Development of the Level-1 track trigger with Central Drift Chamber detector in BelleII experiment and its performance in SuperKEKB 2019 Phase 3 operation

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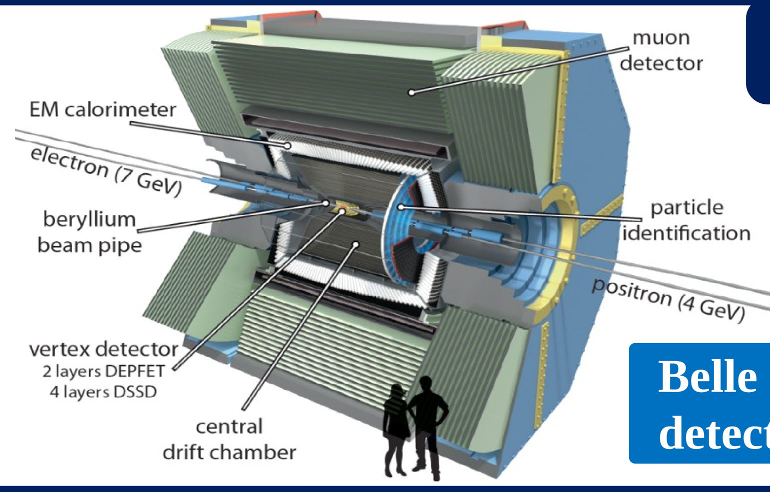
on behalf of the Belle II Collaboration

Introduction

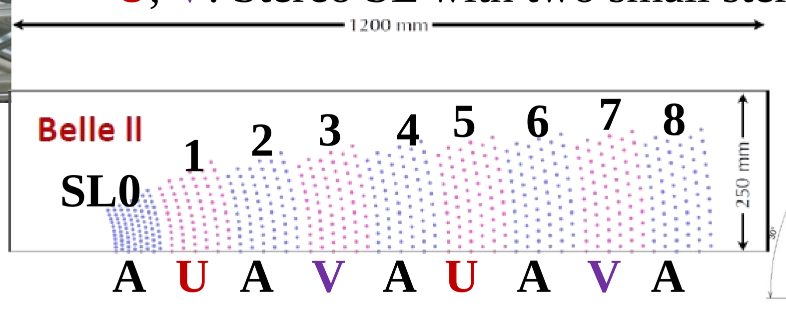
- Belle II experiment at the SuperKEKB collider is designed for rare *B*/charm/τ physics study, Dark Matter search, and *CP* violation in *B* decays with 40 times higher expected luminosity compared to that in Belle. We have achieved Lint = 10.57 fb^{-1} up to 2019.
- Level-1 trigger system (TRG): designed to select physics events with interest and to reduce the beam background in the data acquisition.
- Central Drift Chamber (CDC) TRG: Real-time charged particle trajectory reconstruction with FPGA chips.
- Performance of CDCTRG in SuperKEKB 2019 phase 3 operation will be presented.

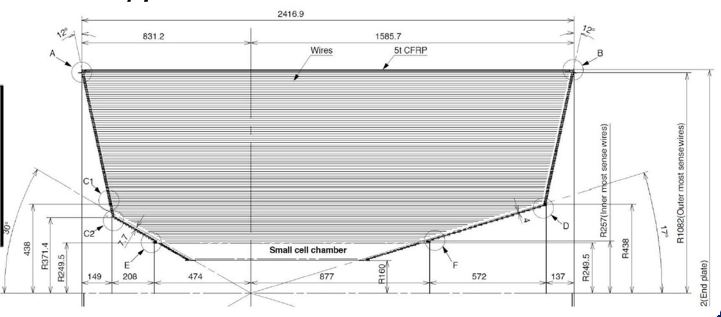


Belle II detector

CDC detector

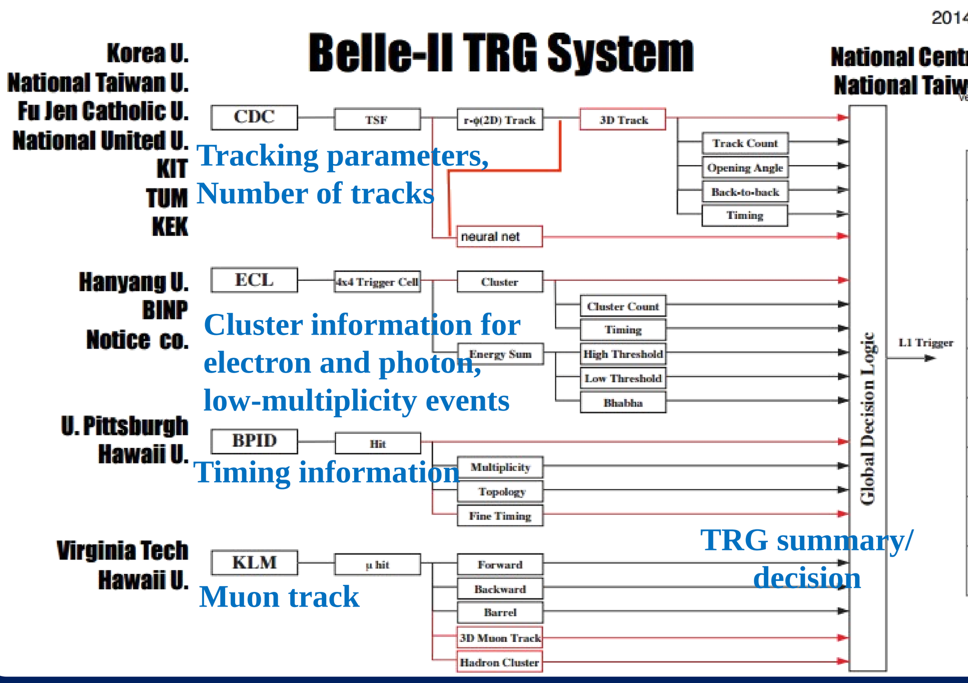
- About 14 thousand of sense wires and mixture of He and ethane as ionization gas.
- Gas atoms' ionization will accumulate charges on sense wires when charged particles go through.
- AUAVAUAVA configuration for 3D information:
  A: Axial super-layer (SL) parallel to z-axis
  U, V: Stereo SL with two small stereo angles.





L1 TRG system

- Why L1 TRG? Buffer storage are not enough for all data due to high event rate and short bunch spacing in collider experiment.
- Determines data section of interest with physics event from continuous data flow, and issues trigger to DAQ.
- Requirements:
  - Overall latency < 4.4 μs
  - ~100% for Υ(4S) events.
  - Max 30 kHz @ $8*10^{35}$ $cm^{-2}s^{-1}$
  - Timing precision: < 10 ns
  - Event separation: 500 ns



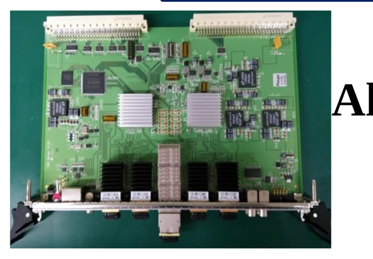
Phase2 Lum. Record

Process	C.S. (nb)	R@L=5.5x10³³ (Hz)	R@L=8x10³⁵ (Hz)	TRG logic
Upsilon(4S)	1.2	6.6	960	CDC 3trk(fff) ECL high energy(hie) ECL 4 clusters(c4)
Continuum	2.8	15.4	2200	
μμ	0.8	4.4	640	CDC 2trk(ffo) etc
ττ	0.8	4.4	640	
Bhabha	44	242	350 *	ECL Bhabha(bhabha, 3D bhabha)
γ-γ	2.4	13.2	19 *	
Two photon	13	71.5	10000	CDC 2trk(ffo) etc
Total	67	357.5	~15000	

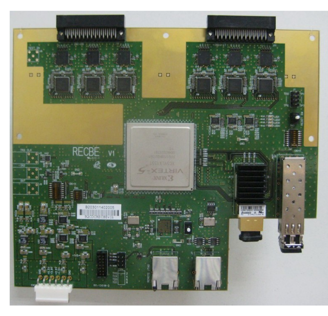
CDCTRG

FE x 292 → Merger x 73 → TSF x 9 → 2D x 4, ETF x 1 → 3D, NN x 4 → Global triggers

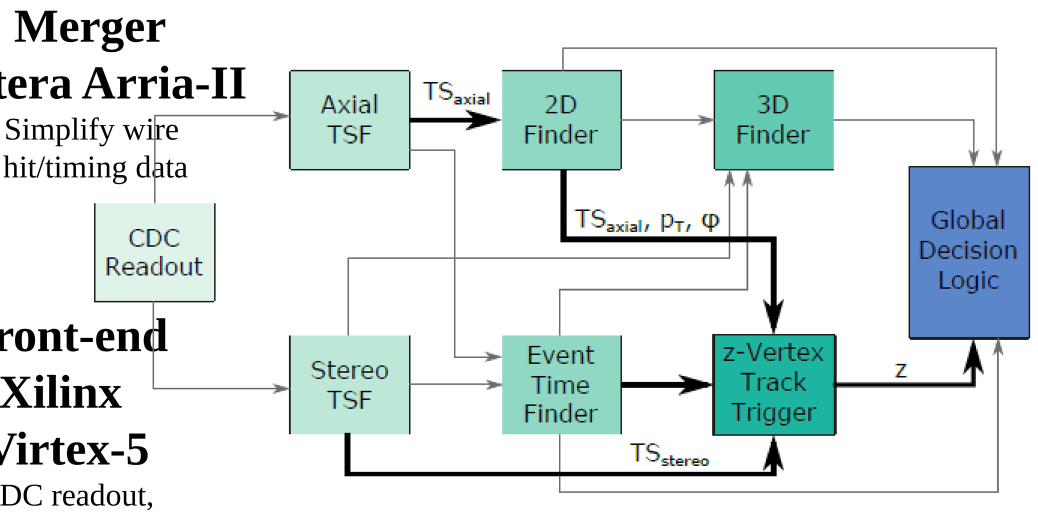
UT3
Xilinx Virtex-6
General purpose: tracking, timing.



Merger
Altera Arria-II
Simplify wire hit/timing data



Front-end
Xilinx Virtex-5
CDC readout, wire hit/timing raw data



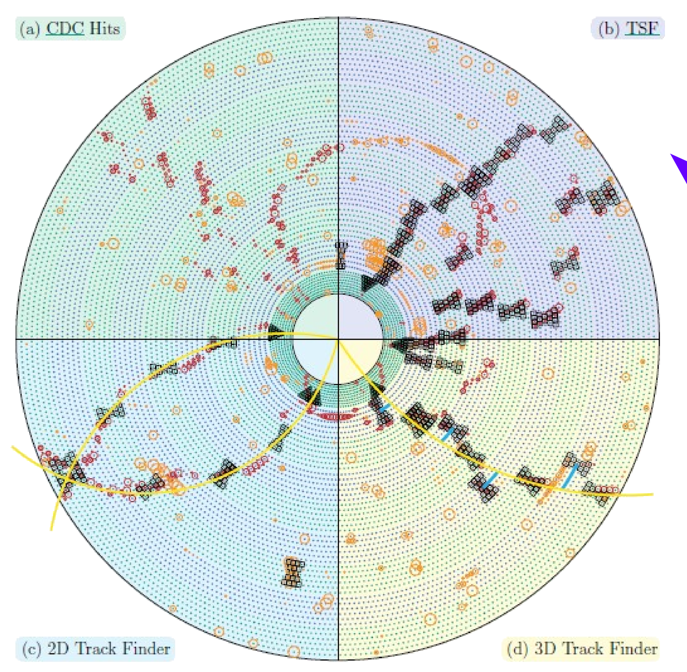
- User-defined protocols for optical data transmission developed by CDCTRG group:
  - Smaller latency than Aurora's: **Latency reduction is critical for L1 TRG!**
  - User-friendly interface like Aurora's
  - 8B/10B and 64B/66B encoding
  - Support Xilinx Virtex-5 GTP, Virtex-6 GTX and GTH, and Altera.
  - Bit error rate < 10^{-18} /s with few weeks BERT.
  - Flow control functionality.
- Latency comparison of our designs:

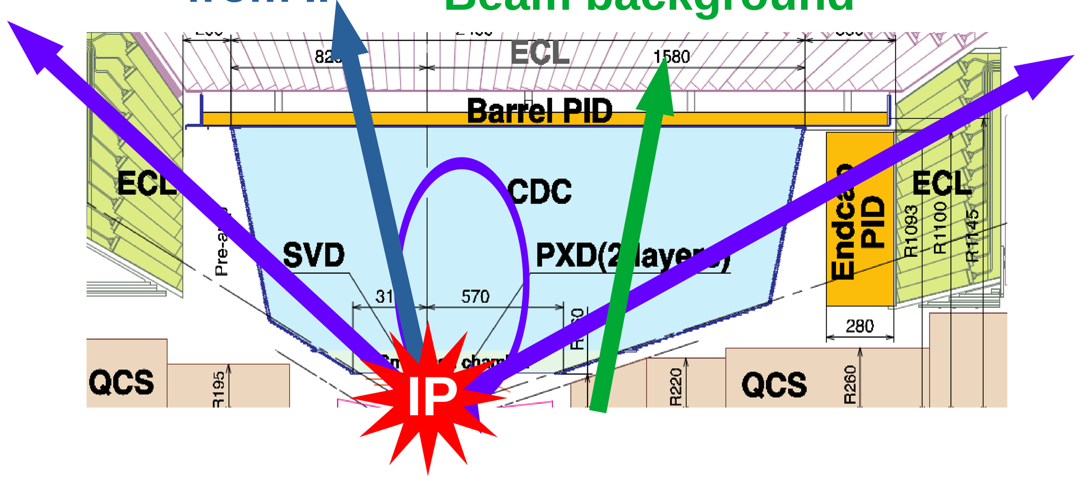
Protocol	Lane rate	user_clk	Link type	Latency (ns)
Aurora 8B/10B	5.08 Gbps	254 MHz	GTX-GTX	185~190
Raw-level 8B/10B	5.08 Gbps	254 MHz	GTX-GTX	132~136
	5.08 Gbps	254 MHz	GTH-GTX	132~136
	5.08 Gbps	254 MHz	GTH-GTH	91~95
	5.08 Gbps	254 MHz	GTX-GTH	91~95
Aurora 64B/66B	10.16 Gbps	158.75 MHz	GTH-GTH	296~302
Raw-level 64B/66B	11.176 Gbps	169.33 MHz	GTH-GTH	106~112

- UT4: Next generation of universal trigger board. Support up to 25 Gbps. Higher speed transmission design is under development.

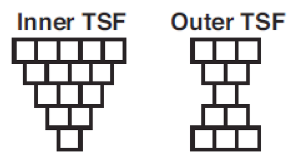
UT4
Xilinx Virtex UltraScale

Tracking performance

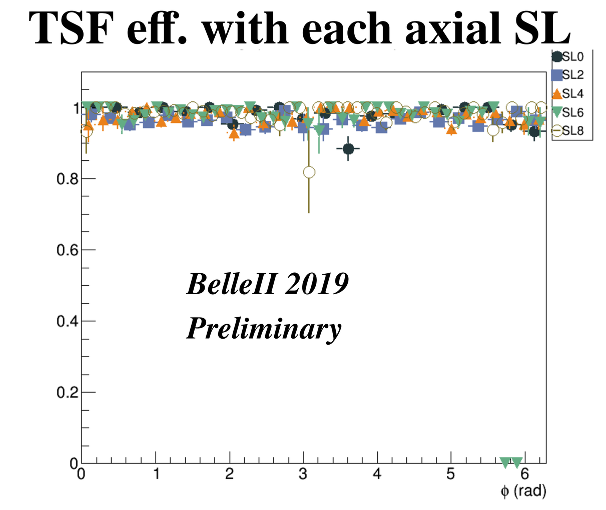




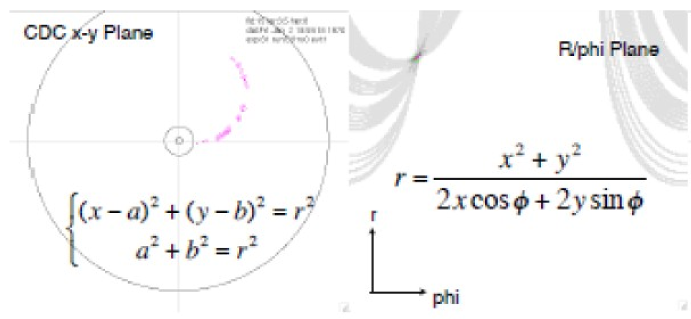
- **Track Segment Finder (TSF)**:
  Basement of all tracking modules in CDCTRG.
  Collection of wire hit with specific shape in each SL.
  ~100% efficiency is confirmed by using 2D track-associated TS.



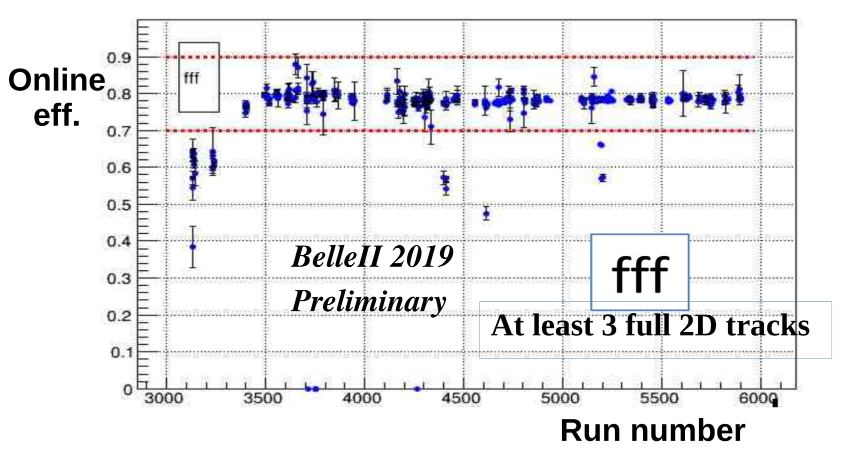
TSF eff. with each axial SL

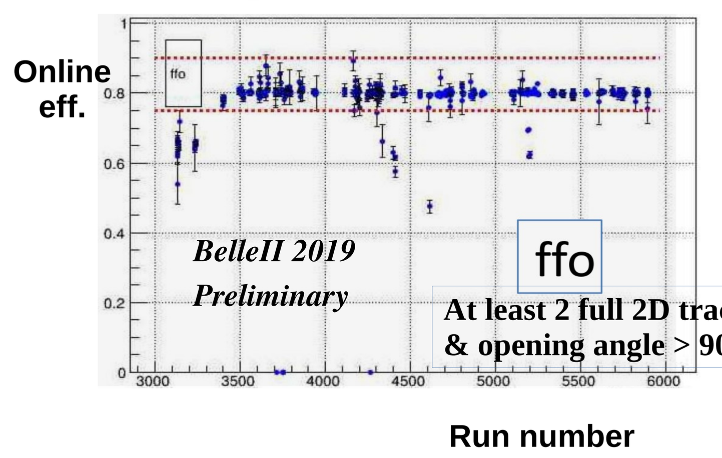


- **Full 2D tracking**:
  Finding full tracks passing through all axial SL and reaching barrel region.
  Based on Hough transformation algorithm.

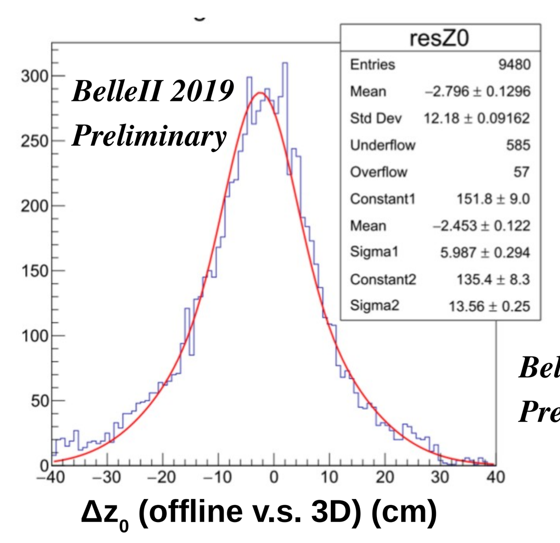


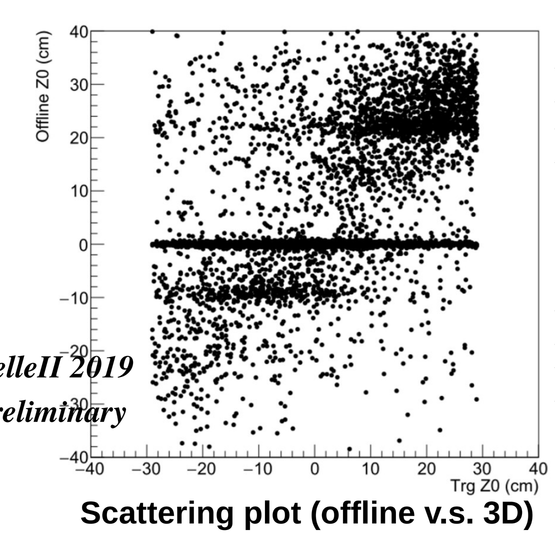
Effective eff. within hadronic events: Stable in 2019 operation.





- **Conventional 3D tracking**:
  Although 2D associated trigger bits have high eff., high trigger rate from beam background causes stress in DAQ.
  By using 2D tracking and stereo TSF, 3D calculates the intersection of the track and the z-axis (z_0) by fitting method. z_0 is critical to reduce off-IP 2D full tracks

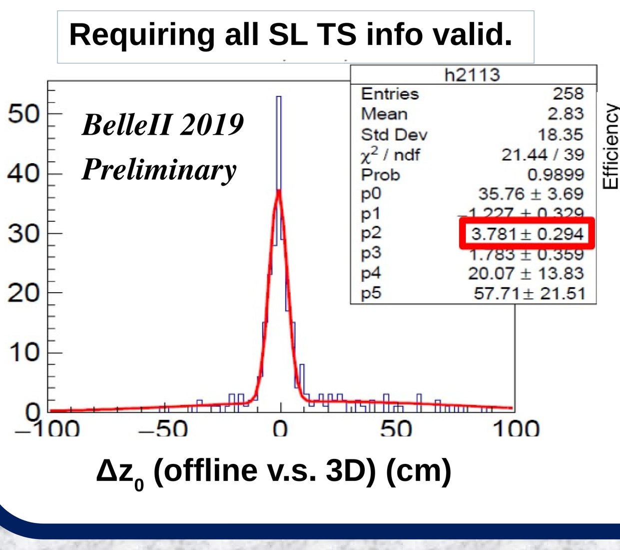




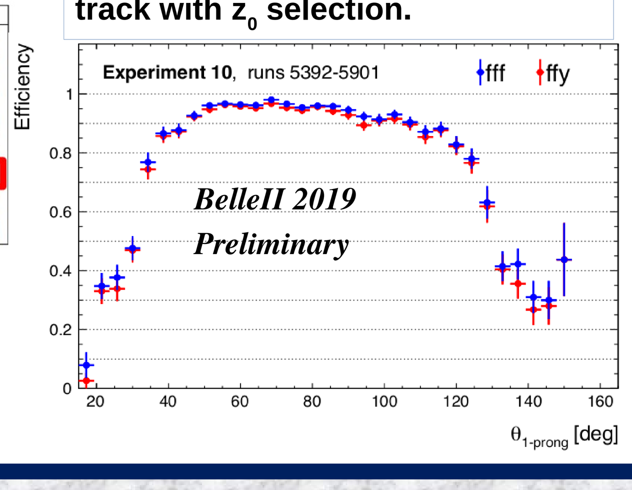
- Resolution is close to expectation.
- Correlation between offline z_0 and 3D z_0 can be roughly seen.
- Still in debugging stage.
- Will be ready within Spring 2020 after more improvement.

- **Neuro-3D tracking**:
  Alternative 3D tracking by using neural-network technique.
  Networks are trained with simulated or recorded data to calculate z_0.
  Good resolution and online trigger eff. Basically ready.

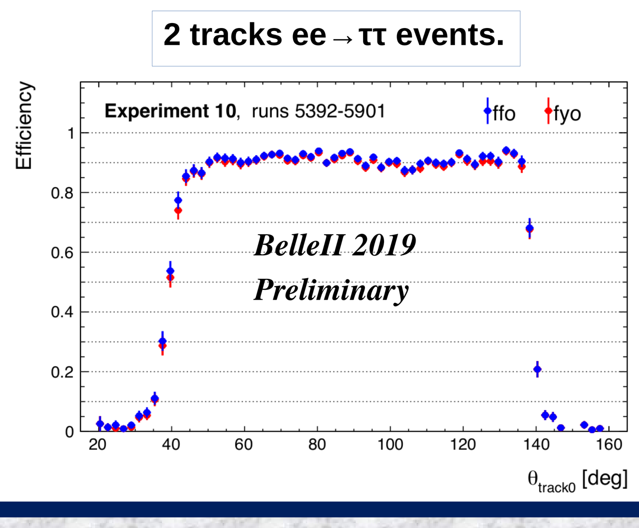
Requiring all SL TS info valid.



4 tracks ee→ττ events.
ffy: At least 2 2Dtrack & 1 neuro track with z_0 selection.



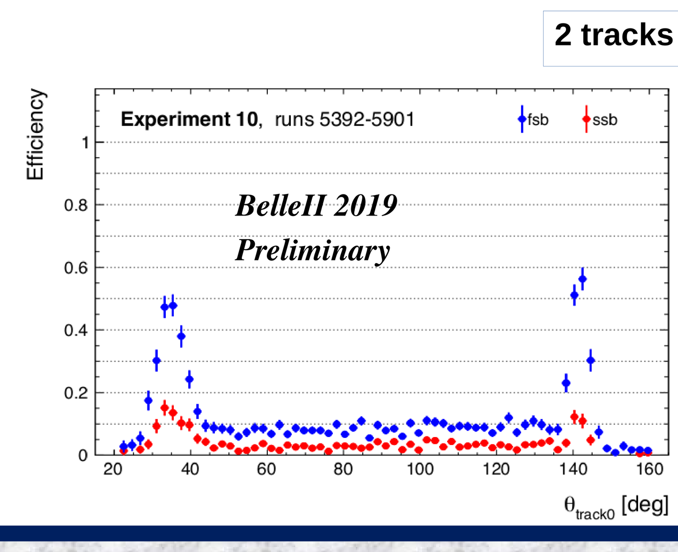
2 tracks ee→ττ events.

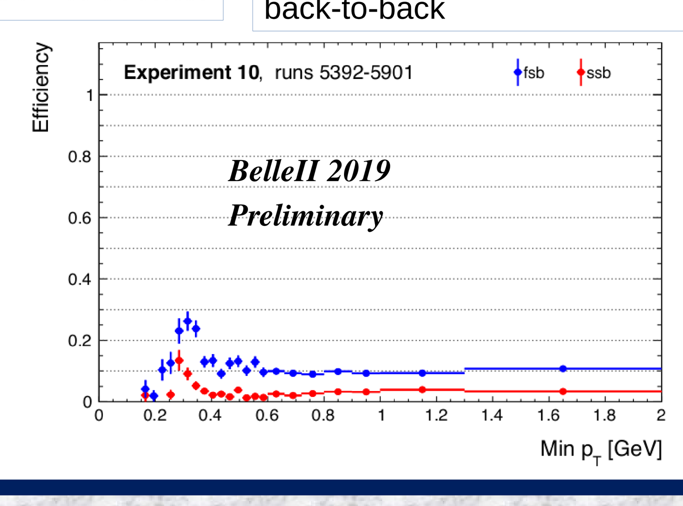


- **Short tracking**:
  Tracks finding up to SL4. → Reaching endcap region or curling-back inside CDC.
  Critical to enhance Bhabha/γγ separation, and low-multiplicity physics trigger.
  Compensating the full 2D tracking.

2 tracks ee→ττ events.

fsb: full track short track back-to-back
ssb: short track short track back-to-back





- Occupancy in endcap region.
- Improvement in low-p_t tracking.