Tracking and Vertexing in Belle II

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On behalf of the Belle II tracking group

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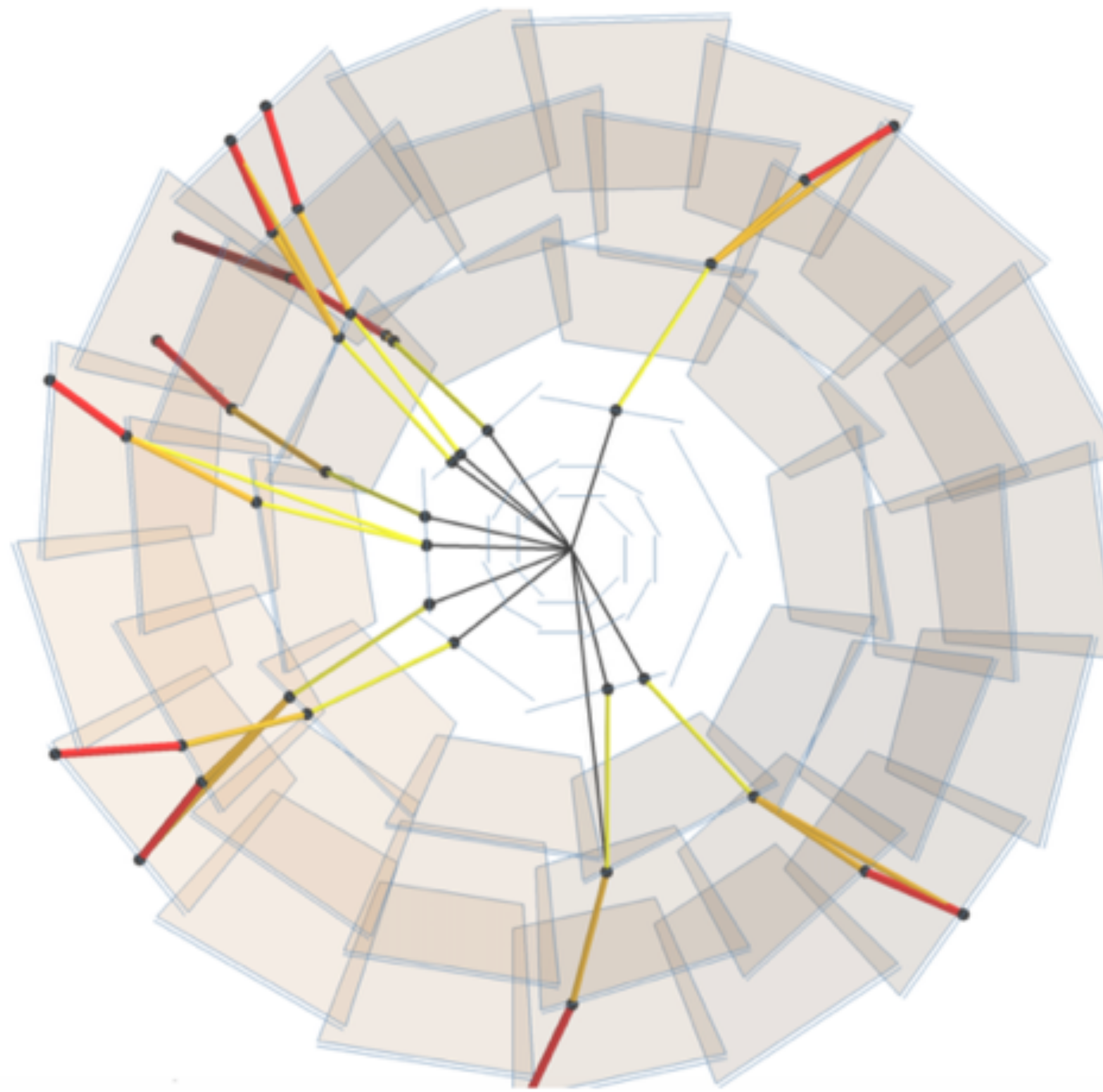
Outlook

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



The challenges of tracking at Belle II

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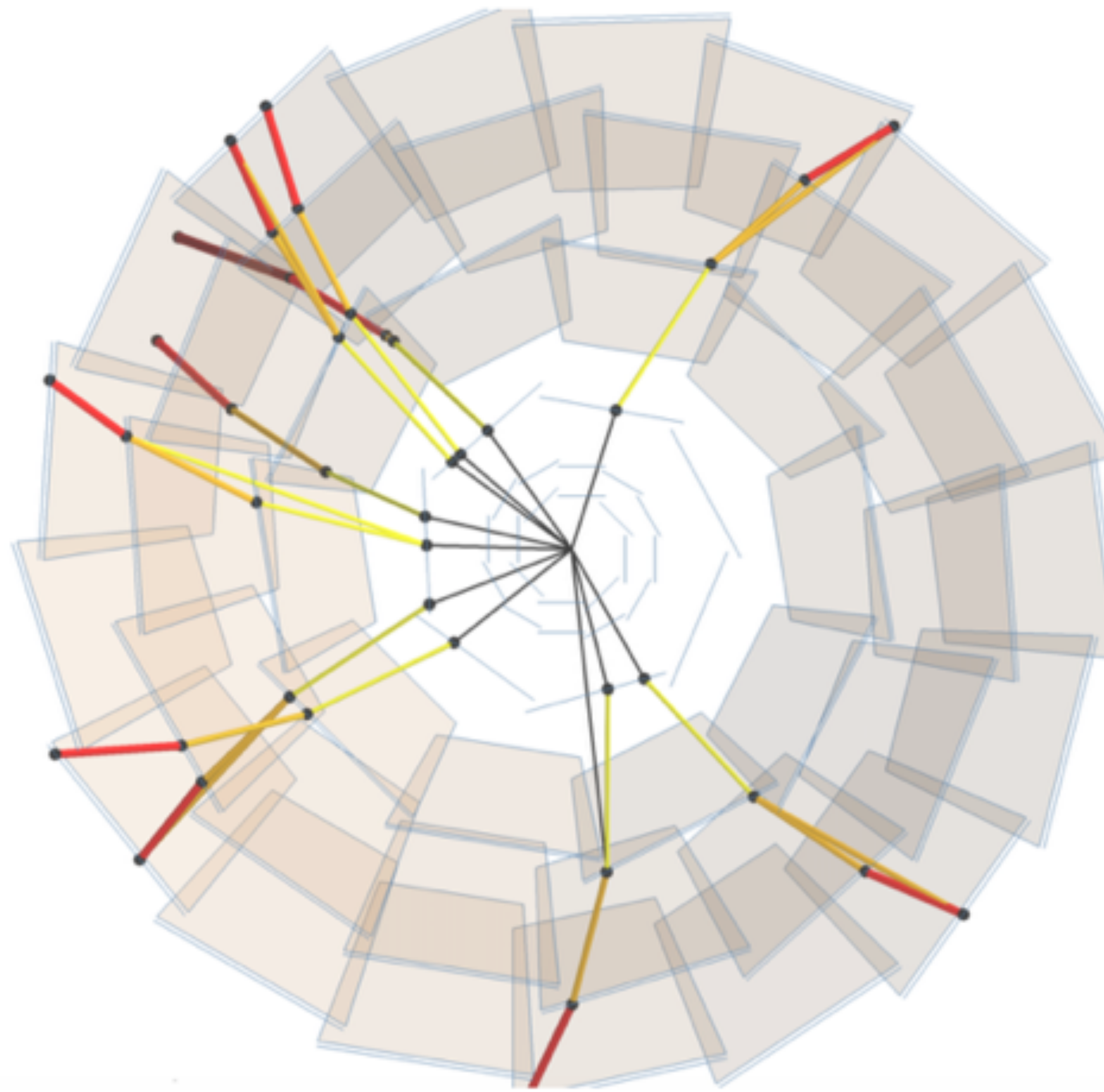
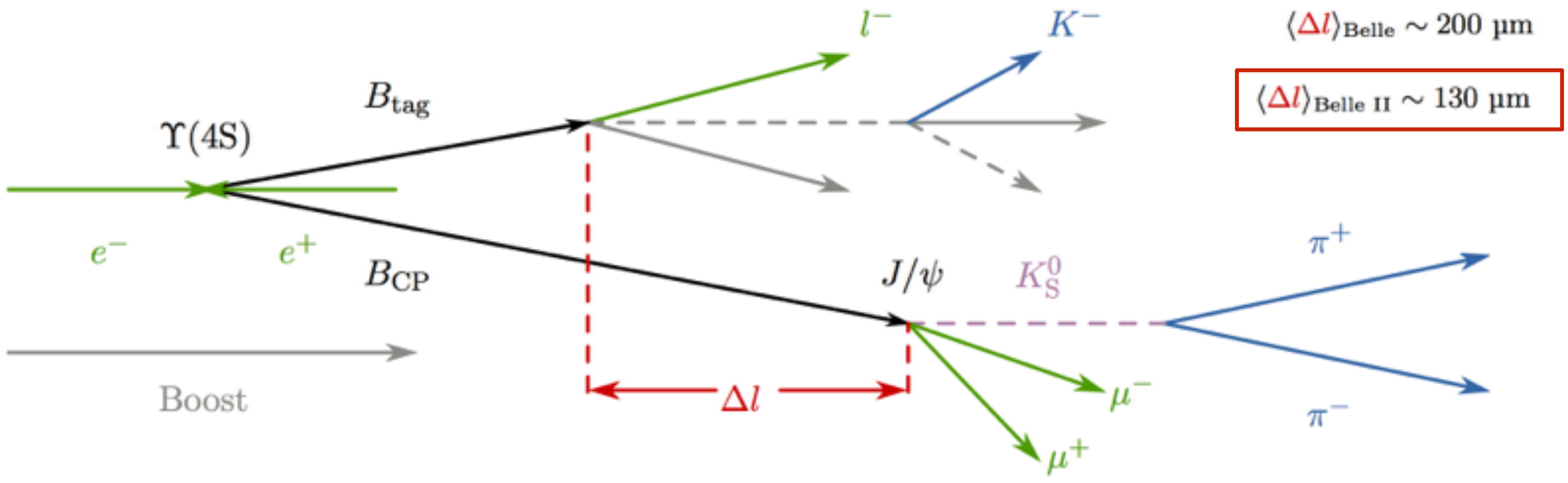
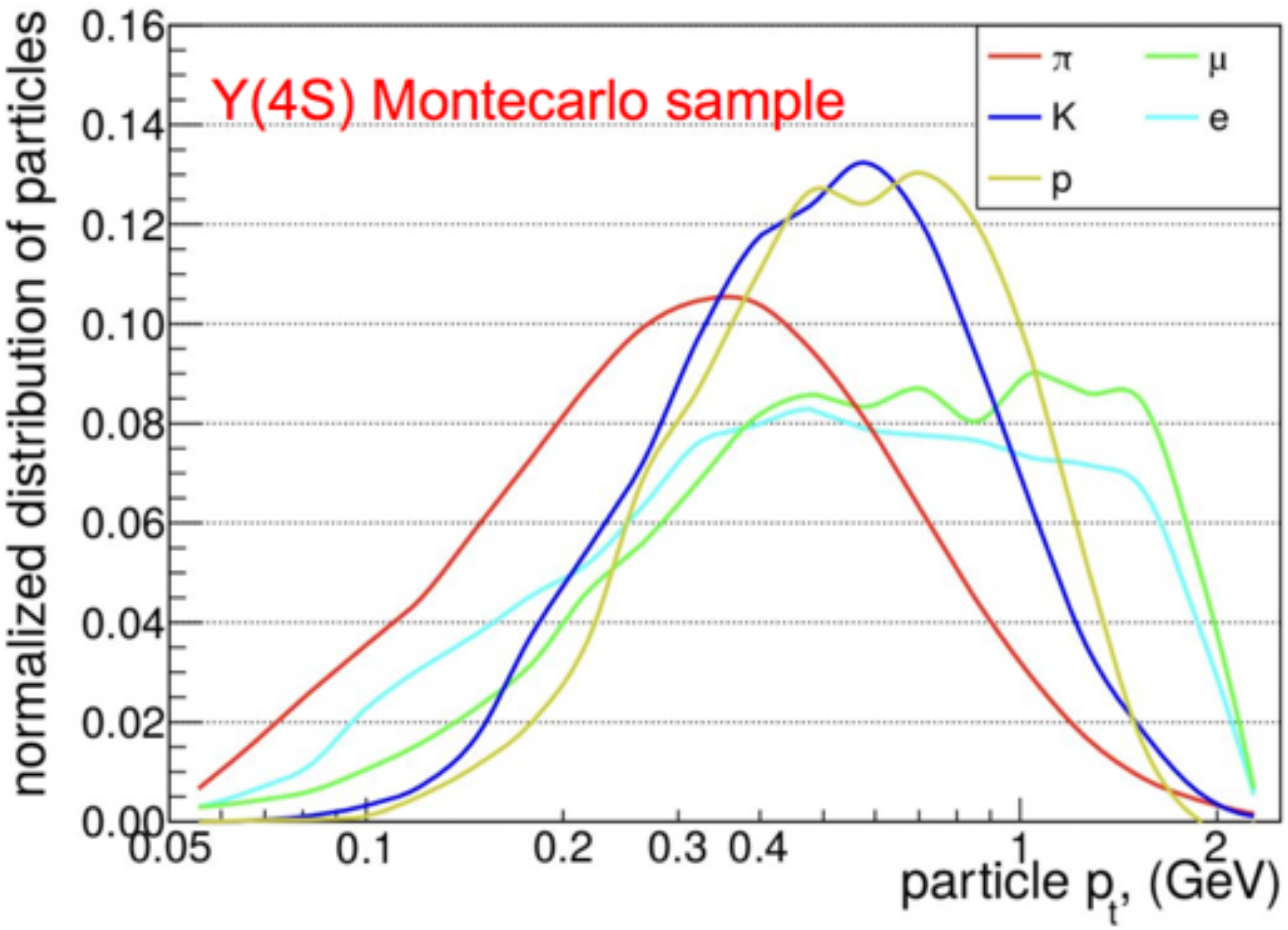


The challenges of tracking at Belle II

- 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)



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



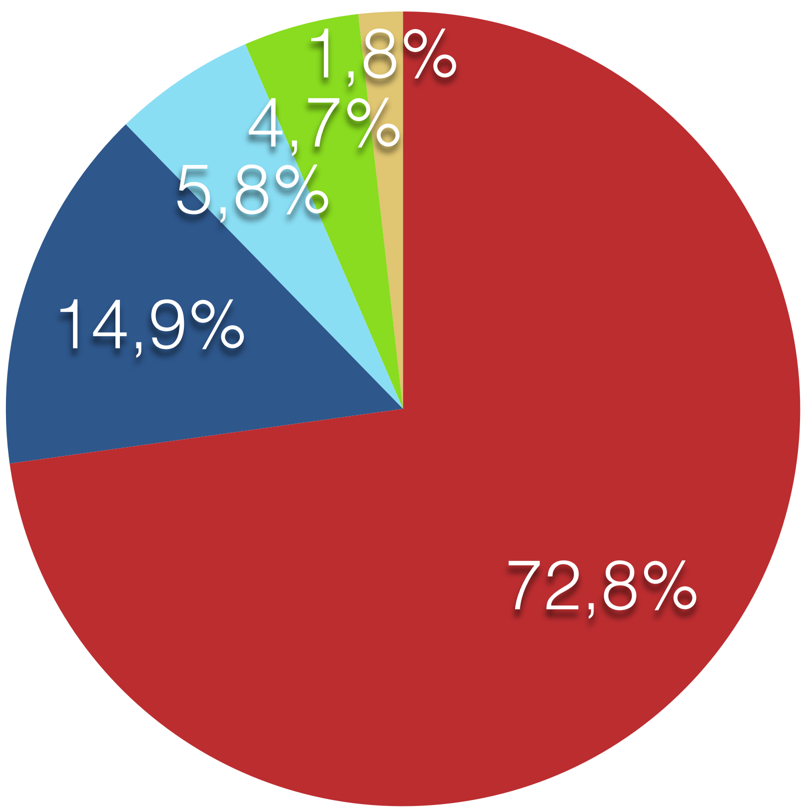


Fig: Average fraction of particles produced according to the type

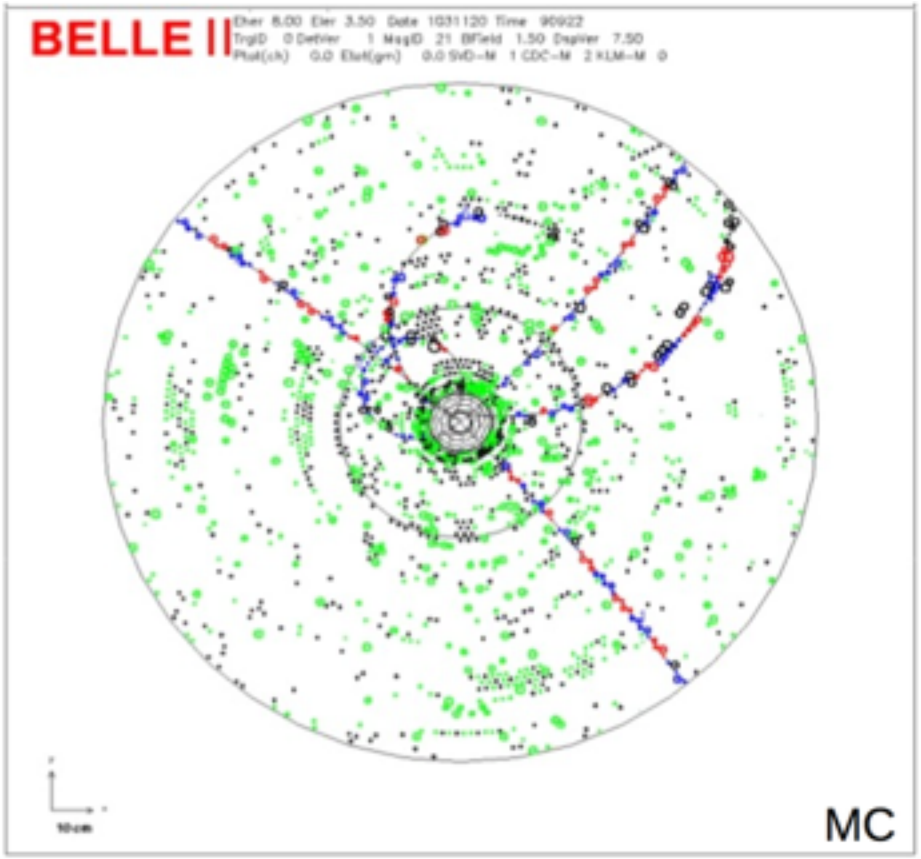
- Large fraction of π
- Mostly particles with p below 1 GeV

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 → few hundreds signal hits
  10^4 background hits



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

The challenges of tracking at Belle II

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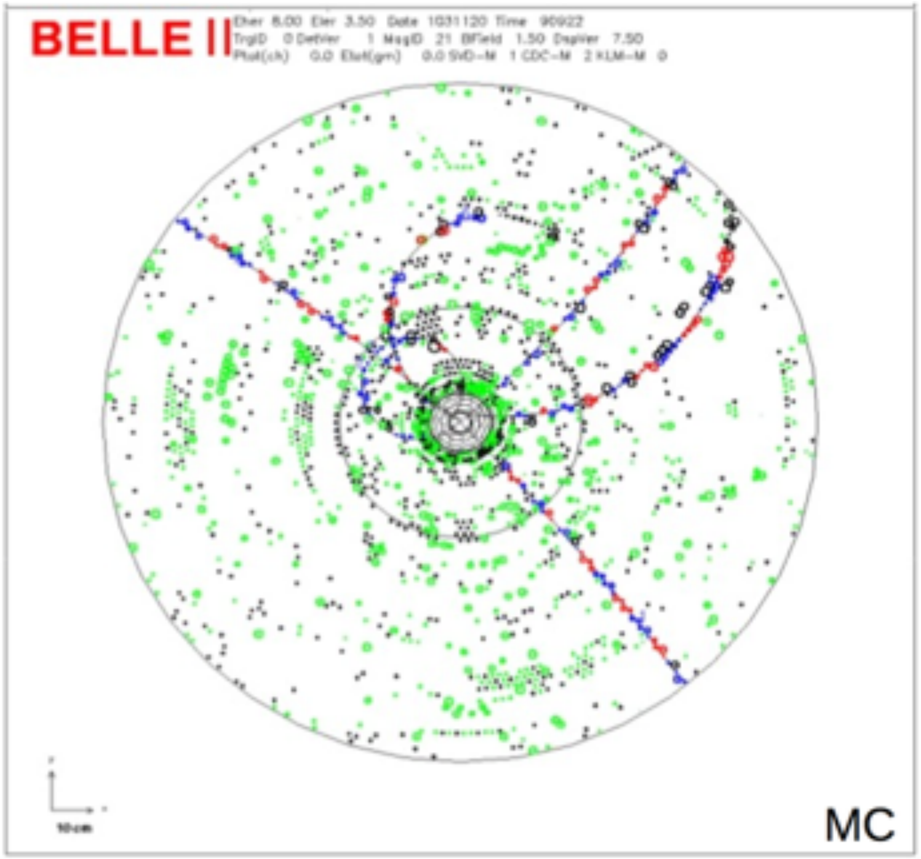
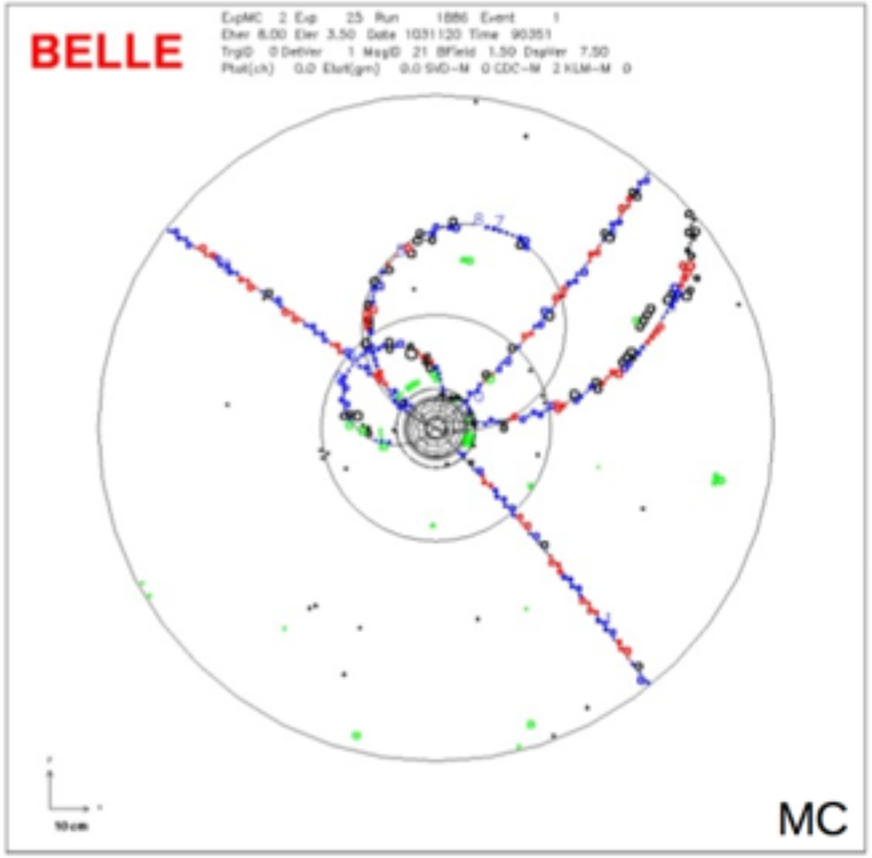
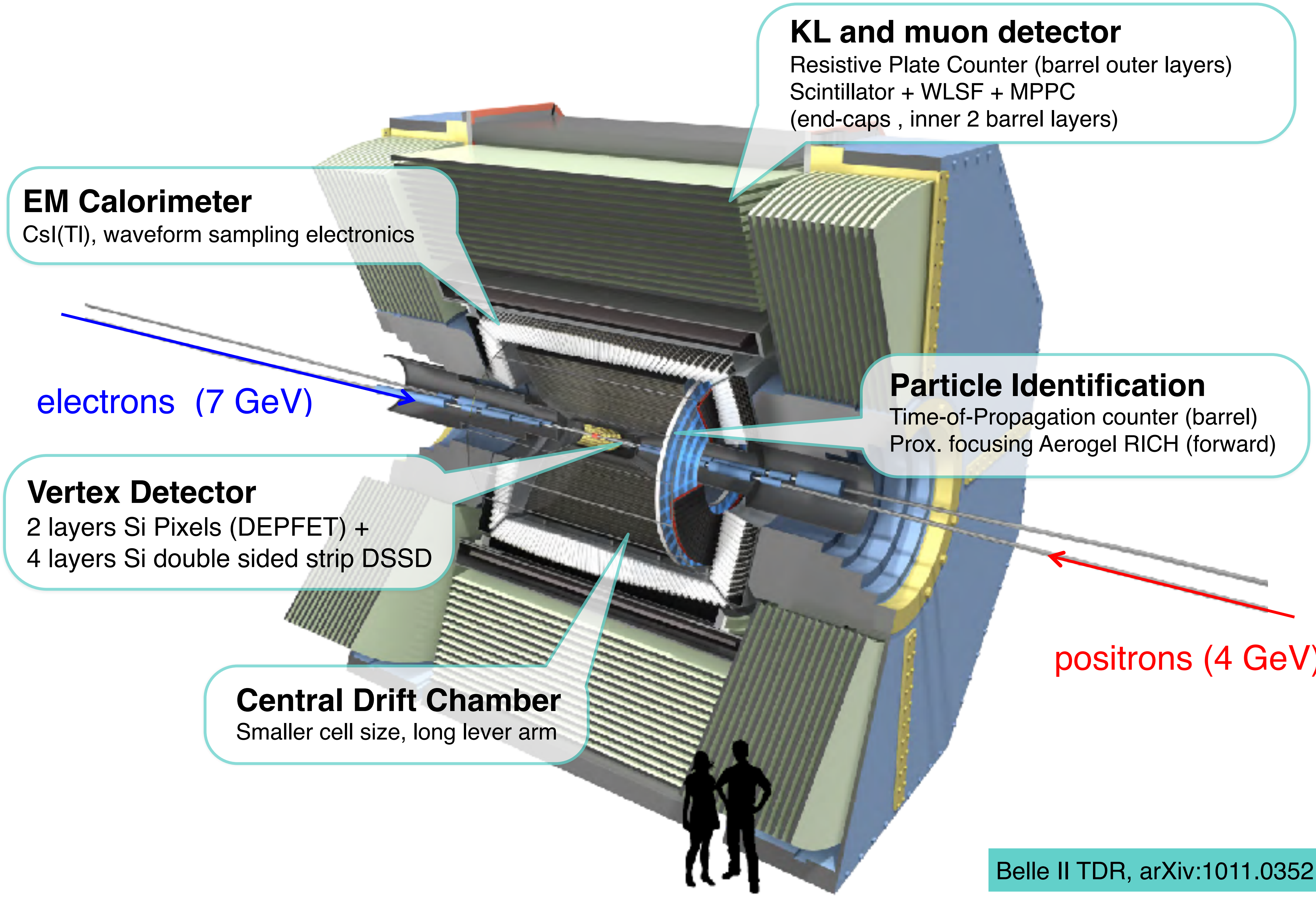


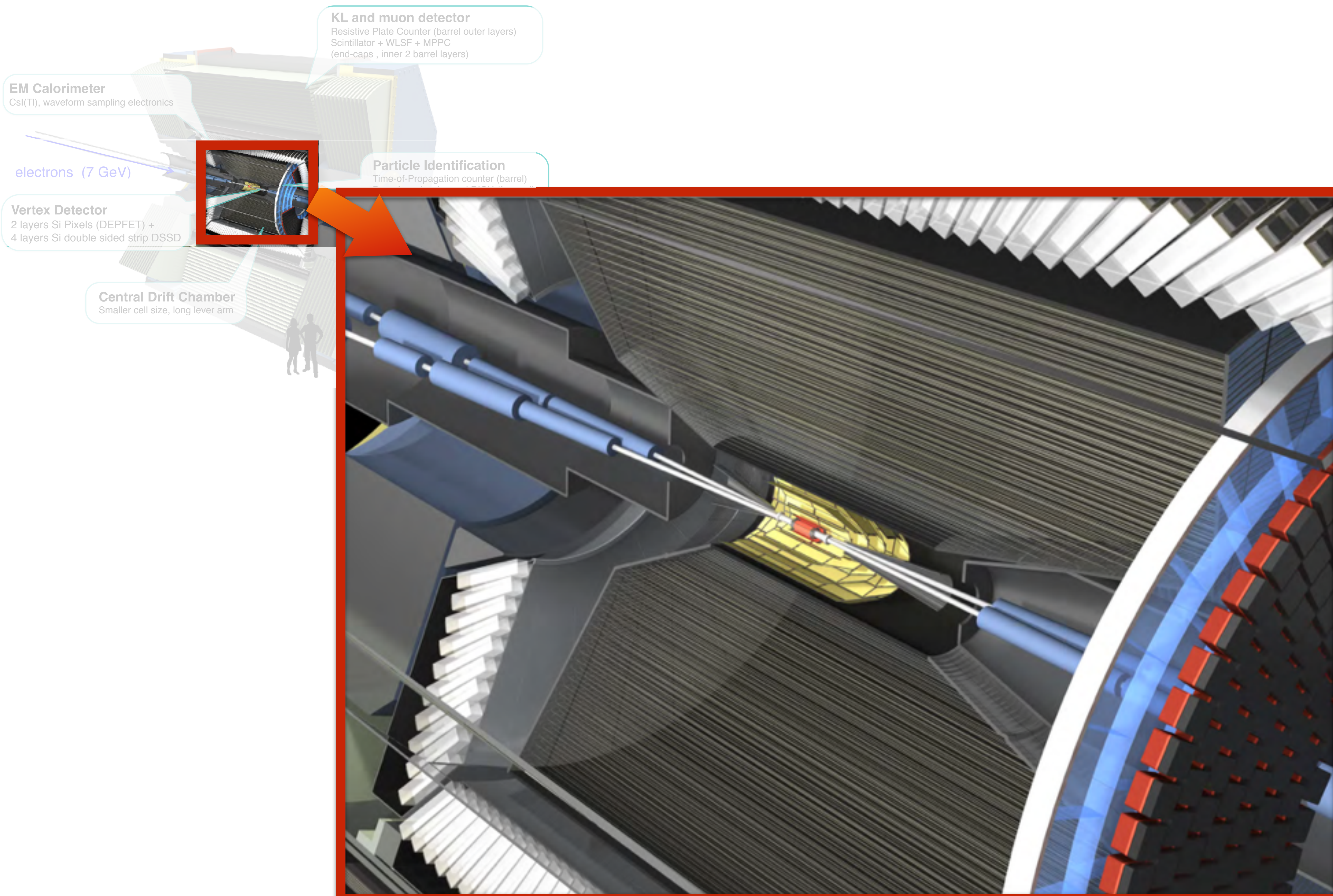


The Belle II detector



Belle II TDR, arXiv:1011.0352

The Belle II detector



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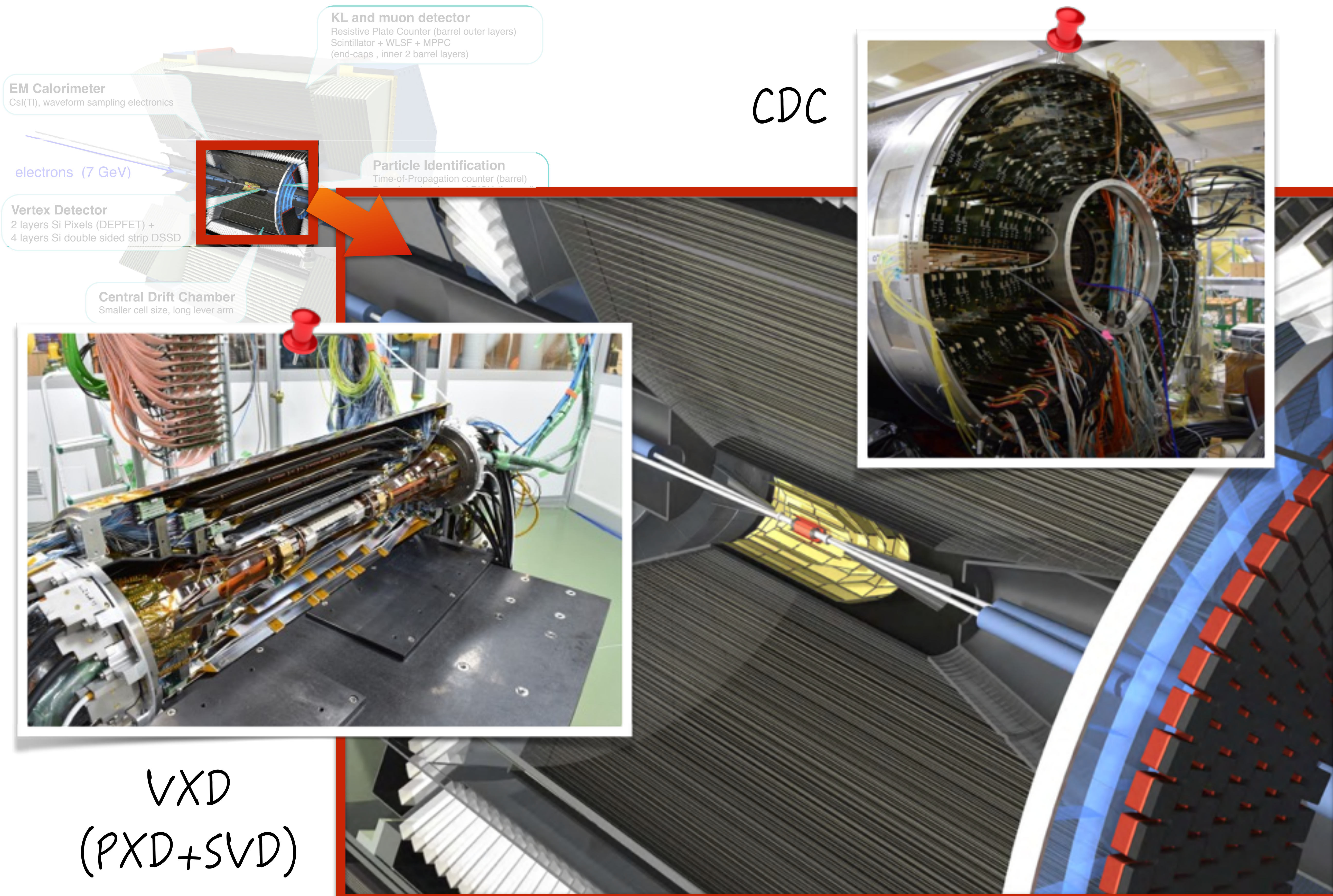
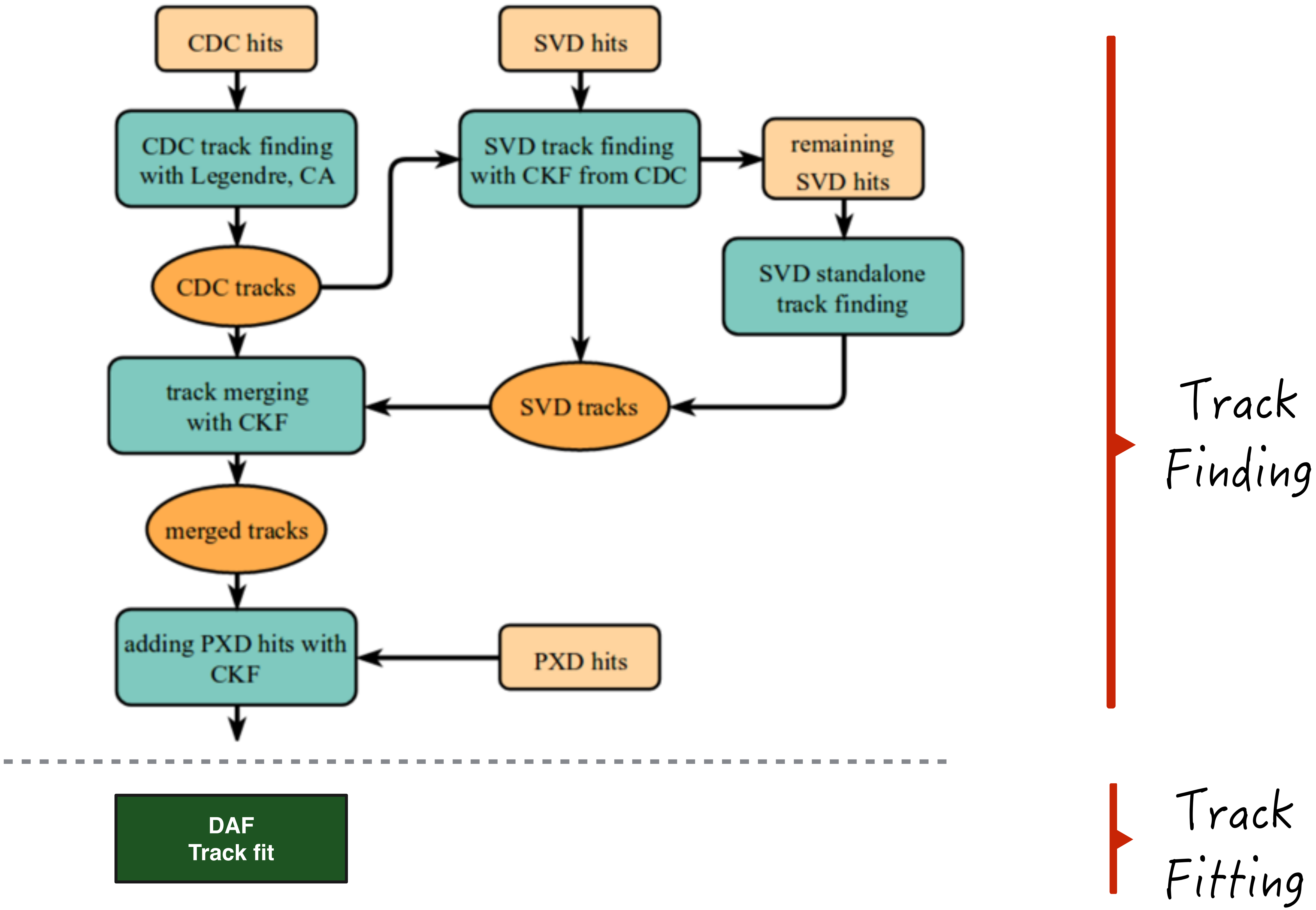


Tracking design



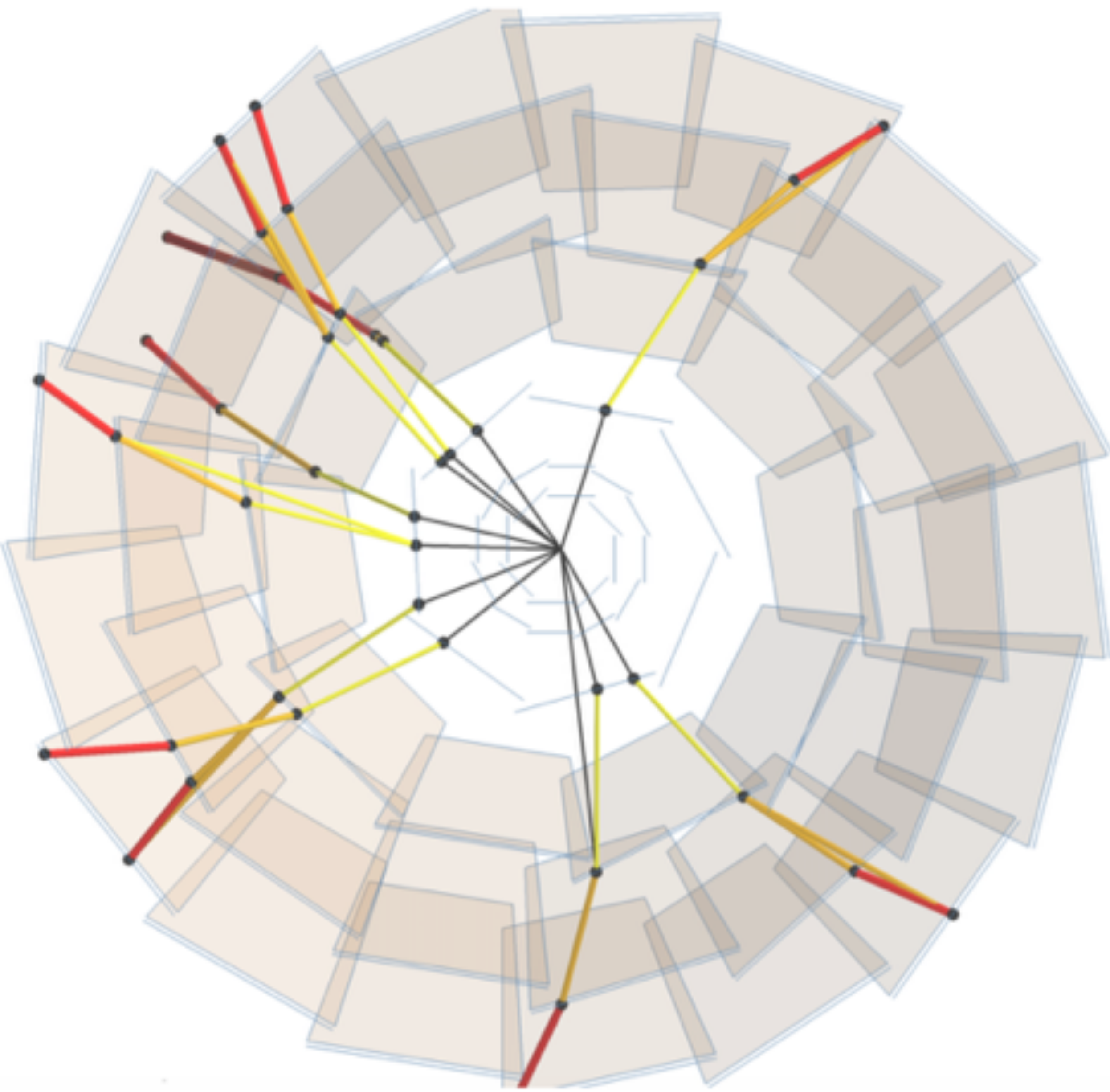
The challenges of tracking at Belle II

Track Finding

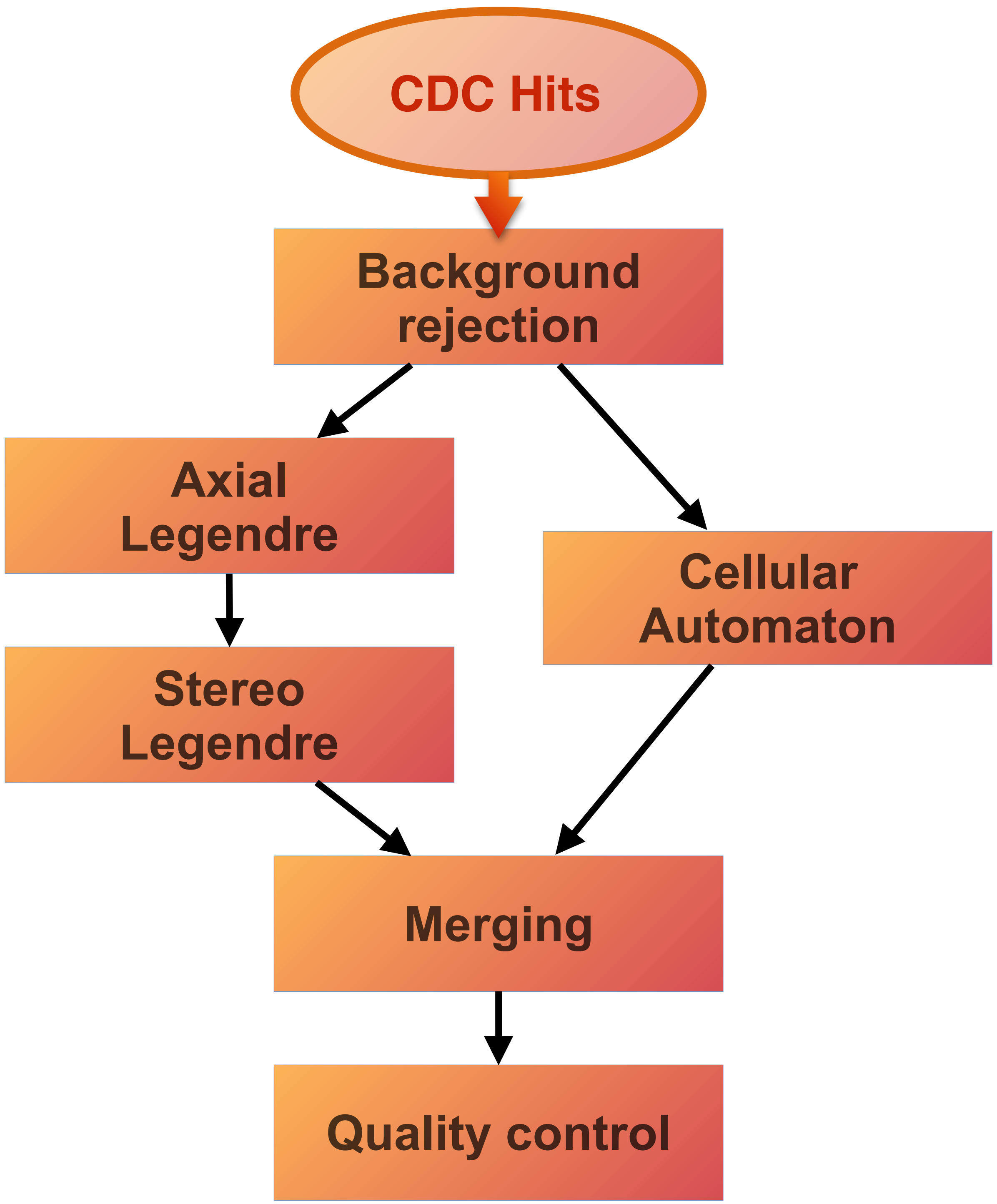
Track Fitting

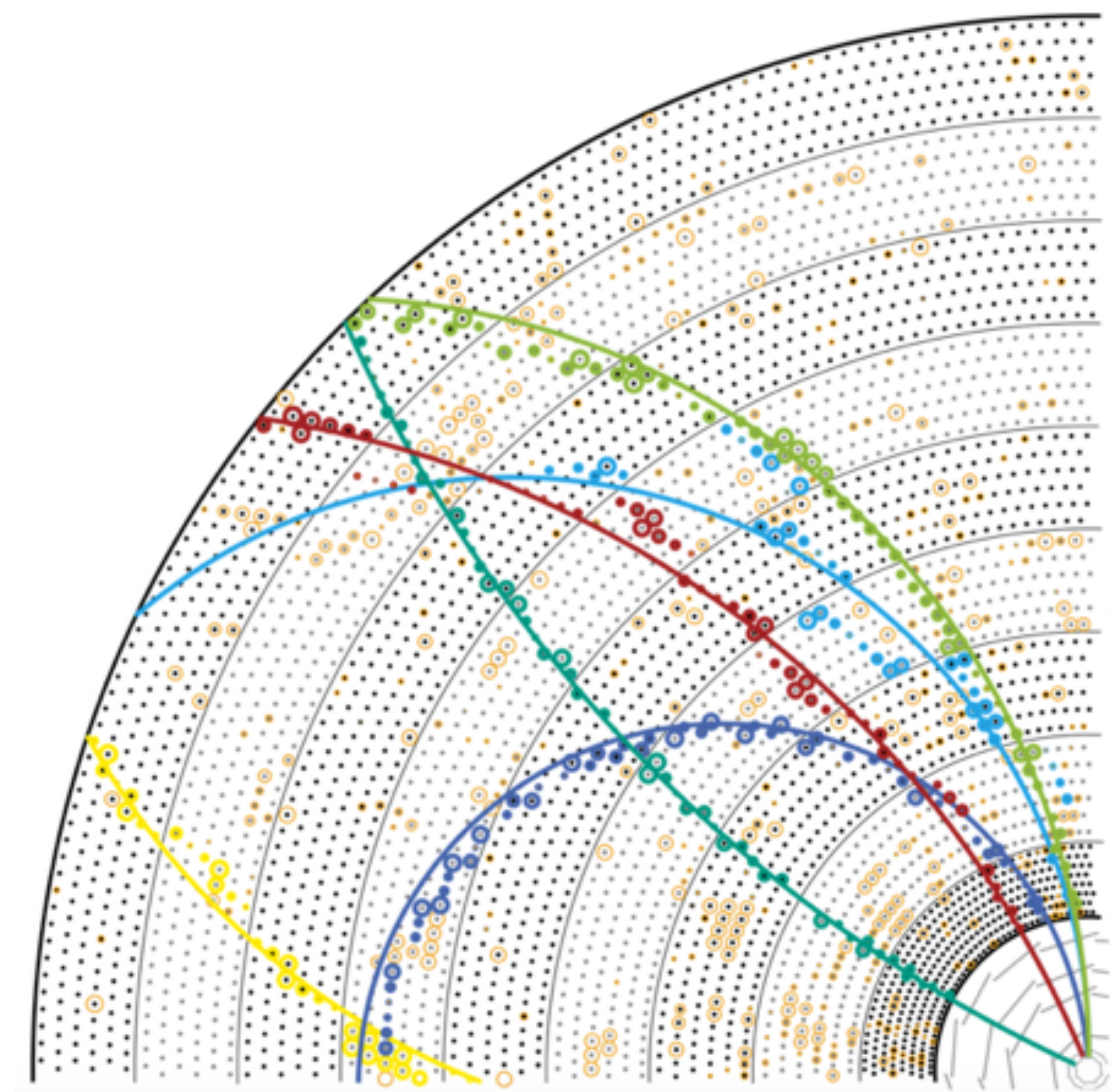
Vertexing

Performances

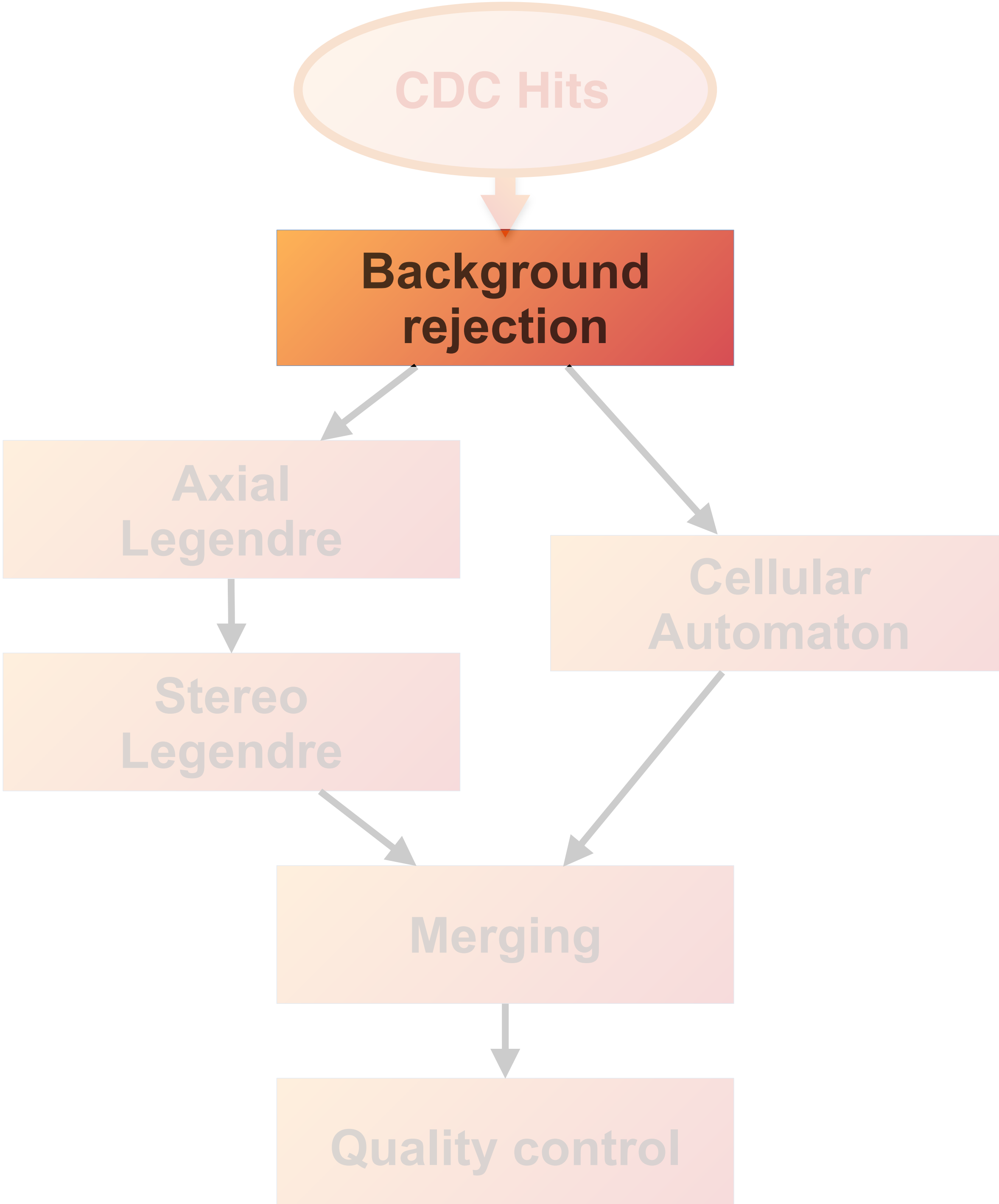


CDC track finding

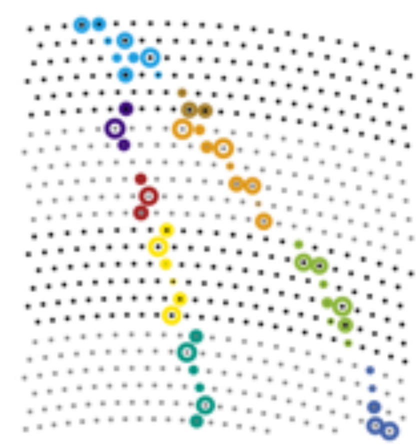




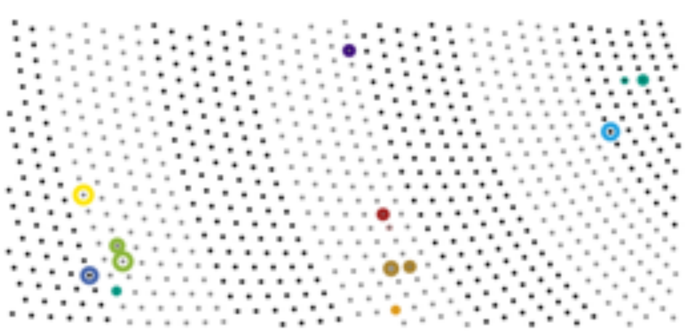
Background filter



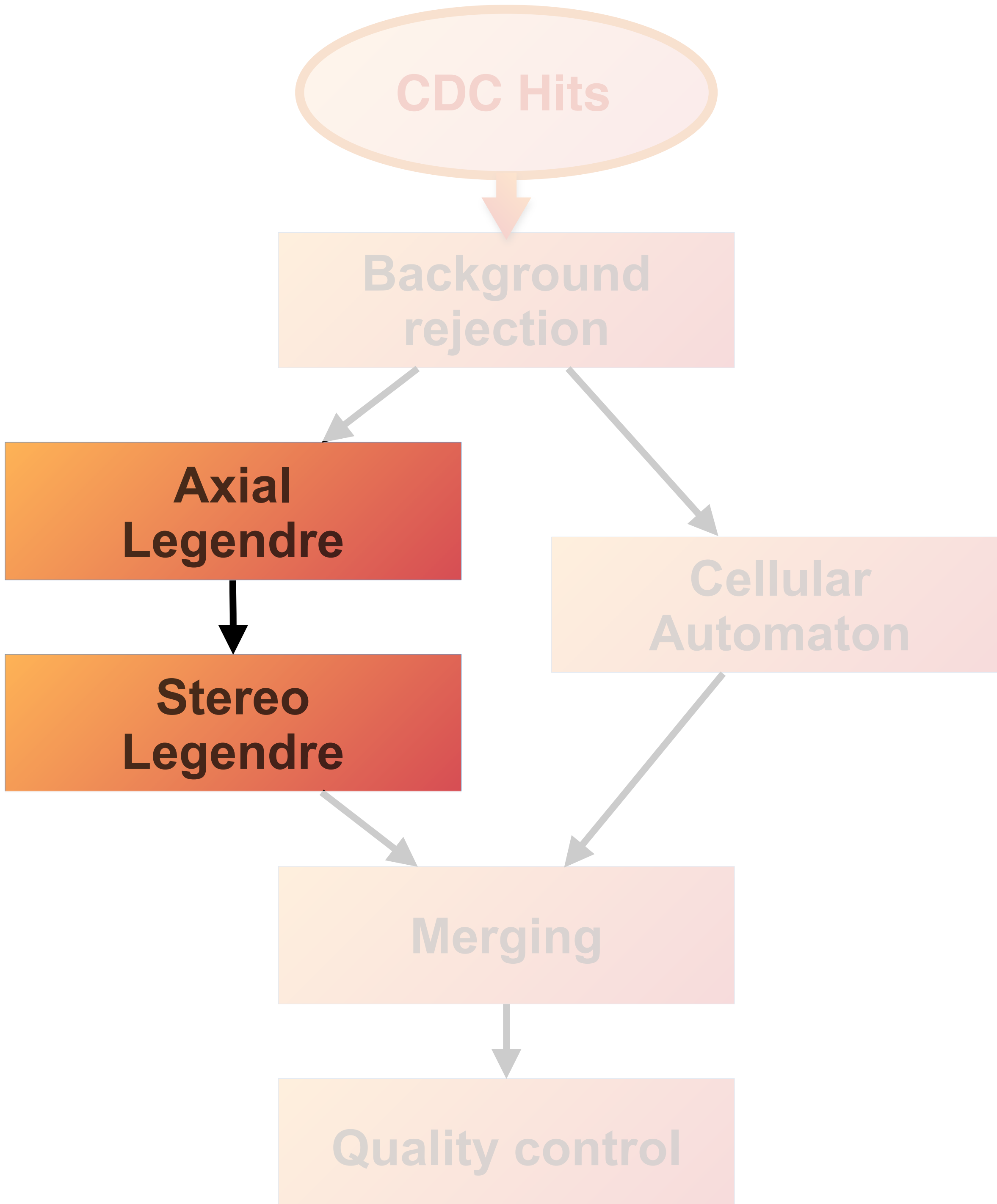
- Background filter implemented with a MVA (FastBDT)
- Based on variables from clustered hits
- Will be tuned with single beam data



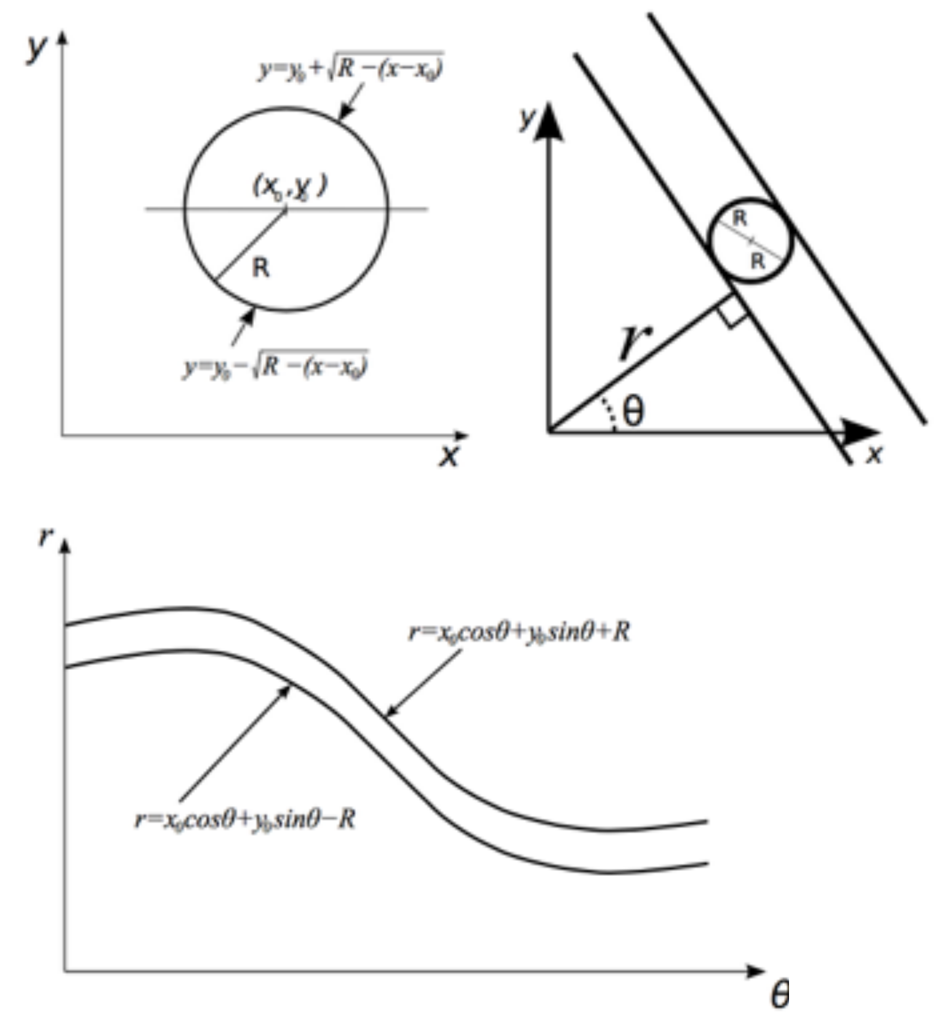
Signal



Background

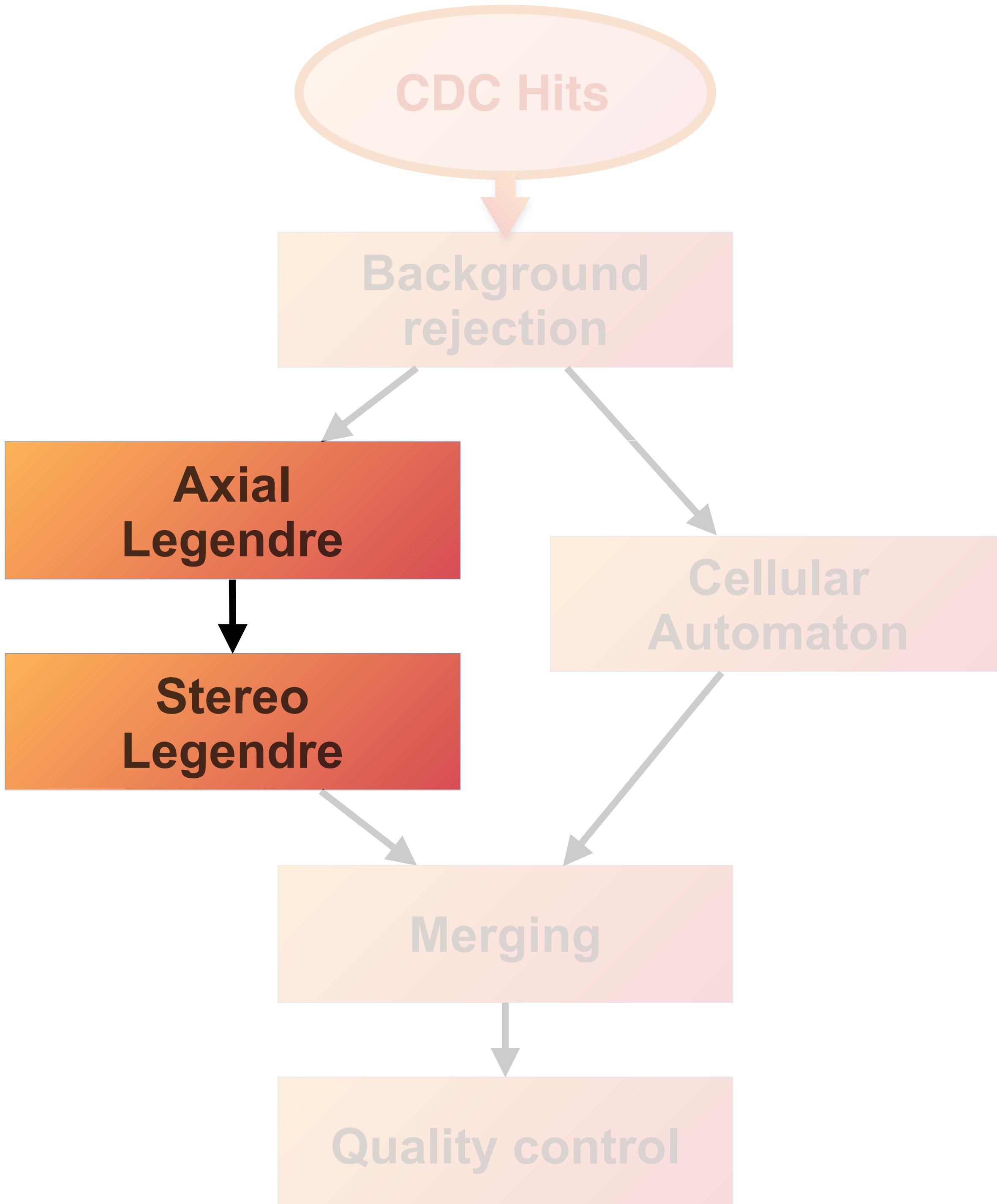


- Idea: transformation of the drift circles using Legendre transform and mapping of hits onto Legendre plane

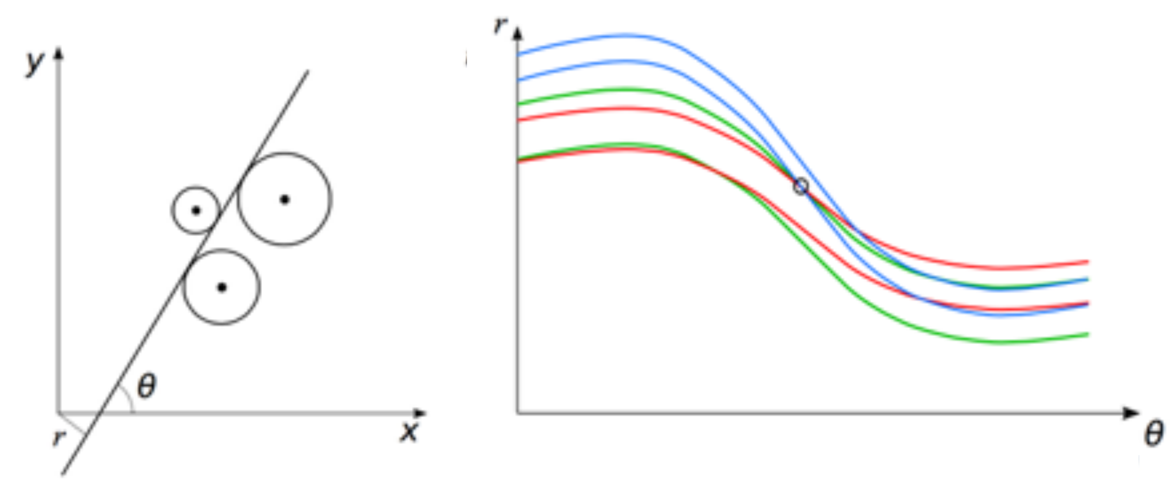


$$r = x_0 \cos\theta + y_0 \sin\theta \pm R_{dr}$$

Global Legendre Algorithm

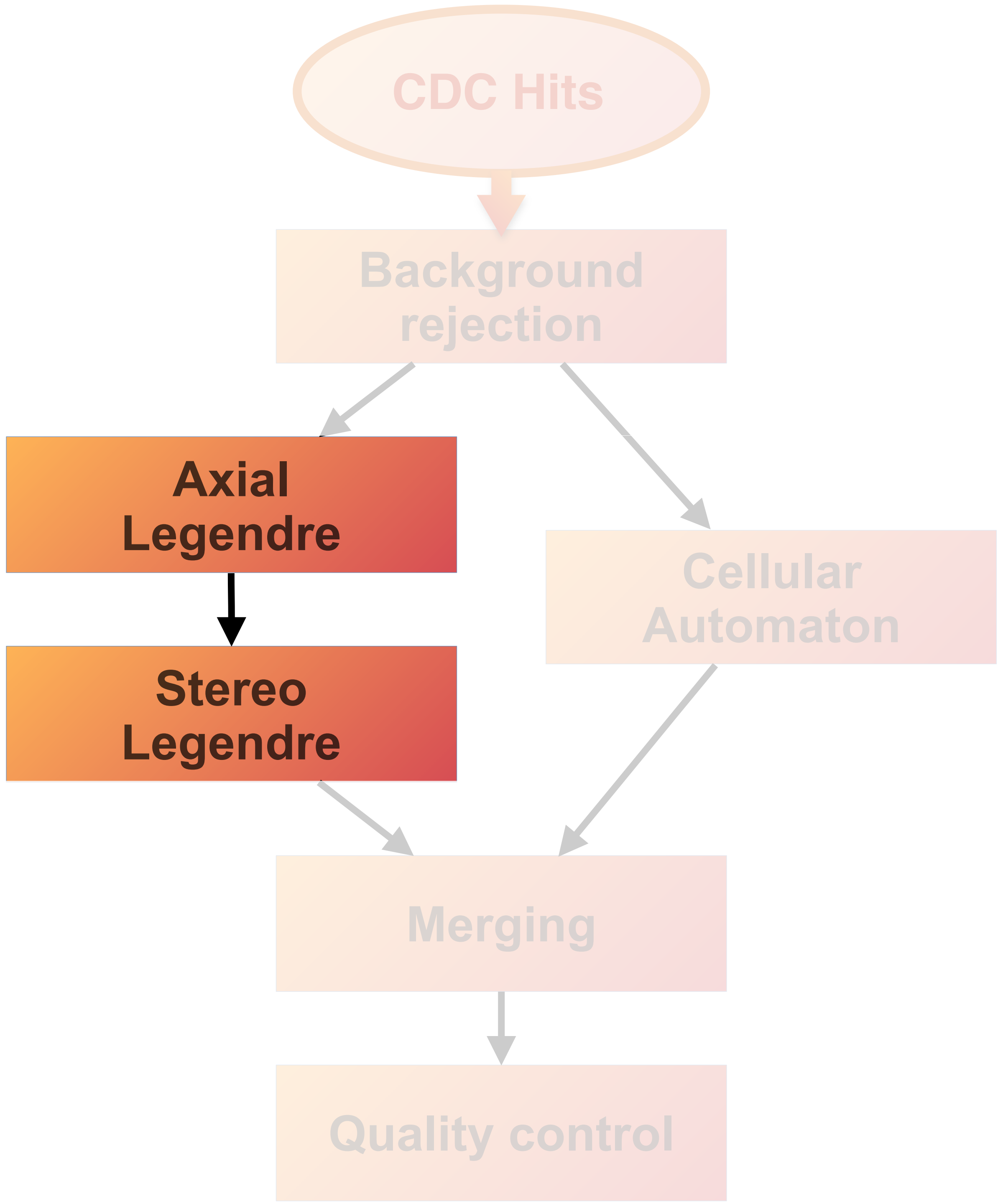


- Hits in the CDC be can geometrically represented as circles
  - Center: fired sense wire
  - Radius: hit drift length



- Drift circles sharing the common tangent → the intersection of sinograms in Legendre space corresponds to the parameters of the common tangent

Global Legendre Algorithm



- It is possible to reduce the problem of the Legendre-based global pattern recognition to the problem of the identification of the most populated regions in the Legendre space
- 2-dimensional binary search toward the possible track candidate

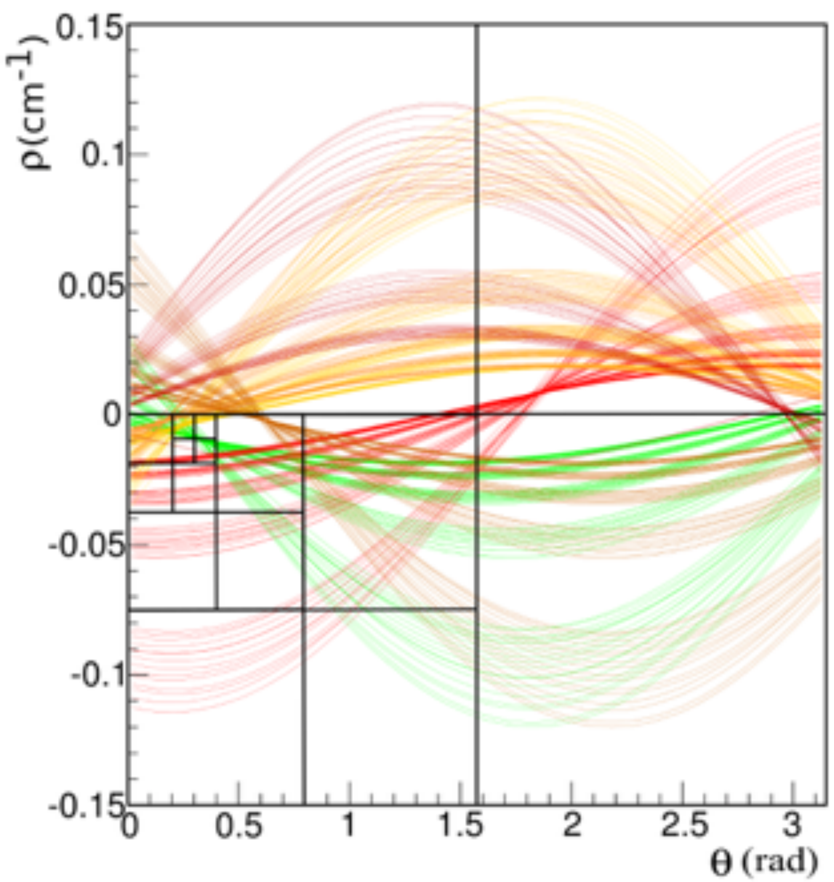
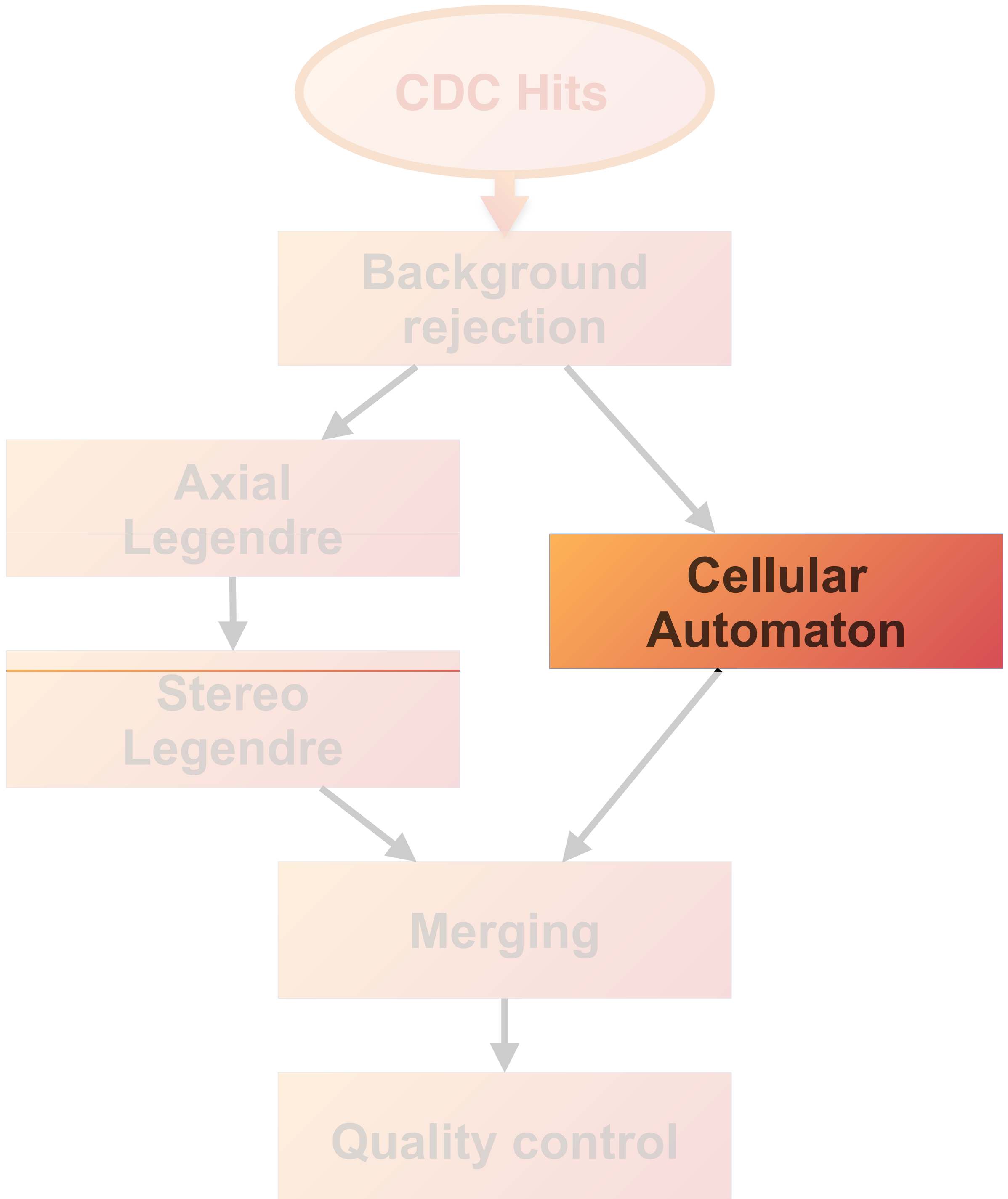


Fig: Simulated $B\bar{B}$ event with 6 tracks in the Legendre plane

Cellular Automaton



Clusters

↓

Triplets

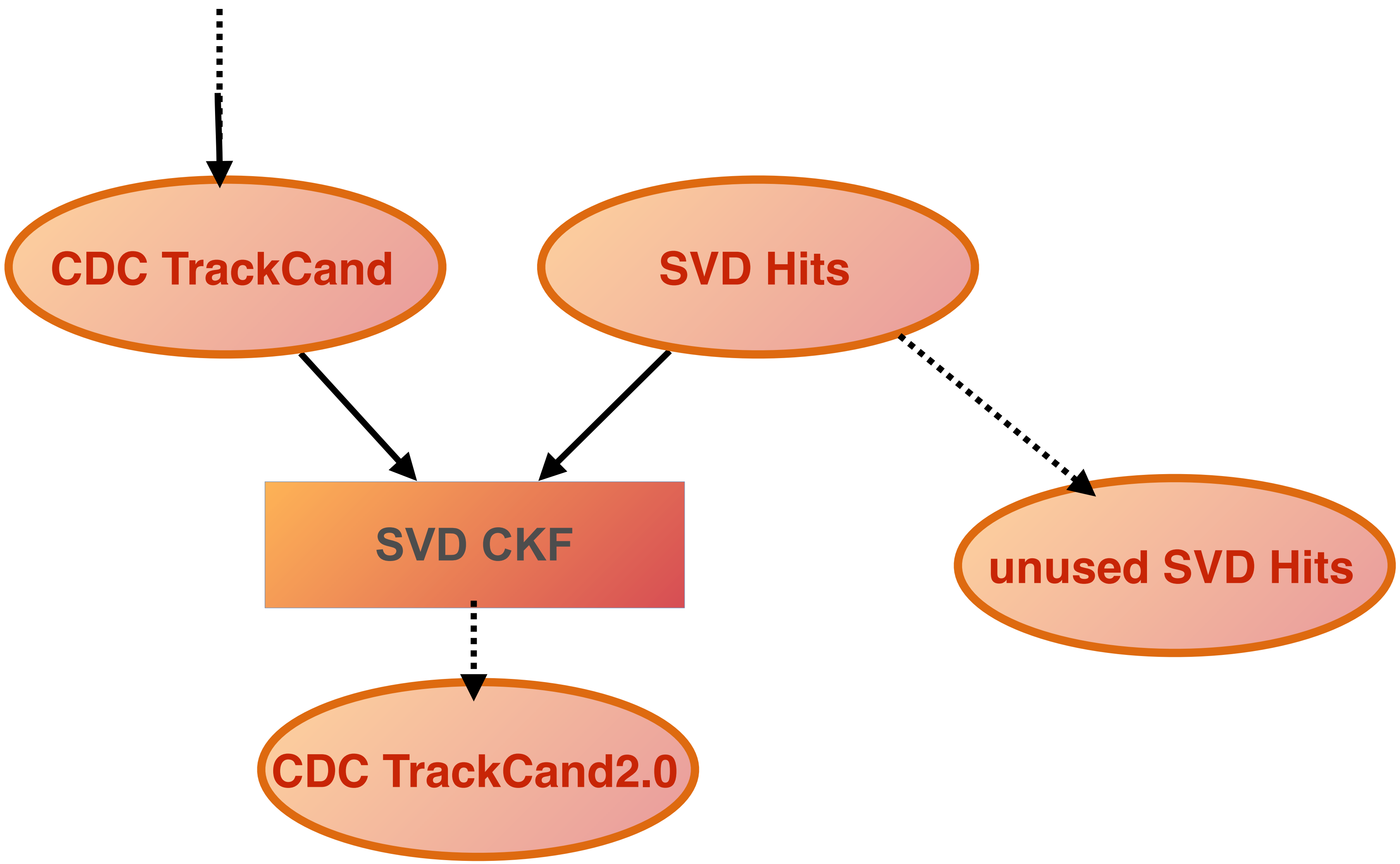
↓

Segments

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

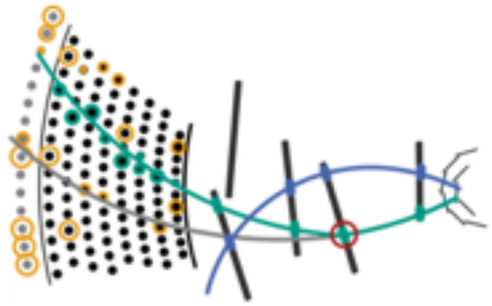
- Build segments from individual hits in each super layer
- Build tracks from segments

SVD CKF

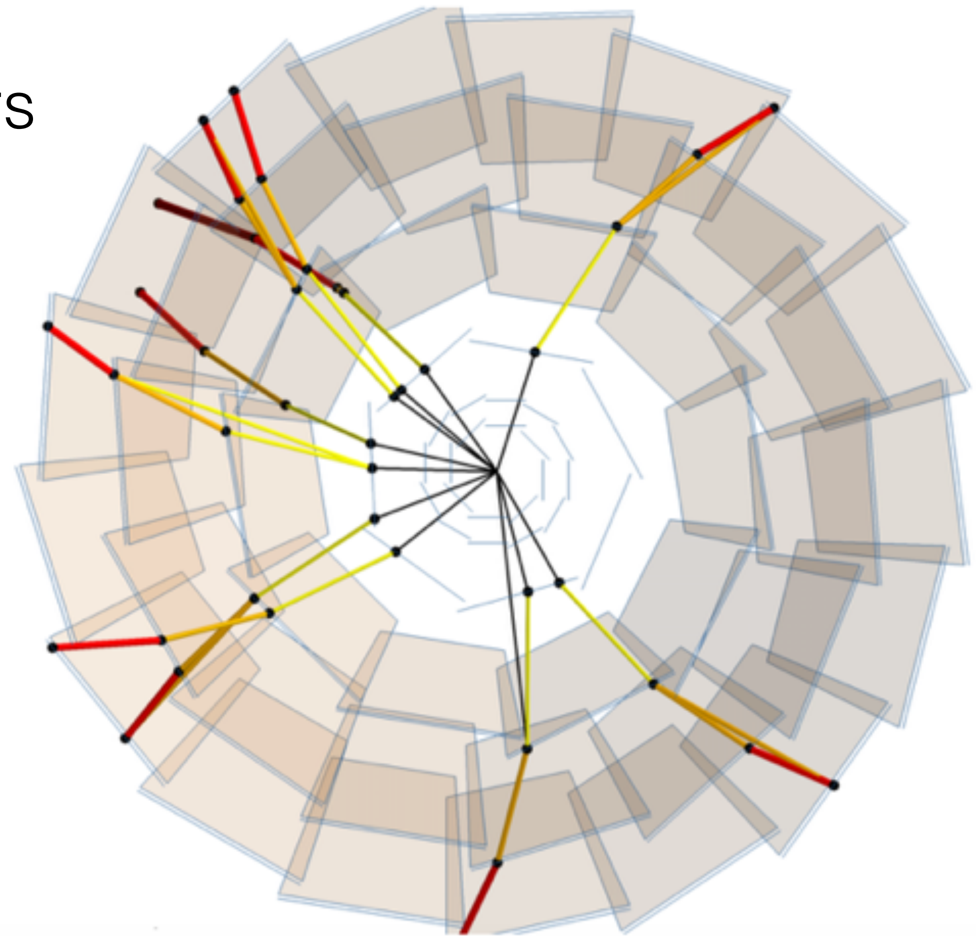


- SVD track finding with CFK from CDC
  - A Combinatorial Kalman Filter uses the principles of the Kalman Filter for track finding
  - Starting with a seed it adds hits with Monte Carlo Tree Search algorithm

SVD standalone track finding

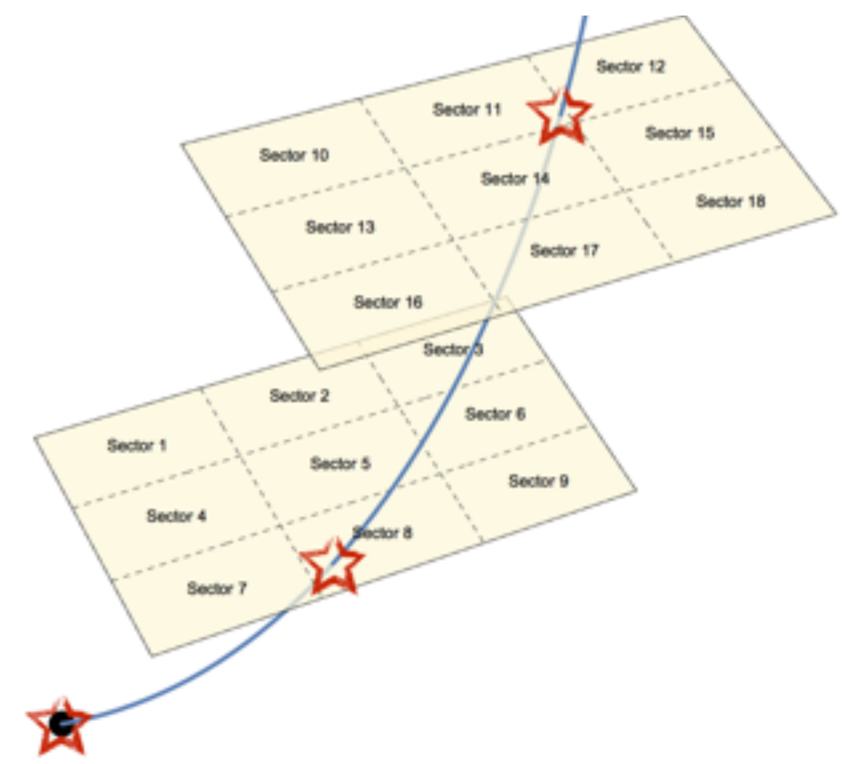


- Cellular Automaton collects paths beginning with outermost SVD 3D-hits
- Based on the concept of a sector on sensor (SectorMaps)
- Neighboring 3D-hits are given by a set of filters
- Reduction of combinatorics
- Allows for multiple scattering
- The final set of tracks is chosen from all paths such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



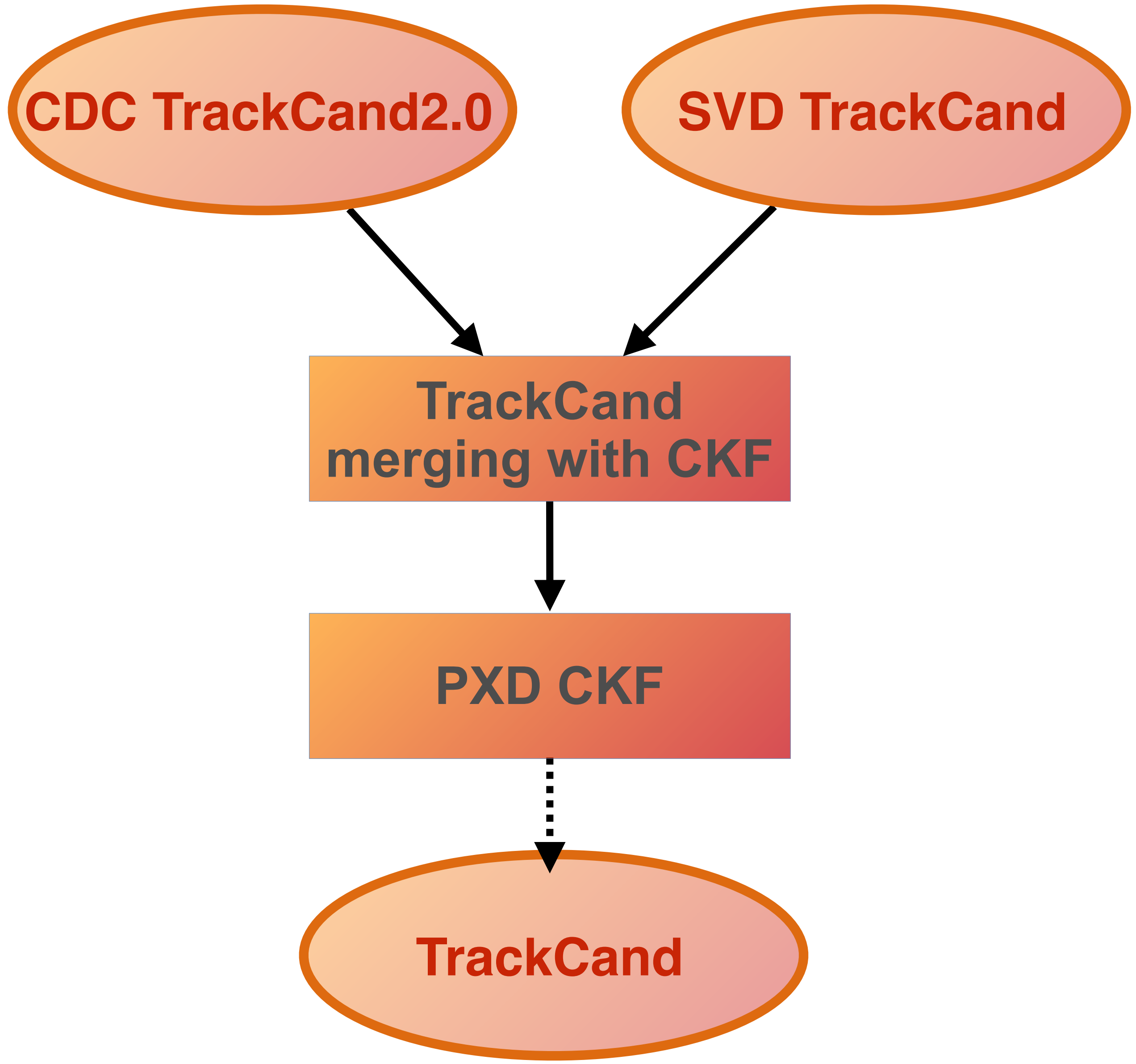
SVD standalone track finding

- 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 and time information
- Cut values obtained using simulations
- Cellular automaton → set of tracks potentially overlapping
- Greedy 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

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- **Track Fitting**
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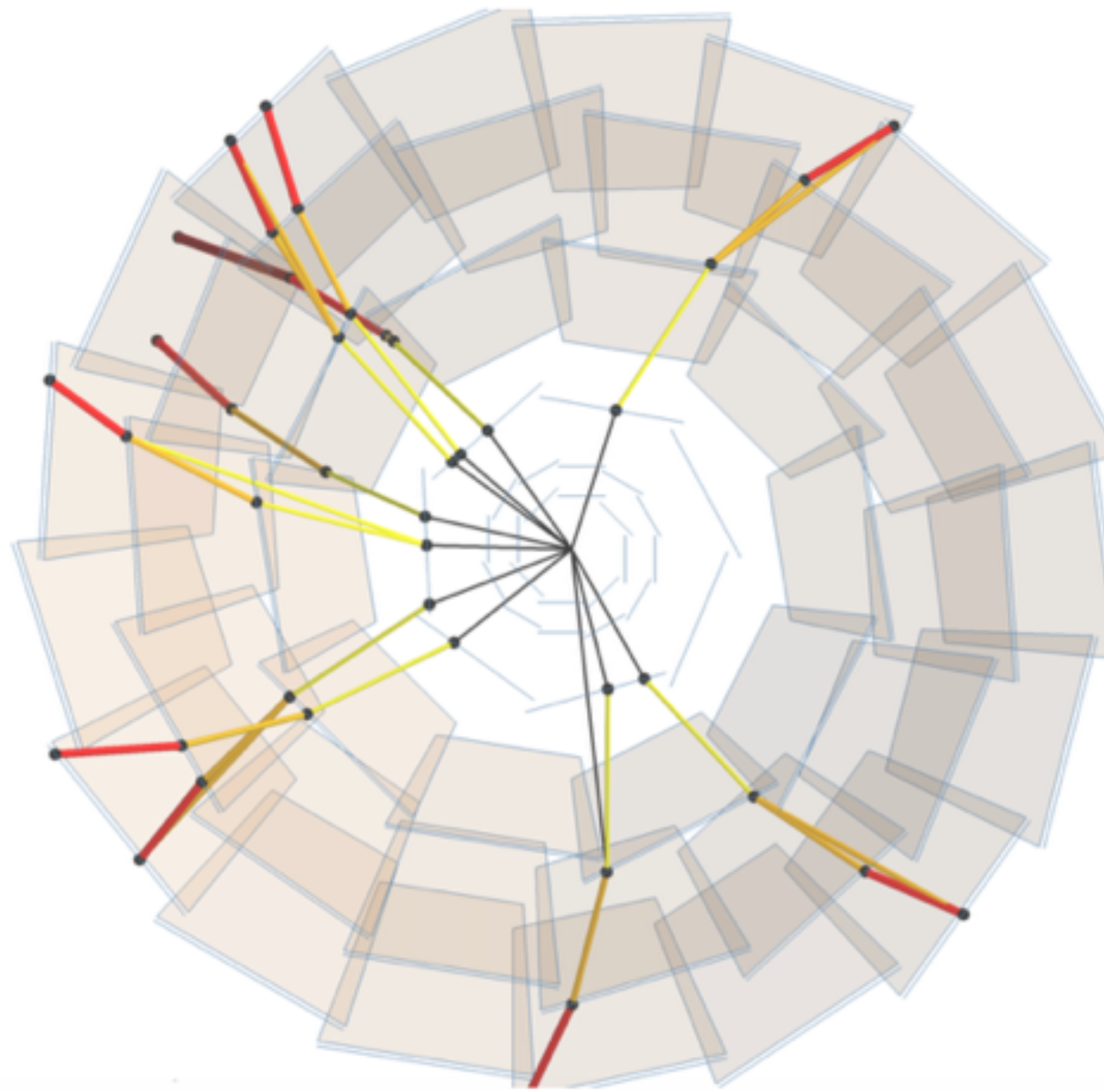
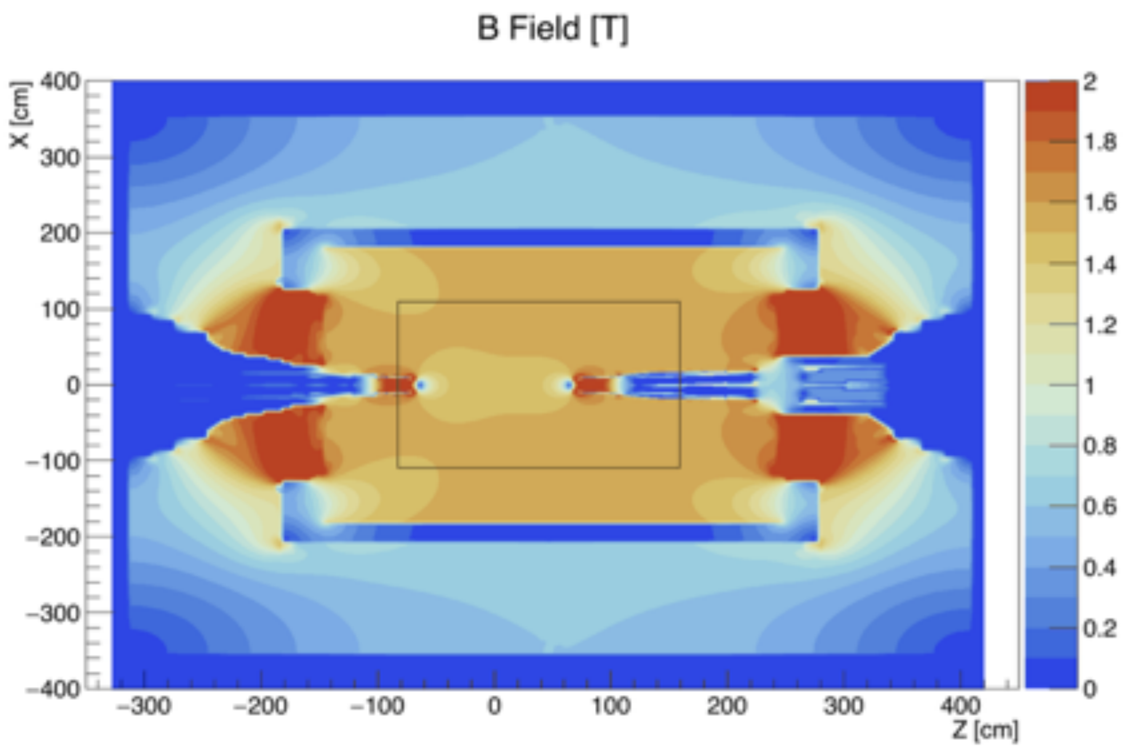


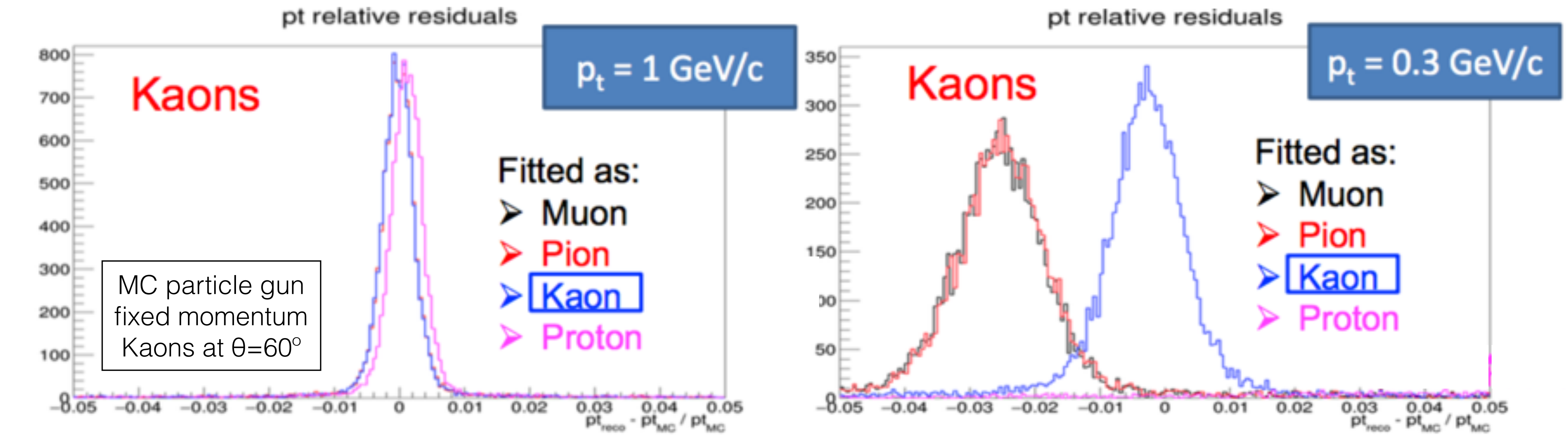
Track fitting

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



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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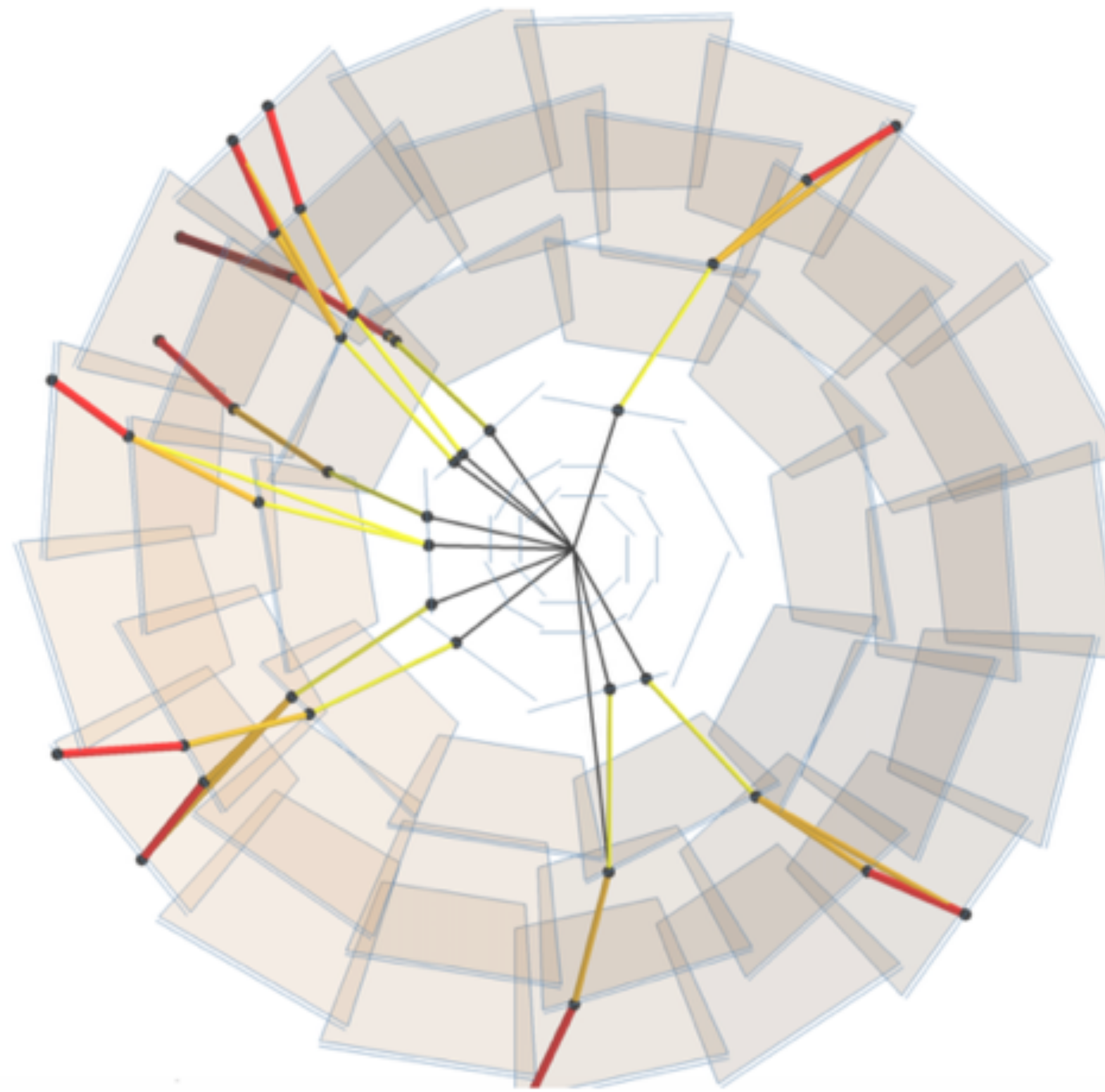


Vertex fitters in the Belle II code

- KFit
  - Belle (I) implementation
  - Based on a least square minimization approach
    - Can fit neutrals assuming the vertex is {0,0,0}

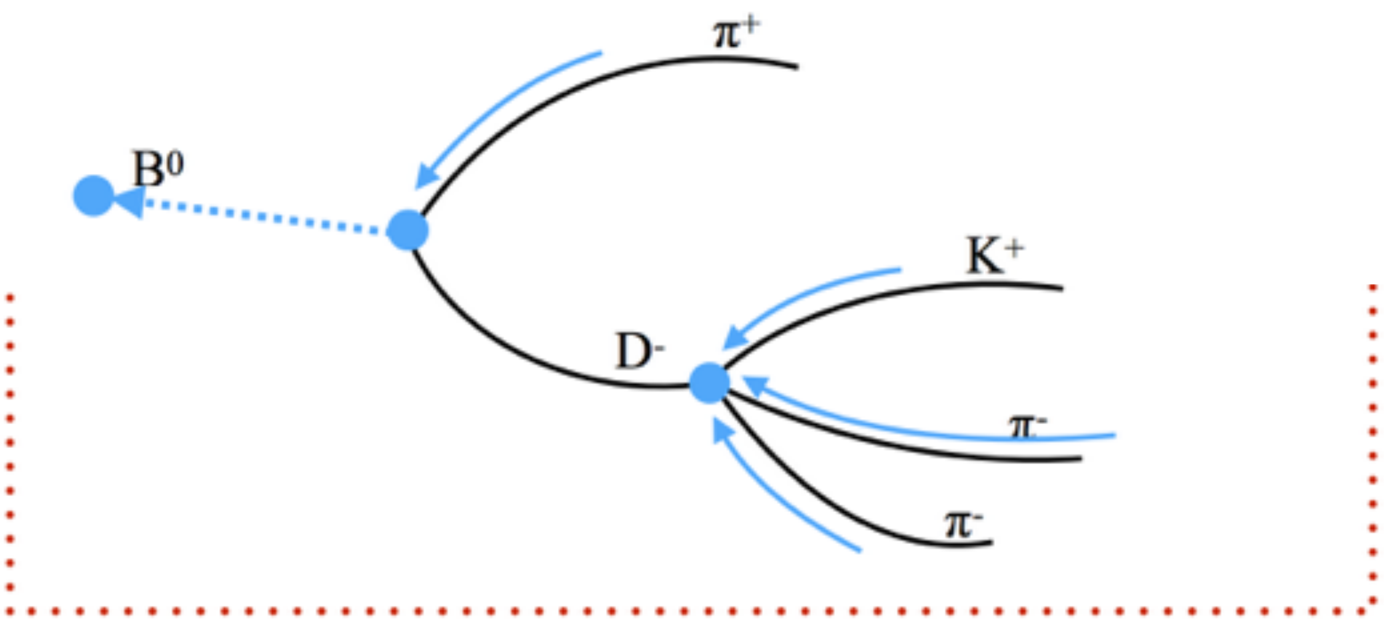
- RAVE
  - Standalone implementation of CMS libraries
  - Kalman filter approach
    - Weights tracks when using it to fit multiple tracks
    - Can only fit charged particles and single vertices

- 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

The challenges of tracking at Belle II

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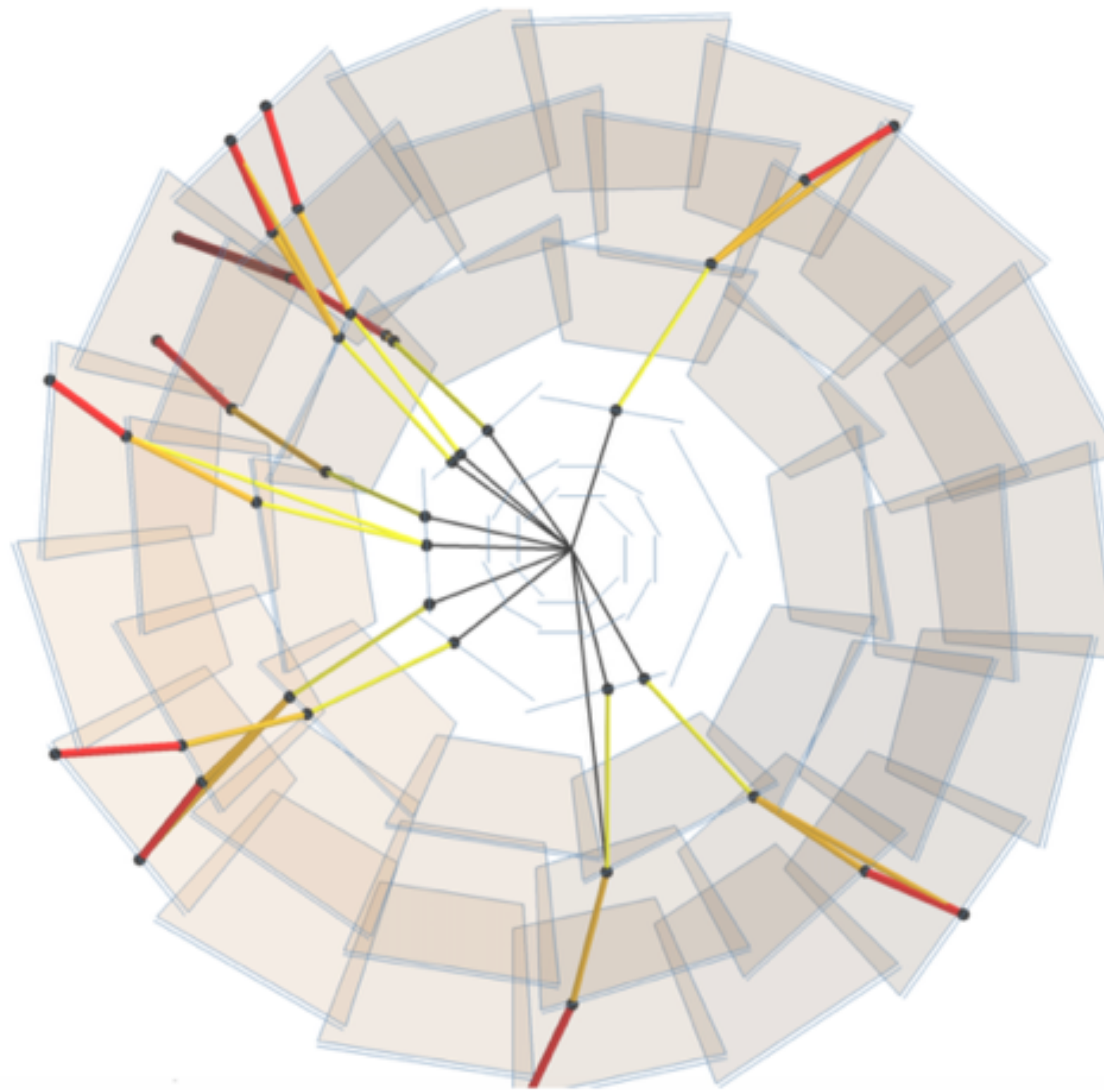
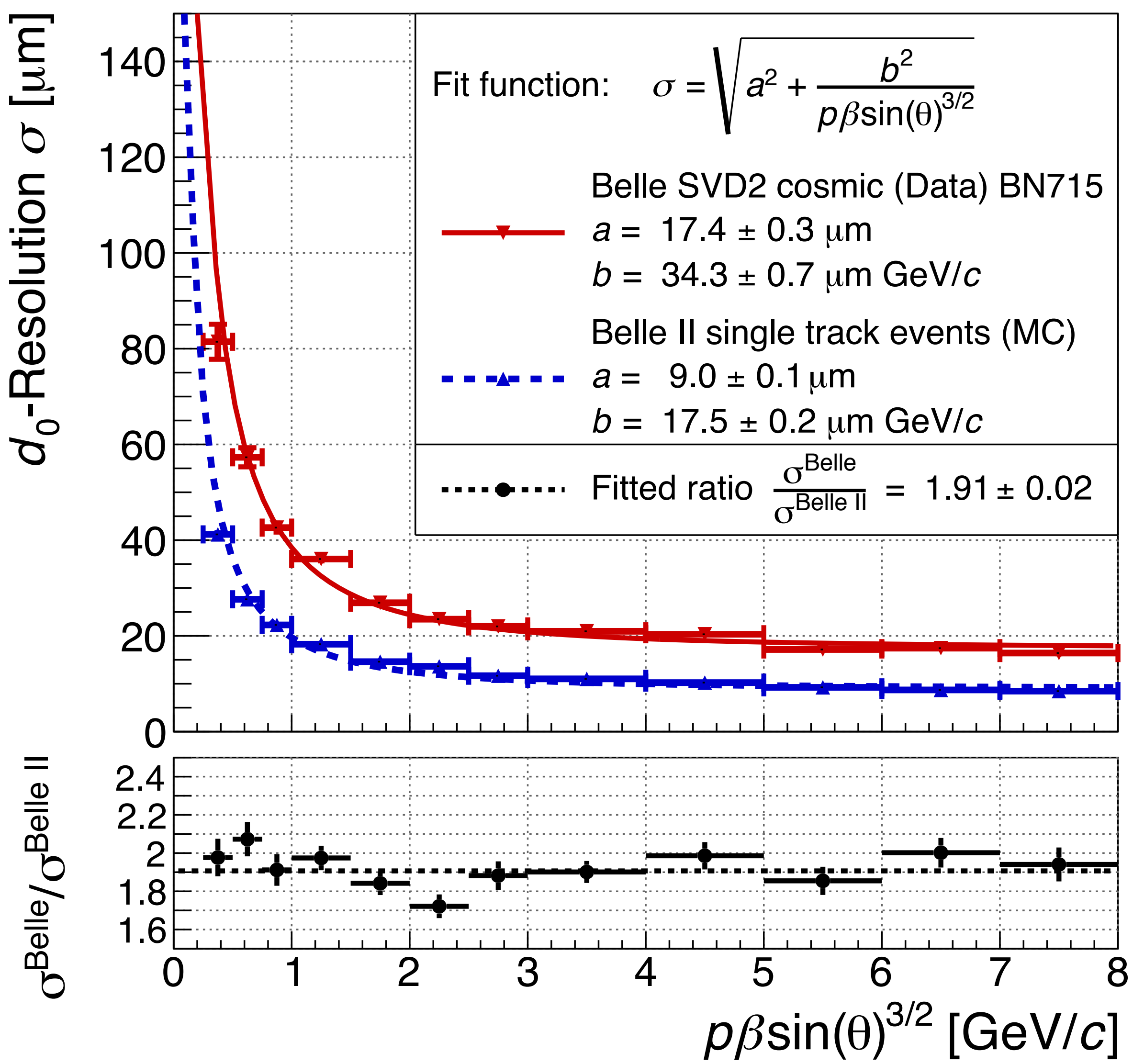
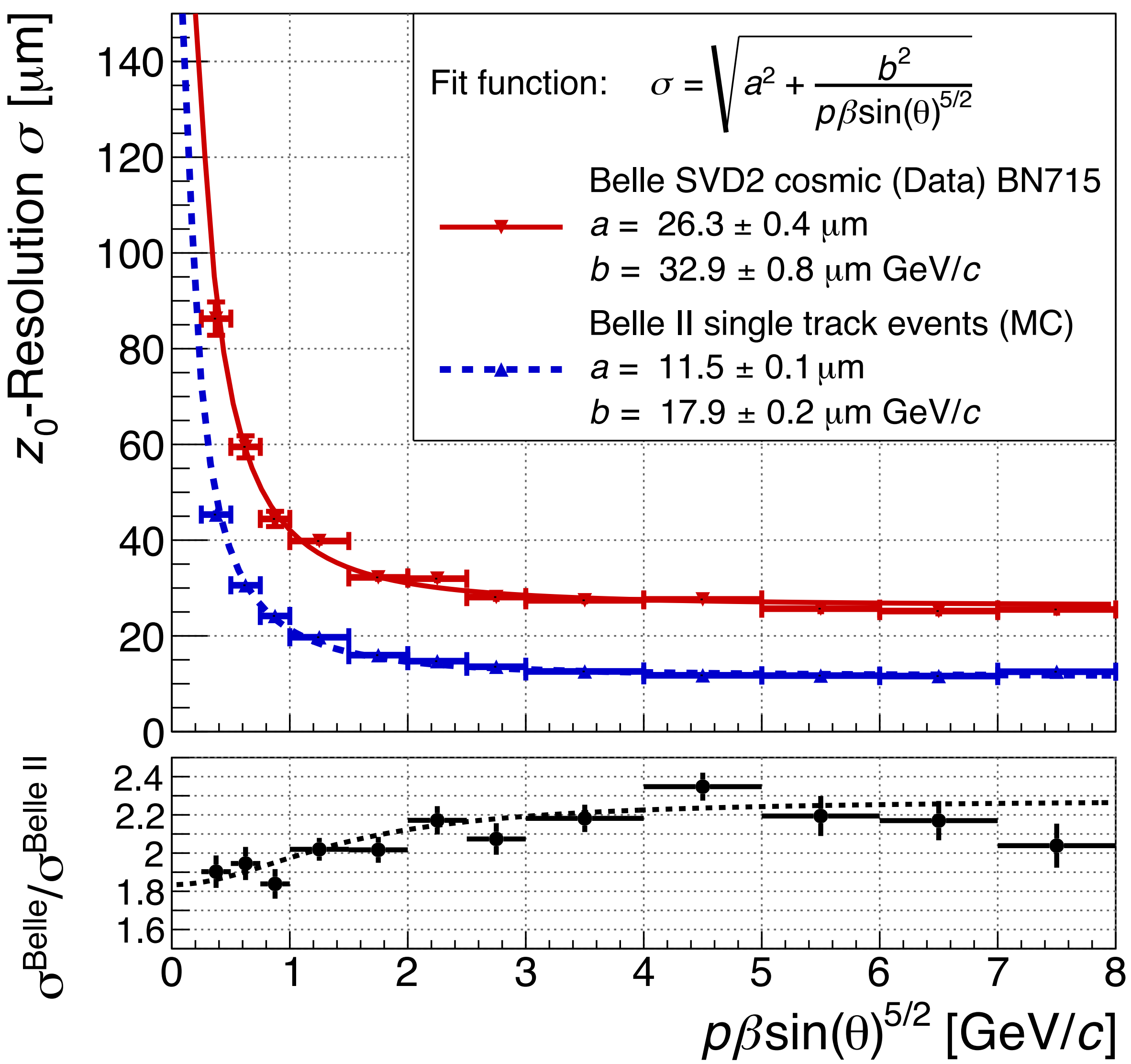


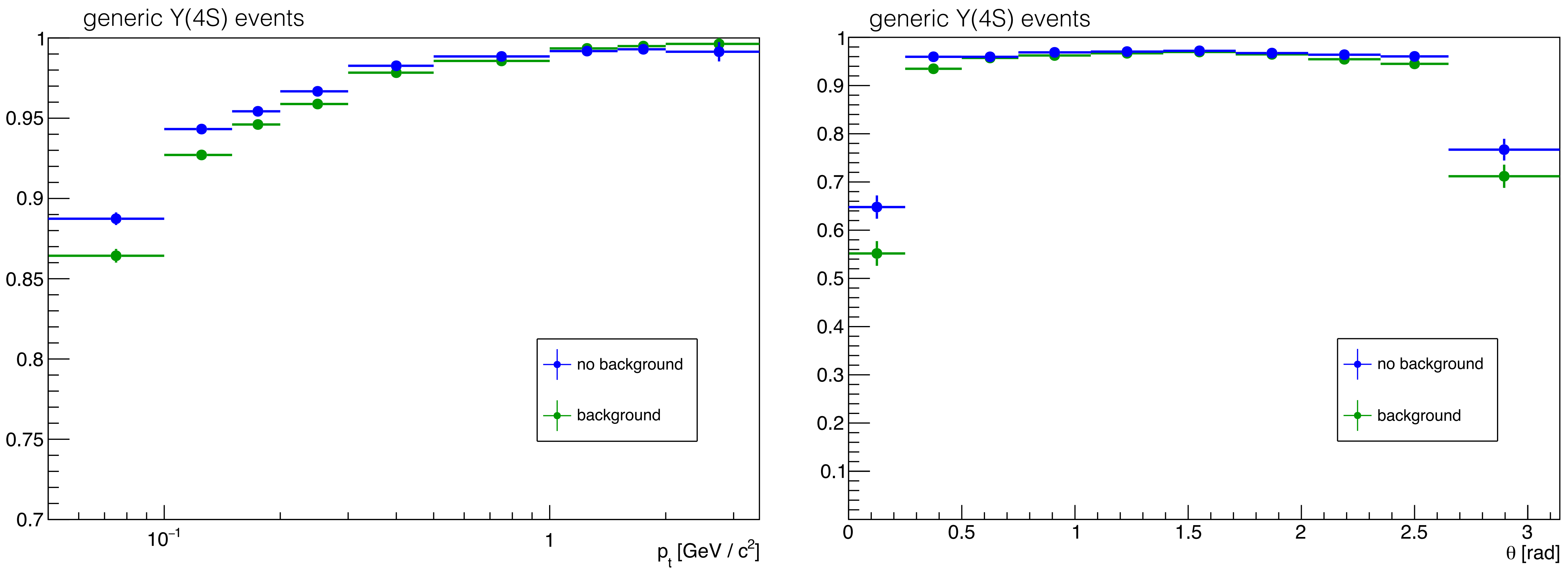
MC simulation





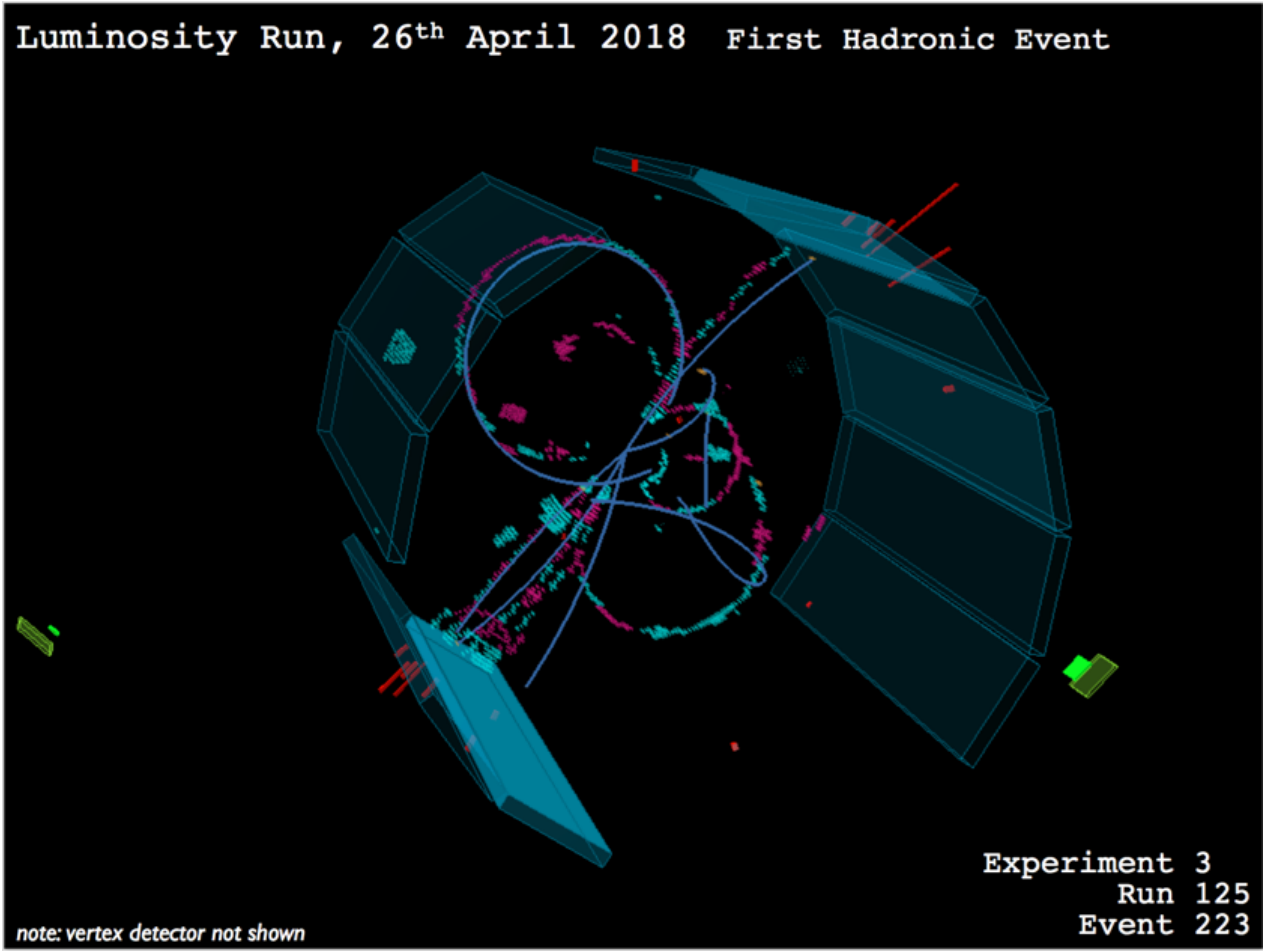
- Resolution of the transverse (d_0) and longitudinal (z_0) impact parameters
- Belle II MC events with a single muon tracks are compared with results of Belle cosmic events

MC simulation



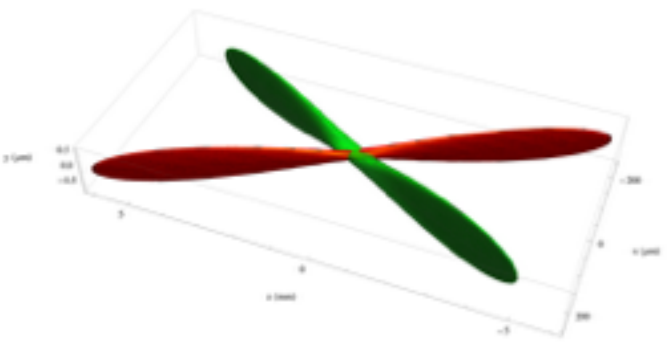
- Track finding efficiency as a function of p_t and θ
- Integrated efficiency w/o background is ~96.5%, w/ is ~95.8%

What about real data?

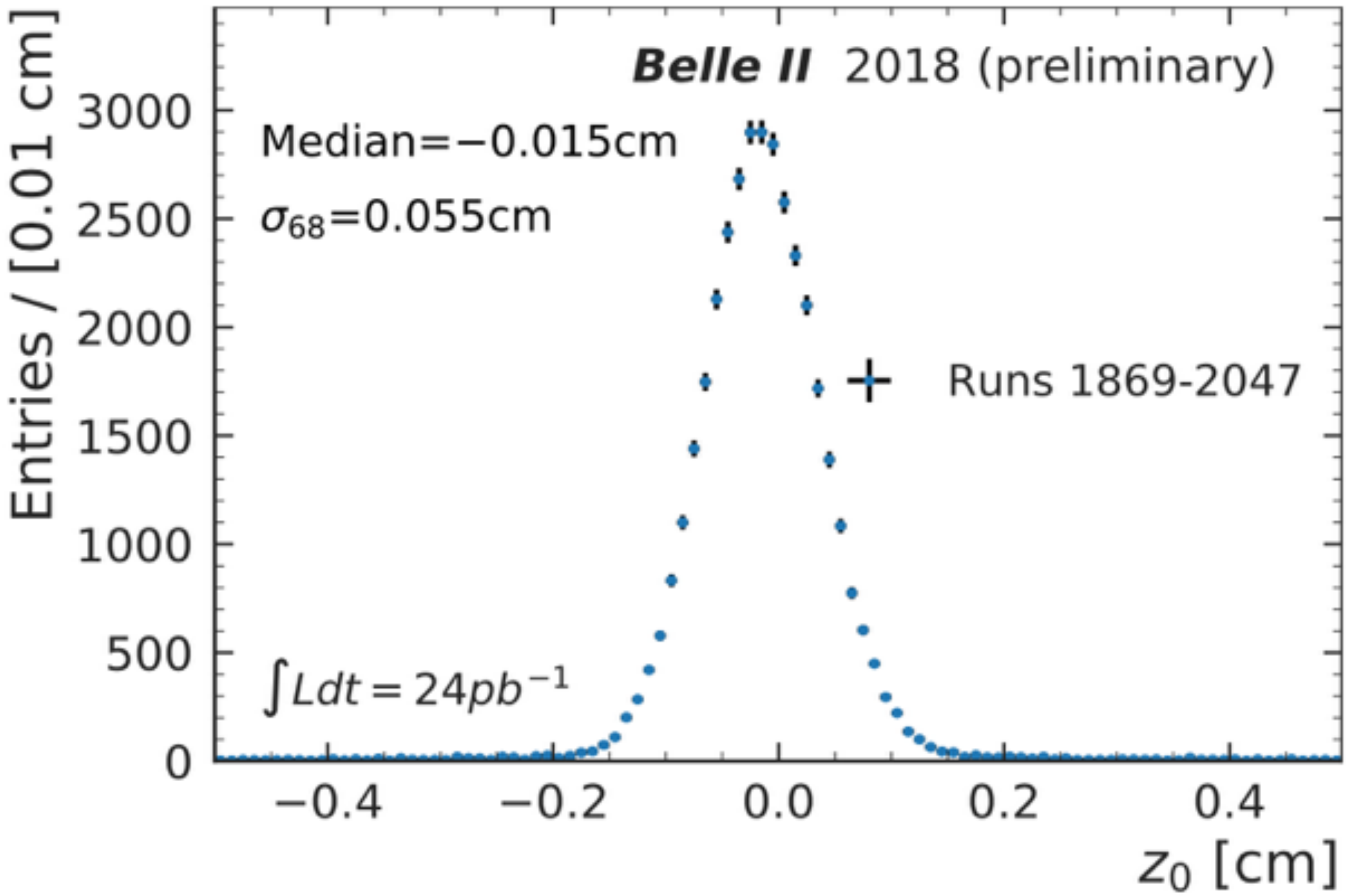


What about real data?

SuperKEKB

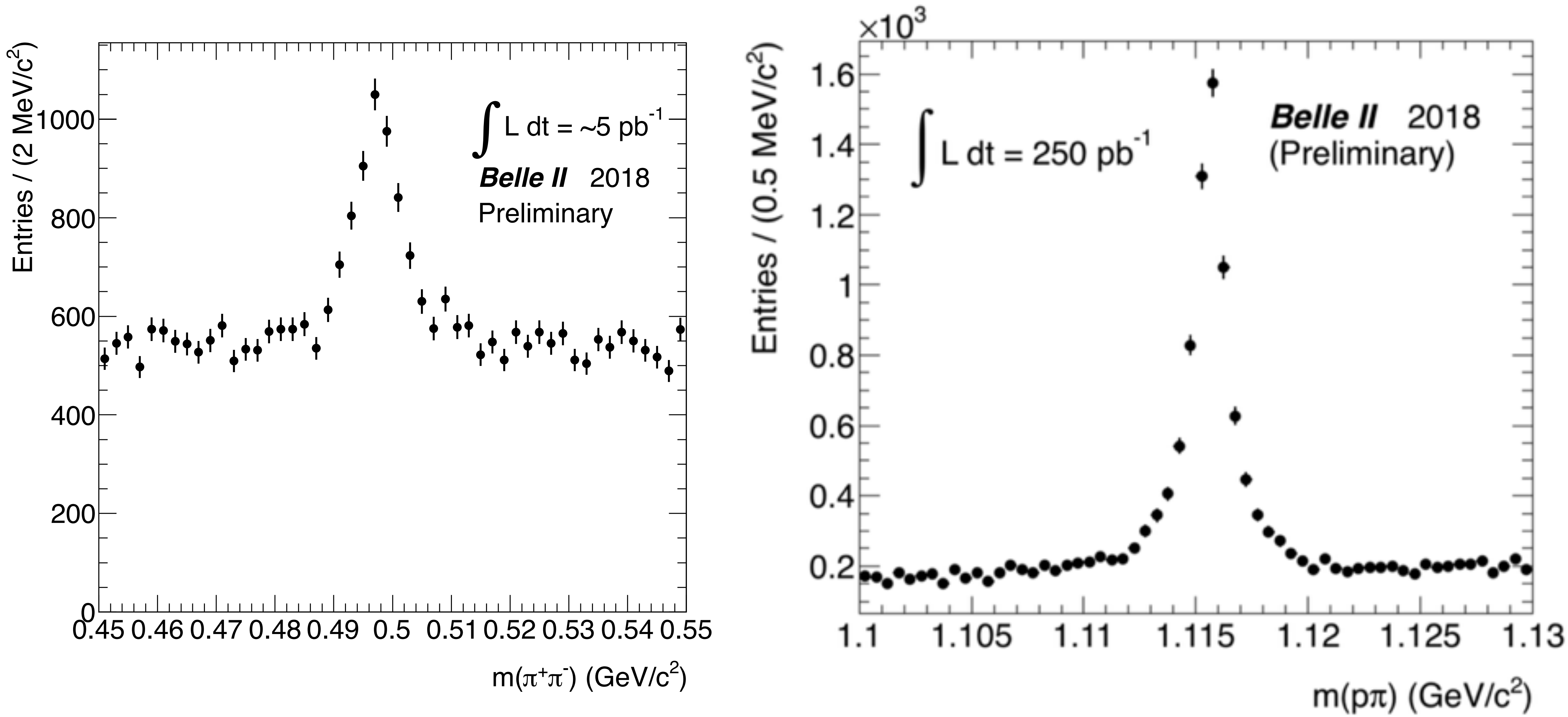


$\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x}$ = 0.049 cm



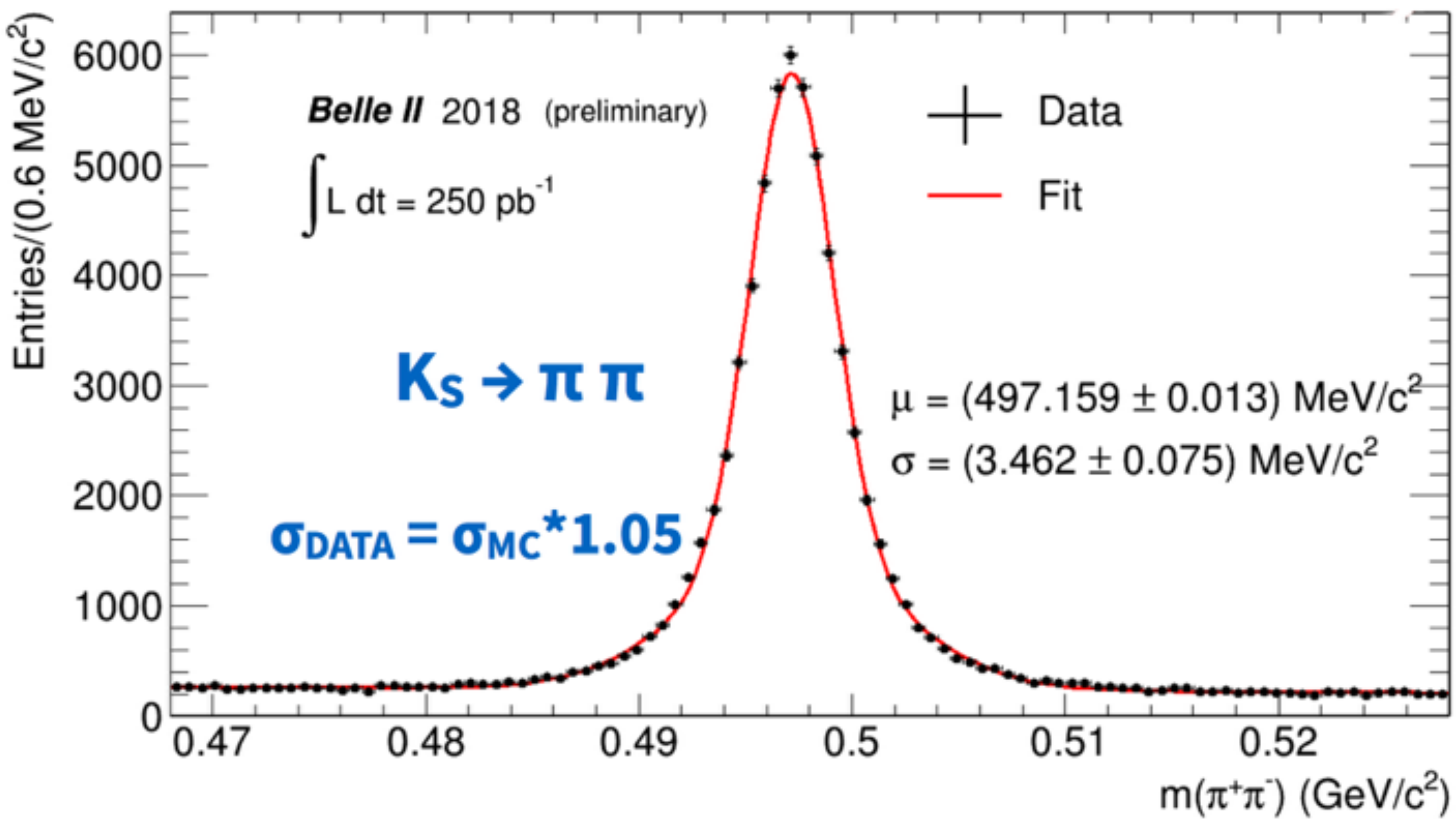
We measured the effective bunch length it in two track events with one wedge of the silicon detector in early Belle II data

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

What about real data?



- Ks peak fitted using KFit (~250 pb^{-1})
- $\sigma_{DATA} = \sigma_{MC} \times 1.05$

Summary

- Belle II offers exciting tracking challenges

- 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 machine commissioning phase

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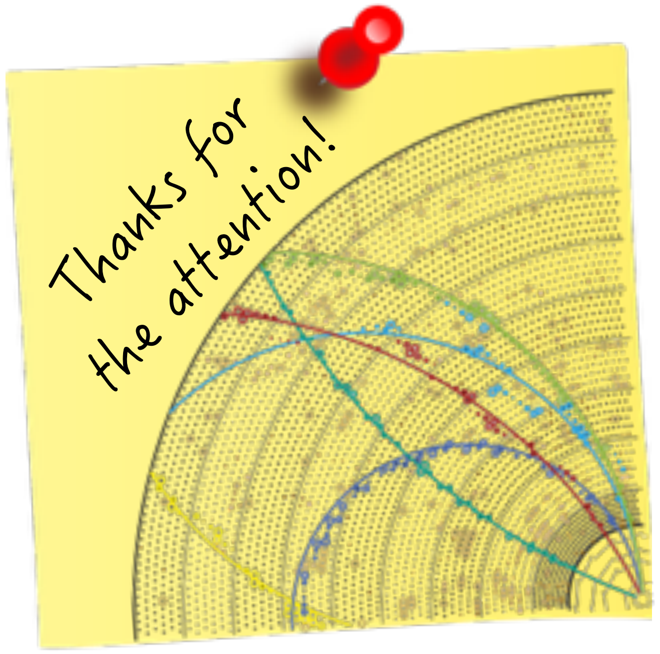
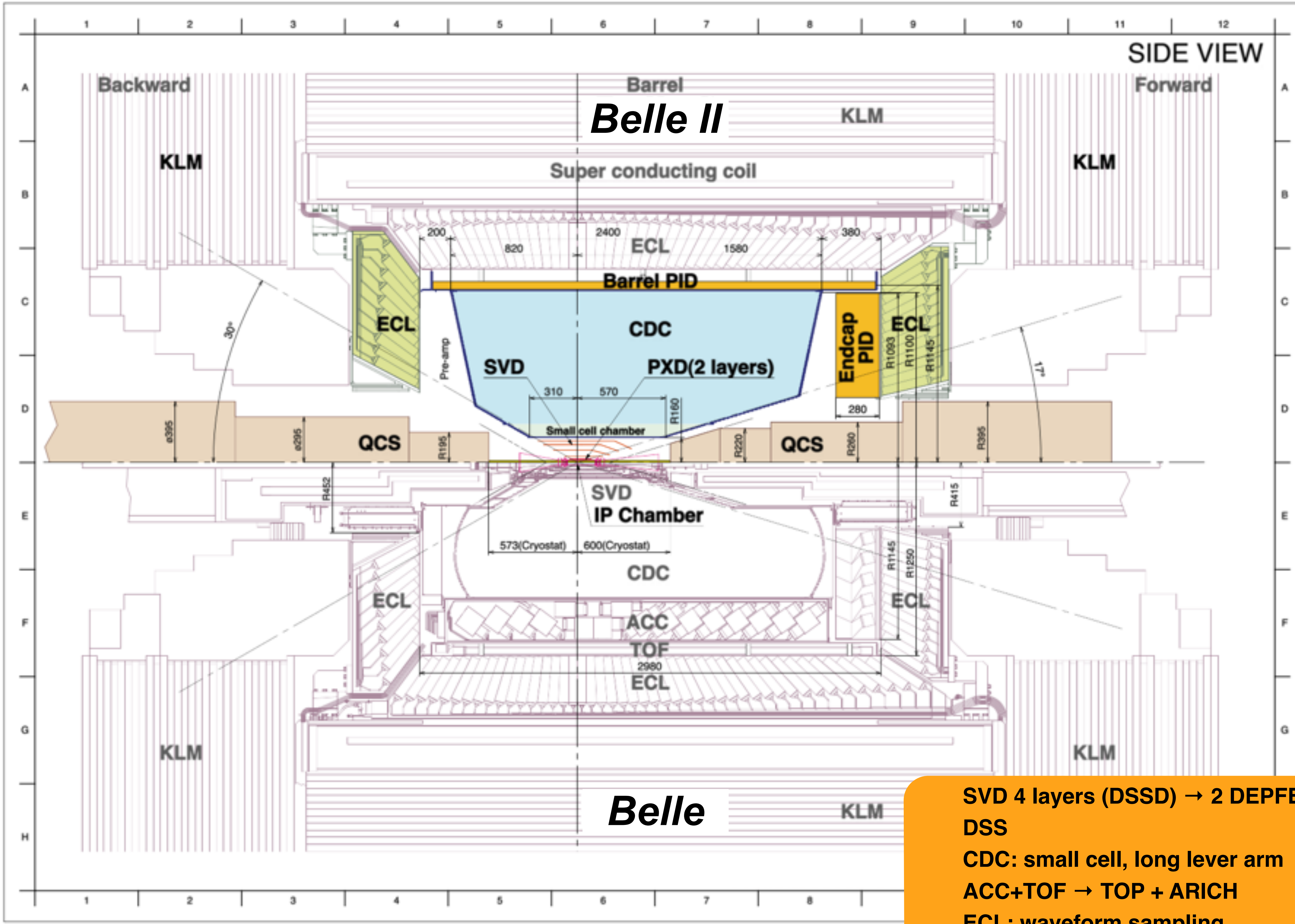


BACKUP

KEKB VS SuperKEKB

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
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}		$cm^{-2}s^{-1}$

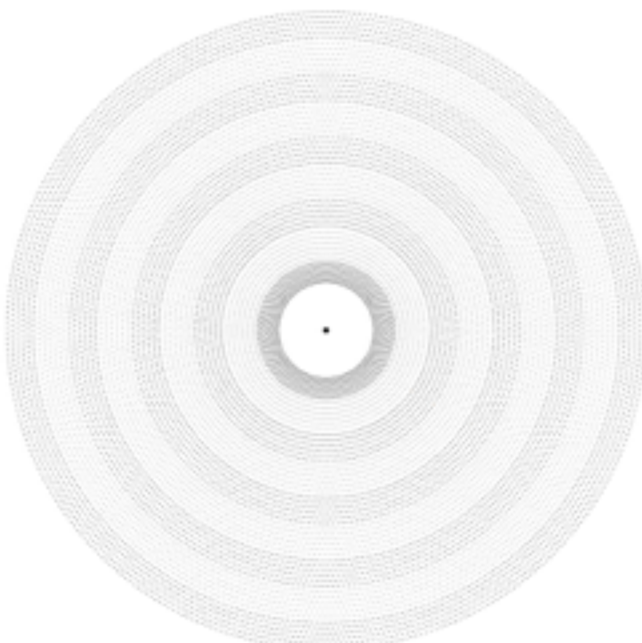
From Belle to Belle II

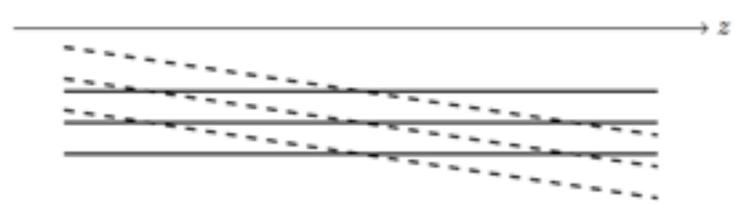


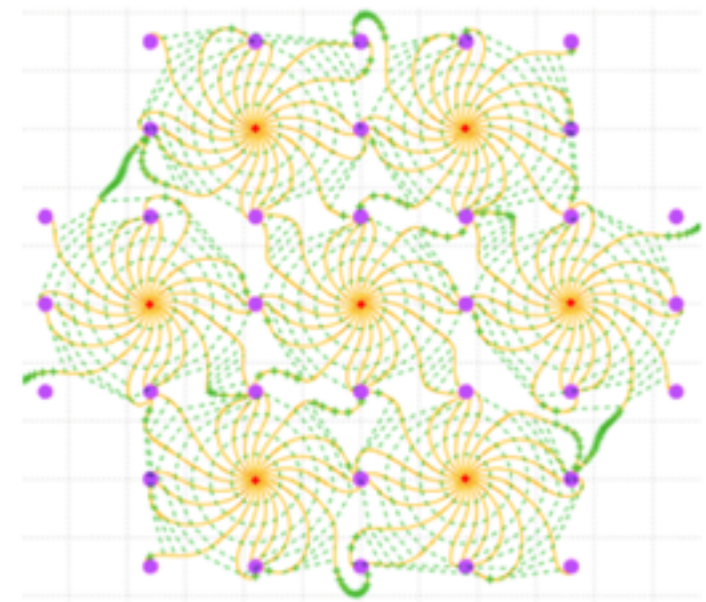
- SVD 4 layers (DSSD) → 2 DEPFET + 4 DSSD
- CDC: small cell, long lever arm
- ACC+TOF → TOP + ARICH
- ECL: waveform sampling
- KLM: RPC → Scintillator+SiPM

CDC

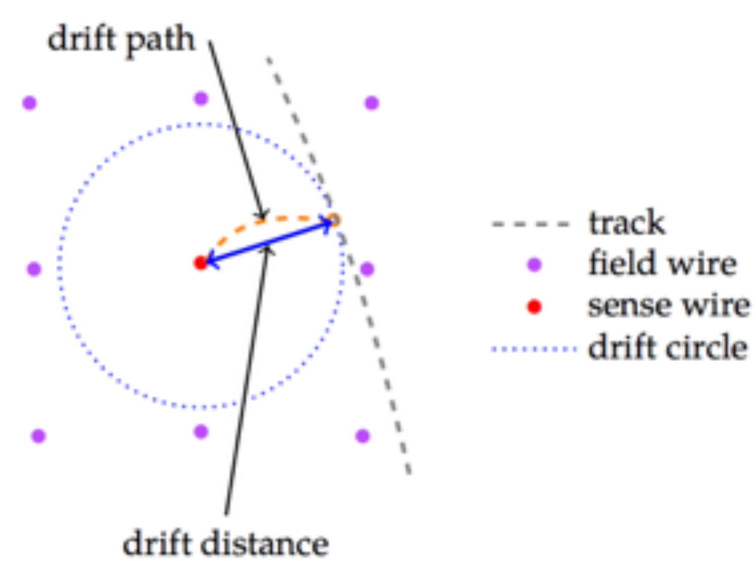
9 superlayers and 56 layers
A: axial → aligned with the solenoidal magnetic field
U and V: stereo → skewed with respect to the axial wires



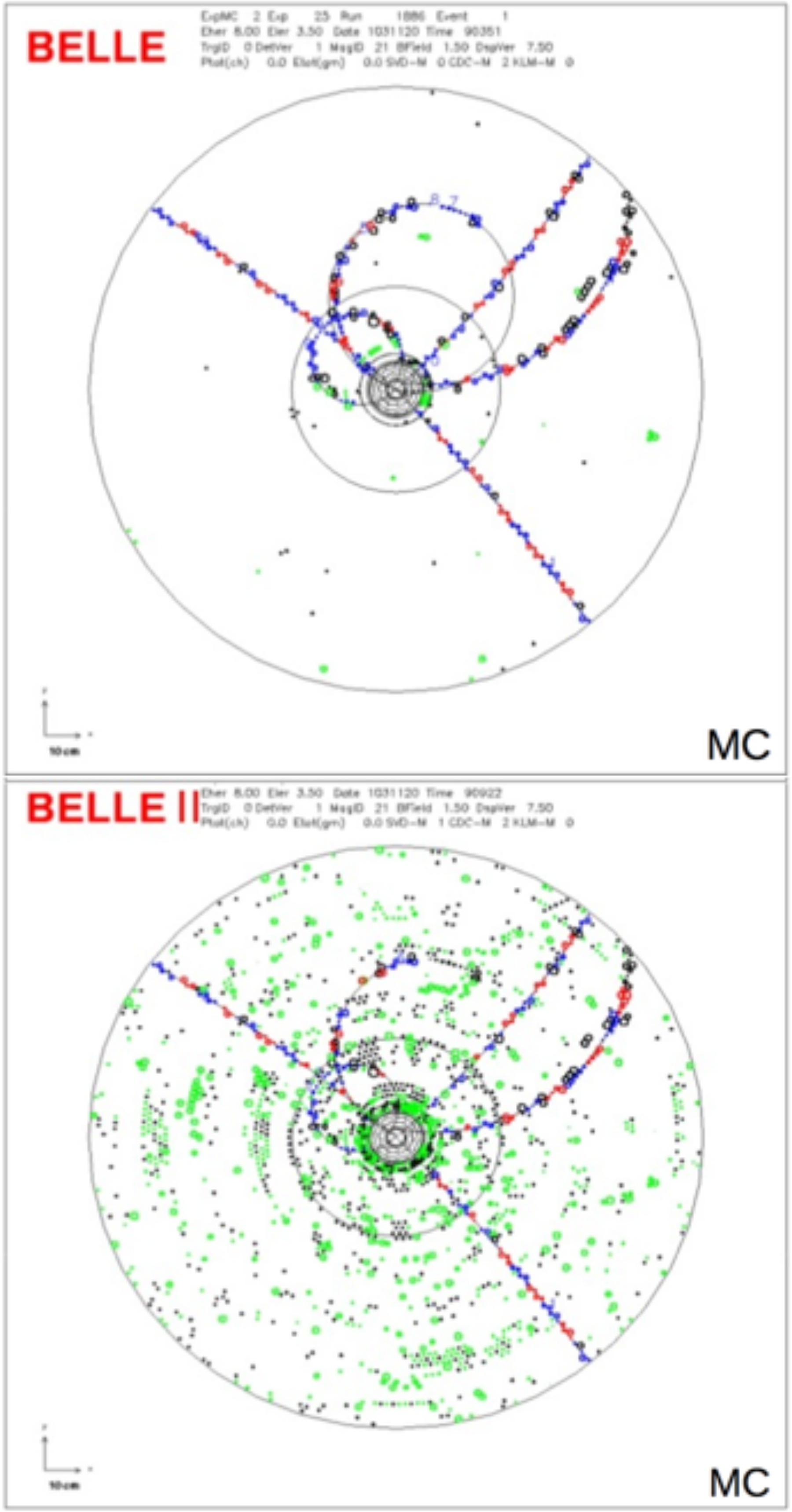




	Belle	Belle II
Radius of inner cylinder (mm)	77	160
Radius of outer cylinder (mm)	880	1130
Radius of innermost sense wire (mm)	88	168
Radius of outermost sense wire (mm)	863	1111.4
Number of layers	50	56
Number of sense wires	8,400	14,336
Gas	He–C_2H_6	He–C_2H_6
Diameter of sense wire (μm)	30	30



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+3); {x,y,z} → (4+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