CDCTRG status

2025/10/21

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Motivation

-Introduction to CDCTRG system

-major functionality is summarized

  -sorry for long talk..

  -I hope this slide will be used when student starts CDCTRG work ☺

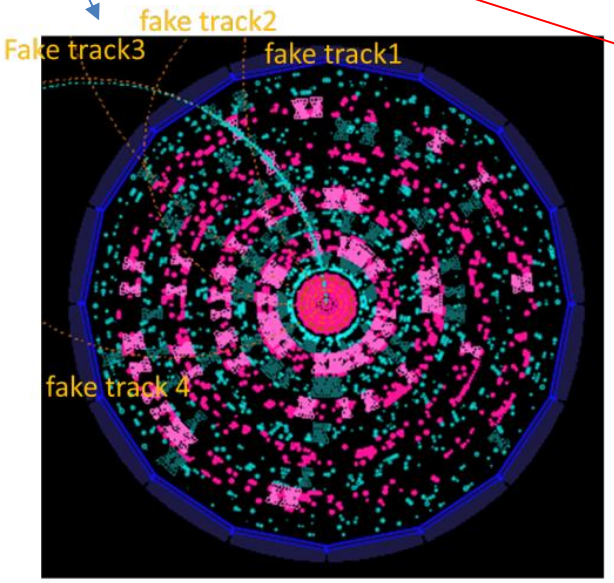
role of CDCTRG

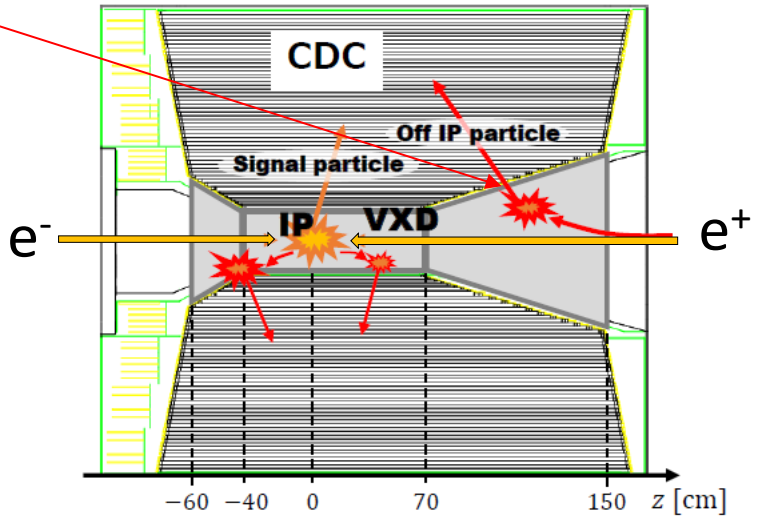
-trigger charged particles with high efficiency

- -must: charged particle @ pt>0.3GeV (non-carling track) at barrel
- -better to have: charged particle @ endcap

-keep total trigger rate <30kHz by rejecting beamBG efficiency

- -fake track: high detector occupancy or cross talk: $\propto (\text{beamBG})^2$
- -off-IP particle: real charged particle outside from IP $\propto$ beamBG





CDC detector

-Central drift chamber (CDC)

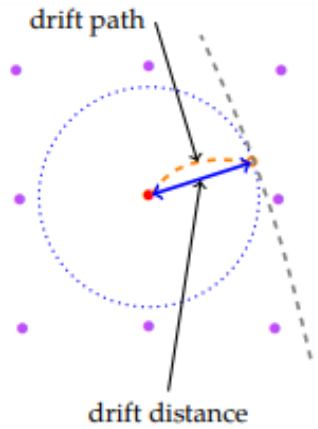
-Reconstruct charged particle

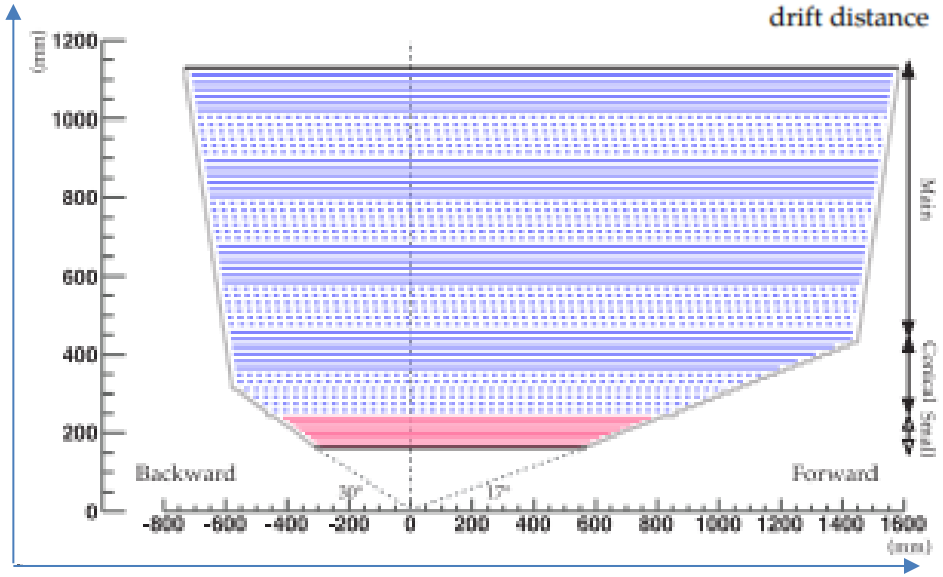
-~14000 axial and stereo sense wire

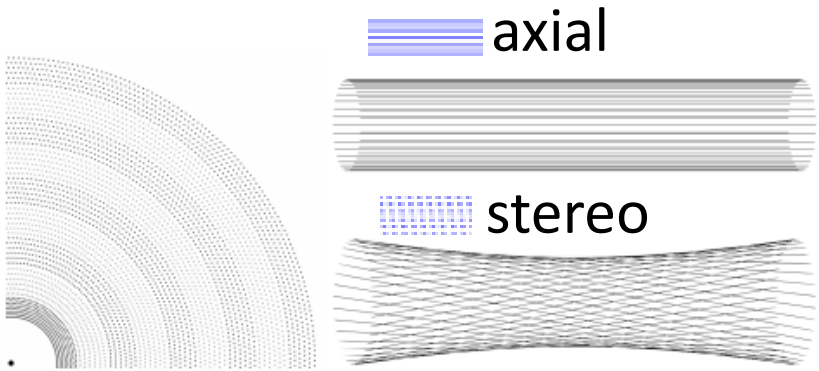
-Precise tracking

-drift time ⇔ drift distance

-drift time ~500ns





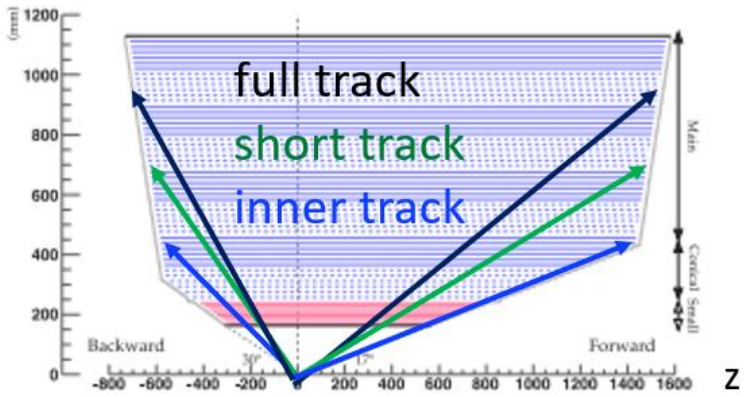


CDC Trigger

-Role: Trigger charged particles

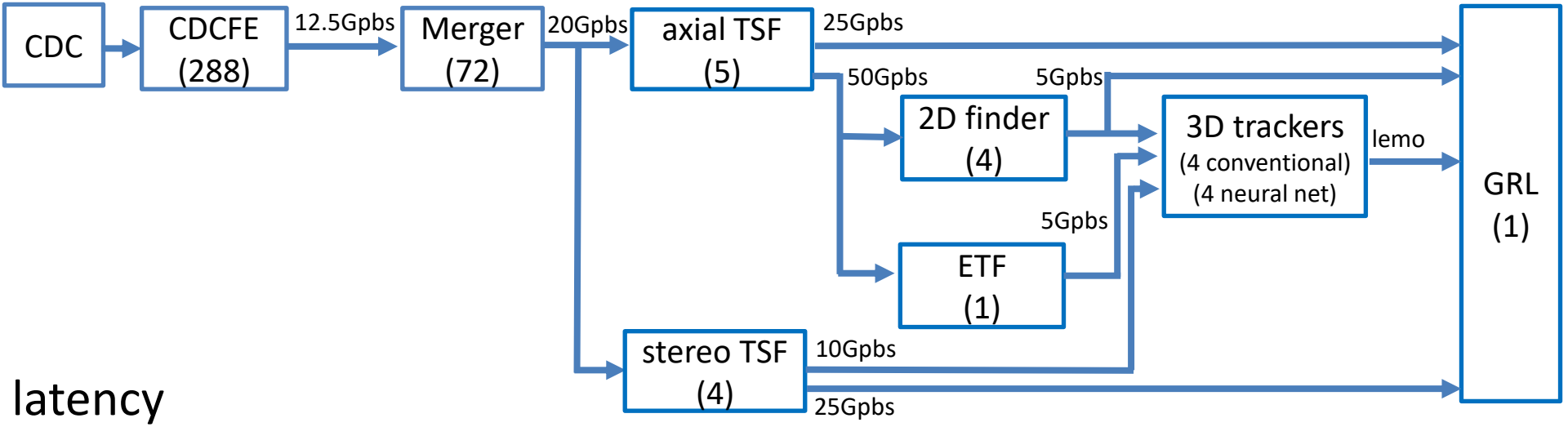
-Three kind of track with different θ region:

- -full track (f,y)
- -short track (s)
- -inner track (i)



-Consists of ~100 boards

(): number of boards



latency

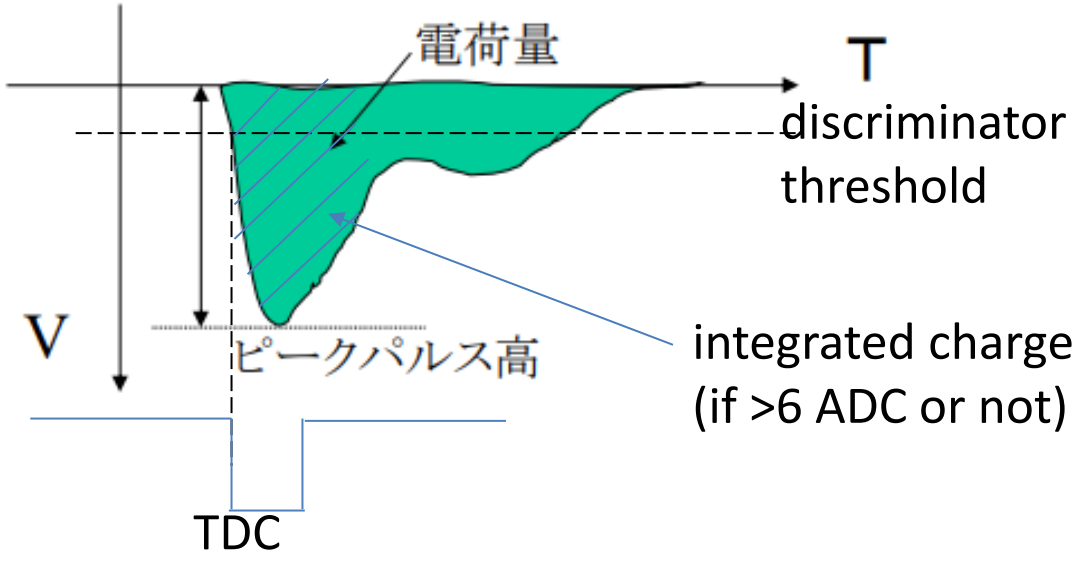
~500ns ~400ns ~600ns ~100ns ~500ns ~100ns ~250ns ~100ns ~250ns ~400ns ~32ns

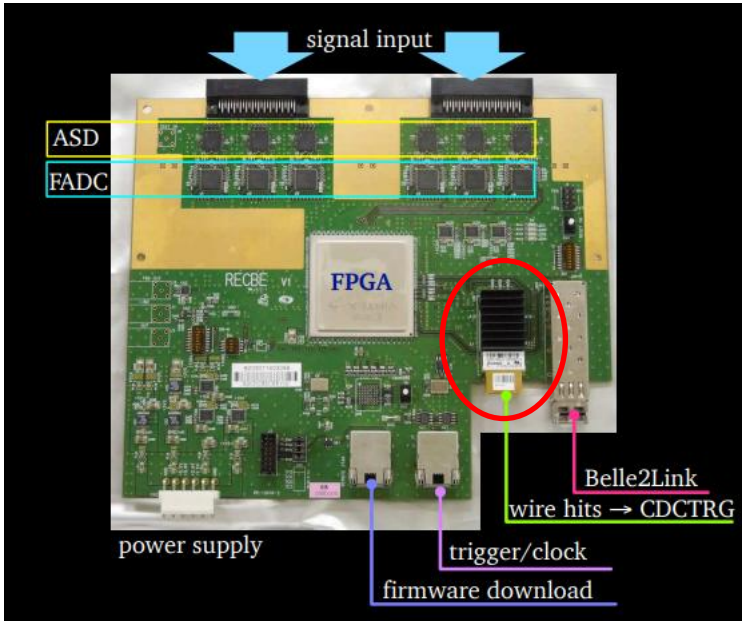
total: ~3.3μs

CDC front end

https://iopscience.iop.org/article/10.1088/1748-0221/12/06/C06014

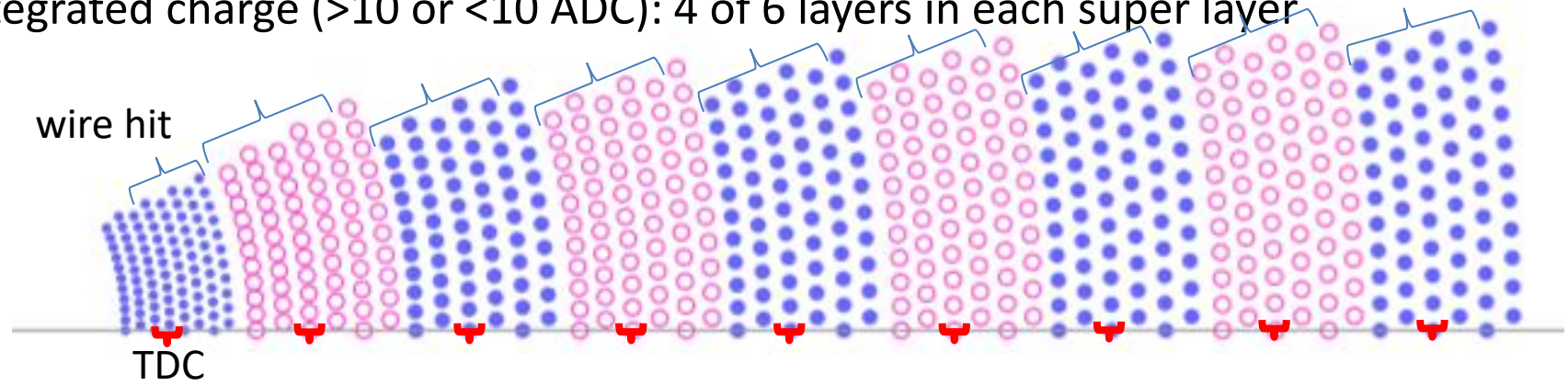
-digitize analogue signal on CDCFE



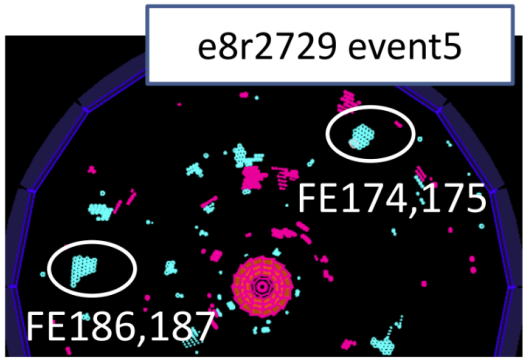


-Only part of information is sent to CDCTRG

- -wire hit existence (0 or 1): 5 of 6 layers in each super layer
- -wire hit timing (2ns precision TDC): 1 of 6 layers in each super layer
- -integrated charge (>10 or <10 ADC): 4 of 6 layers in each super layer



noise filter

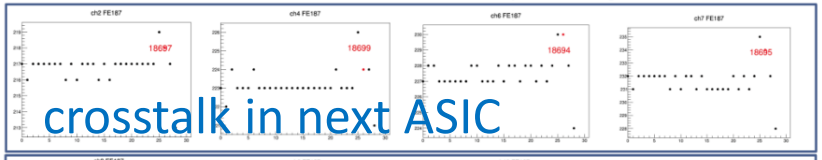


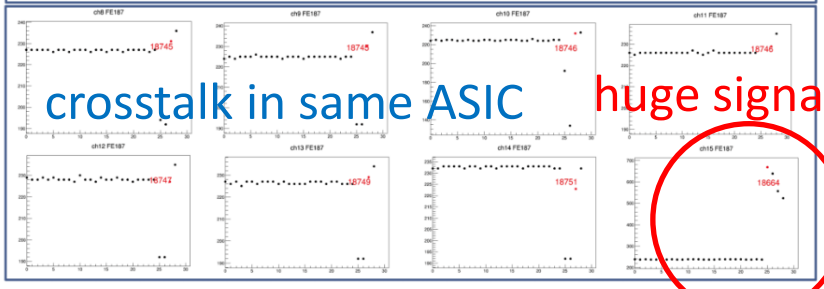
-TDC-based noise filter on CDCFE (link1, link2), 2020

- -if #hits >=4 on an ASIC at the same time, they are filtered
- -two times trigger rate reduction while keeping efficiency

Waveform: crosstalk FE187

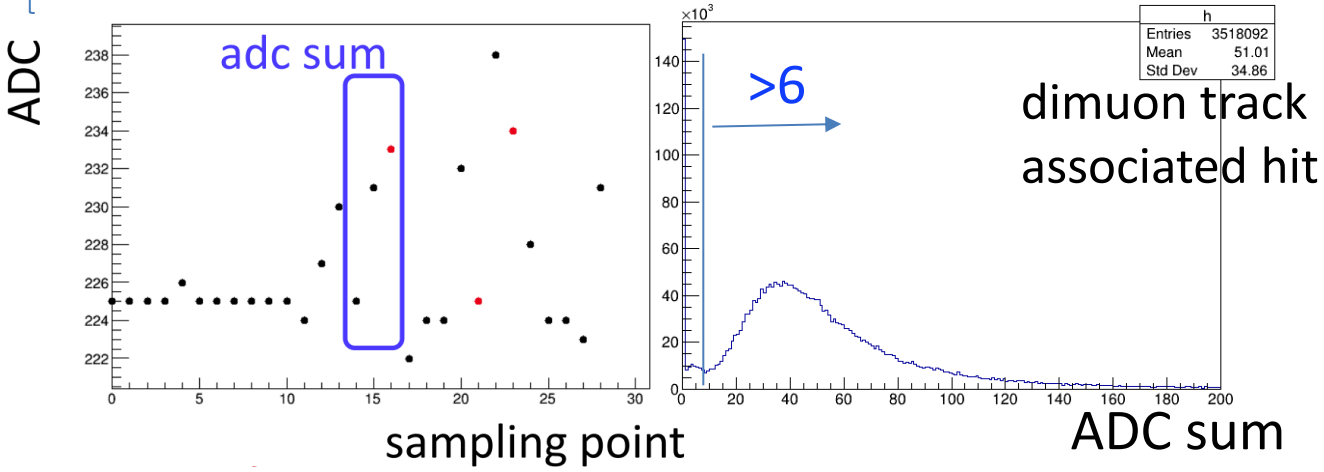
4hit, 30ns delay from signal, wihin10ns



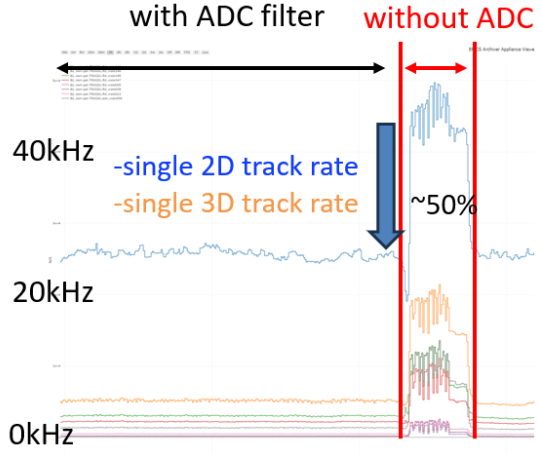


-ADC-based noise filter (link1), 2024

- -if three-point sum of ADC <=6, the hit is filtered
- -two times trigger rate reduction while keeping efficiency



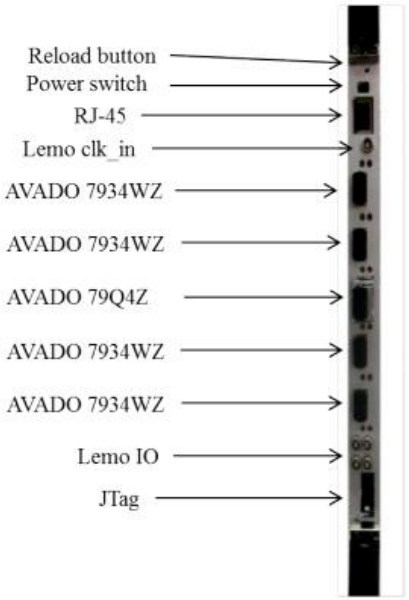
1+7hit, 60ns delay from signal, wihin10ns

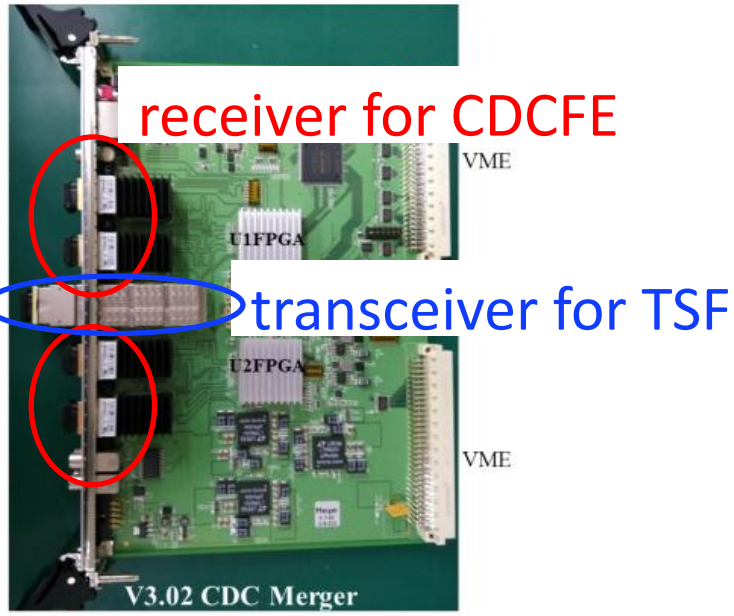


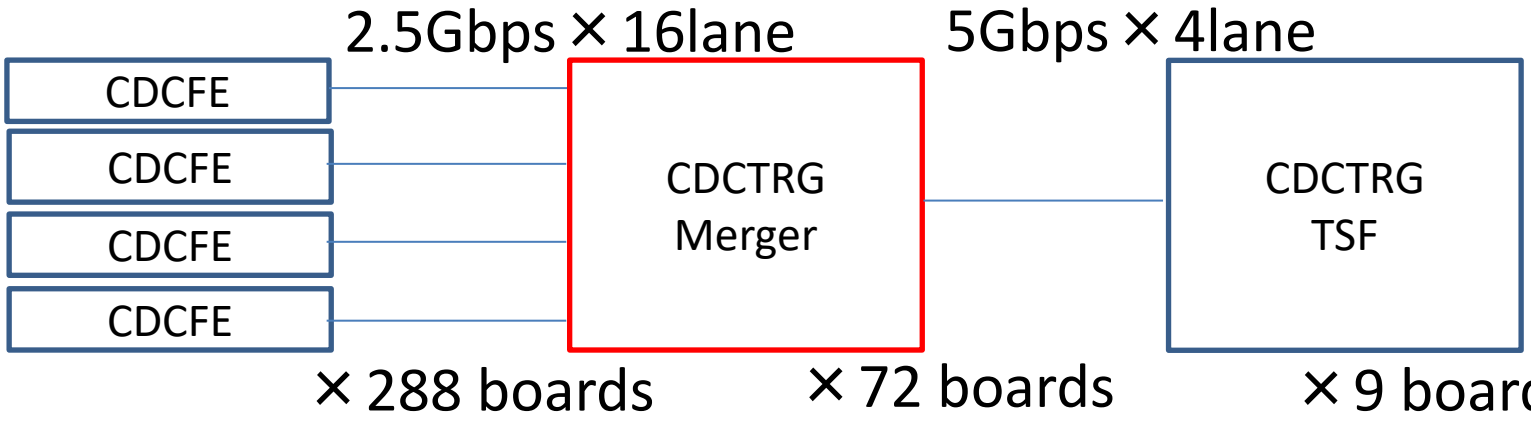
Merger (MGR)

-merge signal from four CDCFE
-send merged signal to TSF

https://docs.belle2.org/record/439/files/BELLE2-NOTE-TE-2016-013.pdf

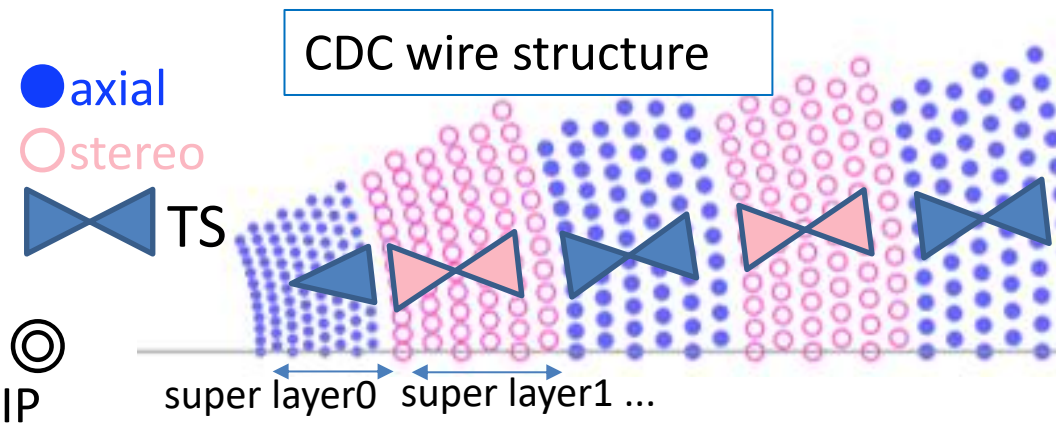


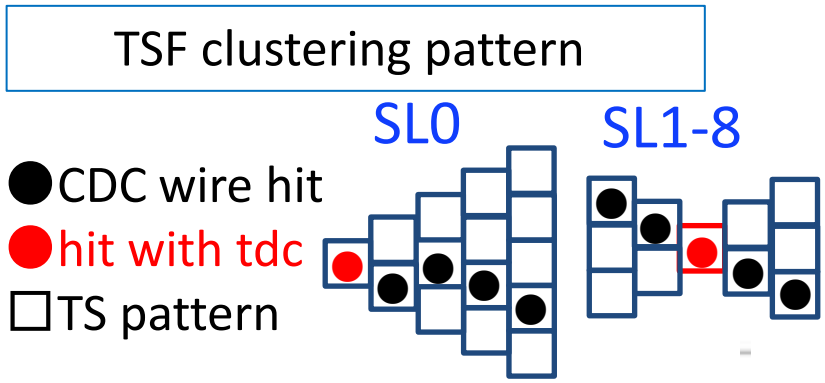




Track segment finder (TSF)

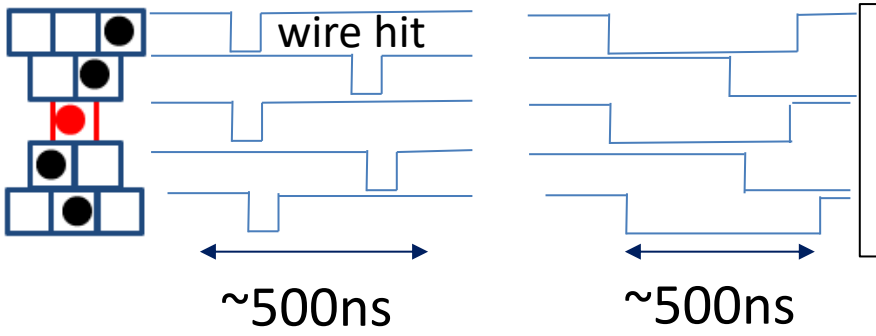
-Find bunch of wire hits (Track segment, TS) to reduce noise and data size
- -require 4 of 5 layer hits in each super layer
- -pt>~0.35 GeV is required: curing track is not reconstructed at this stage





TSF algorithm

receive wire hit with ADC>6 → 500ns buffer → AND (4 of 5 layer hits) → Pack TS info



Look Up Table

-TS found or not

-Left/right flag (pre-calculated in table)

-TS position
-wire hit pattern
-TDC of central wire
-Left/right flag

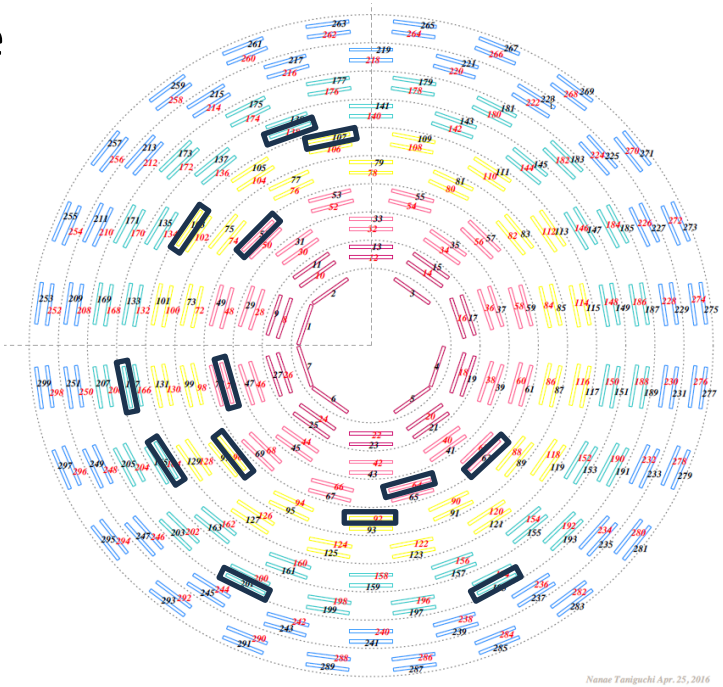
Dead channel mitigation

-There are ~5% (~15 of ~288 board) masked CDCFE on CDCTRG

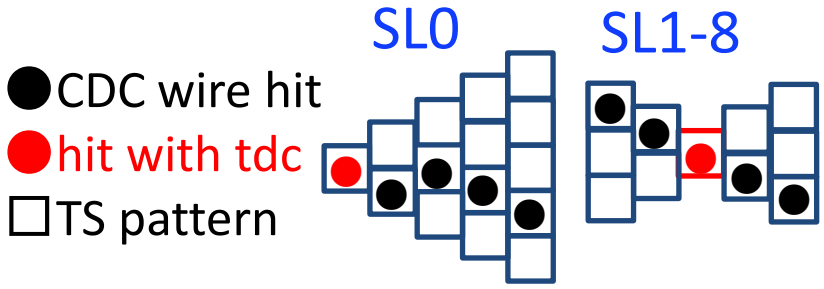
- -dead channel due to optical link down/unstable
- -impact to efficiency was huge

-TSF requirement is loosen on the masked FE to recover efficiency in 2022

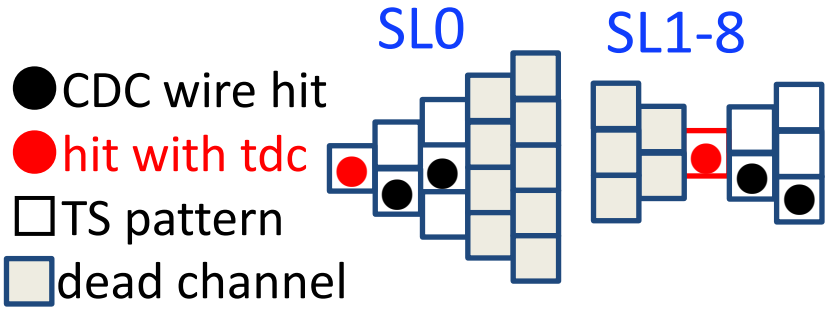
- -recover efficiency with a few percent increase of trigger rate



usual TSF: 4 of 5hits required



TSF on deadch: 2 of 2/3hits required



2D tracking

-Find 2D track by axial layer, by using Hough transformation.

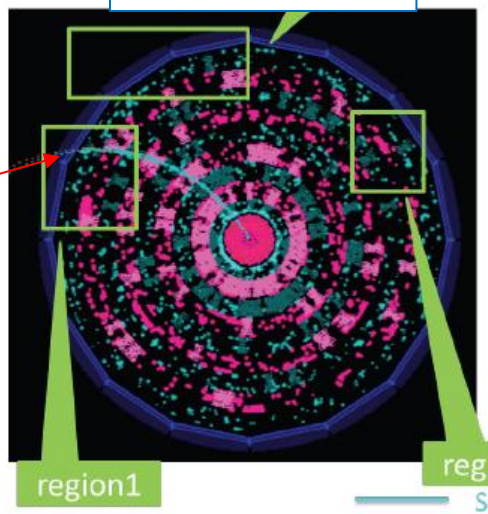
- -pt: 34bin in [0.3-10] GeV, ϕ: 160 bin in [0-360] degree
- -#wires>=20 is required (now >=16) in Hough peak
- ->98% efficiency at barrel, pt>0.4 GeV

https://docs.belle2.org/record/3592/files/BELLE2-MTHESIS-2023-012.pdf

phase3 BG MC

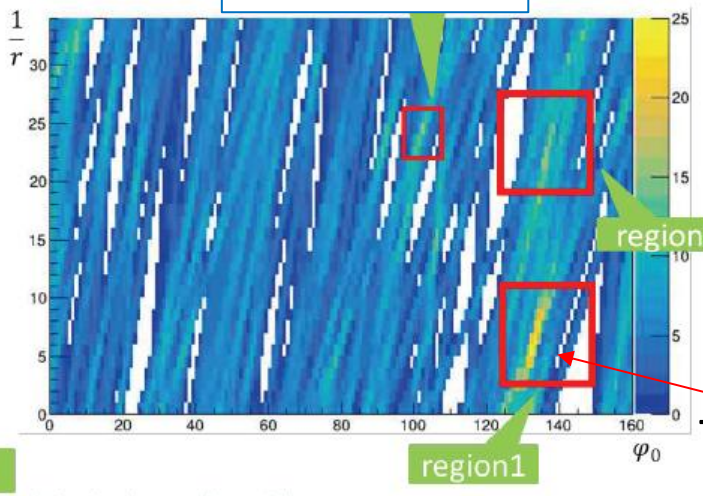
True track

event display



Hough plane

#wire



True track

Simulated single charged particle

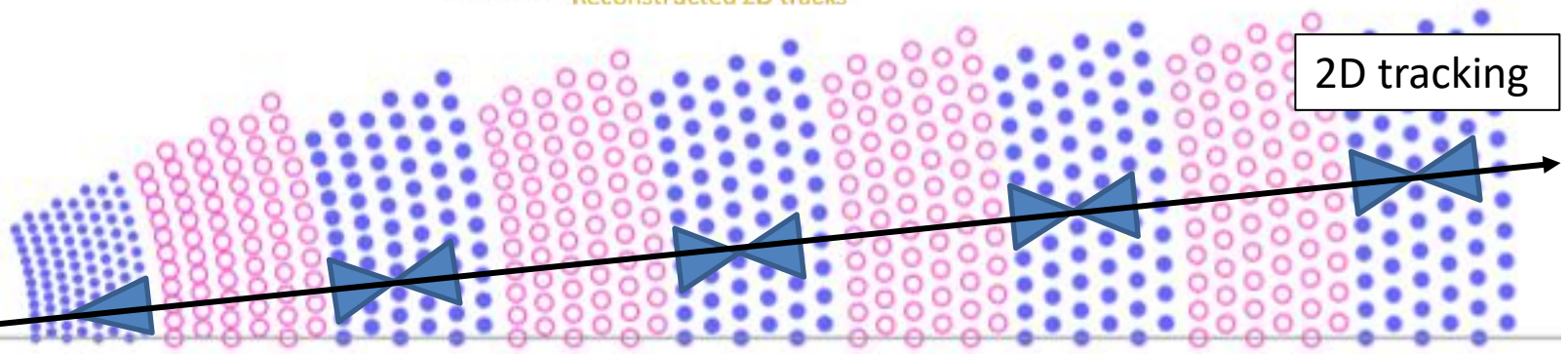
Reconstructed 2D tracks

axial

stereo

TS

IP



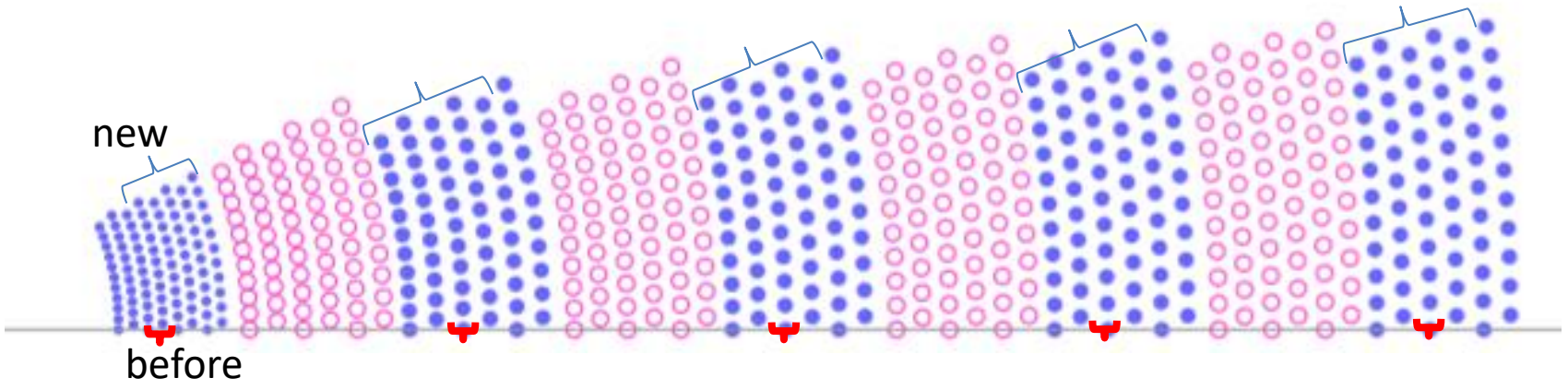
new 2D tracking

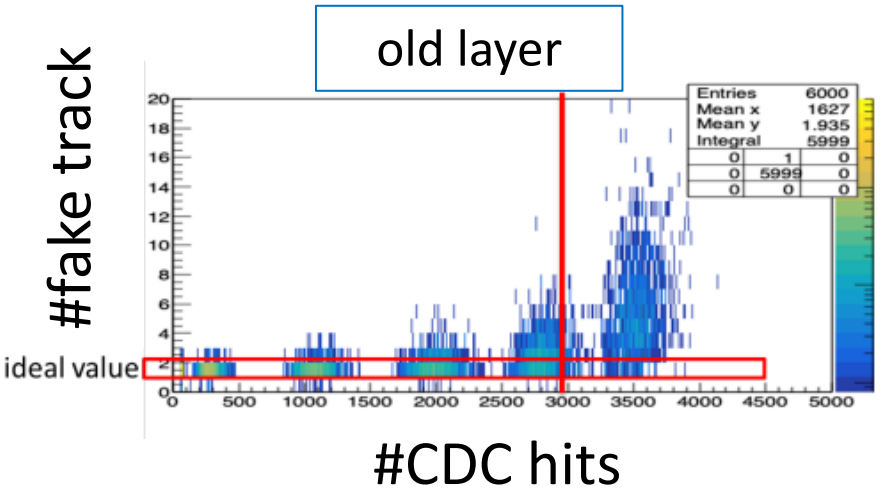
-In 2024, 2D tracking logic is updated to increase #layer from 5 to 25

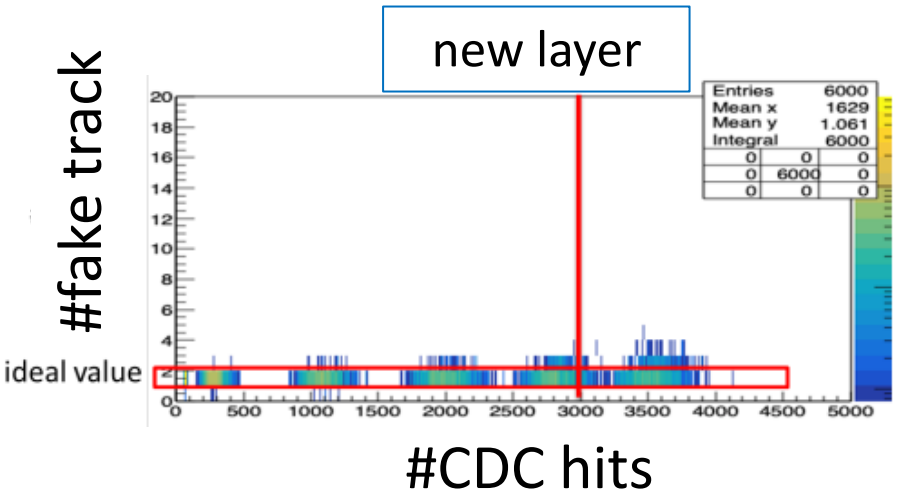
-#hit requirement increased from 4 to 16 in Hough map

-significant fake track reduction (by simulation)

https://docs.belle2.org/pub_data/documents/3951/





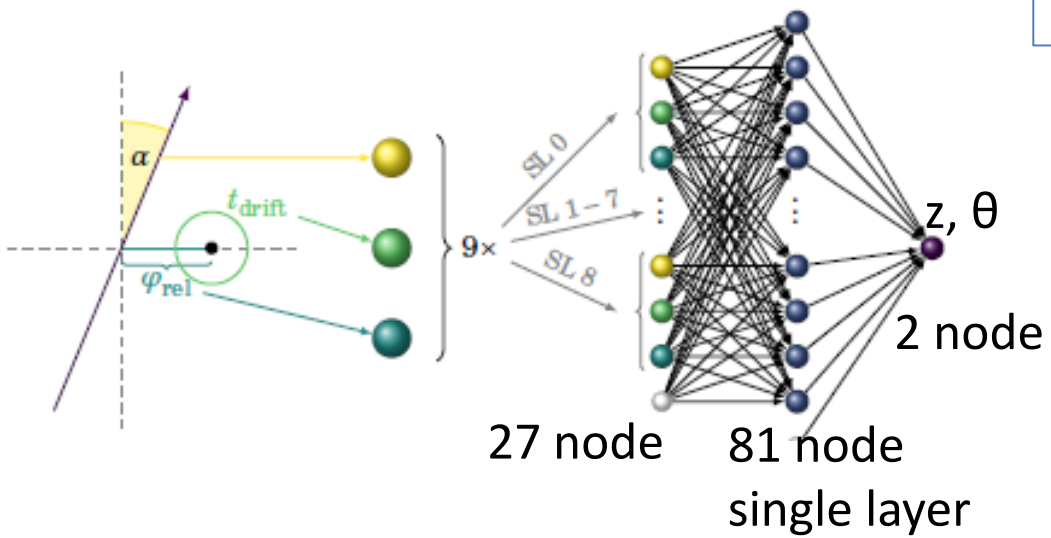


NN 3D tracking

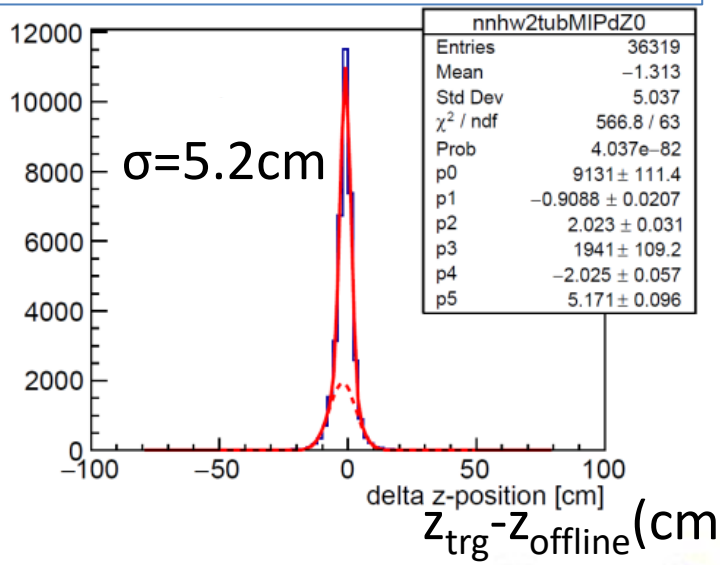
-3D track fitting to measure z position, by using neural network

- -input: 2D track(ϕ_{rel}, α), central wire hit timing of TSF
- -output: z,θ of 3D track
- -Training is done at offline with offline reconstructed track

https://arxiv.org/abs/2402.14962

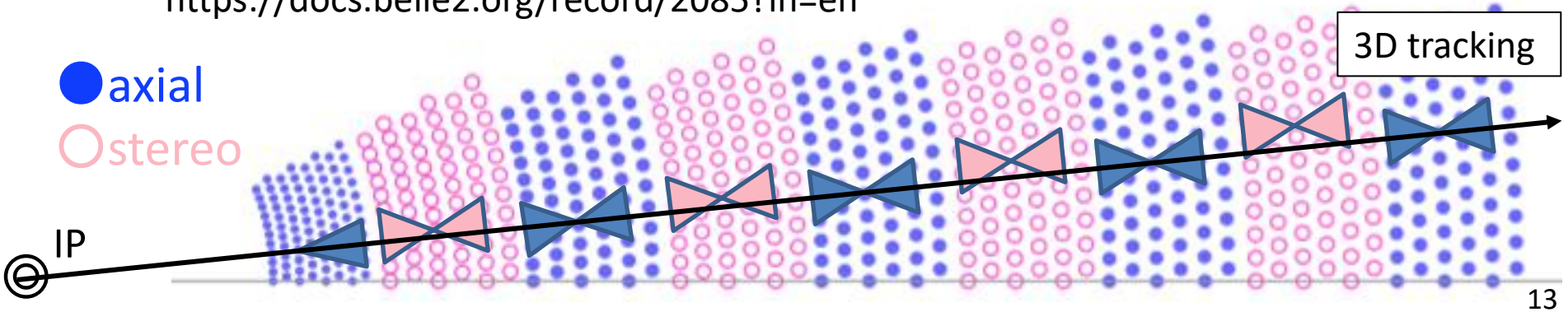


CDCTRG Z resolution at IP



z_{trg}-$z_{offline}$(cm)

https://docs.belle2.org/record/2085?ln=en



new DNN 3D tracking

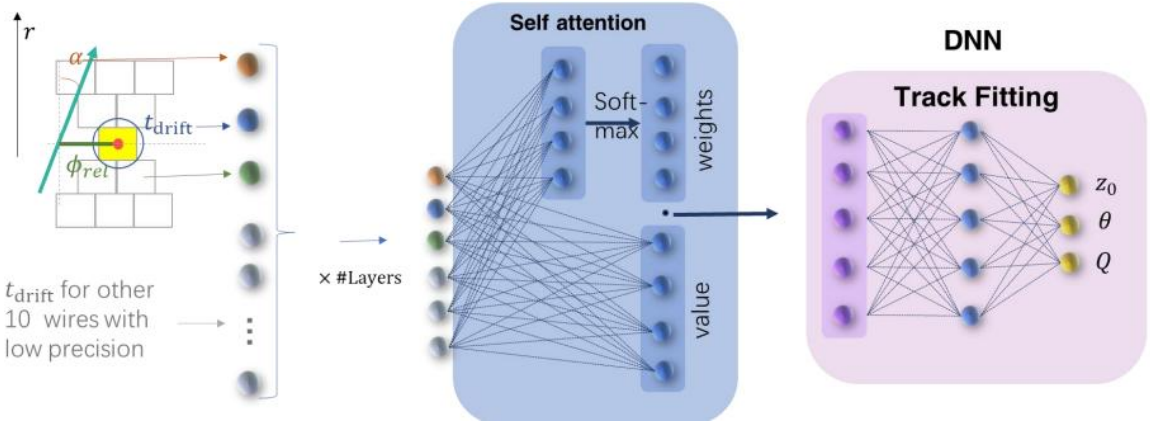
-In 2024, network is updated to use multiple layer (deep neutral net)

-increase #layer input from 9 to 45

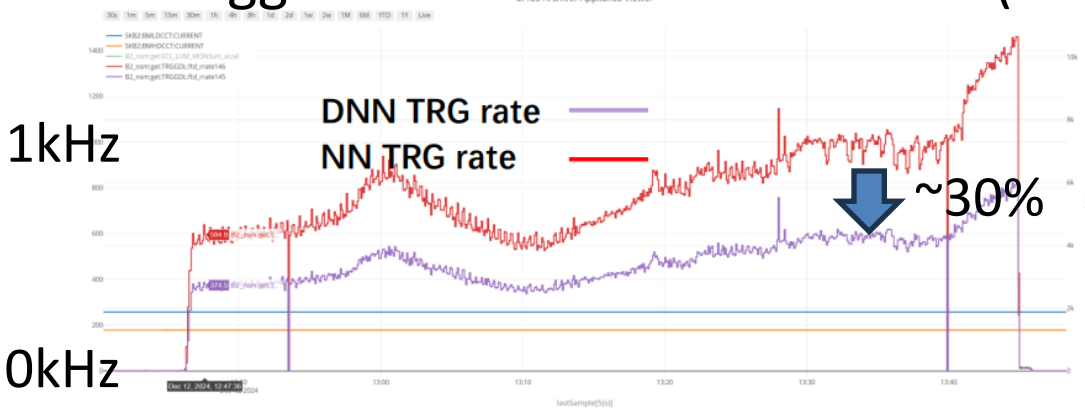
-three hidden layer with self attention

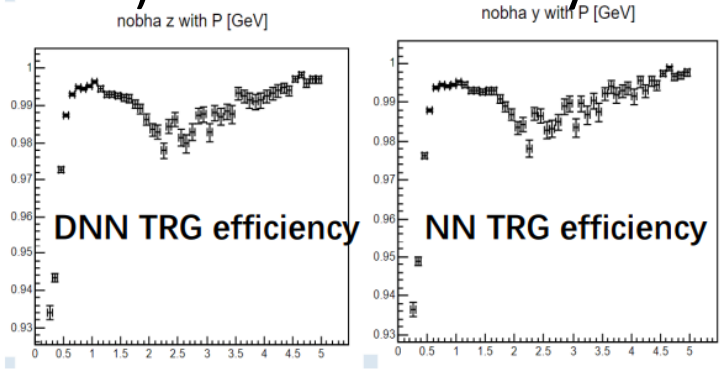
-output: signal track probability is added

https://docs.belle2.org/pub_data/documents/3920/



-30% trigger rate reduction with ~2% (96→98%) better efficiency





NN trigger apply cut as : $abs(z) < 15cm$

DNN trigger apply cut as: $abs(z) < 50cm$ && $q < 0.8$

short tracking

-Endcap track is not triggered by 2D/3D tracking (full track)
- -acceptance is limited to barrel
- -required to reach super layer8

-short tracking is used to increase θ acceptance
- -required to reach super layer5 (extend to super layer4 in 2025)
- -look-up-table pattern matching
- -**trigger rate is too high** and need to disable in future:
  upgrade with Hough method is on-going

https://arxiv.org/abs/2503.02192

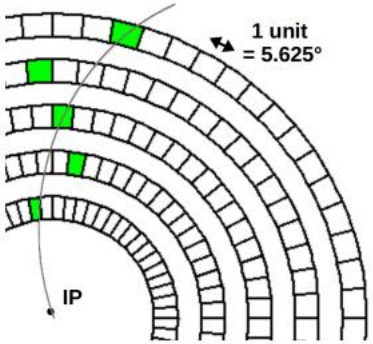
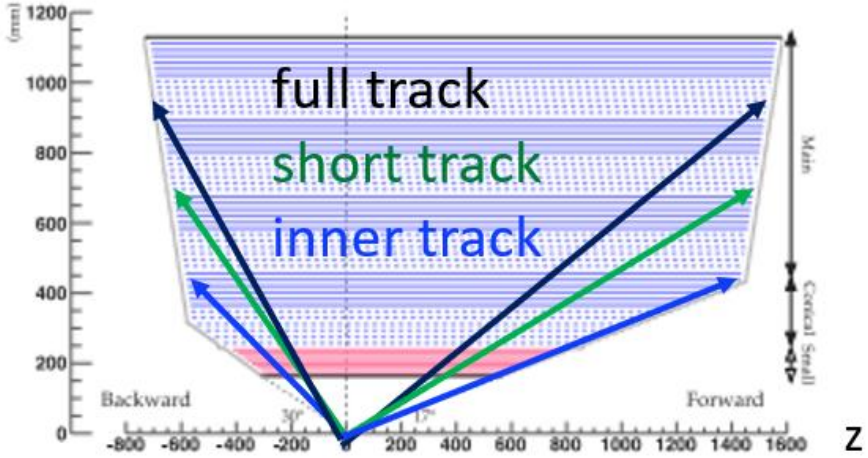


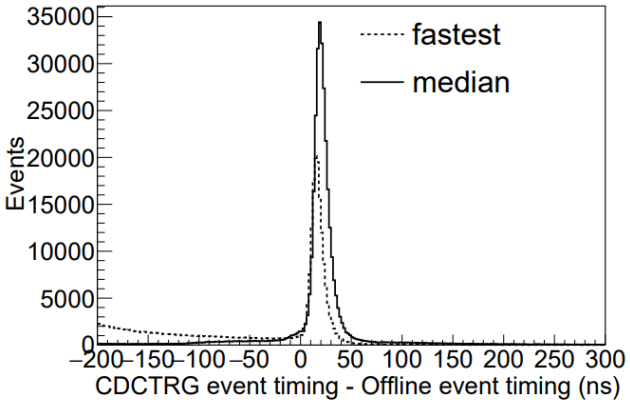
Figure 7: Illustration of the short track identification algorithm in the GRL, showing the pattern recognition process using hits across SL0 to SL4, where the green cells represent one example of the 130 possible track patterns used in the algorithm (see text for details).



Event time finder

https://iopscience.iop.org/article/10.1088/1742-6596/2374/1/012103

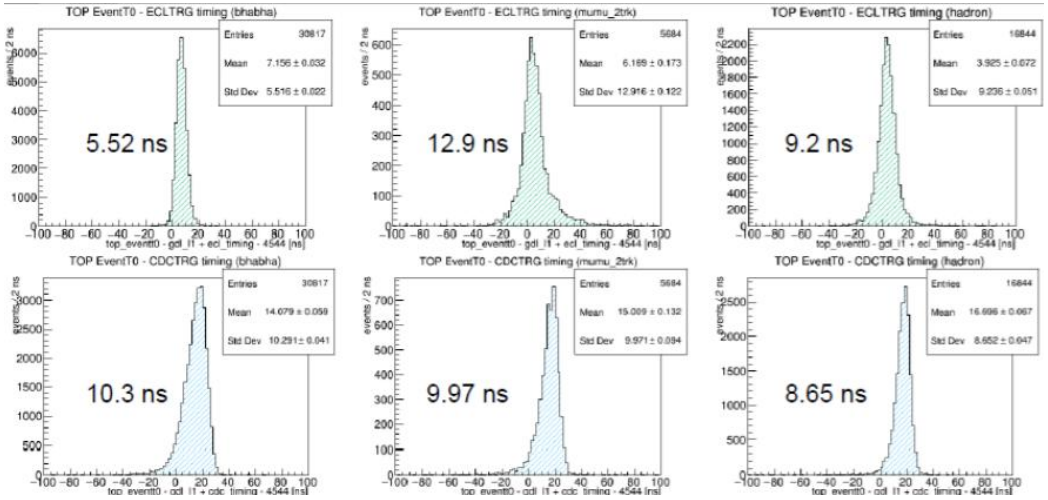
-Estimate event timing
- -similar logic to 2D finder
- -event timing is estimated by median of tracked TSF TDC
- -8~10ns timing resolution



ECLTRG

CDCTRG

Bhabha μμ hadron



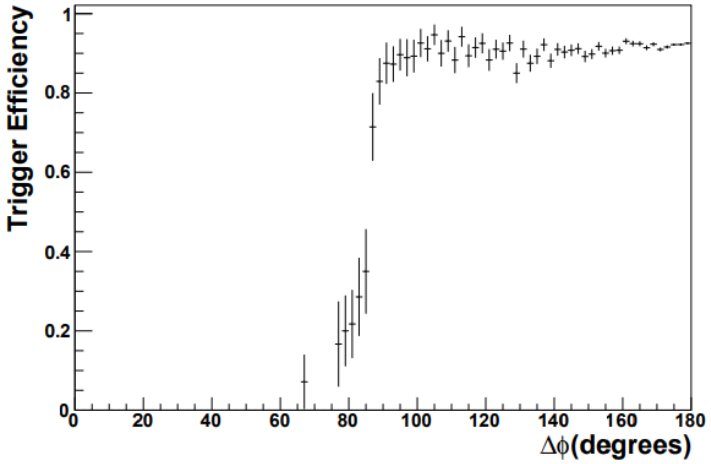
trigger timing – offline eventT0

performance: efficiency

-Major trigger conditions:
- -#track>=1, p>0.7GeV (stt)
- -#track>=2, opening angle Δϕ>90deg. (fyo)
- -#track>=3 (ffy)

-~95% efficiency per track is achieved

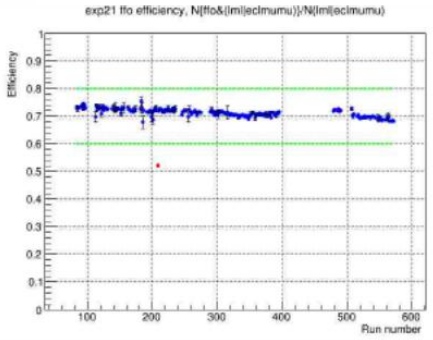
dimuon efficiency of back-to-back 2track trigger



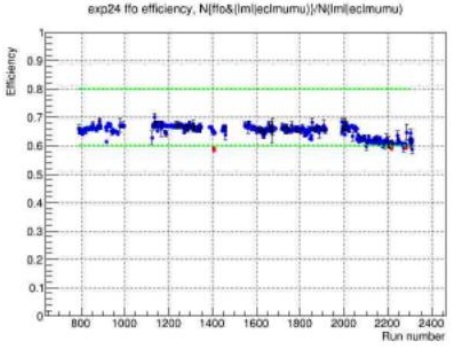
-large run dependency due to CDC gas gain, dead channel etc:
At maximum ~10% change of efficiency. (much improved in 2024)

two track efficiency with mumu

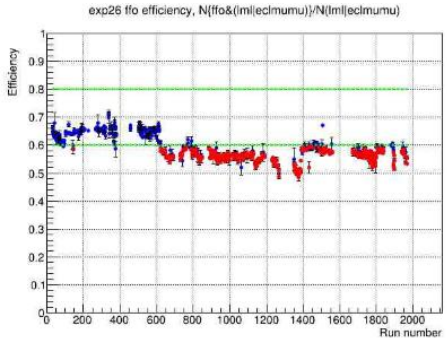
2021c



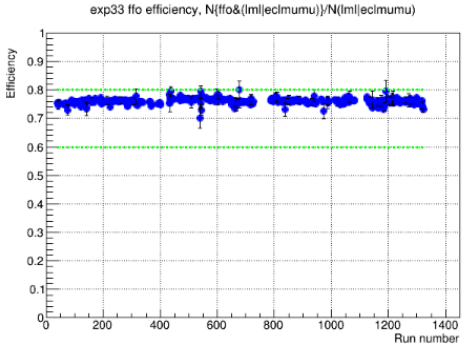
2022a



2022b



2024b



performance: trigger rate

-Trigger rate is enoughly low for 2024c, probably not at designed lumi.

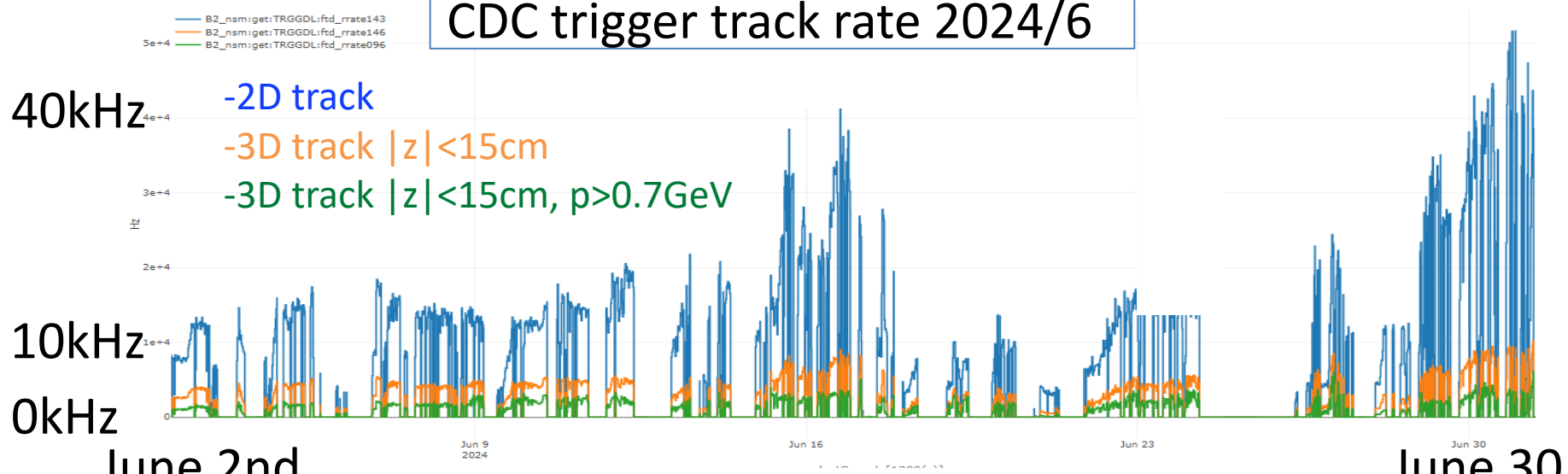
-may be difficult to keep single track trigger (stt) at designed luminosity

-upgrade will reduce trigger rate ☺

link

rate	2024 @L=~4×10^{34}	designed lumi. (w/o ADC, DNN)
#track>=1, p>0.7GeV (stt)	1.9kHz	35kHz
#track>=2, opening angle Δϕ>90deg. (fyo)	0.9kHz	13kHz
track>=3 (ffy)	0.6kHz	5kHz

CDC trigger track rate 2024/6



History of CDCTRG development

-major developments and link

year	new core logic	TSIM
2018?	part of TSF, 2D. all MGR.	--
2018?	Neighborhood suppression	available
2019	all TSF, 2D	available (TSF, 2D)
2019	Many firmware bug fixed	--
2019	(Increase CDC TDC discriminator threshold)	? (not TSIM but CDC sim.)
2020	CDCFE TDC based cross talk filter (link1, link2)	available but OFF in default due to CPU time increasement
2020	short tracking	available
2020	ETF	available
2021	NN	available (but not latest)
2022	dummy hit to masked board	not available (instead, board is not masked)
2024	2D with full wire	available
2024	new TSF core logic	-- (no effect to fast TSIM)
2024	TSF ADC (link1,link2)	available but OFF in default
2025	DNN	not available

turned on in this slide

Summary

-Introduction of CDCTRG system

-major functionality is summarized

  -sorry for long talk..

  -I hope this slide will be used when student starts CDCTRG work ☺

backup