3D development Commissioning status

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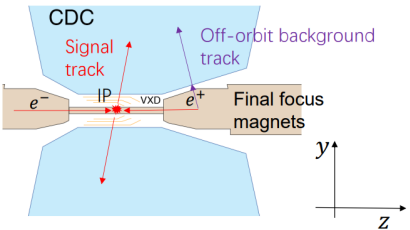
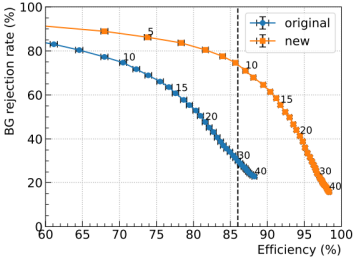
Motivation of CDC 3D track trigger

- Trigger rate will exceed the limitation of 30 KHZ at target luminosity
- New 3D track trigger is developed to reduce trigger rate
  - Z resolution is better
- Off-orbit background
  - Most of background is not coming from collision point
- Expected performance of new 3D algorithm
  - Efficiency: $= \frac{number\ of\ triggered\ signal\ tracks}{number\ of\ signal\ tracks}$
  - Background rejection rate $:= \frac{number\ of\ NOT\ triggered\ BG\ tracks}{number\ of\ BG\ tracks}$





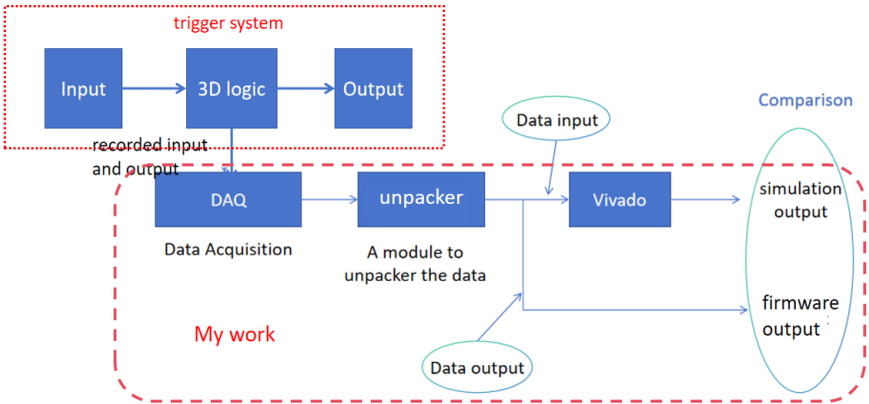
Validation of 3D firmware

- Development status: New 3D firmware has been developed and installed to Belle II trigger system since March 2024
- Goal of my work: Commissioning of the 3D firmware with real cosmic data
  - Compare firmware and simulation(using vivado software) output of 3D track
  - Validation if firmware is working as expected

Figure: Universal Trigger Board

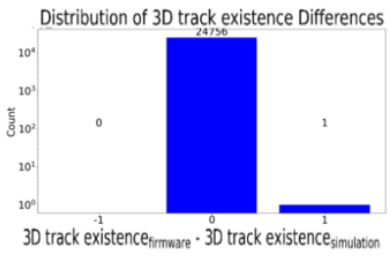
New system for firmware validation

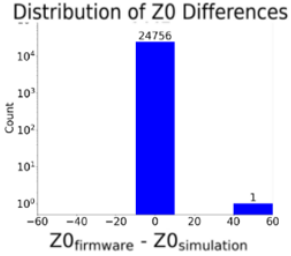
- I build a new system to check consistency of firmware and simulation
  - record all input and output data from firmware
  - Vivado software simulation by using the input data

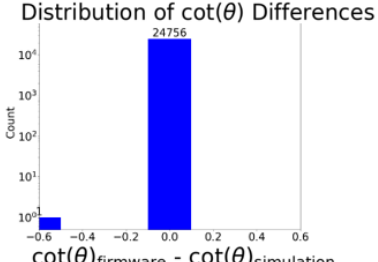


Second cosmic test

- Second cosmic run is taken with fixed firmware and simulation
- Flip-flop register is added to fix it
- Buffer is cleared on testbench to fix it
- Date: July 25 Total 24757 tracks
- Firmware and simulation outputs are consistent: 24756 events
- Firmware and simulation outputs are inconsistent: 1 events

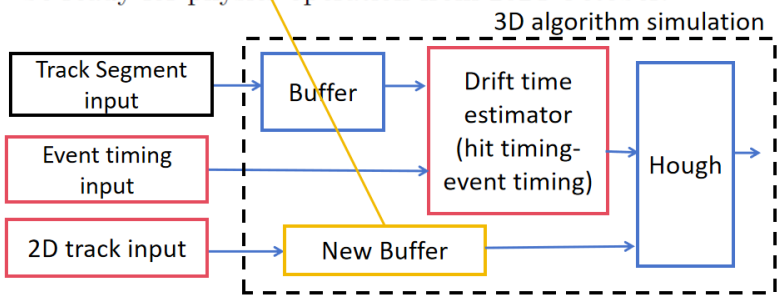


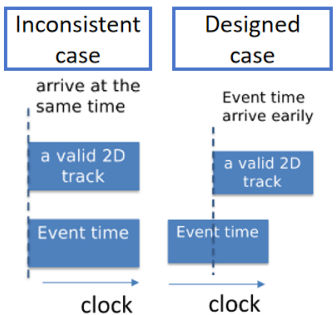




Reason of remained inconsistency

- Large jitter of event timing:
  - In the problematic event, latency of Event timing input is same as that of 2D track due to large jitter
  - Drift time estimation is failed, because 3D algorithm is designed to receive the Event timing earlier than 2D track
- We added a new buffer to 2D track input, in order to fix the issue. 3D firmware will be ready for physics operation from 2024 October.



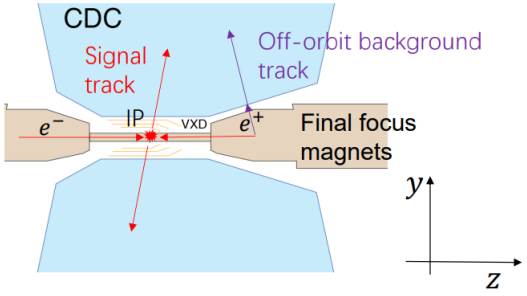


Offline reconstruction VS firmware

Offline reconstruction result VS firmware result

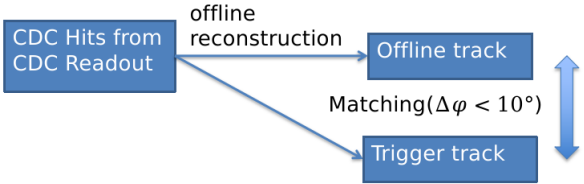
Motivation

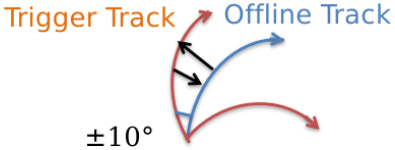
- Evaluate the trigger with real data
  - The results of the offline tracking could be used as reference
  - Evaluate the Z_0 resolution
  - Evaluate the efficiency: $= \frac{number\ of\ triggered\ signal\ tracks}{number\ of\ signal\ tracks}$
  - Evaluate the background rejection rate $:= \frac{number\ of\ NOT\ triggered\ BG\ tracks}{number\ of\ BG\ tracks}$



Matched track pair

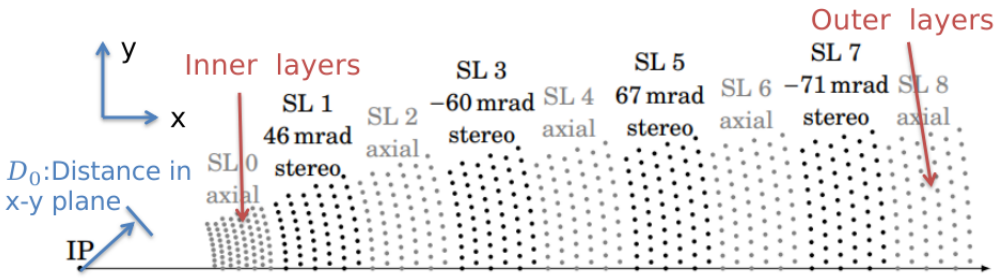
- In general, the number of triggered track differs from the number of offline track
  - Not every triggered track necessarily has a matching offline track
- Define the matched track pair:
  - Find the closest Trigger track with Offline track(minimize $\Delta\phi$)
  - Find the closest Offline track with Trigger track(minimize $\Delta\phi$)
- Flow of Performance Evaluation





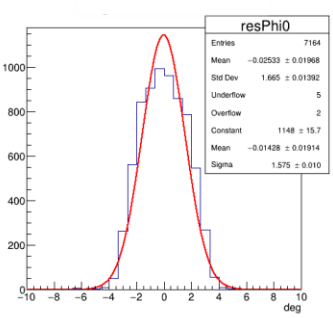
Track selection criteria

- Offline track selection:
  - Matched track pair
  - The transverse momentum $P_T > 0.3 GeV/c$
  - Long track: There is a hit within the 5 layers of the inner and outer layers of the CDC.
  - $D_0 < 1 cm$(for cosmic)
- Using only matched track pairs: exclude issues arise from 2D track reconstruction

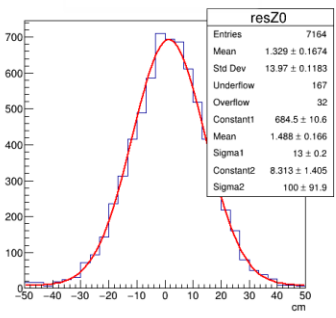


Result

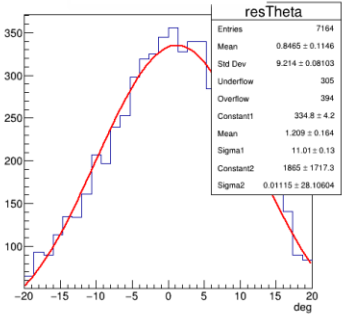
- **Dataset: exp34run00142**
- RunType: cosmic
- Matched Rate = $\frac{matched\ track\ number}{total\ track\ number} = 93.65\%$



Δφ=φ_trigger - φ_offline(deg.)



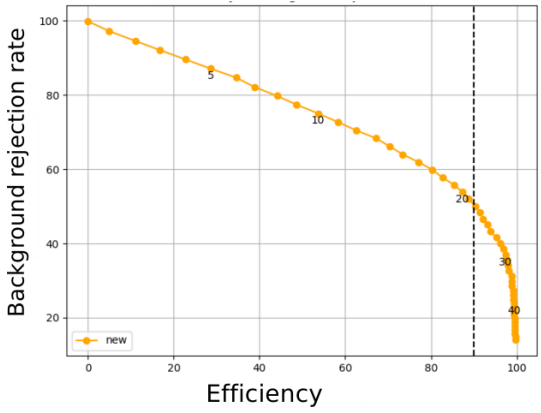
ΔZ0=Z0_trigger - Z0_offline(cm.)



Δθ=θ_trigger - θ_offline(deg.)

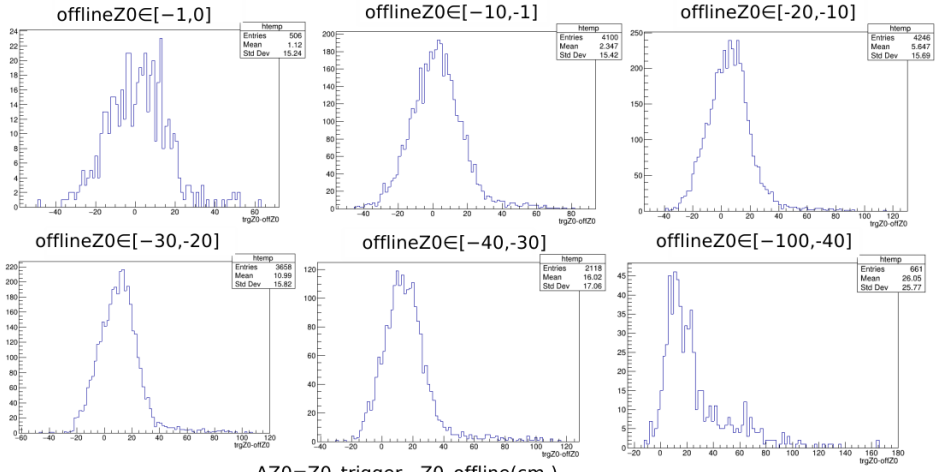
Result

- Efficiency VS Background Rejection Rate
  - Efficiency =87.25% (when trigger Z_0 cut is ± 20)
  - Background rejection rate=53.85%(when trigger Z_0 cut is ± 20)
- TSIM result will be added later to compare



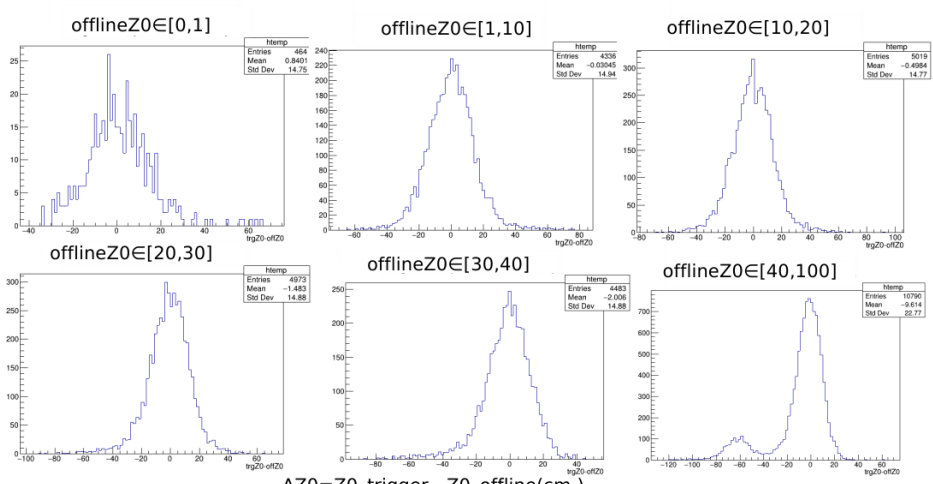
ΔZ_0 distribution for each Z_0 region

- Most of σ *around* 15*cm*
- It looks fine



ΔZ_0 distribution for each Z_0 region

- Most of σ *around* $15cm$
- There is a strange peak in Z_0 resolution plot when $Z_{0,offline} \in [40, 100]$



Summary

1. Firmware and simulation results are compared to valid if firmware is working as expected
2. Most events are consistent in simulation and firmware and remain one
3. We added a new buffer to 2D track input, in order to fix the issue. 3D firmware will be ready for physics operation from 2024 October
4. Compare the firmware results with offline reconstruction result to evaluate the Z_0 resolution
5. It seems there is a strange peak in Z_0 resolution plot when $Z_{0,offline} \in [40, 100]$

End

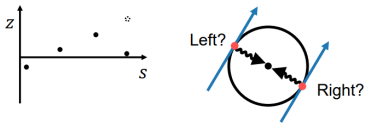
Thank you for listening!

Back up

New algorithm

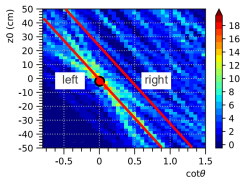
Old algorithm

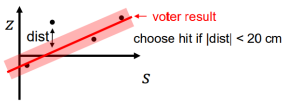
- Limited number of hits used
- Selection of noise hits
- Fit using the least squares method



New algorithm

- Vote for left and right
- noise-robust
- Preliminary track reconstruction to exclude background tracks that are not near the collision vertex



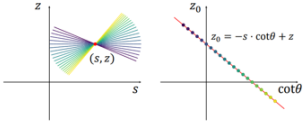


1 Hough Transform:

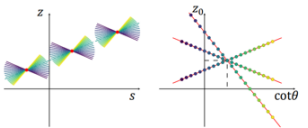
- Hit variables (z_{hit}, S_{hit}) are voted as a line in parameter space ($z_0 - \cot\theta$ plane)

$$z_{hit} = +\cot\theta \cdot S_{hit} + z_0$$

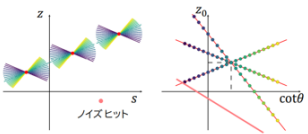
$$z_0 = -S_{hit} \cdot \cot\theta + z_{hit}$$



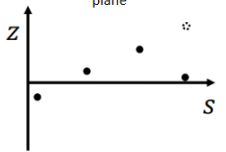
A single point in the s-z plane and the cot θ-z0 plane



Multiple points in the s-z plane and the cot θ-z0 plane



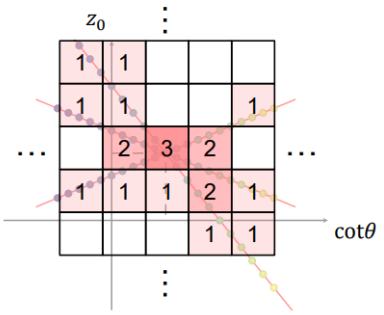
a noise point in the s-z plane and the cot θ-z0 plane



a noise point in the s-z plane influencing fitting

Hough vote

1. **Hough vote:**
   - Voting: In the $cos(\theta) - z_0$ plane, each detected hit can get a vote for each possible track it could belong to. This method accumulates votes to determine the most likely track parameters.
   - determine the parameters of $cos(\theta)$ and z_0



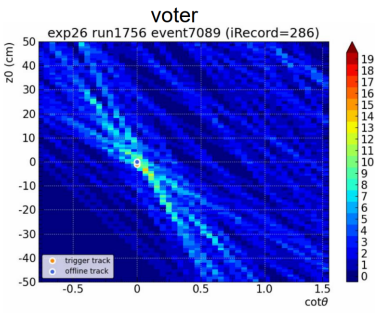
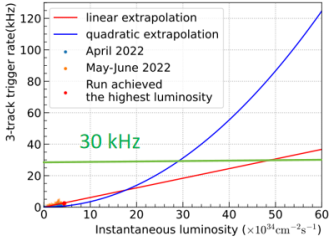
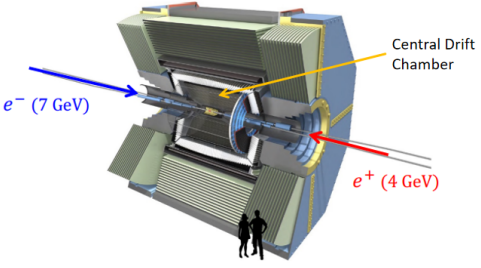


Figure: Voter is noise-robust

Motivation of CDC 3D track trigger

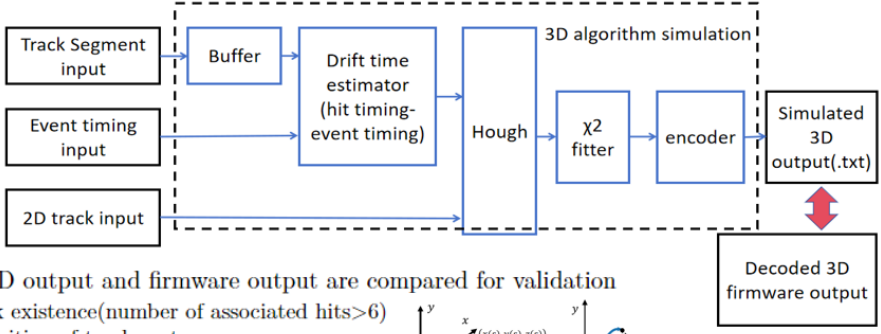
1. Belle II experiment: B-factory in Tsukuba, Japan, upgraded from Belle experiment
   - 7 GeV e^-, 4 GeV e^+
   - instantaneous luminosity: $4.7x10^{34} cm^{-2} s^{-1}$
   - The target luminosity : 6.0 x $10^{35} cm^{-2} s^{-1}$
2. Central Drift Chamber (CDC):
   - Measures the momentum, charge, and decay points of charged particles.
3. CDC Trigger: trigger charged particle from the collision.
4. Trigger rate can exceed limitation of 30kHz in future, which is maximum trigger rate



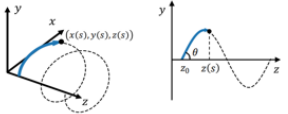


New system for firmware validation

- Input data to 3D is recorded every clock(32MHz), 48 clocks/event
  - Track Segment: wire position, wire hit timing (3146 bit)
  - Event timing (23 bit)
  - 2D track: ϕ, momentum (499 bit)

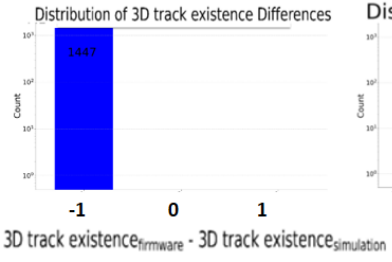


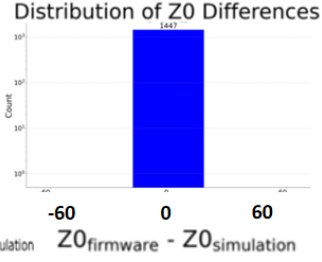
- Simulated 3D output and firmware output are compared for validation
  - 3D track existence(number of associated hits>6)
  - Z_0: z position of track vertex
  - θ: track angle in z − y plane

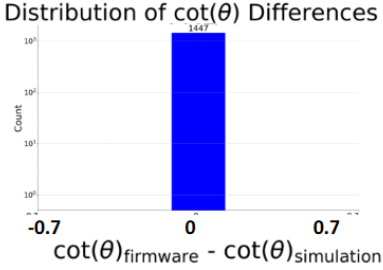


First cosmic test

- Date: July 17 Total 1447 tracks
- A small amount of data was used in first cosmic test
- Z0 and Cotθ are consistent
- 3D track existence are inconsistent

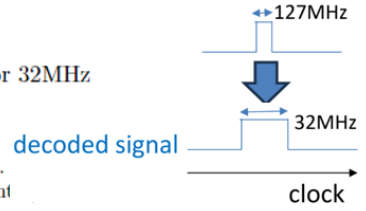


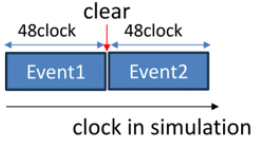


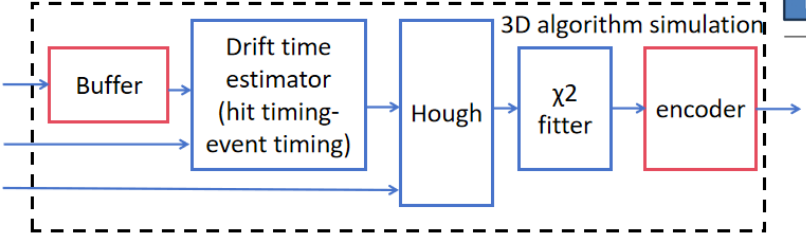


Reason of firmware-simulation inconsistency

- Problem of encoder
  - In encoder module, output signal was not correctly latch for 32MHz
  - flip-flop register is added to fix it
- Problem of buffer simulation
  - Buffer of Track Segment was not cleared between event in simulation. Track Segment in previous event was used for simulation at next event
  - Buffer is cleared on testbench to fix it
- many other small issues
  - firmware bug, inconsistent parameter between simulation and firmware, etc.







plot

- There are some strange events in the red box
- I need to check it