The Level 1 track trigger at Belle II

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10.1109/RTC.2010.5750454 (2010-2011)
The Belle II L1 Neural Network Track trigger (2022 ML-based Trigger)
Introduction to the level1 trigger (2024 Belle II Physics Week)
NIMA 1073, 170279 (2025)

Outline

- What is “trigger”
- Belle II track trigger
  - ✓ Baseline design idea
  - ✓ Moving towards machine learning era
- High speed transmission
- Summary and prospect

What is “trigger”?

When you go to a Kaiten-zushi (conveyor belt sushi) restaurant, the delicious dishes come and go, you have to make a decision to “take or pass” in a limited time.

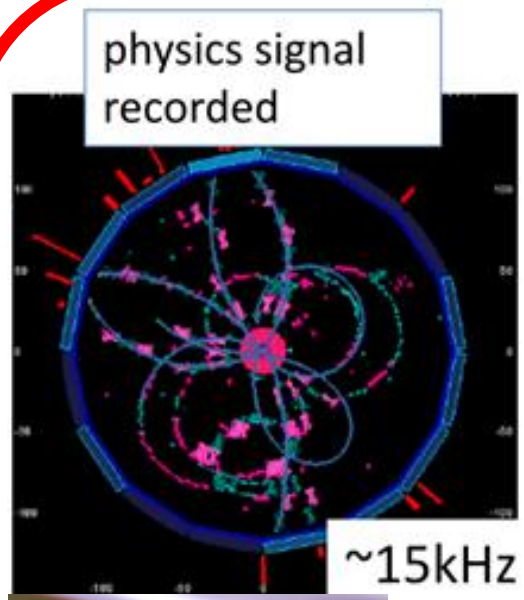
How do you make that decision?
What is your concern?

→ (L1)trigger.

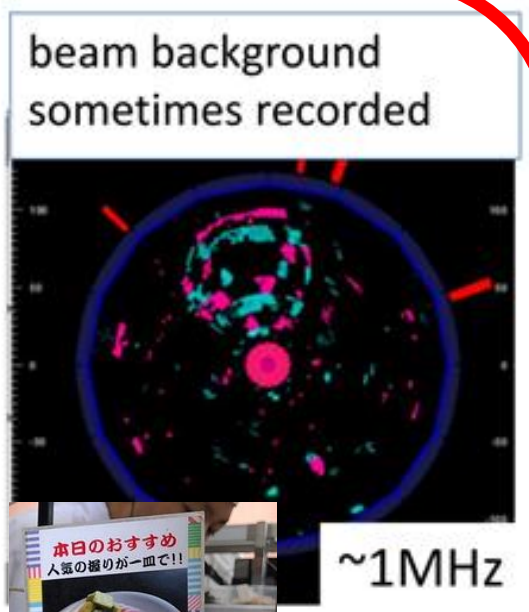
Google AI:

The first level, or Level-1 (L1) trigger, is a hardware-based system designed to reduce the data volume **in real-time** by selecting promising collision events.

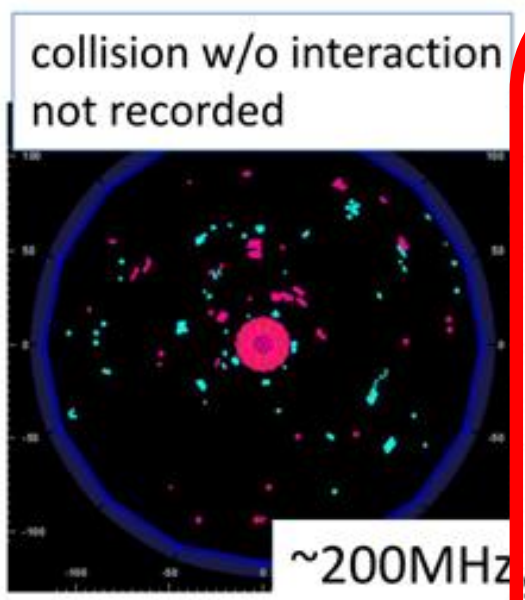
→ What are the key features to distinguish your signal from background?



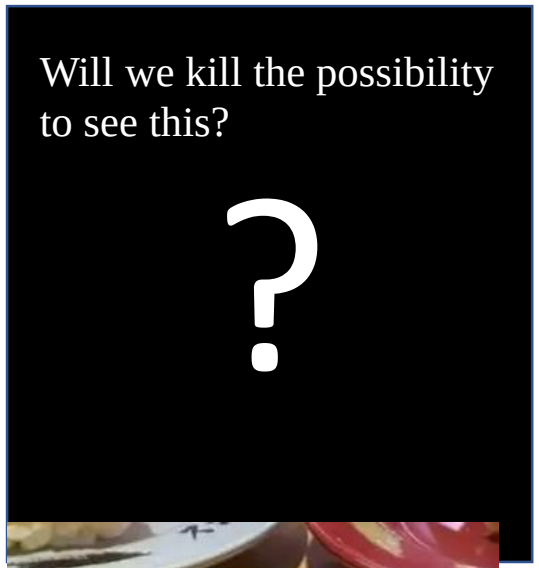
signal



background



empty



unexpected?
new flavour?

Remark

L1 trigger is not HLT

hardware trigger
small part of the detector data
latency constrained

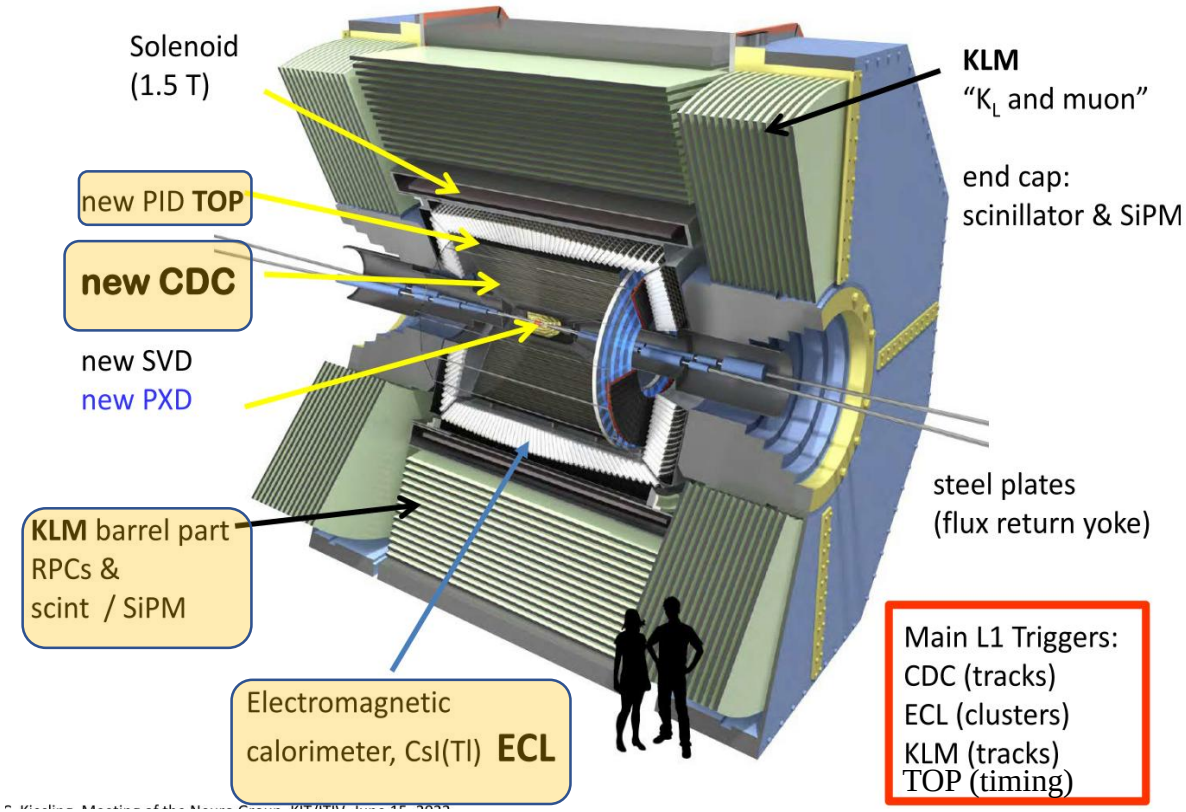
quick decision to keep/drop one event
to reduce the throughput of DAQ to HLT

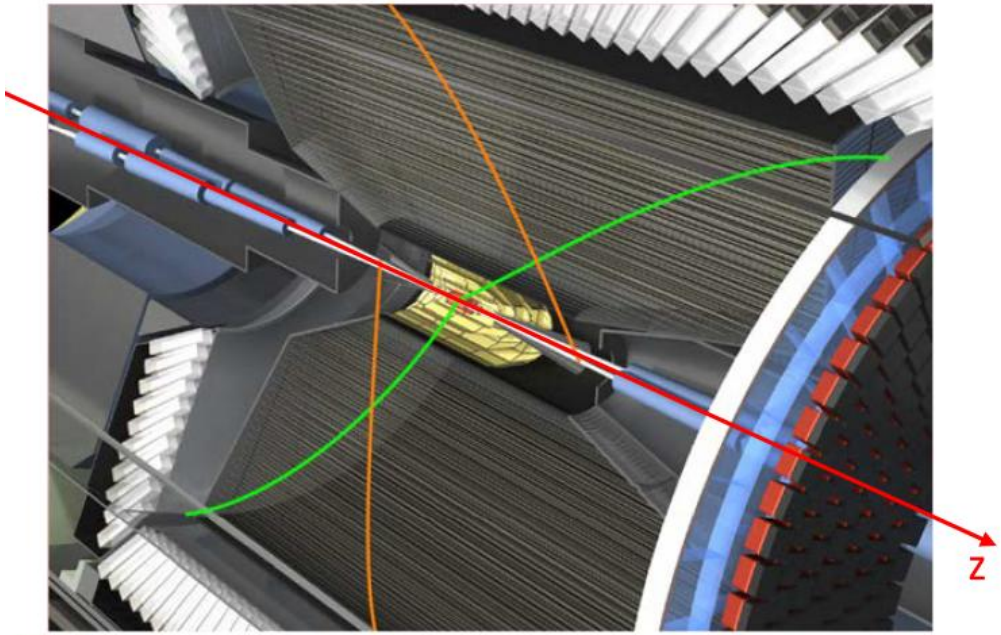
software event reconstruction
full detector data
soft processing time constraint

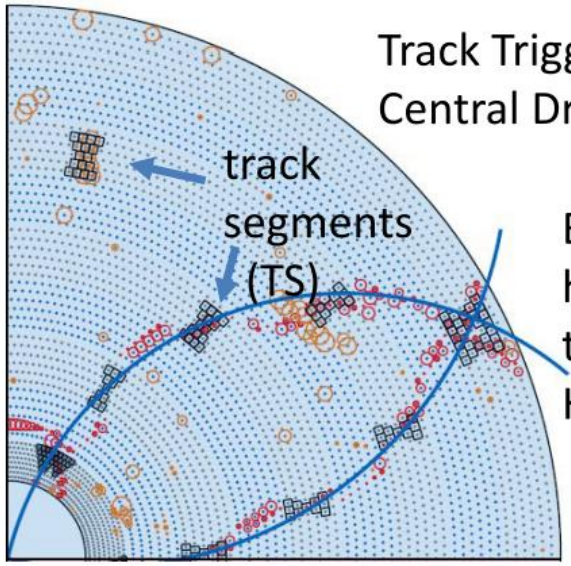
prompt event reconstruction without
finalized run/detector parameters
used for prompt study and detector
monitoring/calibration/…

Belle II track trigger
Baseline design idea

- Partial data set: CDC, ECL, KLM, TOP
- Hardware based: FPGA
- Latency: 4.4 μs
- Max. rate 30KHz → not trigger limit
- Track trigger → partial CDC (~2%)
  - ✓ signature of collision data:
    track coming from the interaction point!
  - ✓ The original baseline design is to start with
    what Belle did: (FJU, MPI, NTU, …)
    2D track finder using Hough transform
  - ✓ New in Belle II:
    including track segment from stereo layers to
    get track z position for beam BG rejection





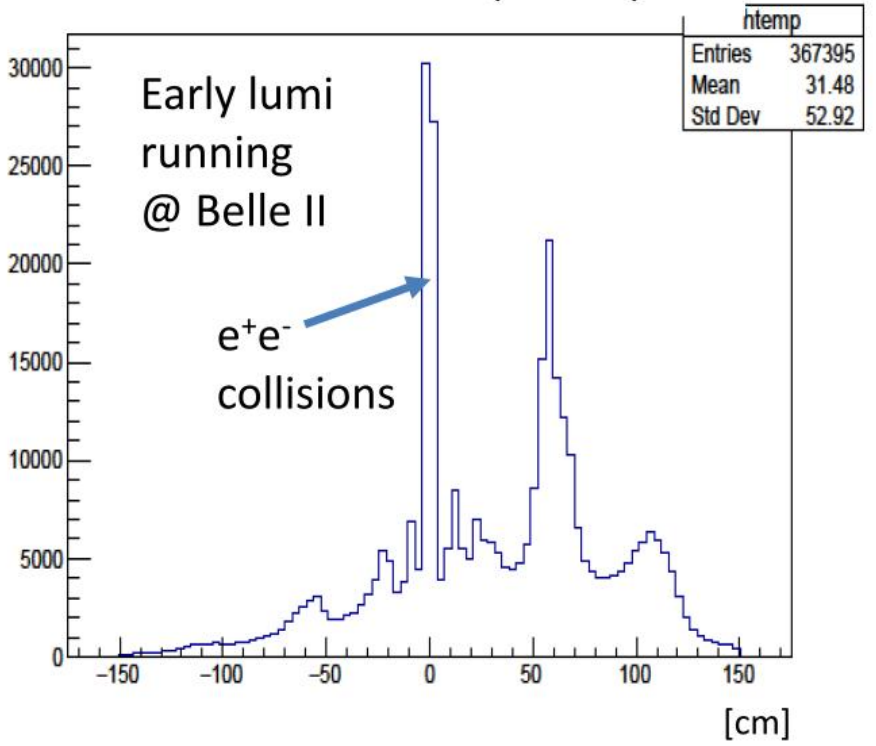


Track Trigger derived from Central Drift Chamber:

Belle II (like Belle) had initially only a track trigger in 2D using Hough transforms:

2D tracks >= 2

z-vertex distribution (offline) :



Belle II: majority of events originate from „obstacles“ outside of the interaction region (IP) (|z| >> 1 cm): only ~10% from IP

→ „z-vertex“ trigger mandatory

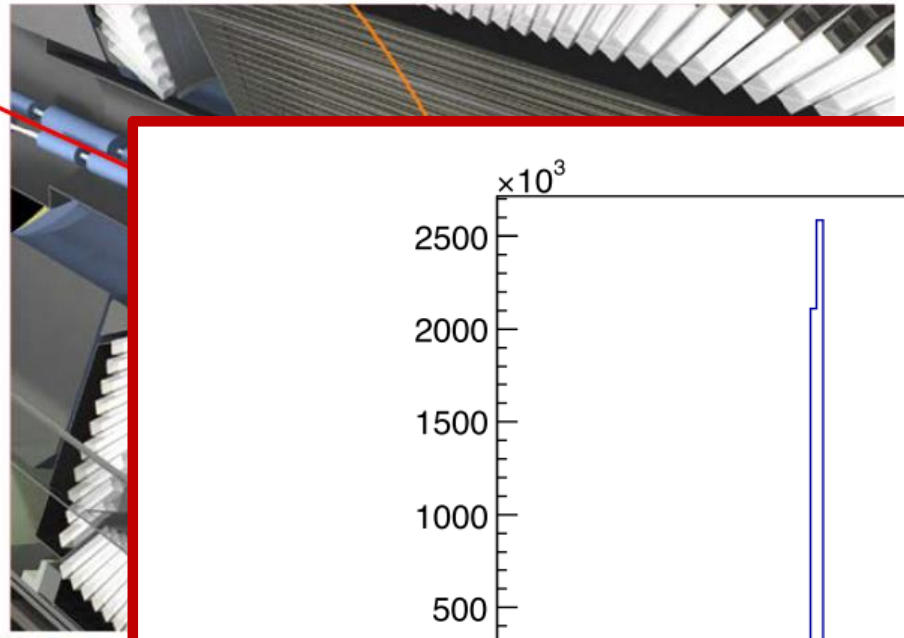
(Courtesy from C. Kiesling)

Well, “clean” not to the sense of beam bg.

Beam background
- beam gas
- injection bg.
- luminosity bg.
- Touschek
- synchrotron rad.

Track can come even from 150 cm away from the IP.

We need 3D track trigger.



z-vertex distribution (offline) :

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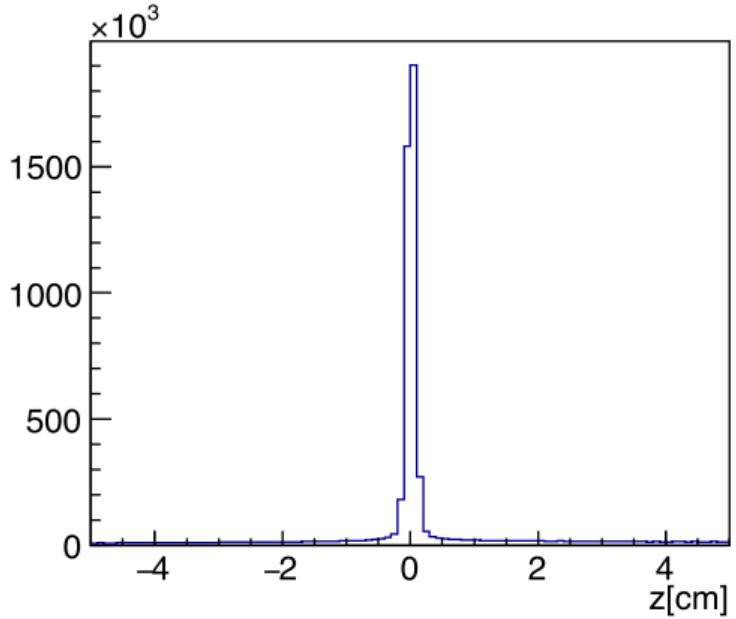
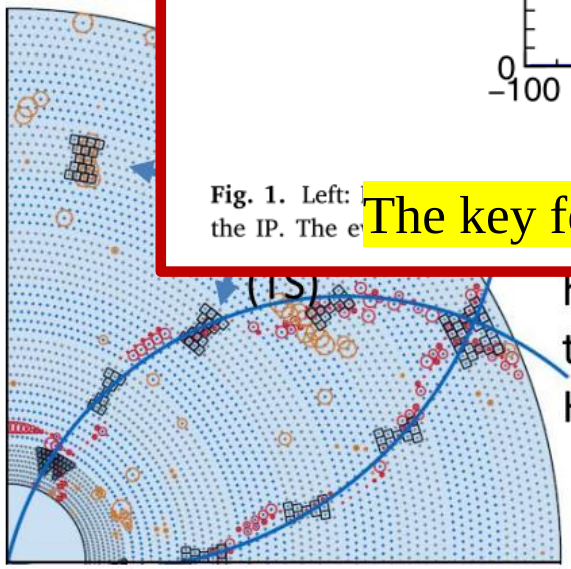


Fig. 1. Left: … z around the IP. The e…

The key features to distinguish signal tracks from background: coming from the IP.



had initially only a track trigger in 2D using Hough transforms:

2D tracks >= 2

of the interaction region (IP) (|z| >> 1 cm): only ~10% from IP

→ „z-vertex“ trigger mandatory

We need 3D track trigger.

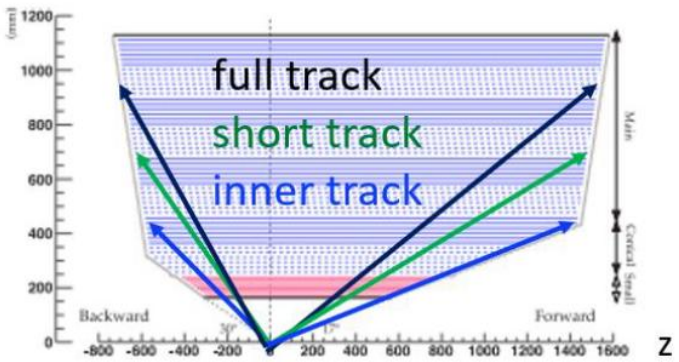
(Courtesy from C. Kiesling)

CDC Trigger

-Role: Trigger charged particles

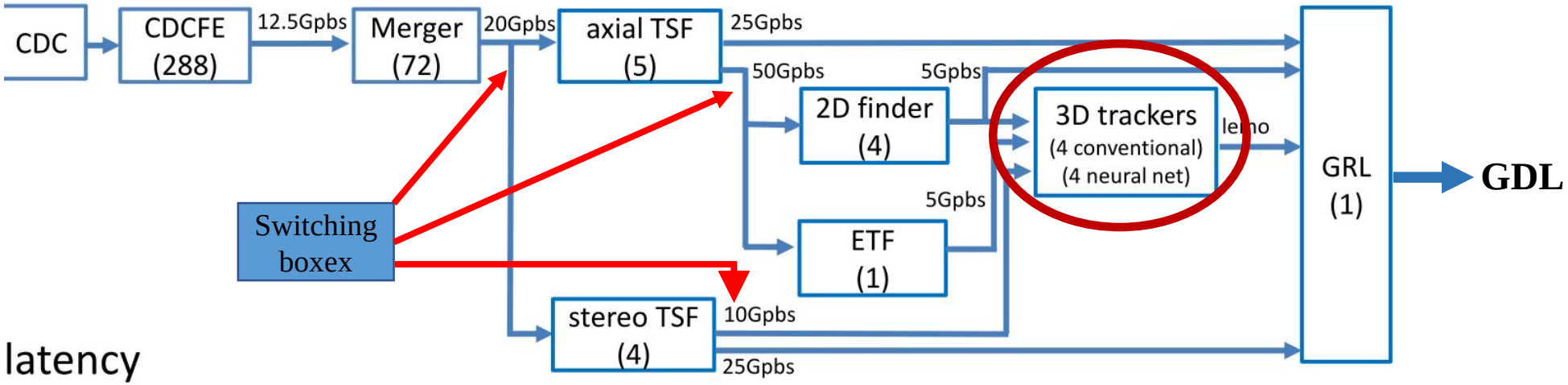
-Three kind of track with different θ region:

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

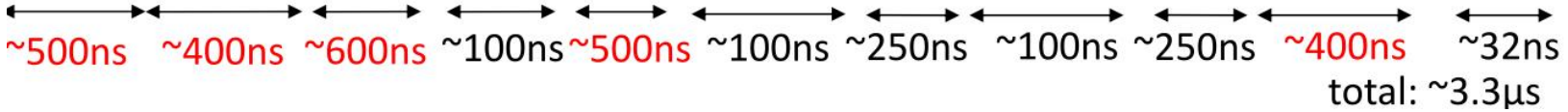


-Consists of ~100 boards

(): number of boards



latency



Move towards machine learning era

- The whole Belle II CDC trigger R&D started in ~2010
- The “conventional 3D track finder” is still under R&D (KU, NTU, …)
  - ✓ 2D output as seed
  - ✓ Searching related track segment in stereo layer in some predefined ROI
  - ✓ Analytic calculation and fitter to get track z_0 and θ.

- In ~2012, a big group joined us and one respected colleague proposed to adopt such a “neuromorphic“ technics in CDC trigger.
  - ✓ At that time, none of us has a clue what that is …
  - ✓ It is not neuro-network, it is more fancy and performs better, …, much better?
- After some evaluation, it is decided to go back to use more “conventional” neural network technics
  - ✓ It is still quite “novel” at that time.

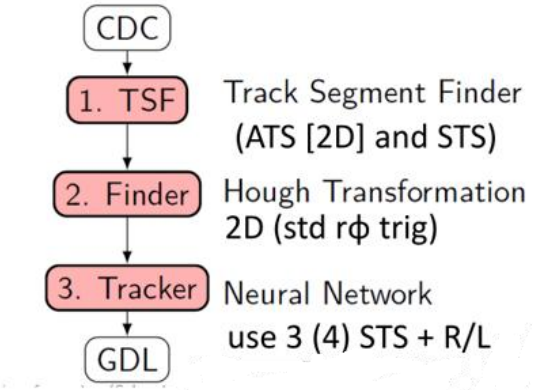
(Both conventional/neural-network 3D trigger are more or less ready in ~2020.)

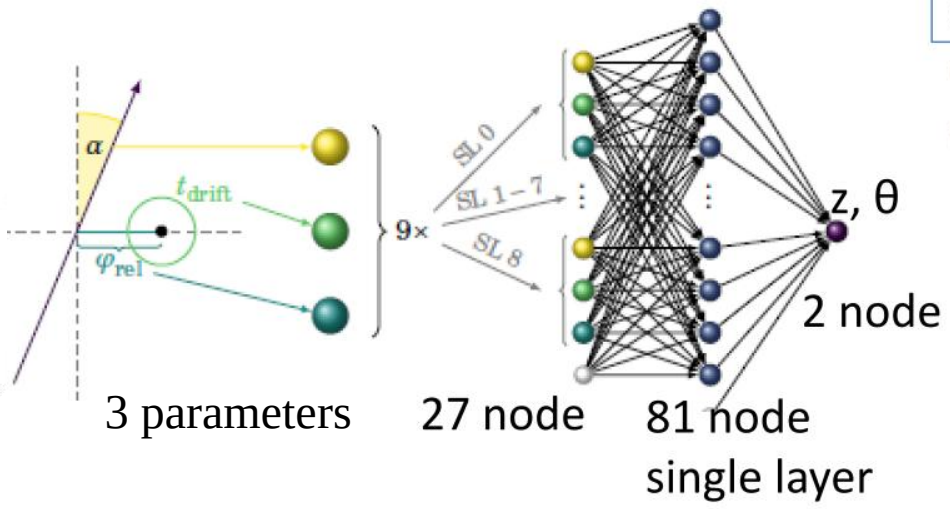
CDC trigger: 3D tracking

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

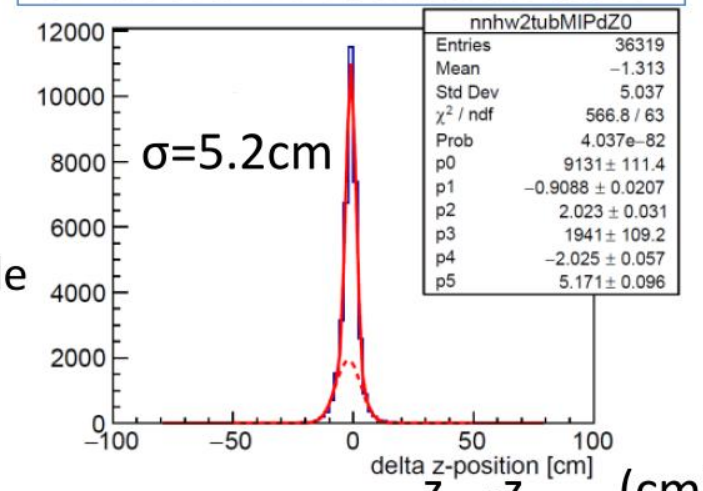
- -input: 2D track(ϕ_{rel}, α), central wire hit timing of TSF
- -output: z,θ of 3D track
- -Training is done at offline with offline reconstructed track

L1 Neuro Trigger pipeline



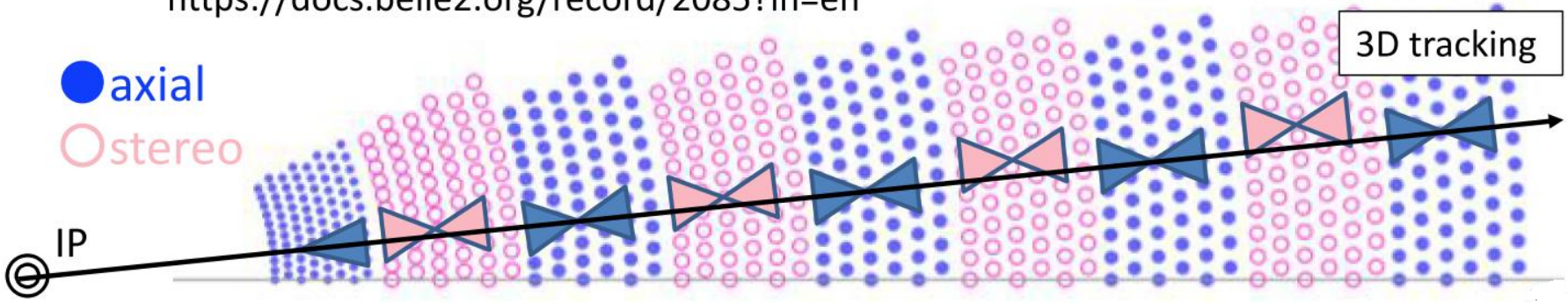


CDCTRG Z resolution at IP



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

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

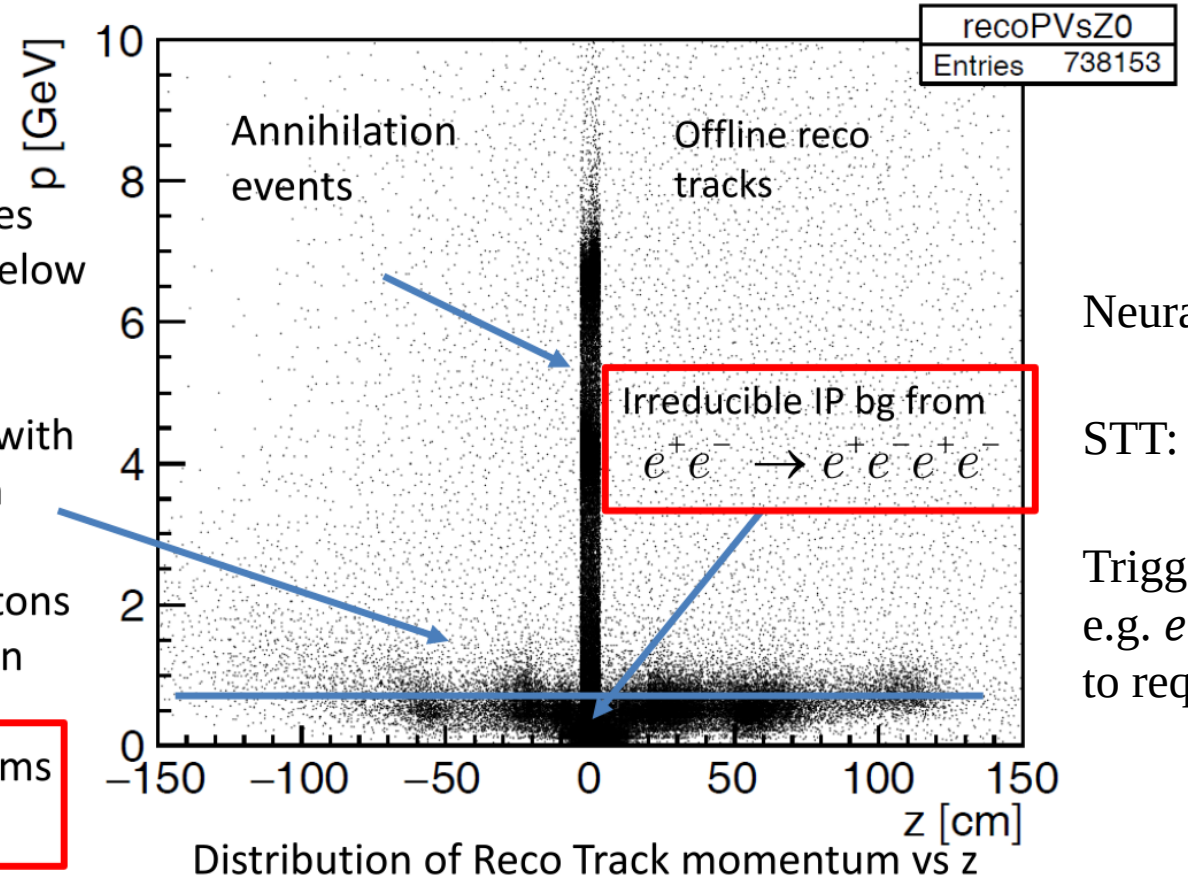


To go one step further to reduce beam background

„STT“: a Minimum Bias Single Track Trigger

Rate from z-Trigger (y=1)
too high due to QED events from IP

STT: require only 1 track in CDC volume, then the other tracks are unbiased !



Distribution of Reco Track momentum vs z

Momentum of particles outside of IP mostly below 1 GeV !!

Collisions of electron with elements of the beam guide system, mainly producing protons from nuclear spallation

cut at p > 0.7 GeV seems OK for a first try

Neural-z trigger online since 2021.

STT: $|z| < 15\ cm, \mathrm{P}_t > 0.7 \frac{GeV}{c}$

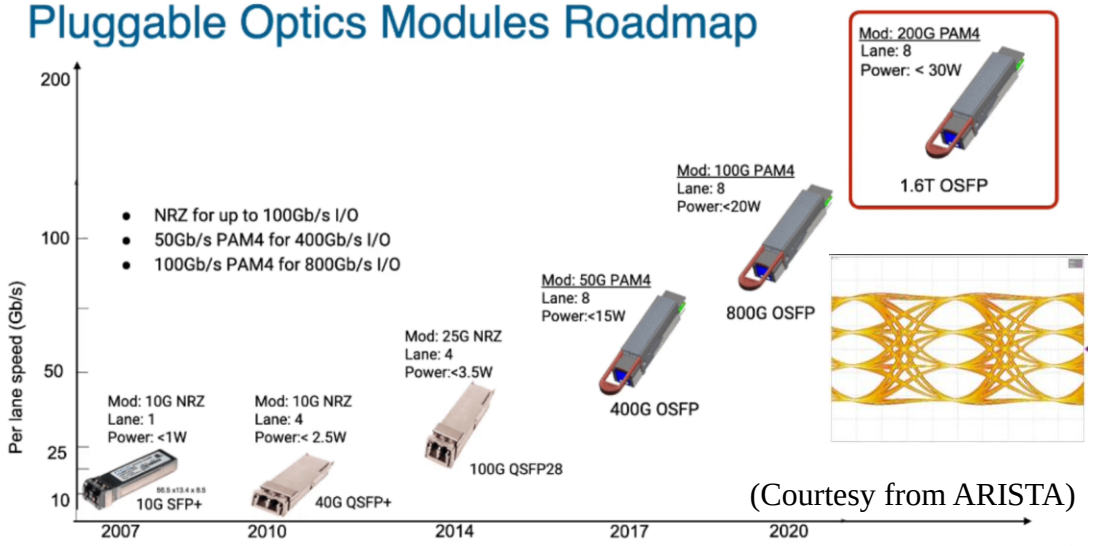
Trigger efficiency of low multiplicity events, e.g. $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$, improved, compared to requiring two tracks.

High speed transmission

- Latency constraint: 4.4 μs
- Optical fiber with high speed transmission transceivers
  - ✓ 10Gbps was novel in 2010
  - ✓ Homemade protocol to reduce input/output latency (compared to Aurora)
  - ✓ Now over 100Gbps using PAM4/6/8 in industry. We are moving in that direction.

- FPGA: pipeline, no dead time, fixed latency
  - ✓ Vertex 6 → UltraScale+ → … → VERSAL
  - ✓ ISE → VIVADO → … → Vitis

- Optical transceiver → photonics (transceiver on chip)



(Courtesy from ARISTA)

Summary and Prospect

- Application of neural network L1 track trigger at Belle II is done.
  - ✓ Commissioning since 2021
  - ✓ Together with the conventional 3D z-trigger,
    sort of complimentary each other.
  - ✓ STT improves the trigger efficiency for low multiplicity events
  - ✓ Further electronics upgrade planned for LS2
- By the end of LS1, electronics is upgraded,
  - ✓ Larger FPGA, 25Gbps transceiver, PCIe 6
  - ✓ More CDC hit information implemented into 2D track finder
- Short track finder is also implemented (mostly for low Pt tracks)
- More under R&D
  - ✓ 3D Hough
  - ✓ new trigger recipes (e.g. …)