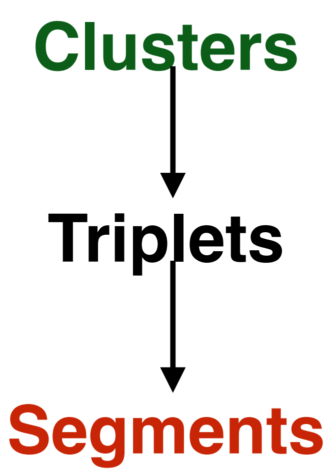


Fig: Simulated $B\bar{B}$ event with 6 tracks in the Legendre plane

Cellular Automaton

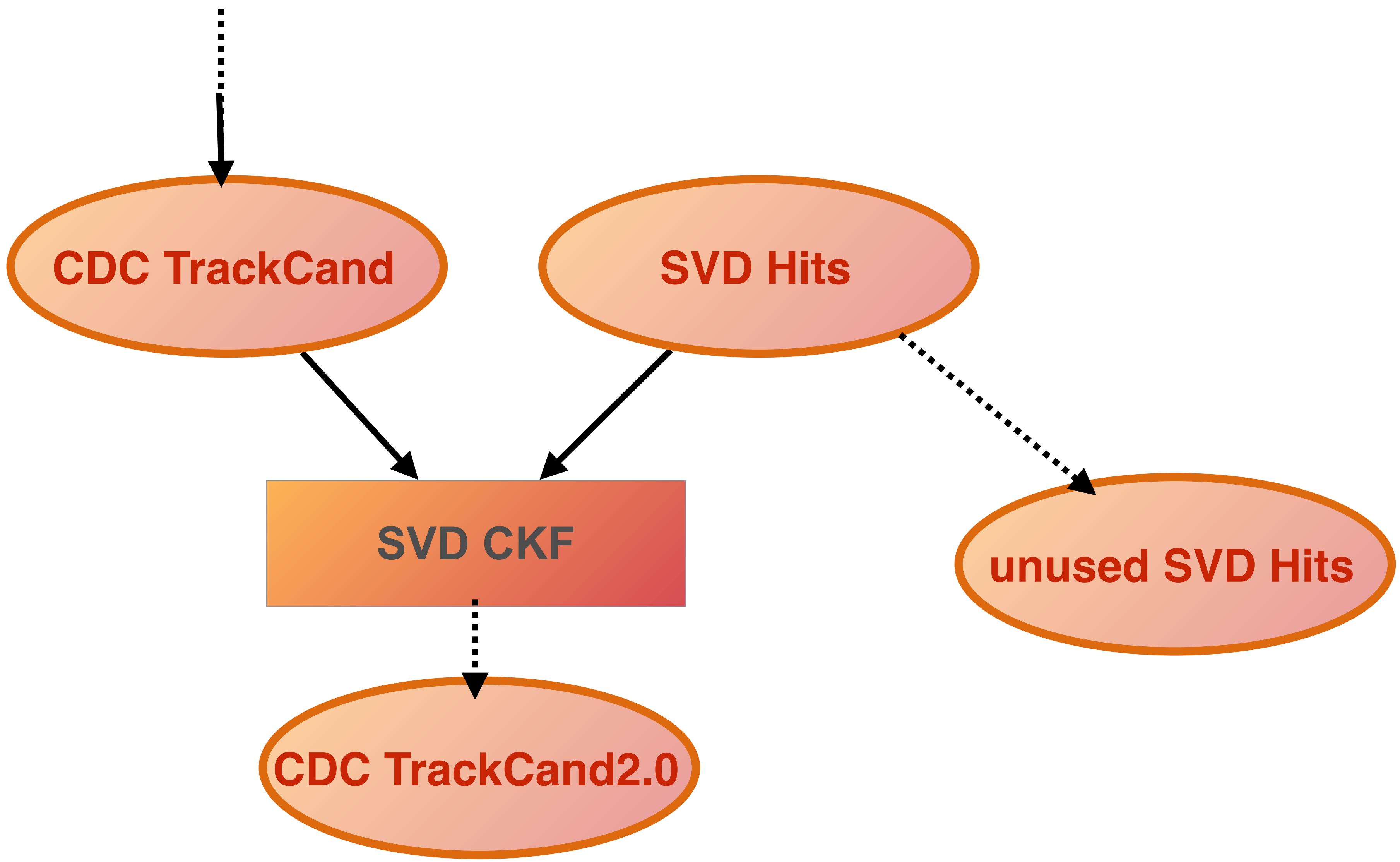




- MVA filters or hand crafted features
- Hit connection through bridging

- Build segments from individual hits in each super layer
- Build tracks from segments

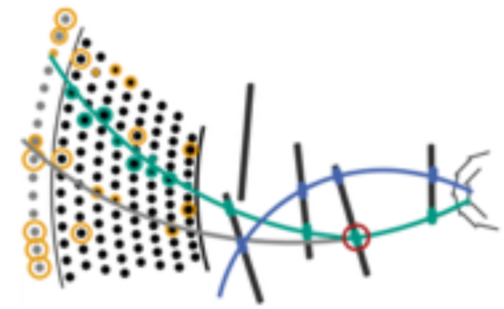
SVD CKF



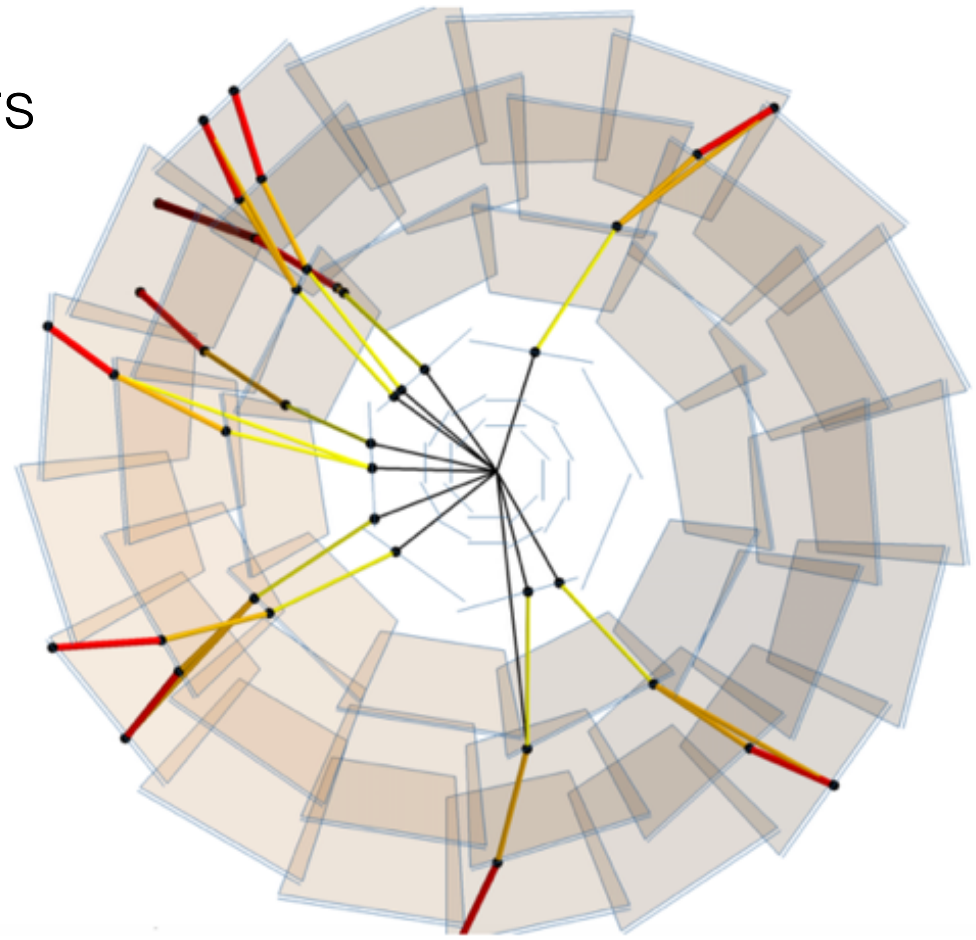
- SVD track finding with CFK from CDC
  - A Combinatorial Kalman Filter uses the principles of the Kalman Filter for track finding
  - Starting with a seed it adds hits with Monte Carlo Tree Search algorithm

SVD standalone track finding

unused SVD Hits

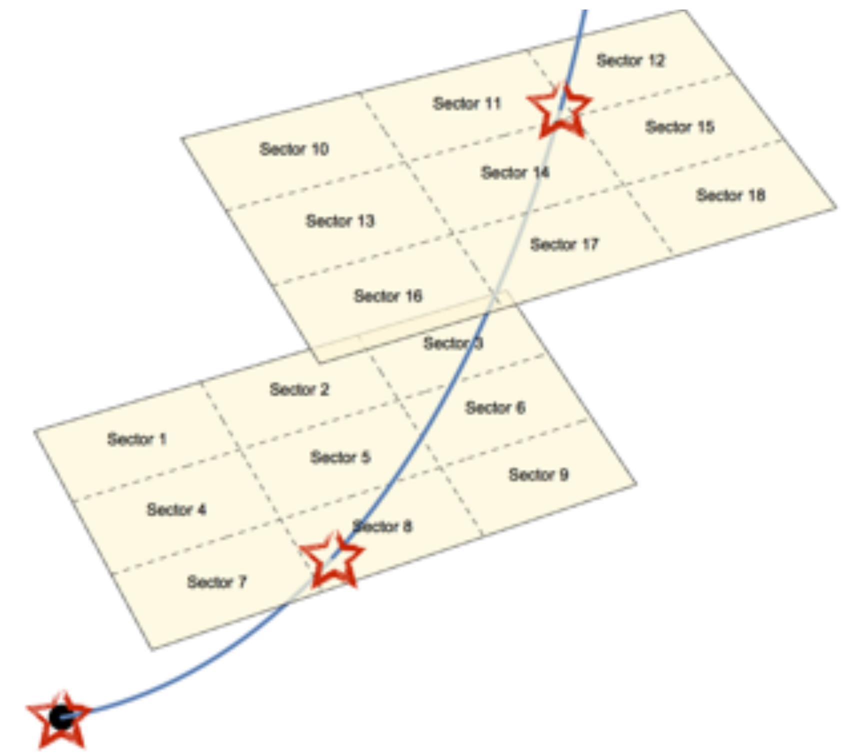


- Cellular Automaton collects paths beginning with outermost SVD 3D-hits
- Based on the concept of a sector on sensor (SectorMaps)
- Neighboring 3D-hits are given by a set of filters
- Reduction of combinatorics
- Allows for multiple scattering
- The final set of tracks is chosen from all paths such that no tracks share a SVD hit



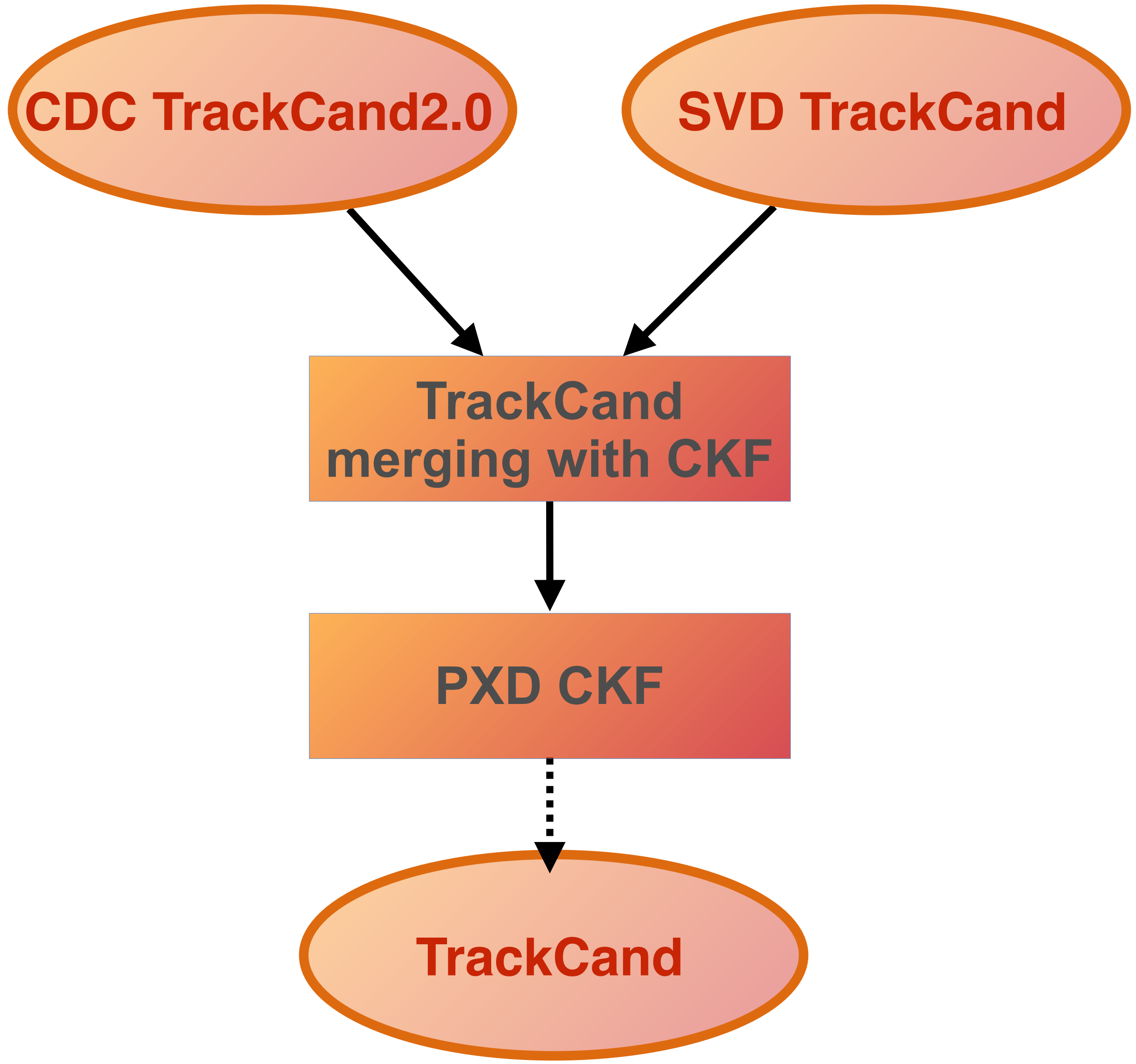
SVD standalone track finding

- SectorsMaps: virtual subdivisions of the sensors
- Segment: combination of two space points
- Friend sectors: sectors passed by the same MC particle during training
- Space points combinations are searched only on friend sectors



- Filtering of space points combinations based on simple geometric cuts
- Cut values obtained using simulations
- Cellular automaton → set of tracks potentially overlapping
- Hopfield neural network → unique set of SVD track candidates

CKF merging and PXD CKF



- CDC and SVD track candidates merging with CKF
- Adding PXD hits with CFK from track candidates

- The challenges of tracking at Belle II
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- **Track Fitting**
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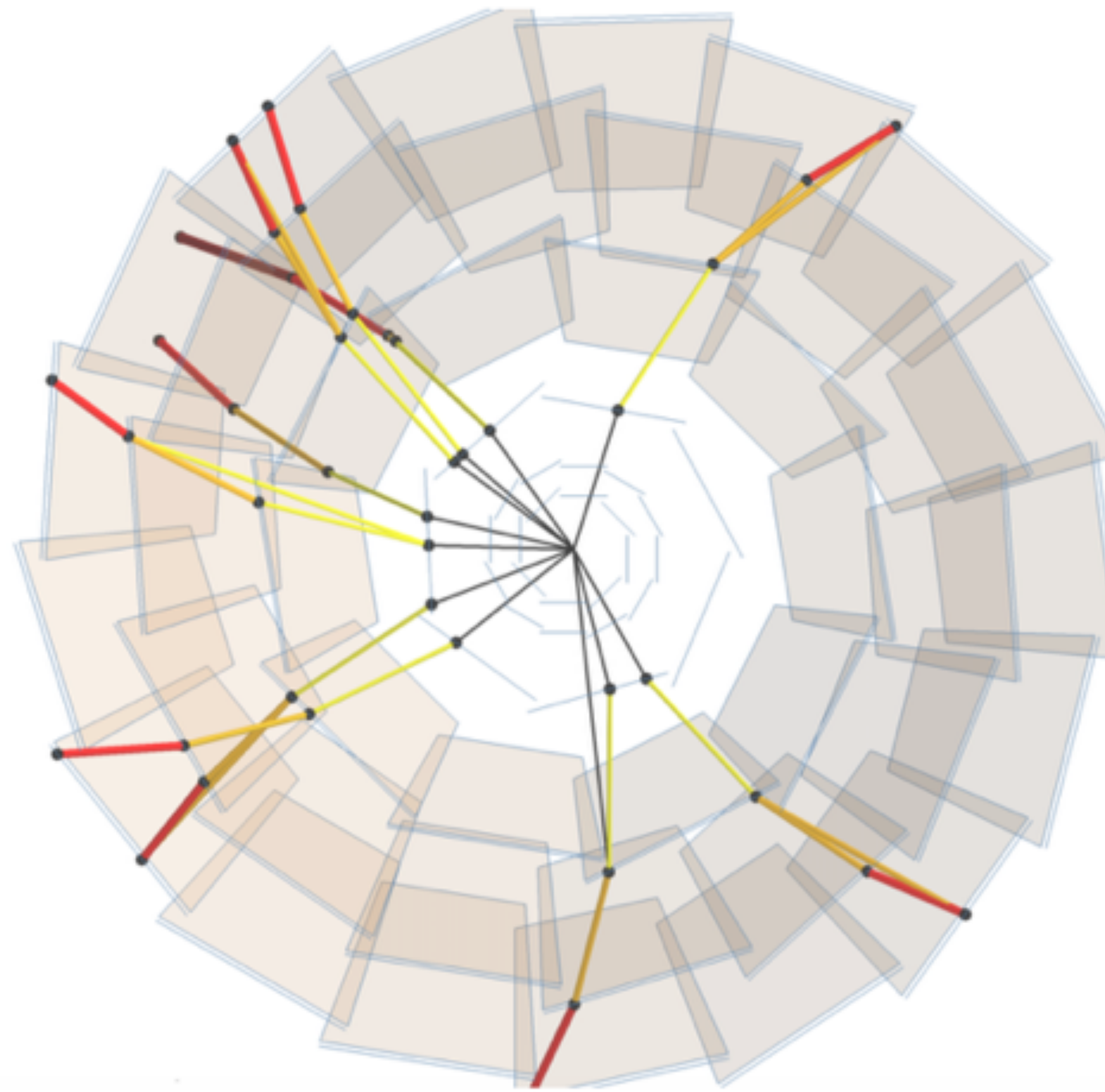
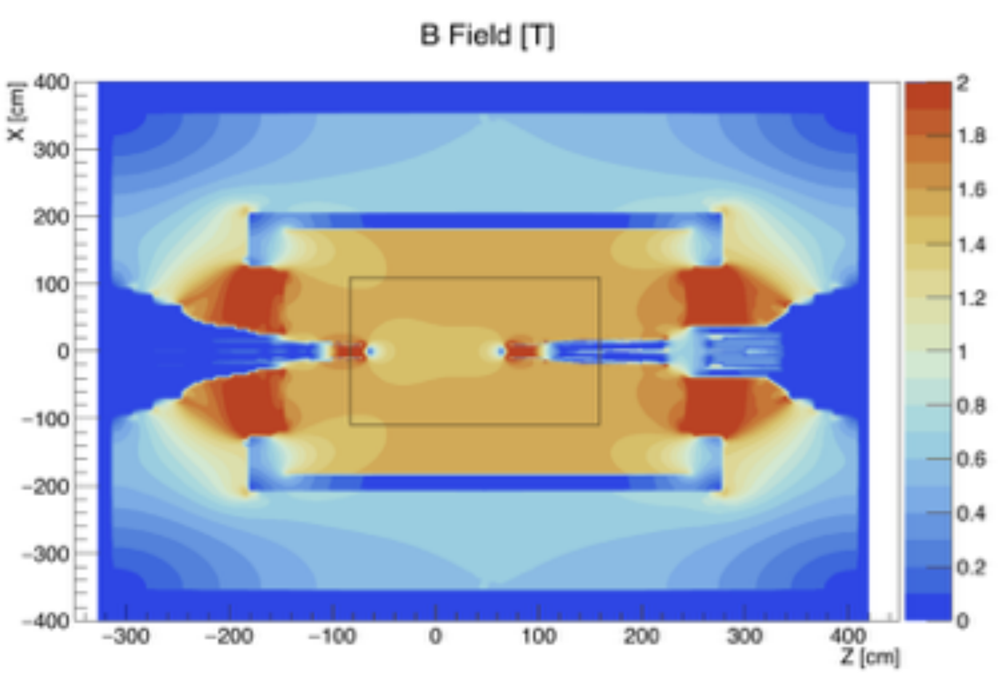


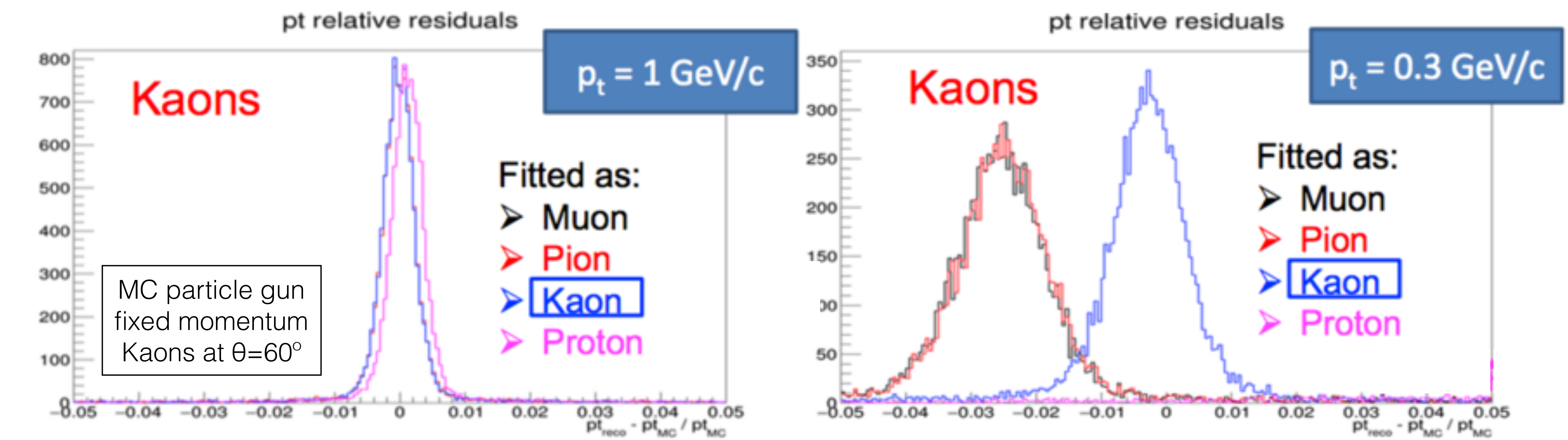
Track fitting

- Tracks are fitted with the track fitting package GENFIT2
  - Rewrite of GENFIT incorporating what we learned in Belle II, PANDA, COMPASS
  - Experiment-independent track fitting software
  - Several algorithms implemented inside
    - Determinist Annealing Filter (DAF) used
      - Hits from different detectors
      - Not uniform magnetic field
      - Energy loss dependent on particle type
    - DAF removes outliers and downweighs distant hits



Different particle hypotheses fit

- Deterministic Annealing Filter with 3 different mass hypotheses in parallel (π, K, p)



- At high momentum → similar results
- At low momentum → large bias in momentum when using the wrong mass hypotheses

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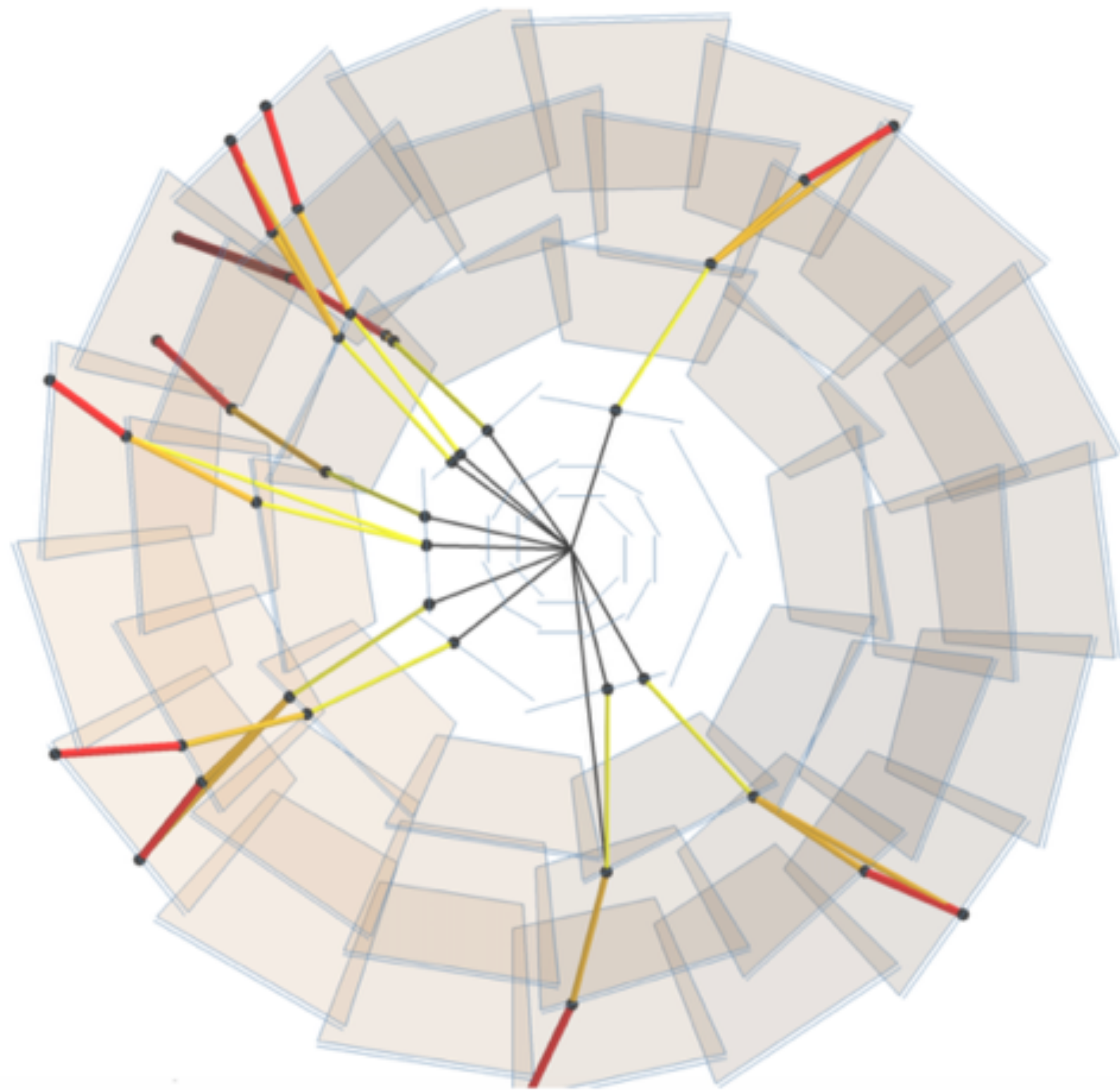


Vertex fitters in the Belle II code

- KFit
  - Belle implementation
  - Based on a least square minimization approach
    - Can fit neutrals <u>assuming</u> the vertex is {0,0,0}

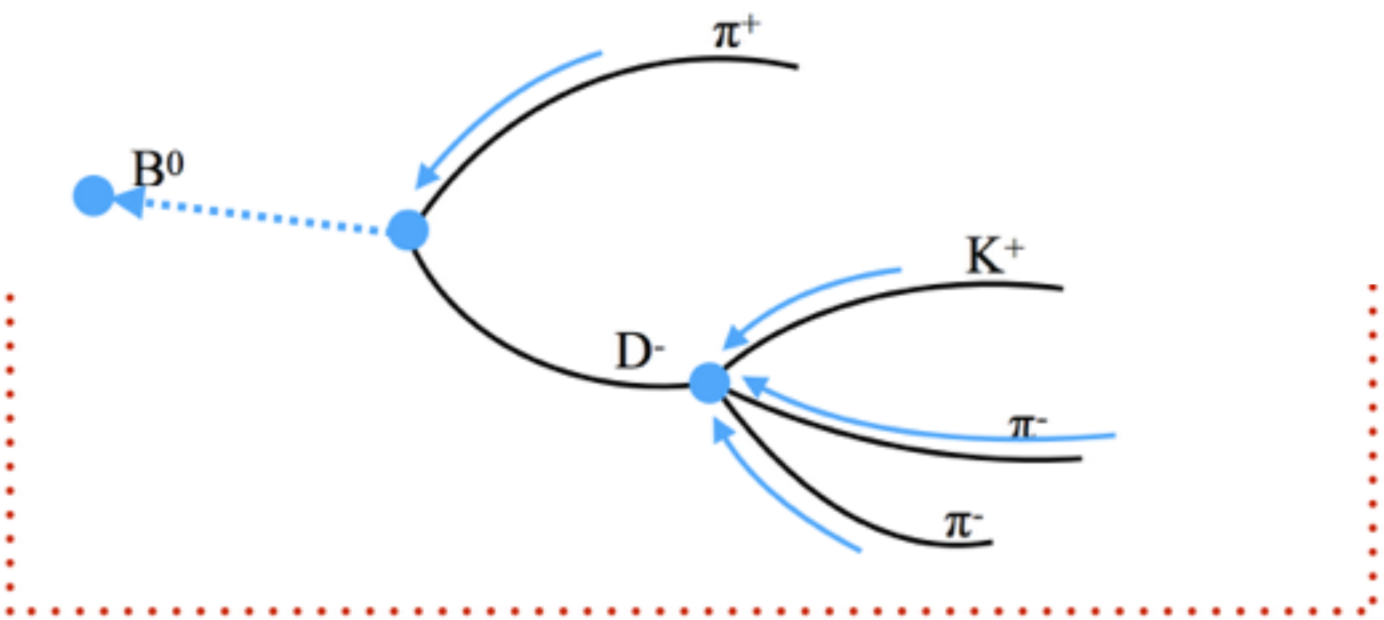
- RAVE
  - standalone implementation of CMS libraries
  - Kalman filter approach
    - Weights tracks when using it to fit multiple tracks
    - Can only fit charged particles and single vertices

- TreeFitter
  - Belle II implementation

TreeFitter

- Kalman filter approach
- Global vertex fitter
  → fit an entire decay chain simultaneously

- Features / Constraints implemented:
  - Kinematic constrain
  - Geometric constrain
  - Mass constrain
  - IP constrain
  - Custom origin constrain



- PRO:
  - Fast
  - High background rejection
  - Can fit neutrals

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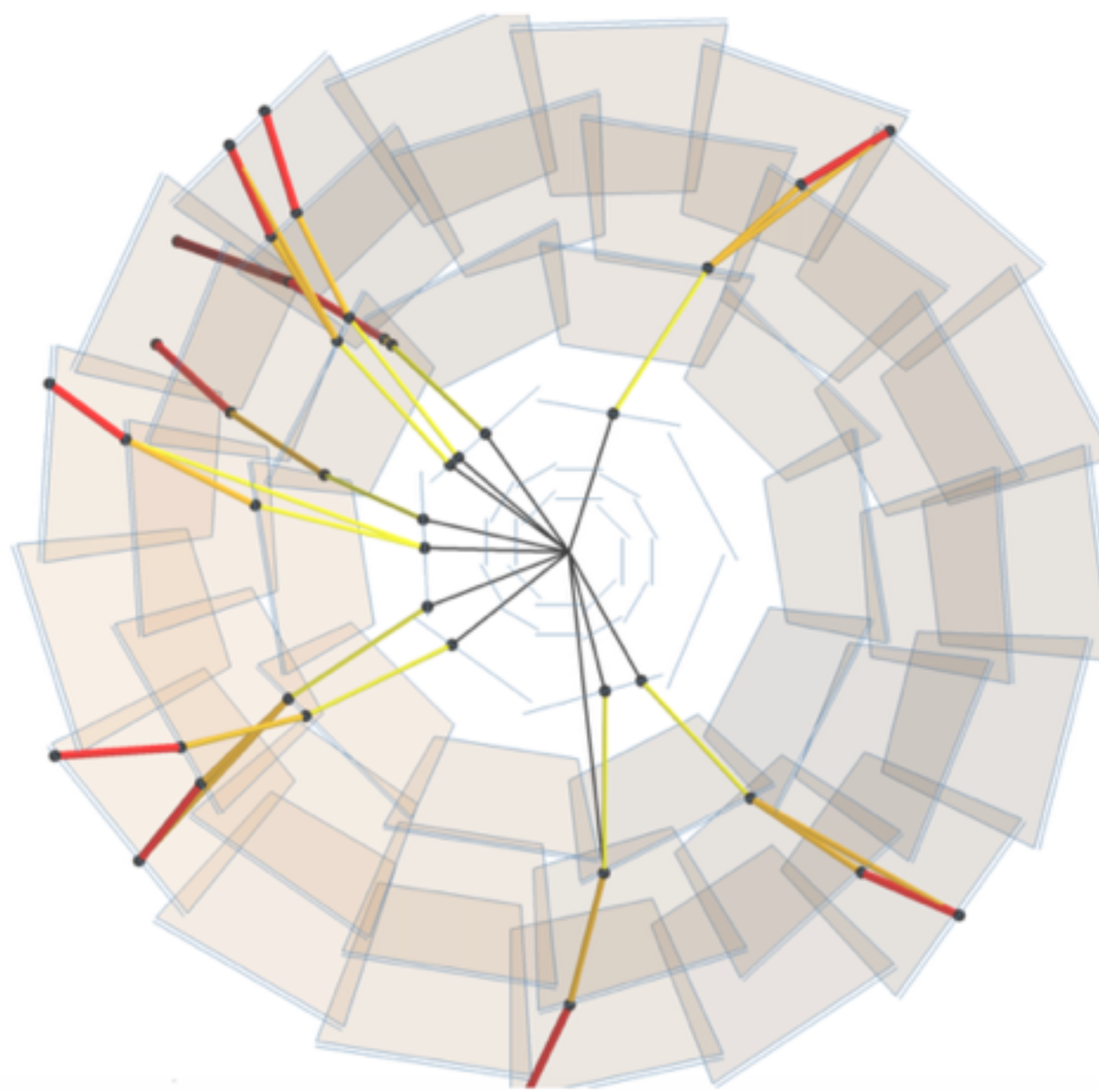
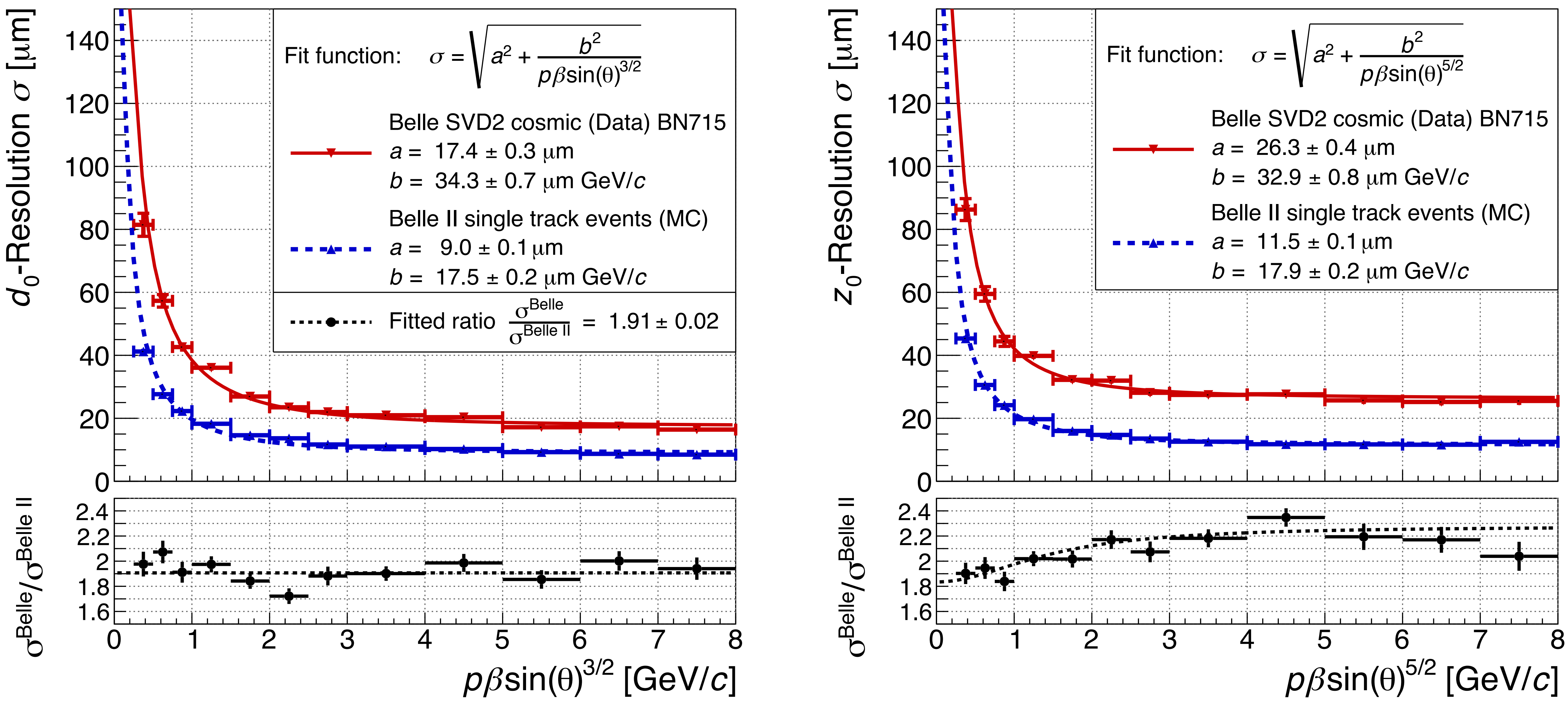
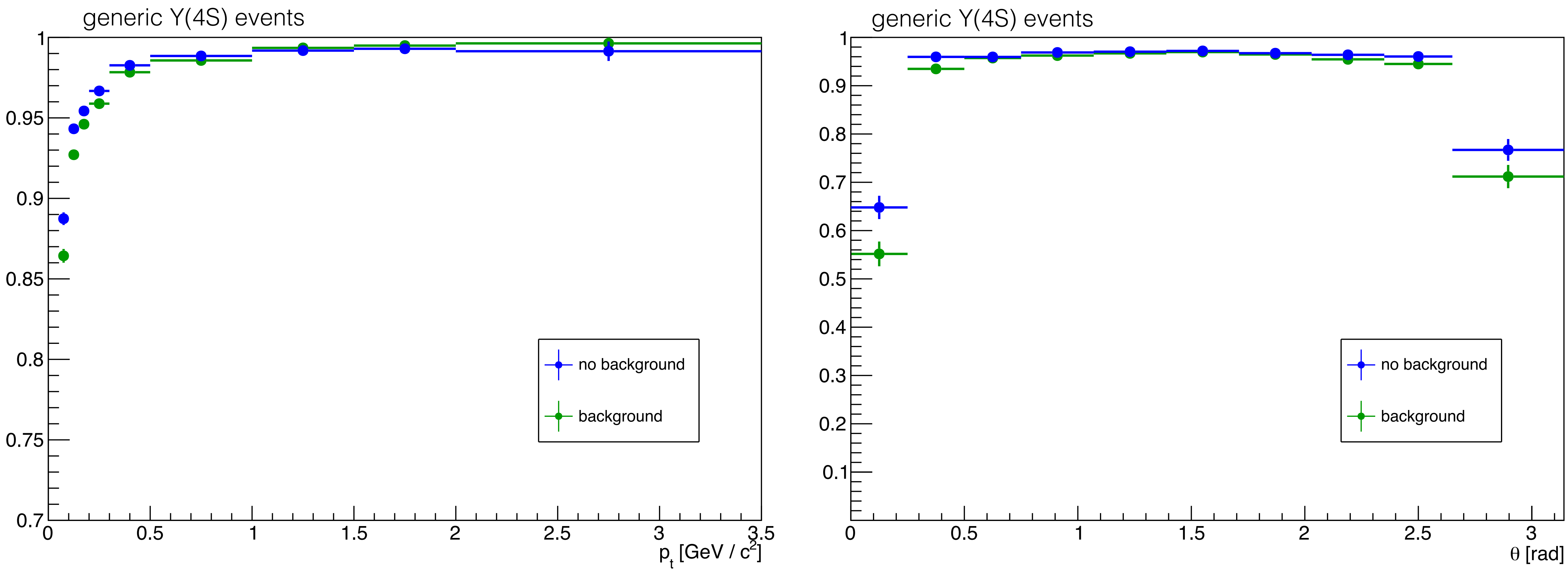


MC simulation



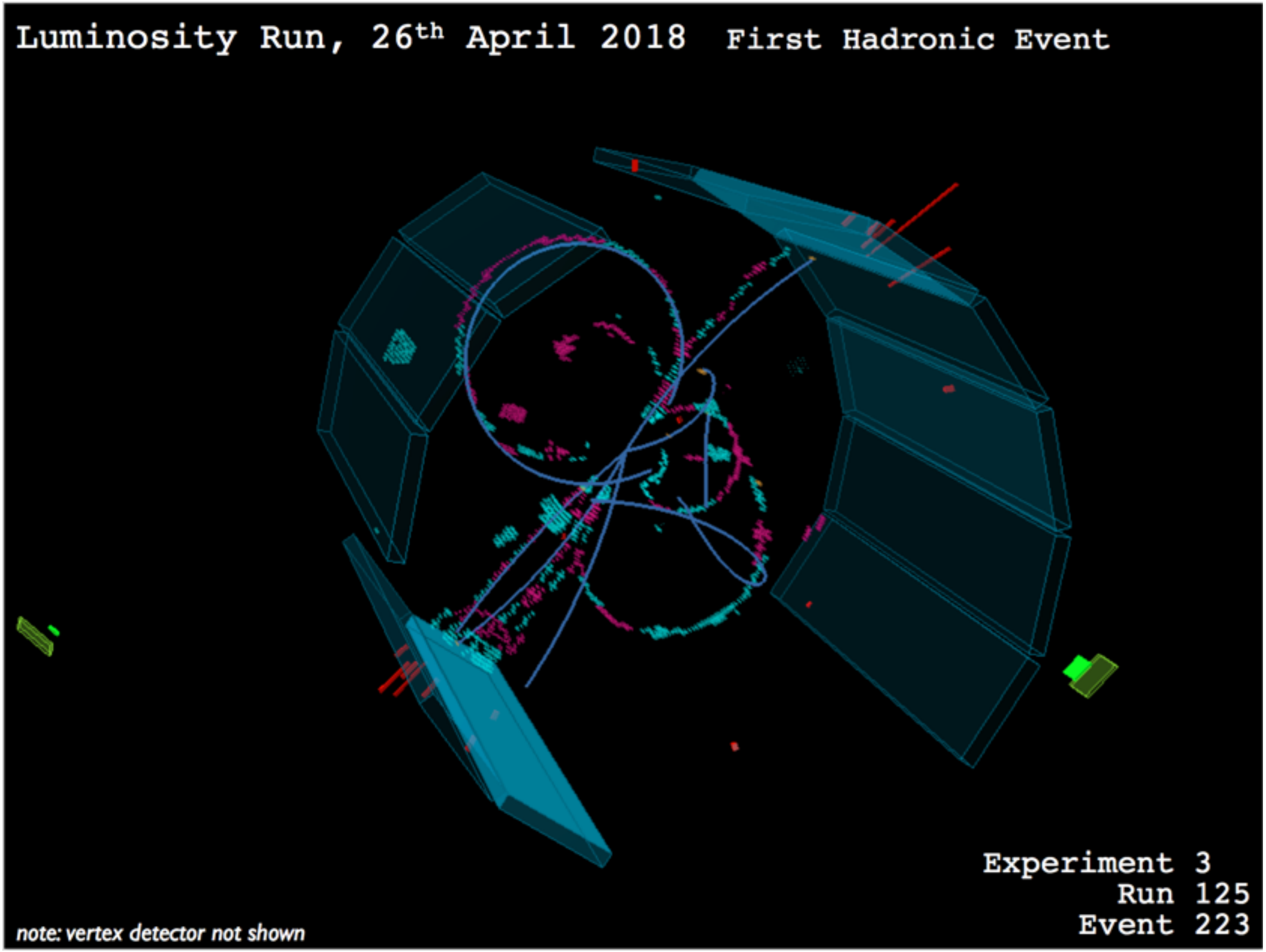
- Resolution of the transverse (d_0) and longitudinal (z_0) impact parameters
- Belle II MC events with a single muon tracks are compared with results of Belle cosmic events

MC simulation



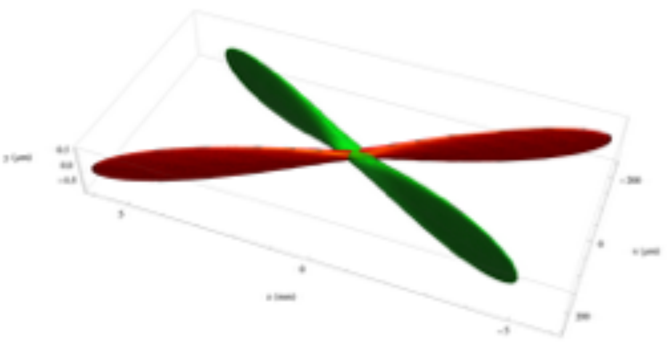
- Track finding efficiency as a function of p_t and θ
- Integrated efficiency w/o background is ~96.5%, w/ is ~95.8%

What about real data?

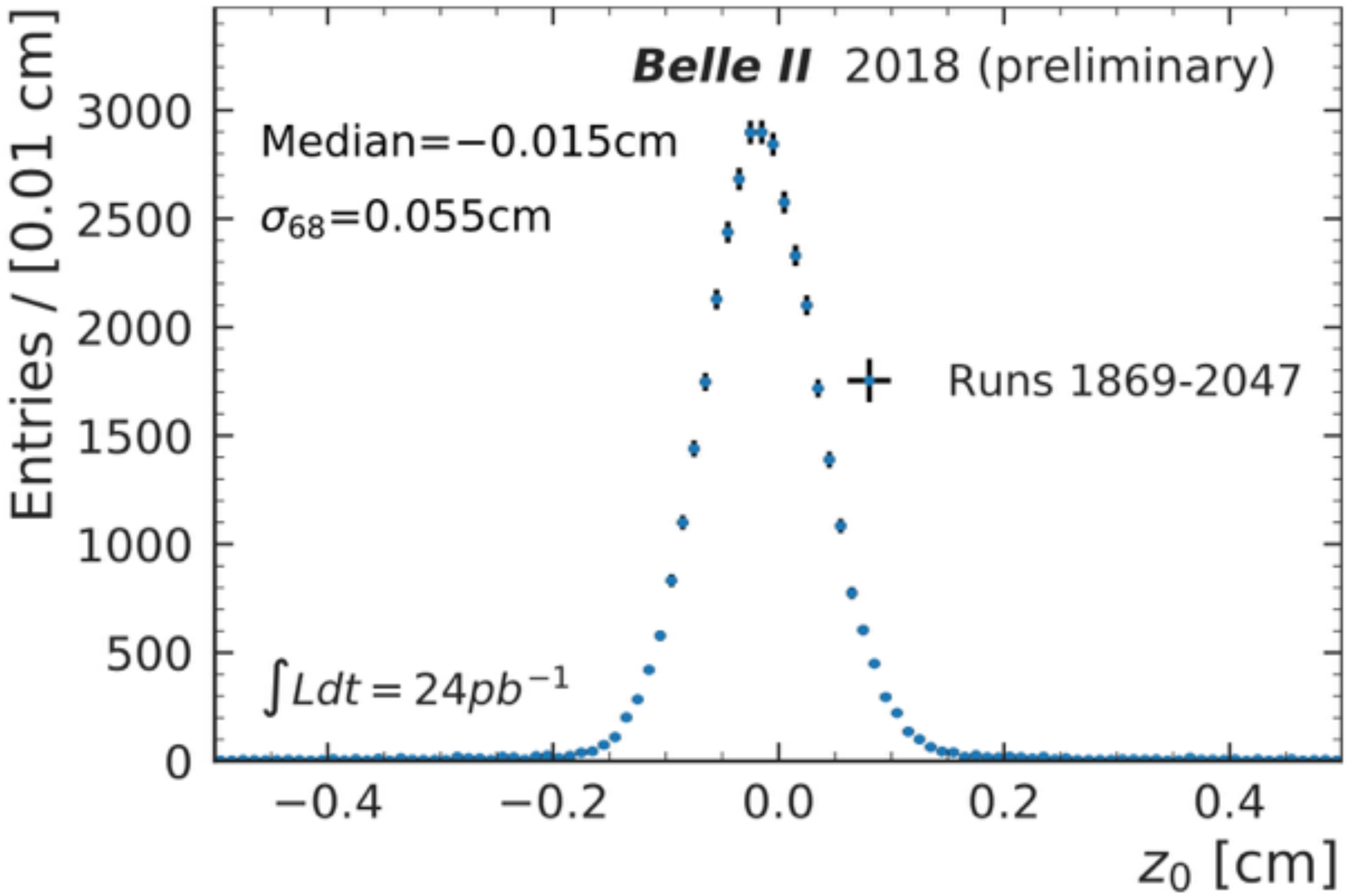


What about real data?

SuperKEKB

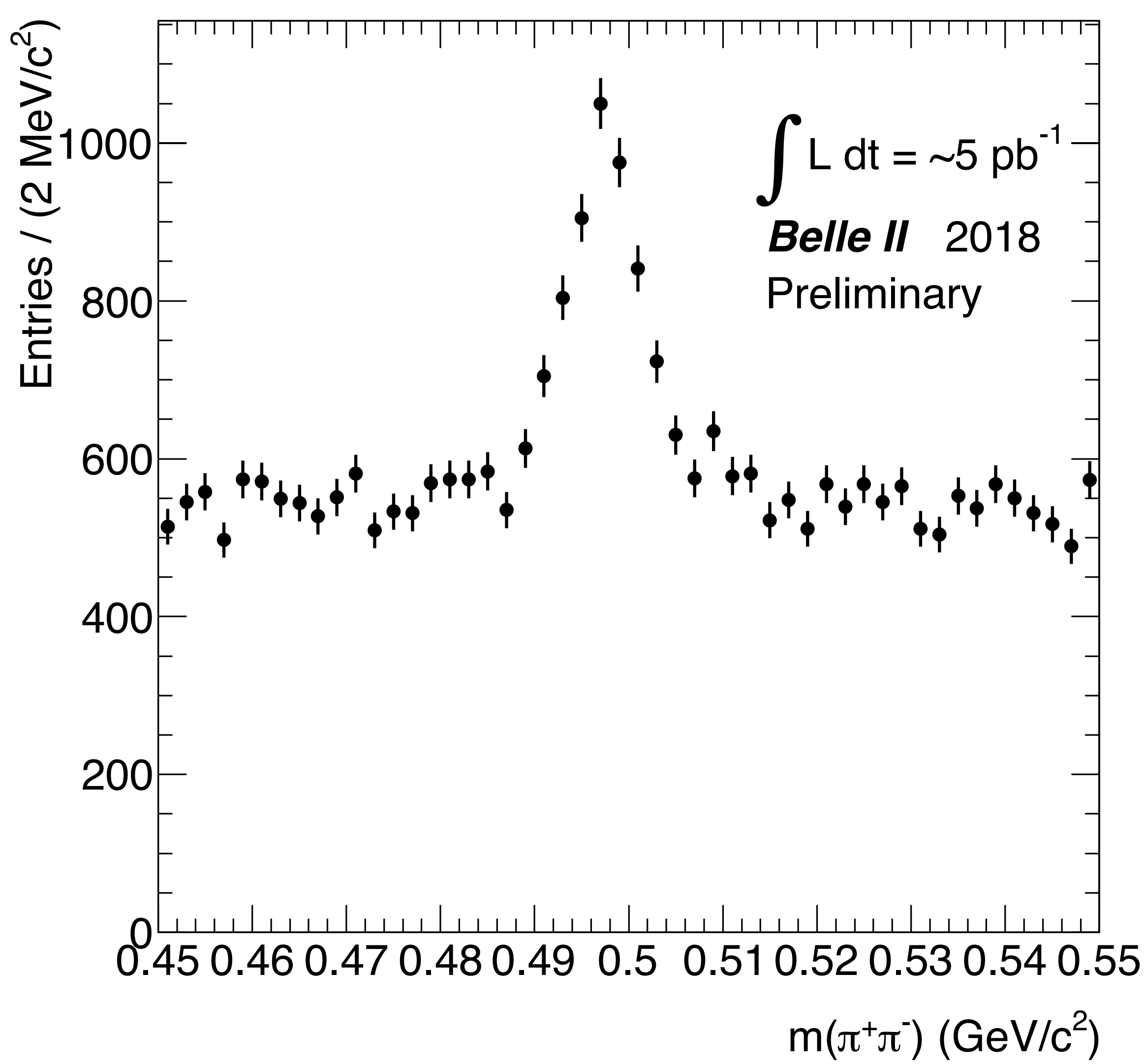


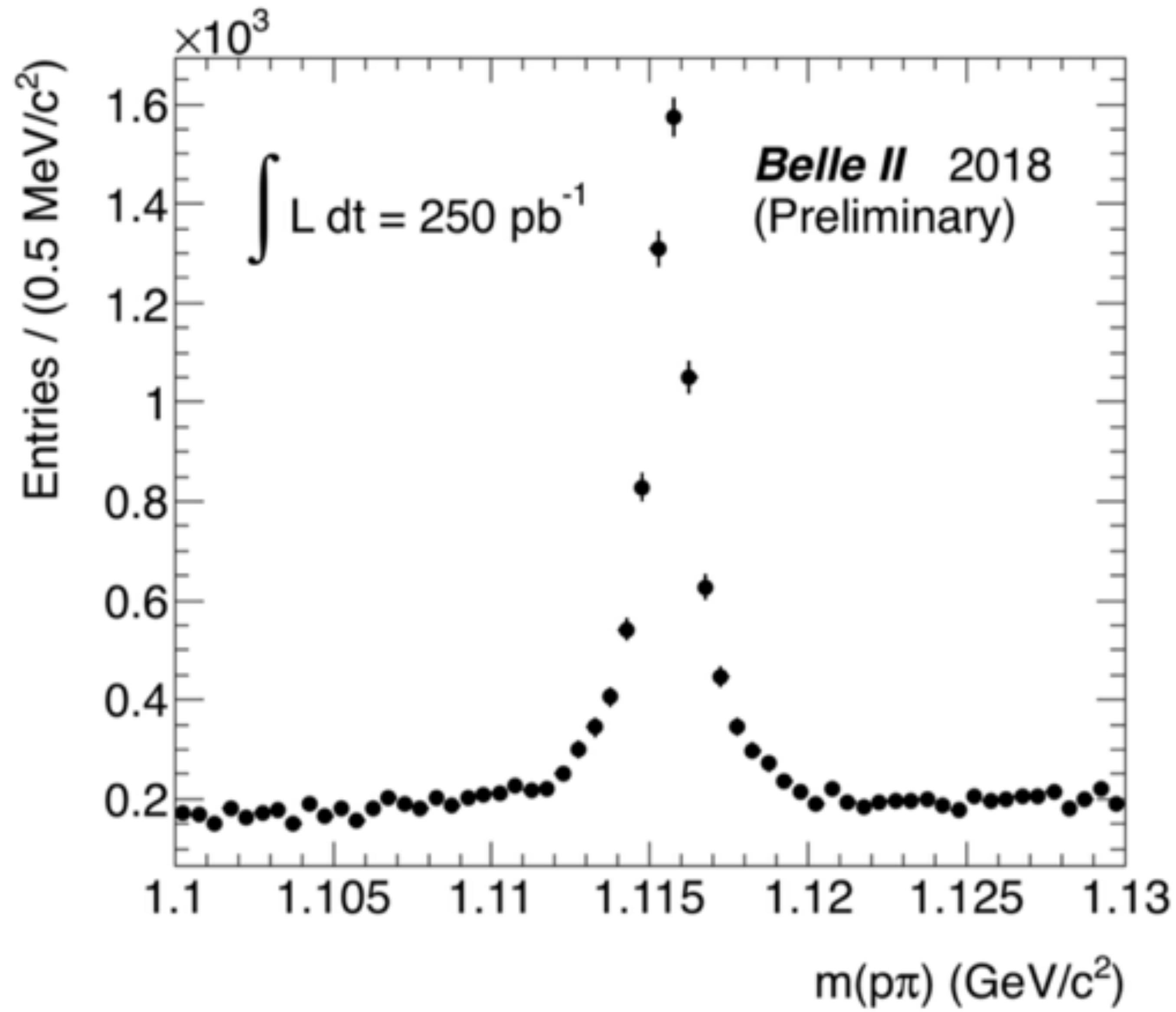
$$\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x} = 0.049 \text{ cm}$$



We measured the effective bunch length it in two track events with early Belle II data

What about real data?





- Evidence of Ks (~5 pb^{-1}) and Λ^0 (~250 pb^{-1})
- Very early stage of data taking during detector commissioning

Summary

- Separate approaches employed for track finding in the CDC and SVD
  - CDC track finding is based on a global Legendre and a local cellular automaton
  - SVD track finding uses a sector on sensor concept
  - CKF-based methods are used to merge tracks and pick up pixel hits

- Track fitting takes into account realistic magnetic field, energy loss for different particles and different kind of detector hits
- Tracks are fitted with three mass hypotheses (π, K, p)

- Global vertex fitter recently implemented

- Tracking and vertexing successfully tested on simulation and on first data collected during detector commissioning phase

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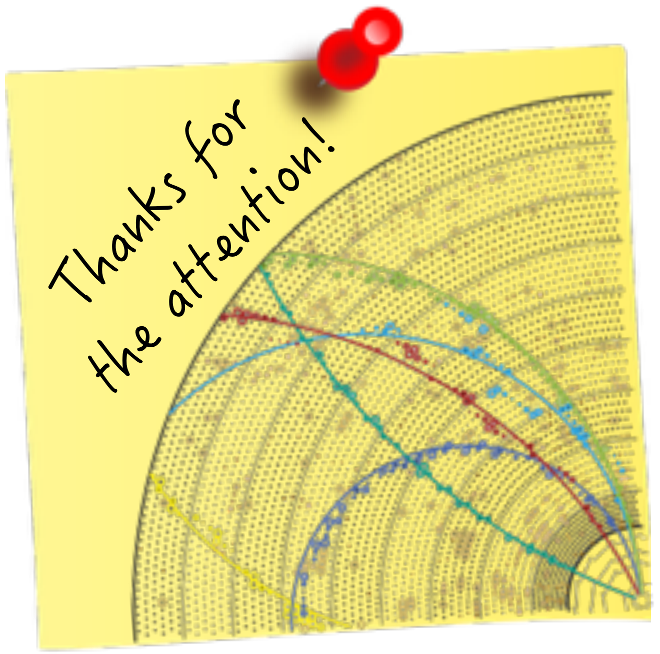
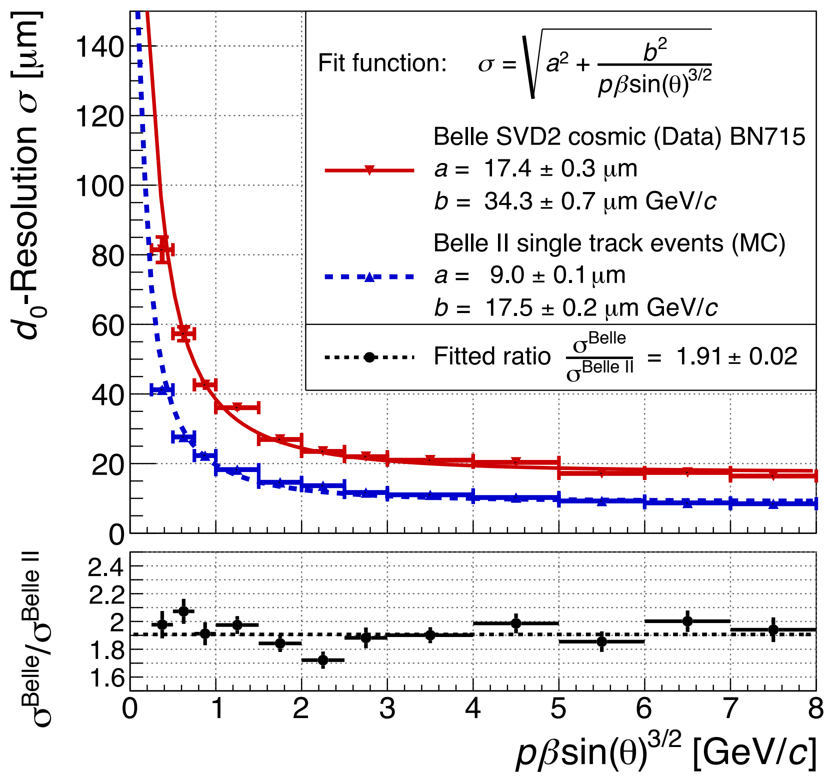
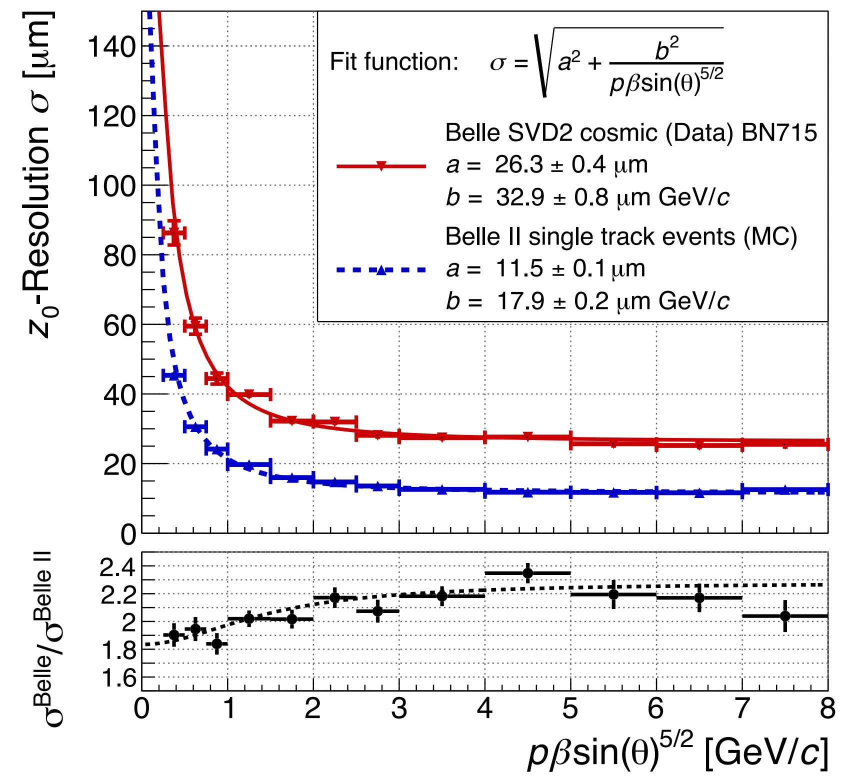
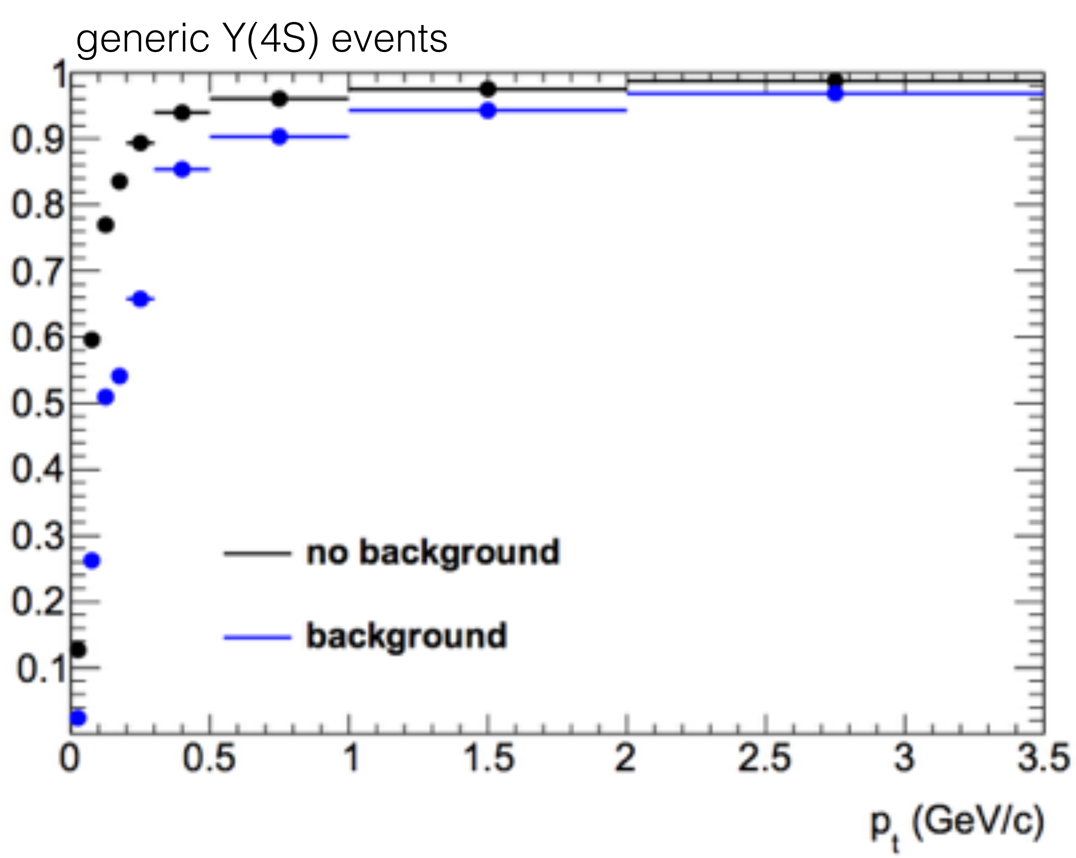


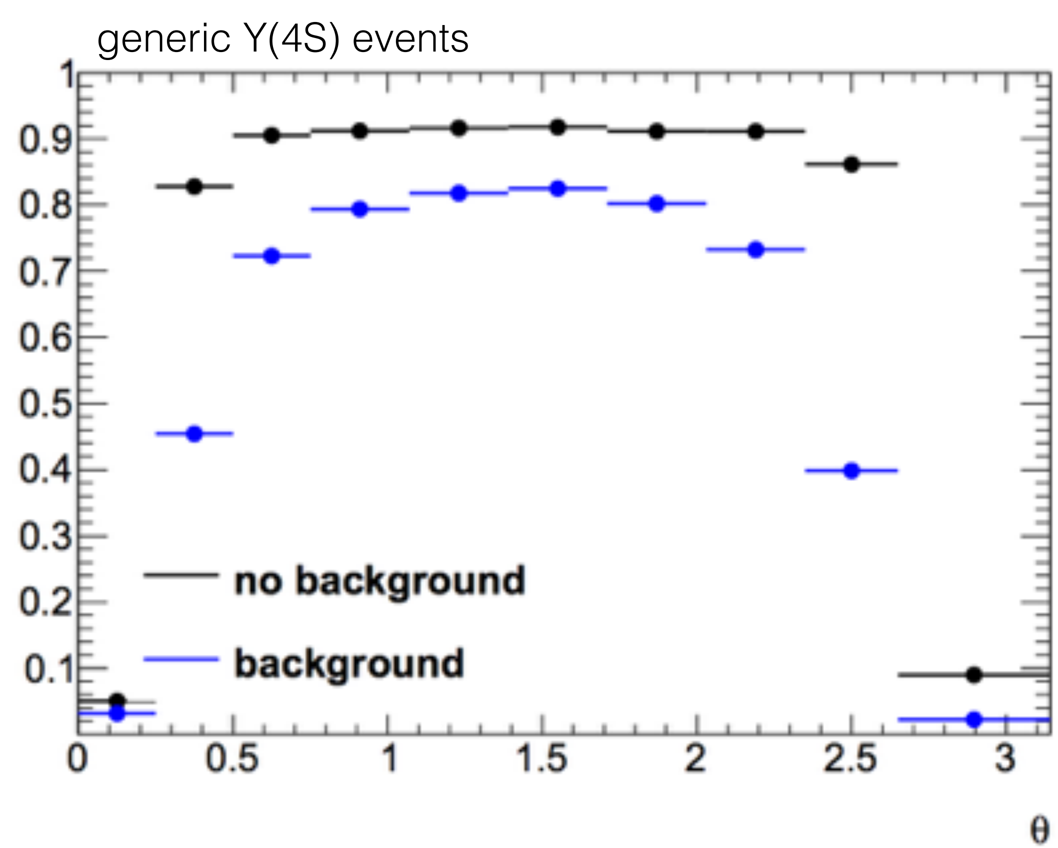
BACKUP

MC simulation





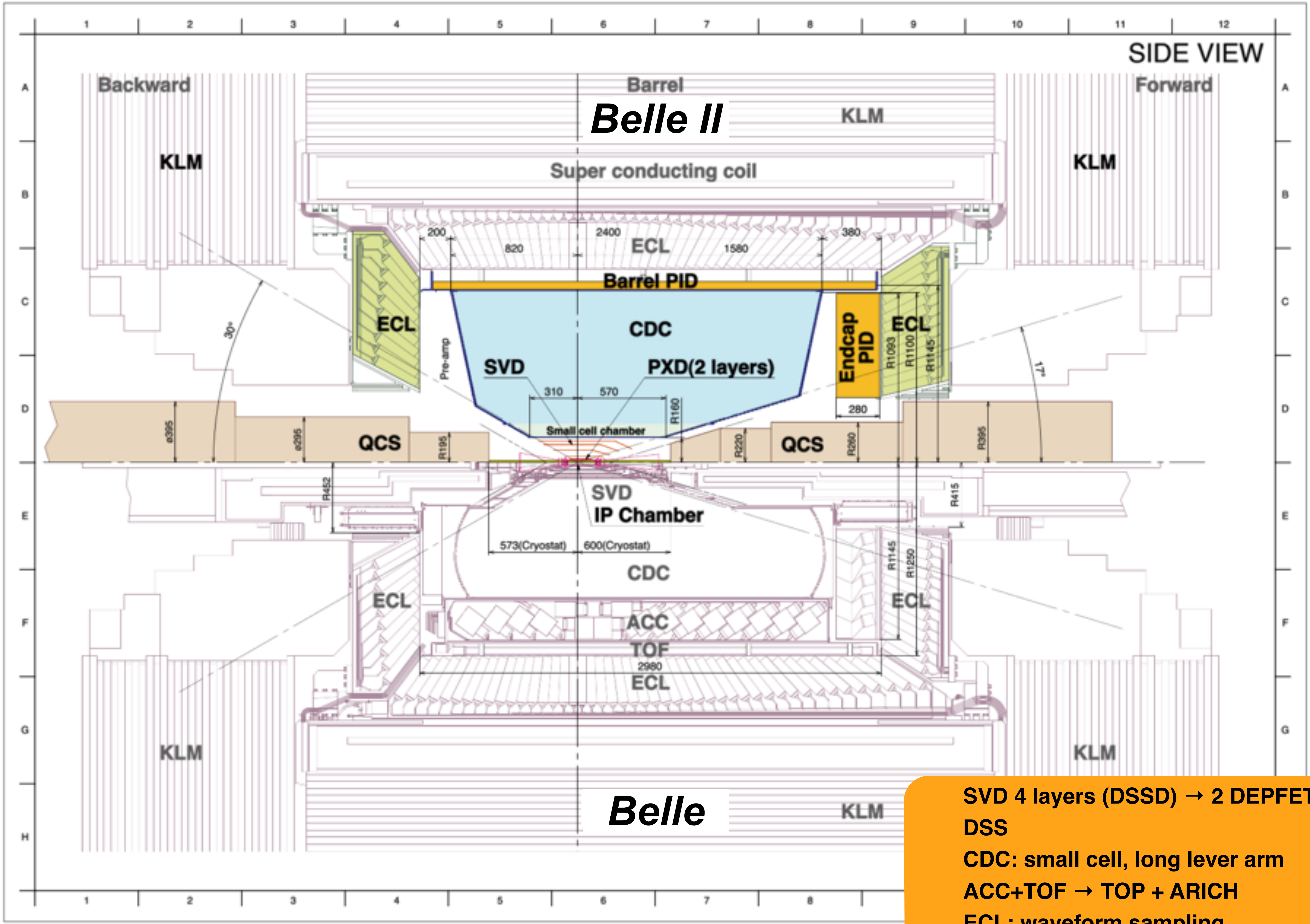




KEKB VS SuperKEKB

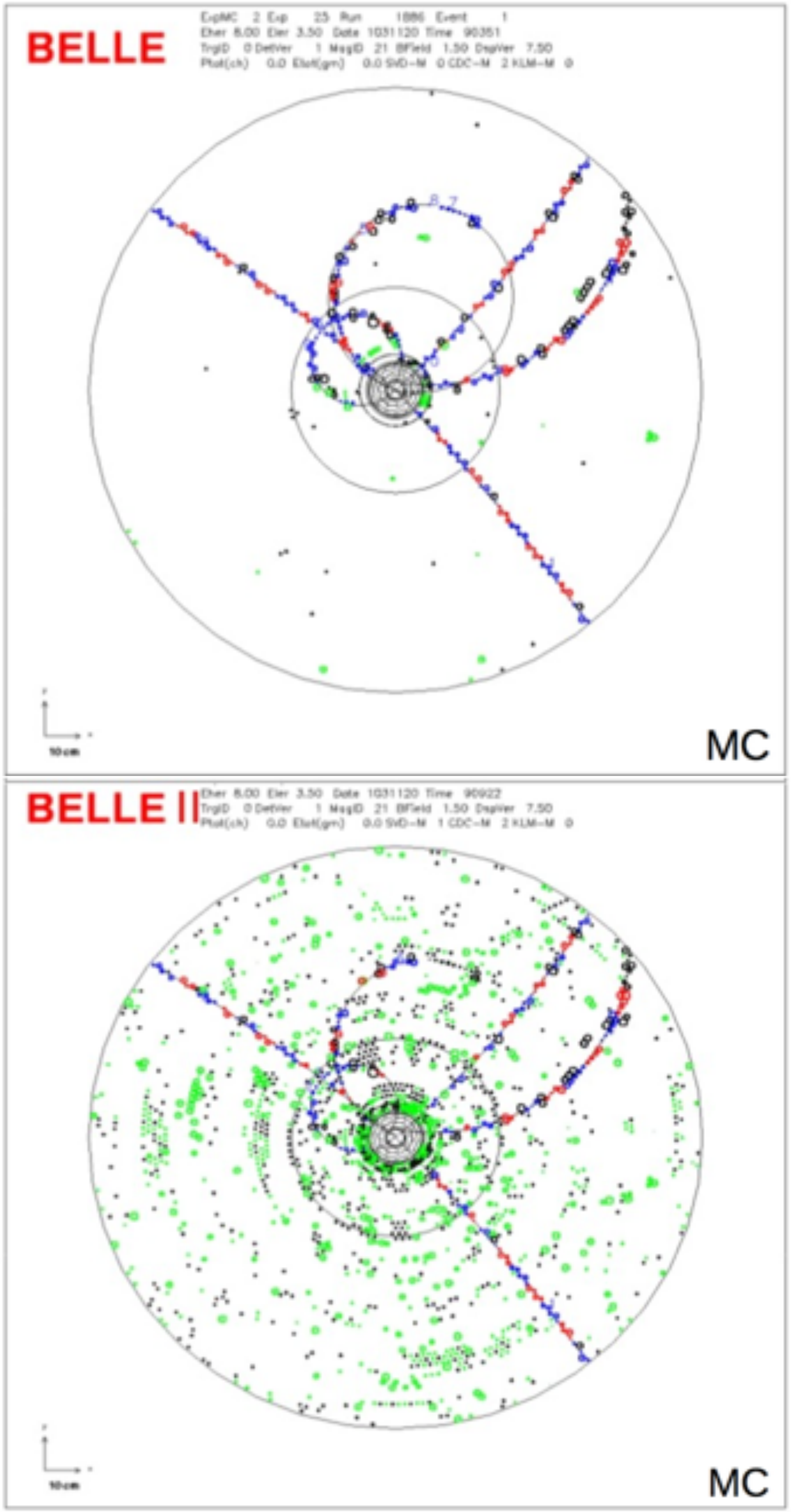
parameters		KEKB LER	KEKB HER	SuperKEKB LER	SuperKEKB HER	units
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta-function at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	129	90	0.0881	0.0807	
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		μm
Luminosity	$\mathscr{L}$	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

From Belle to Belle II



- SVD 4 layers (DSSD) → 2 DEPFET + 4 DSS
- CDC: small cell, long lever arm
- ACC+TOF → TOP + ARICH
- ECL: waveform sampling
- KLM: RPC → Scintillator+SiPM

New challenges



➡ x40 luminosity:

- x40 produced signal events
- Higher background
  (detector occupancy, fake hits, radiation damage)
- Higher event rate
  (trigger rate,DAQ, computing)

➡ Important to have a dedicated phase for background studies, detector response and alignment

Jo-Frederik Krohn

What can it fit?

- You have to count the degrees of freedom (the fit ‘removes’ degrees of freedom)
- NDF = N_equations - N_parameters
- NDF > 0 you can fit it
- Example:
  - $J/\psi \to \mu\mu$
    - NDF: 1 = [4+5+5] - [7+3+3]
  - $\pi^0(\gamma\gamma)$
    - NDF: **-3** = [4+3+3] - [(4+3)+3+3] ({p, E} → (4, {x,y,z} → 3)
  - $D^0 \to K\pi\pi^0(\gamma\gamma)$
    - NDF: 1 =[2*4+2*5+2*3] - [7+4+4*3]
    - π^0 has no {x,y,z} → only 4 parameters (the D^0's {x,y,z} is used)
  - $D^0 \to K_S(\pi\pi)\pi^0(\gamma\gamma)$
    - **NDF: 0** = [4+4+(4+2)+2*5+2*3] - [7+7+4+4*3]
    - → use mass constraint to increase N_equations by one (your job)

K_S has measurable flight length (π^0 does not)
→{x,y,z} extracted for K_S
and geometric constraint used for K_S
(automatically)

	Params	Equations
Track	$\{p_x,p_y,p_z\}$	5
Photon/K_L	$\{p_x,p_y,p_z\}$	3
Composite	$\{p_x,p_y,p_z,E\}$ $\{x,y,z\}$	4 (kinematic) 2 (geometric)
Mass constraint	-	1
Origin Constraint	-	2