Input features for GNN-based Track and Vertex Finding

Belle II Trigger Workshop

Philipp Dorwarth, Lea Reuter, Slavomira Stefkova, Torben Ferber | 30th November 2022

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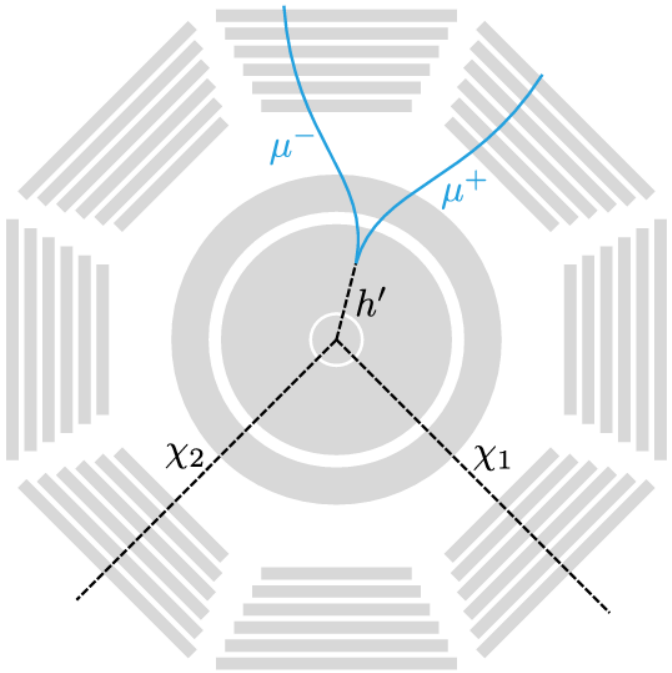
- M. Neu, K. Unger, J. Becker

MPI (MPP)

- E. Schmidt, F. Meggendorfer, C. Kiesling

Motivation



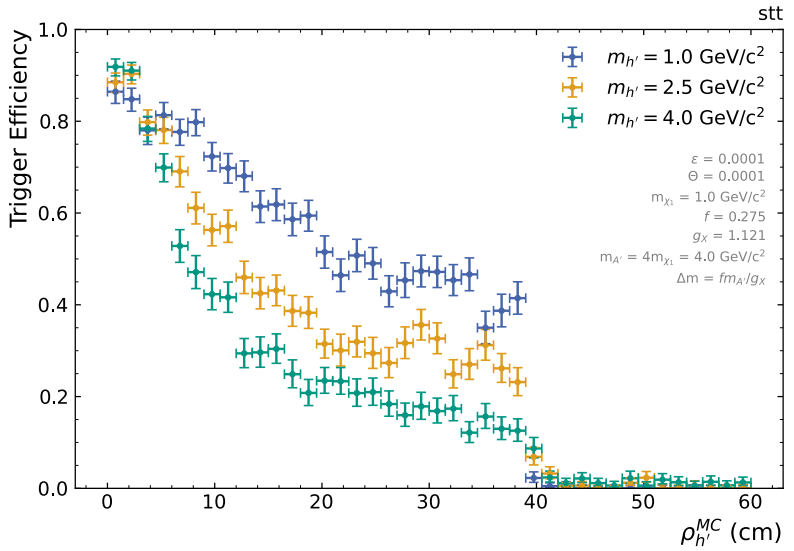
T. Ferber

Searches for displaced vertices

- Displaced vertices are an important signature in searches for new physics
- Single displaced vertex examples: signal decay with dark photon A' and dark higgs h' :
  - $e^+e^- \rightarrow A'h'$
  - $h' \rightarrow \mu^+\mu^-$,
  - $A' \rightarrow \chi_1\chi_2$
  - $\chi_2 \rightarrow \chi_1 e^+e^-$ (outside of CDC)

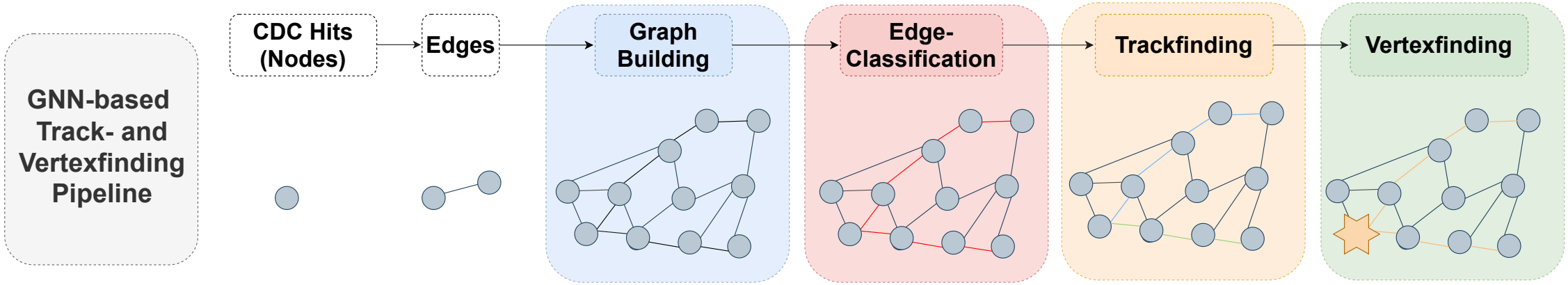
Motivation

- Project Goal:
  Improve Track and Vertex Finding:
  - Displaced vertices are important in searches for new physics
  - Need to improve Trigger and Reconstruction efficiencies
  - ➢ Offline and online Reconstruction
- Current Challenges for Displaced Vertices:
  - Tracks with displacement larger than 40cm are currently not triggered by **S**ingle **T**rack **T**rigger (stt), therefore we need a new or modified trigger to get these tracks
  - Optimize also for non-pointing displaced vertices



Credit: Patrick Ecker

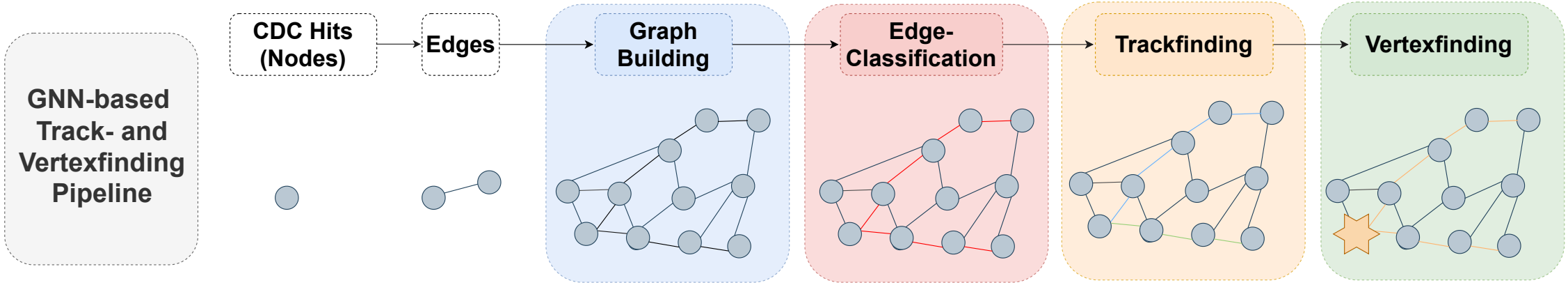
Overview



Graphics: *Lea Reuter*

Overview

Connect Hits in the CDC

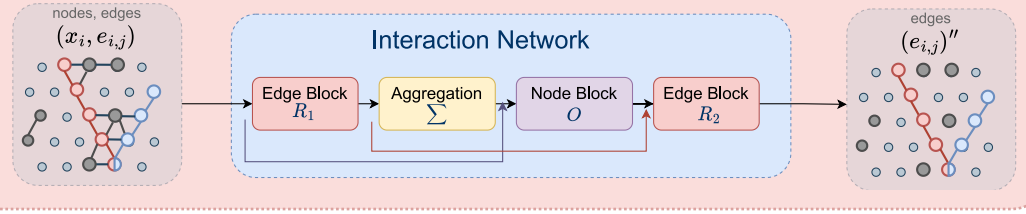


Graphics: Lea Reuter

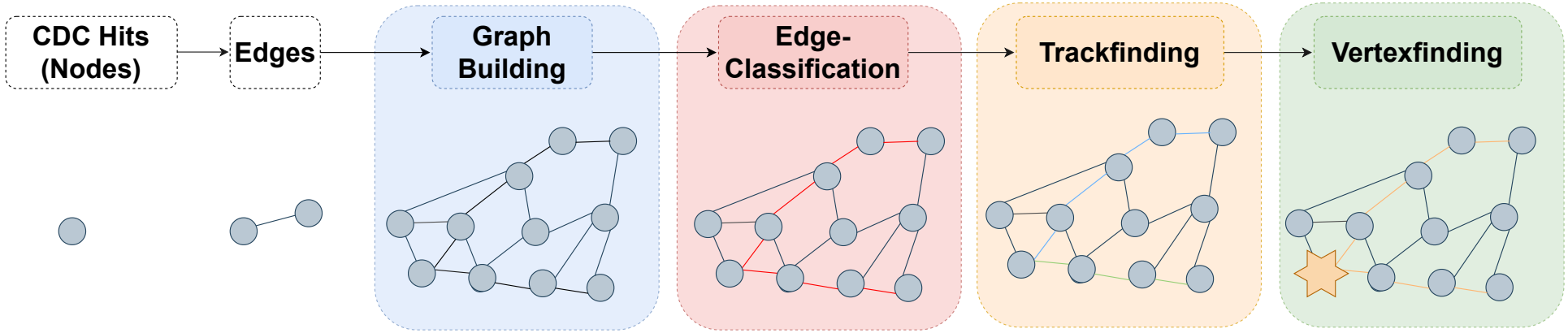
Overview

Graph Building:
Efficient connection of Hits in the CDC

Cleanup beam background with **Interaction Network** (arXiv: 2112.02048)



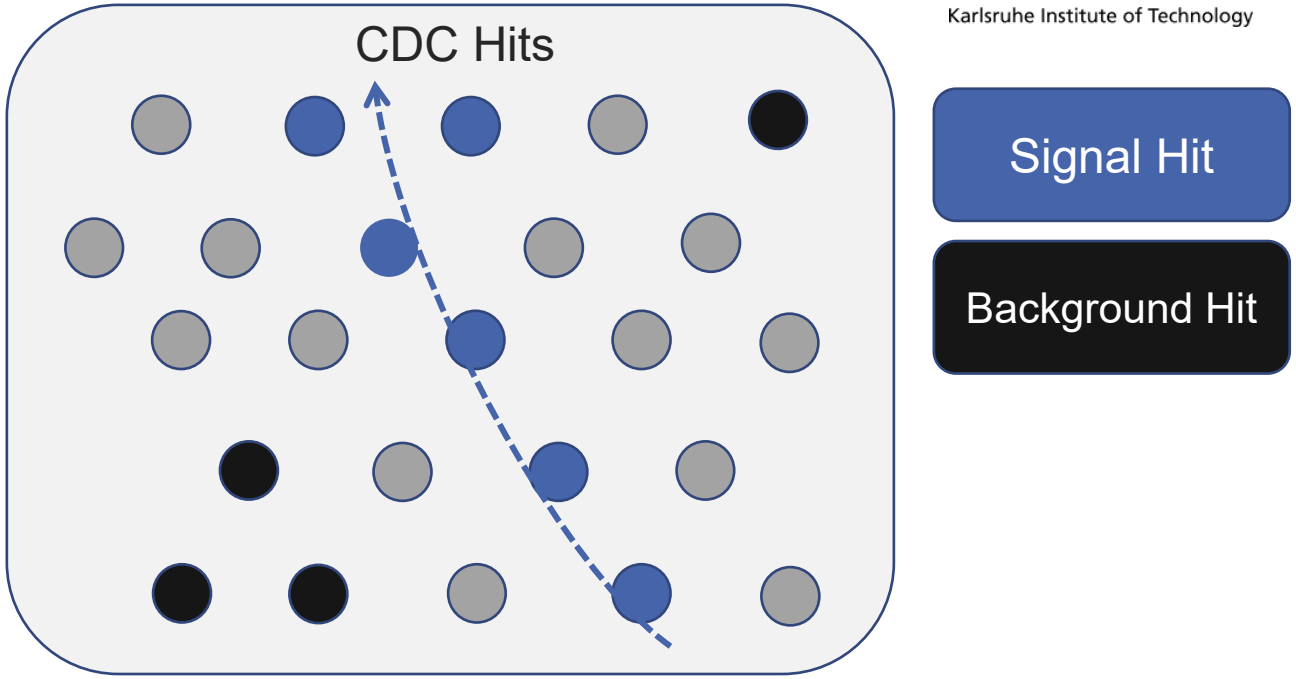
GNN-based Track- and Vertexfinding Pipeline



Graphics: Lea Reuter

Edge Classification

- Lea Reuter showed some promising results using the interaction Network to classify “True” and “False” edges of the graph



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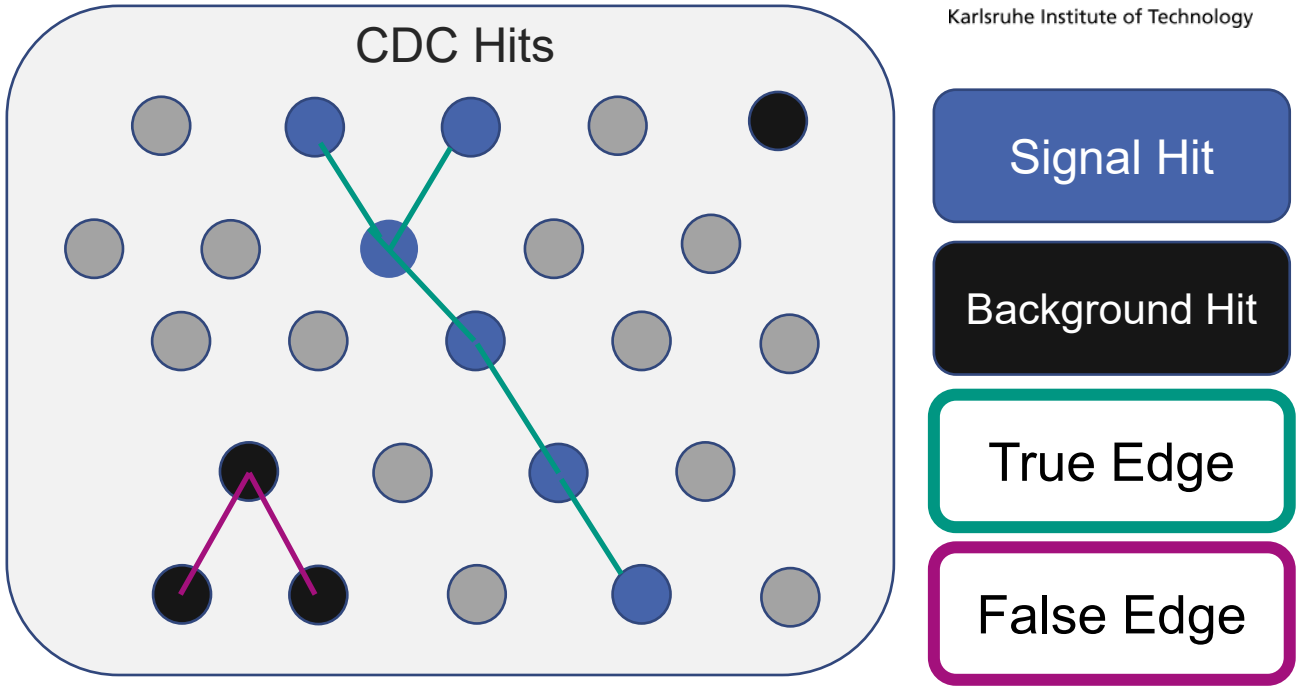
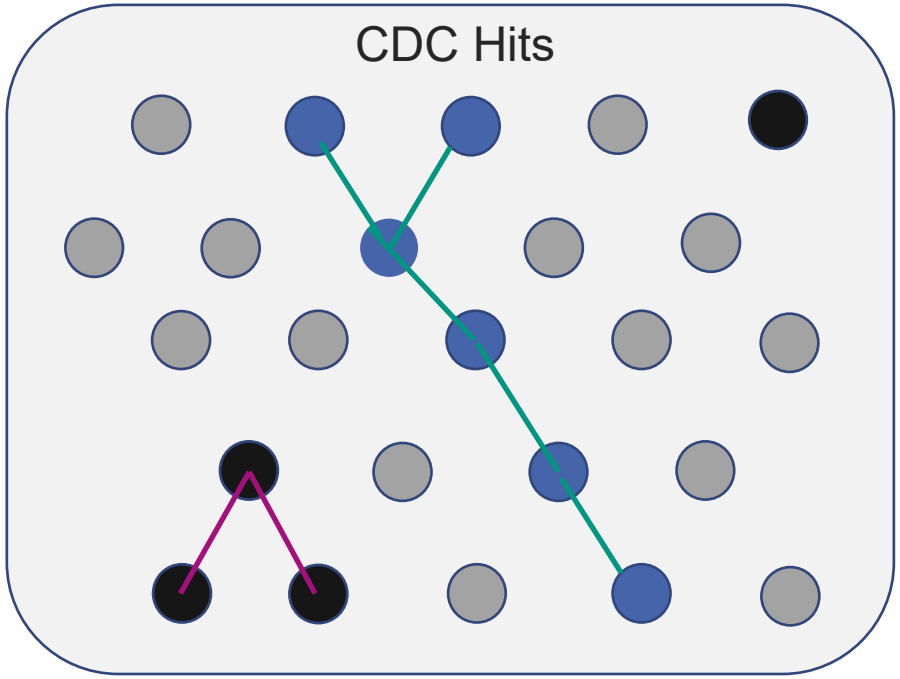


Edge Classification

- Lea Reuter showed some promising results using the interaction Network to classify “True” and “False” edges of the graph
- The classification results could be improve using TDC and ADC as an input feature
  - ρ, ϕ : 83.1% efficiency and 78.9% purity
  - ρ, ϕ, TDC, ADC: 94.1% efficiency and 93.8% purity

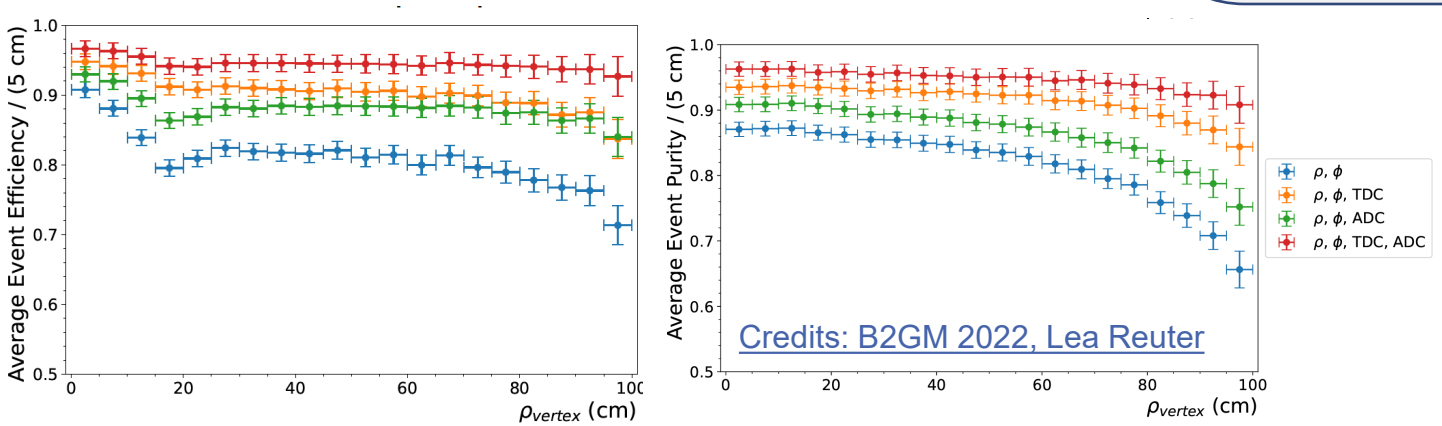


Signal Hit

Background Hit

True Edge

False Edge



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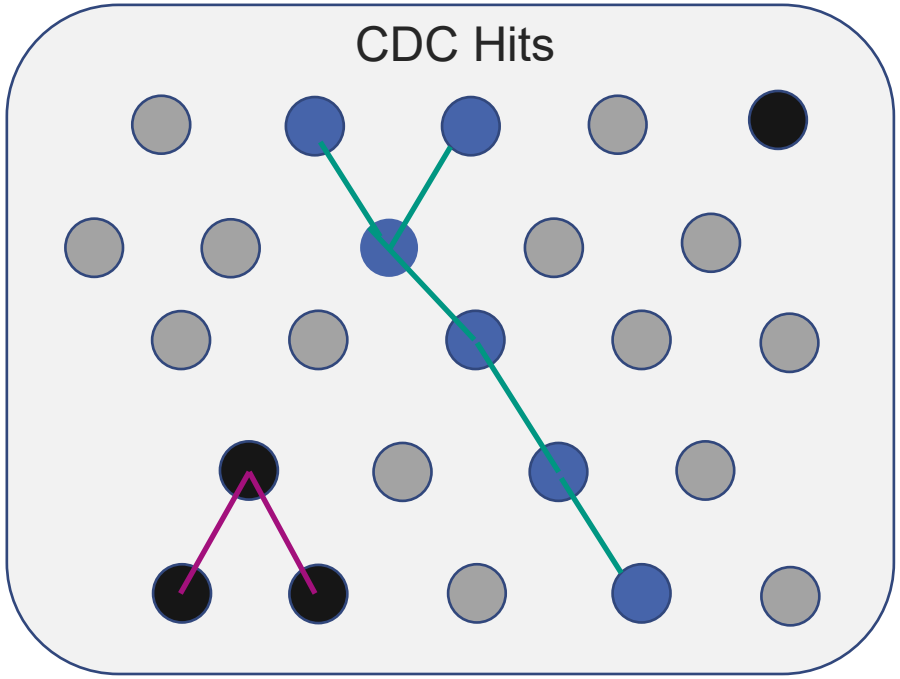
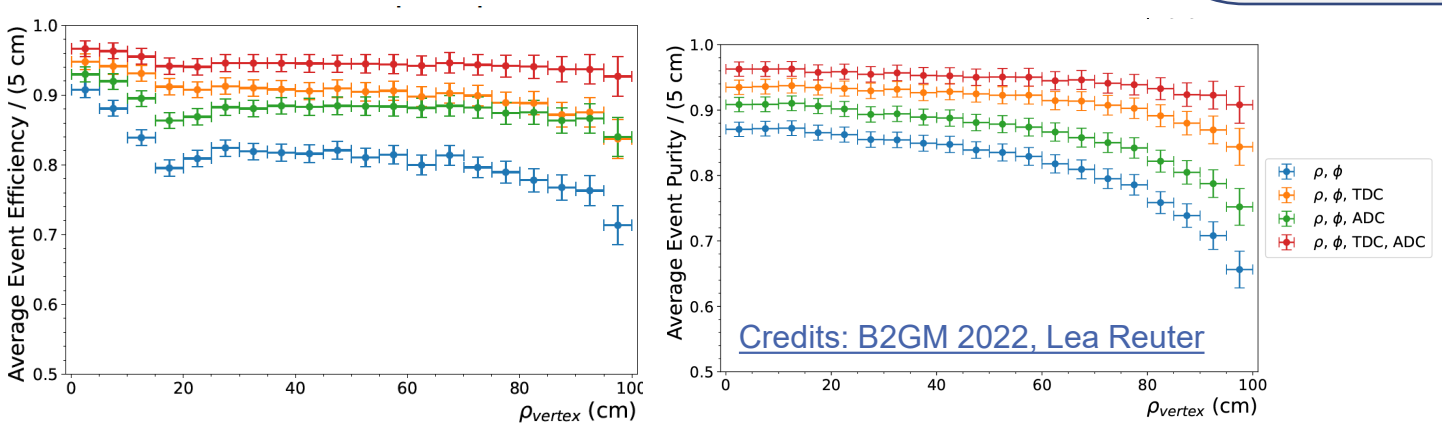


Signal Hit

Background Hit

True Edge

False Edge



Input feature analysis and MC/Data comparison

Data/MC Processing

- Data: skimmed, exp 24, run 888
  - Confluence: https://confluence.desy.de/display/BI/HLT+Skims
  - Global Tag: „`data_reprocesseing_prompt`“
- MC (own simulation):
  - BKG: Early phase 3

    `pre-release-07`
  - Use of default $\mu^+\mu^-$ generator:

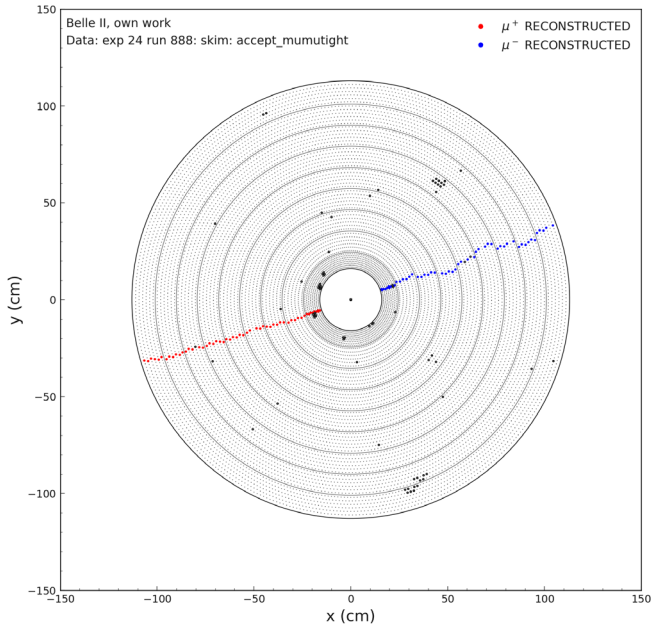
    ```
    ge.add_kkmc_generator(path=path, finalstate='mu-mu+')
    ```
  - Skim: accept_mumutight
  - Global Tag: “`mc_production_MC15ri_a`”

Selection

- Skim: accept_mumutight

```
enECLTrack1 < 0.5 && enECLTrack2 < 0.5
&& EMumutot < 2      && acopPhi < 10 && acopTheta < 10
&& nTracks == 2 &&  Pp1 > 0.5 && Pp2 > 0.5
```

- L1 Trigger bit: “stt”
- Events with two reconstructed tracks
  - each with a Muon PID > 0.9
  - $\theta = [32.2\,°, 128.7\,°]$ (barrel region)
- Dimuon mass cut: $(m_{\gamma\gamma} > 8\ GeV/c^2)$

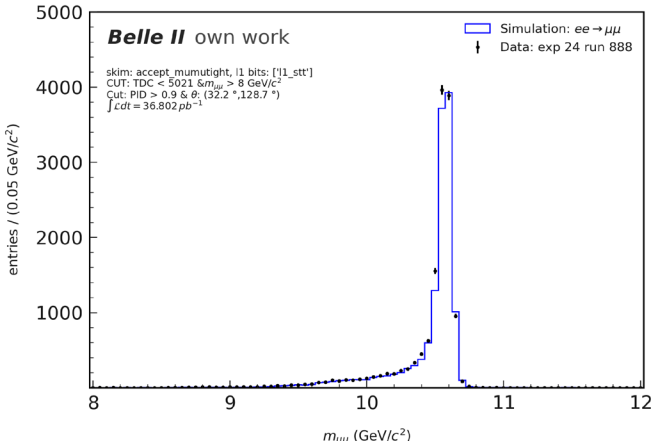


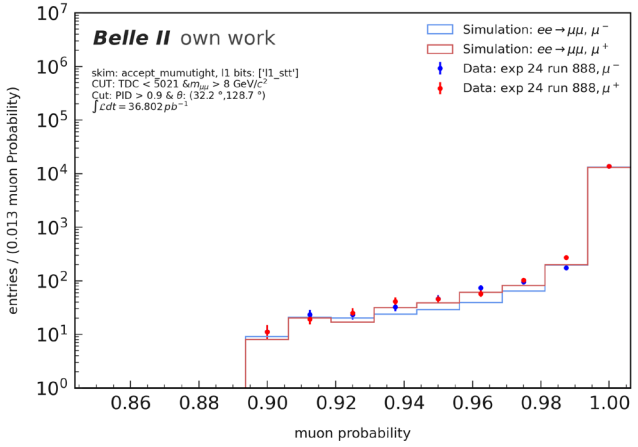
- TDC_{CDCHit} < 5021 (only data is affected)

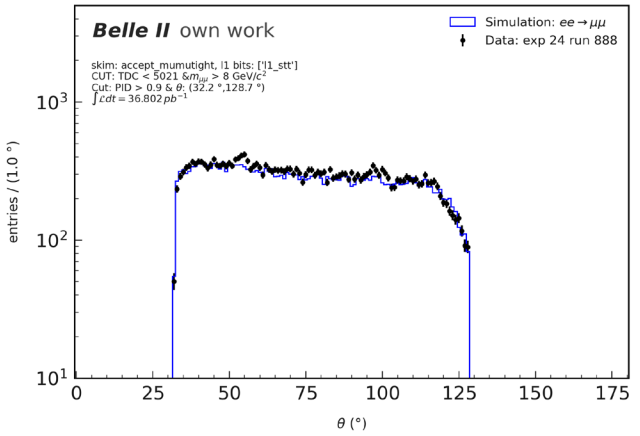
Processing

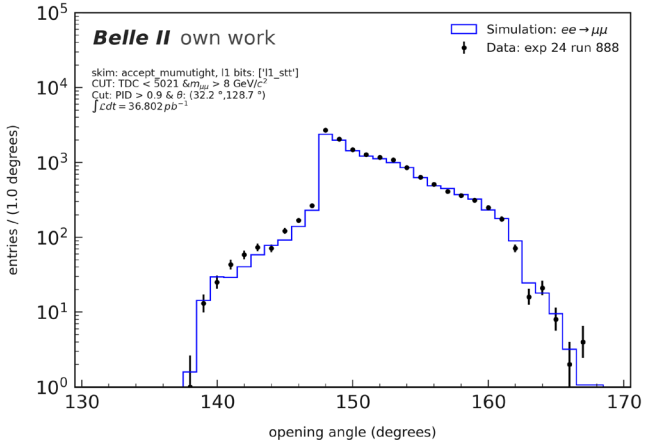
Order No	Selection	Data (exp 24, run 888)	MC (own simulation)
1	Skim (“mumu_tight”)	1.000	0.466
2	Theta cut: $[32.2,128.7]°$	0.764	0.755
3	L1 selection (‘stt’)	0.949	0.996
4	Dimuon selection: events with two tracks, each with a most likely pdg = [13,-13]	0.878	0.955
5	Dimuon mass cut ($m_{\gamma\gamma} > 8\ GeV/c^2$)	0.947	0.998
6	PID cut: $PID > 0.9$	0.944	0.955
	Total efficiency (without skim)	0.569	0.684

Selection distribution



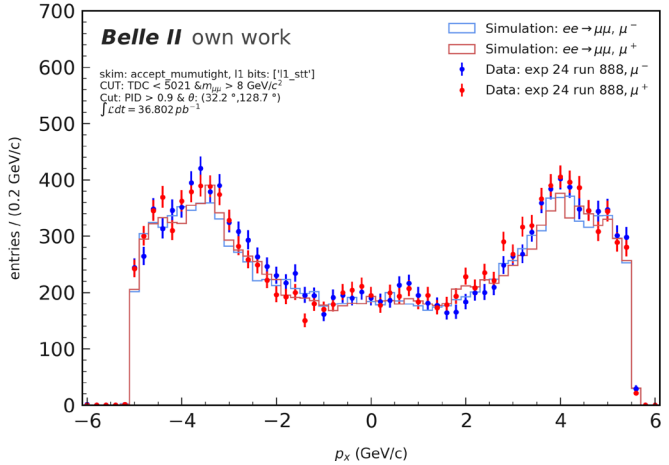


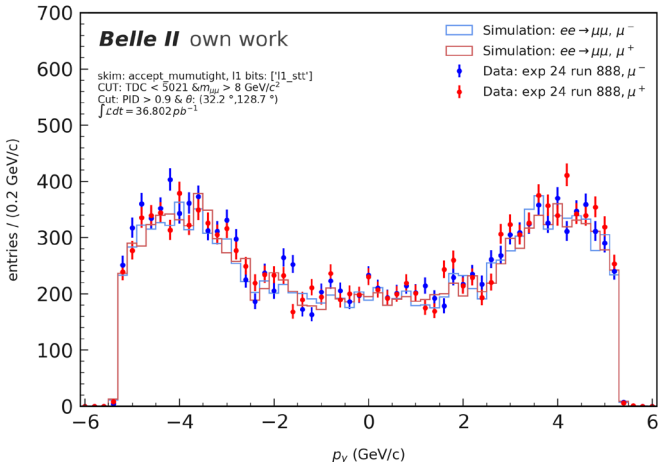


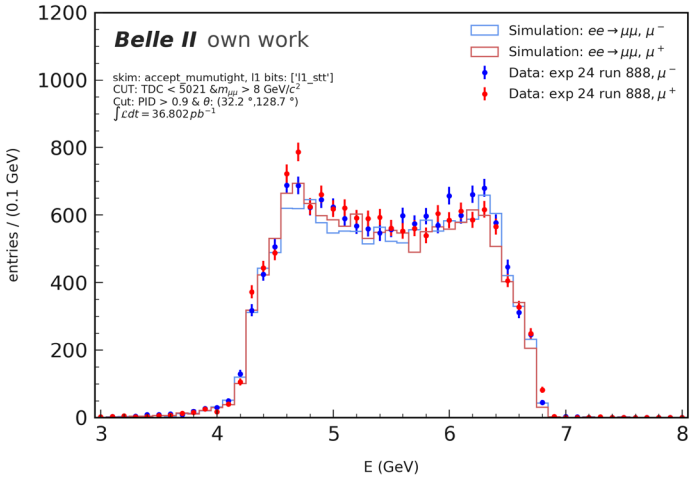


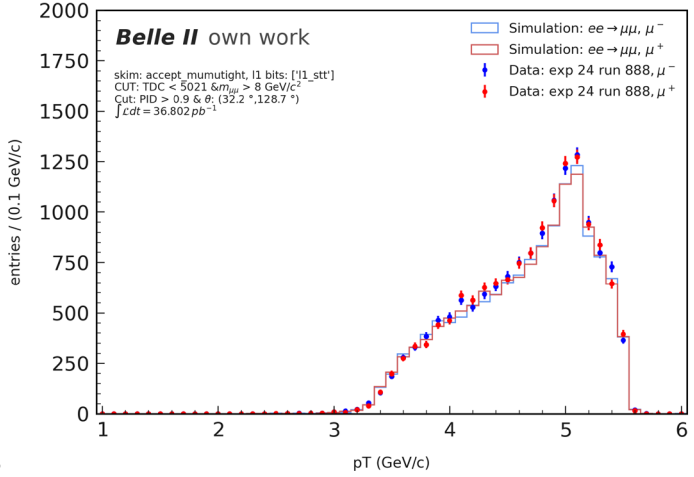
n_{data}/n_{sim} (hits): 0.849
$n_{data,\,sig}/n_{sim,\,sig}$ (hits): 1.088
$n_{data,\,bkg}/n_{sim,\,bkg}$ (hits): 0.782
n_{data}/n_{sim} (tracks): 1.054

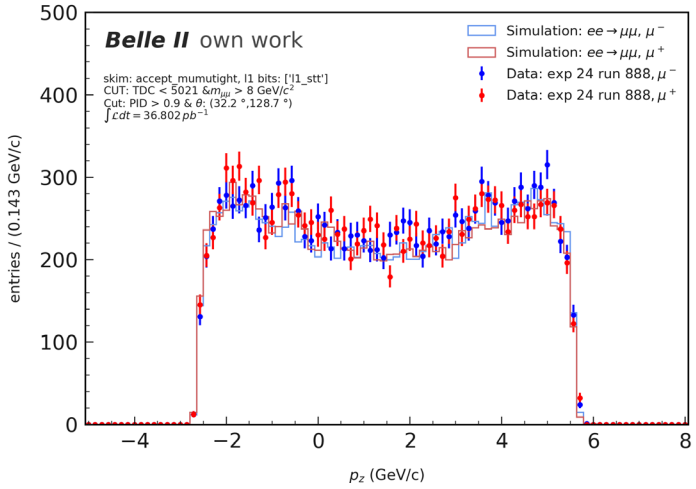
Track properties after selection











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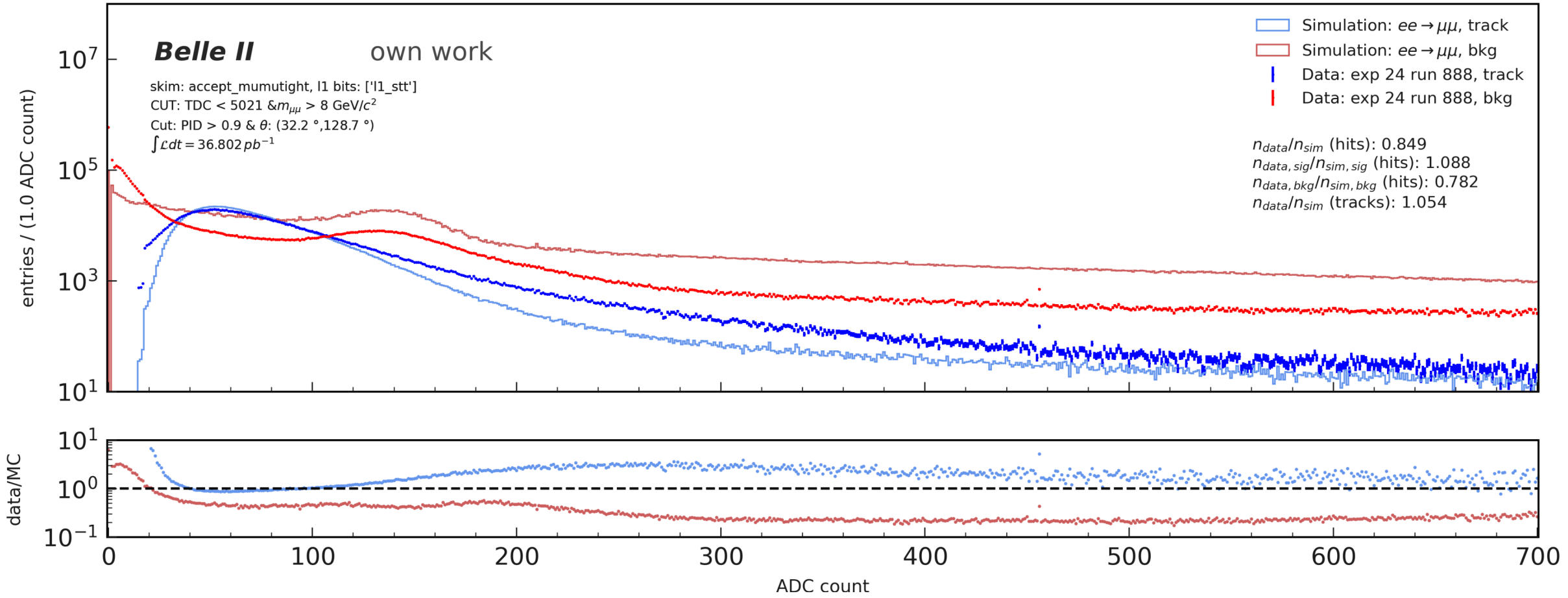
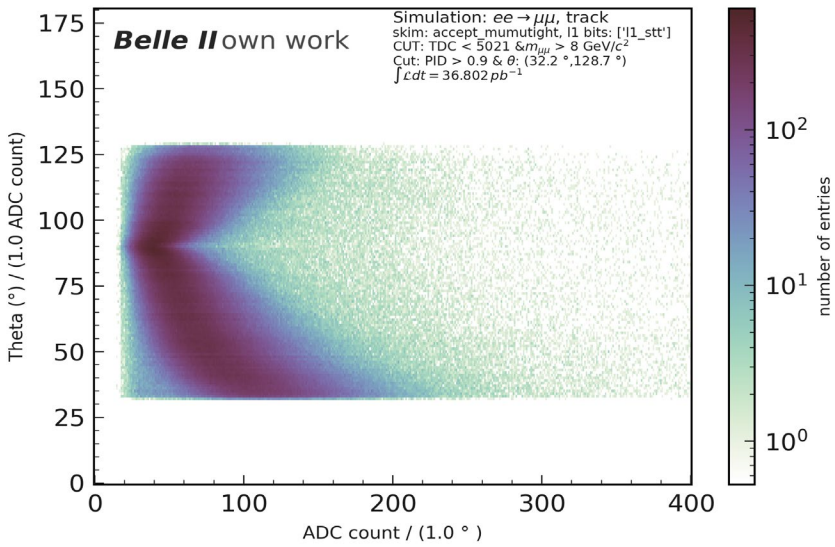
ADC

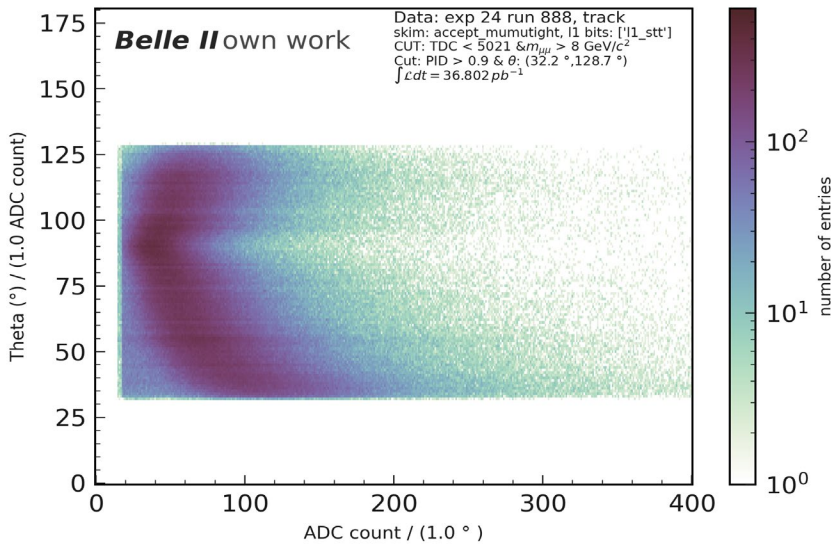
Possible MC / data differences

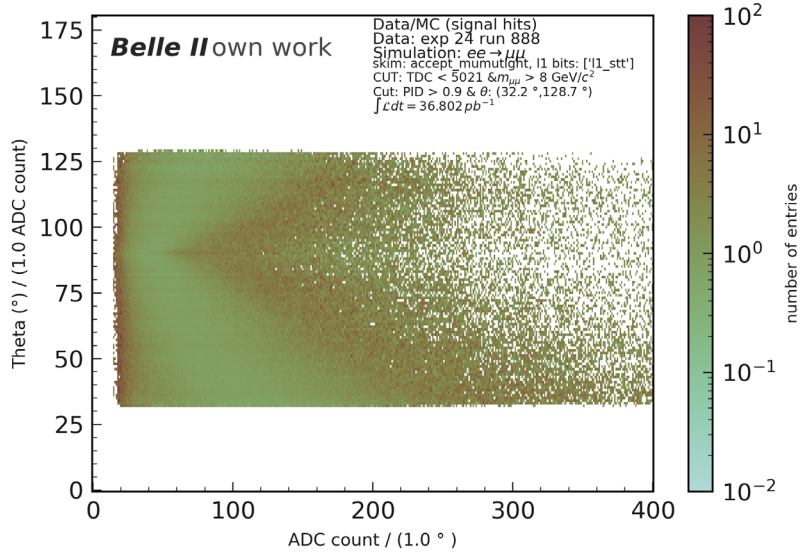
- Only one run (high injection bkg?)
- Simulation: cross talk modeling



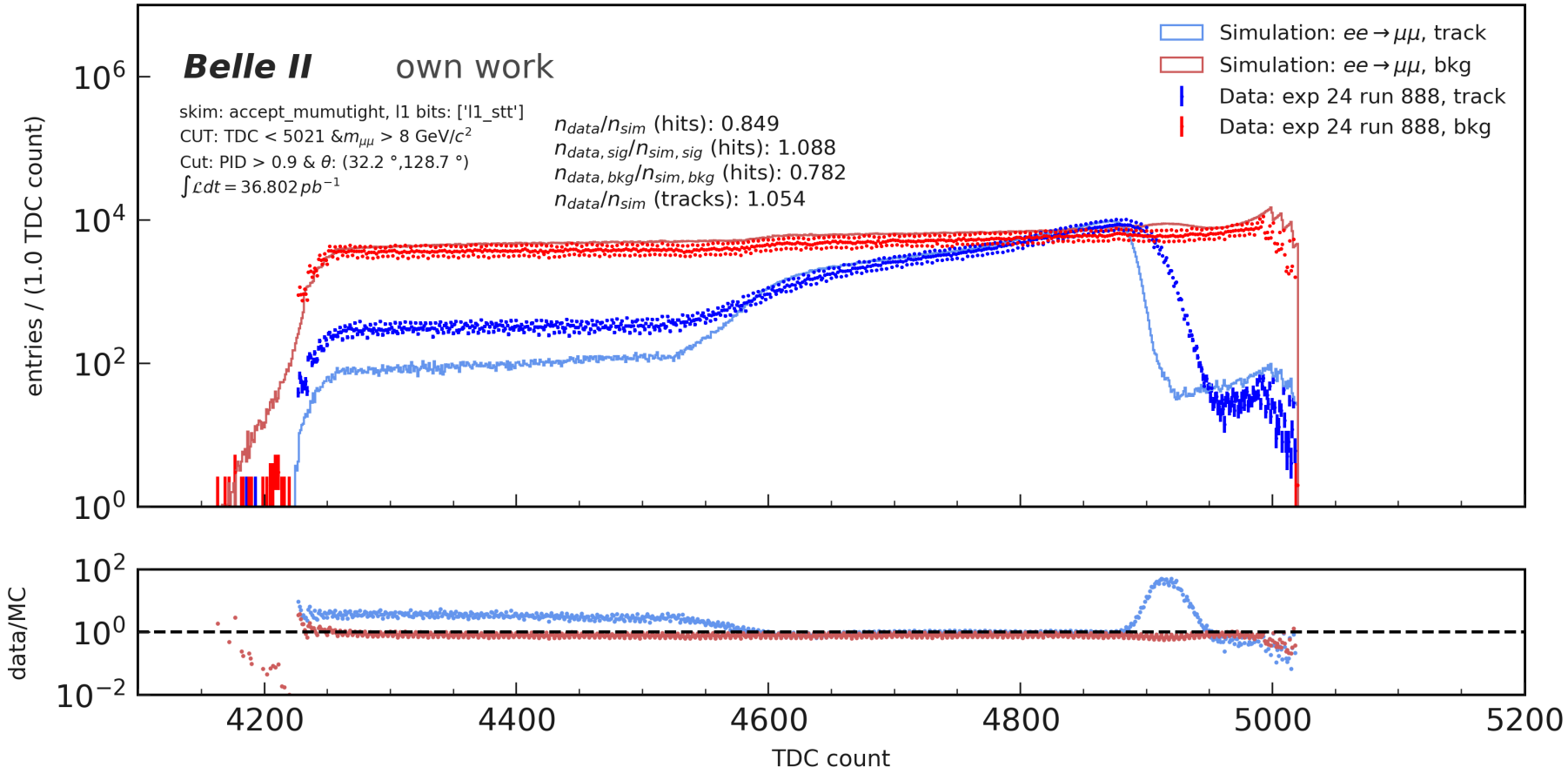
Theta vs ADC distribution of signal hits



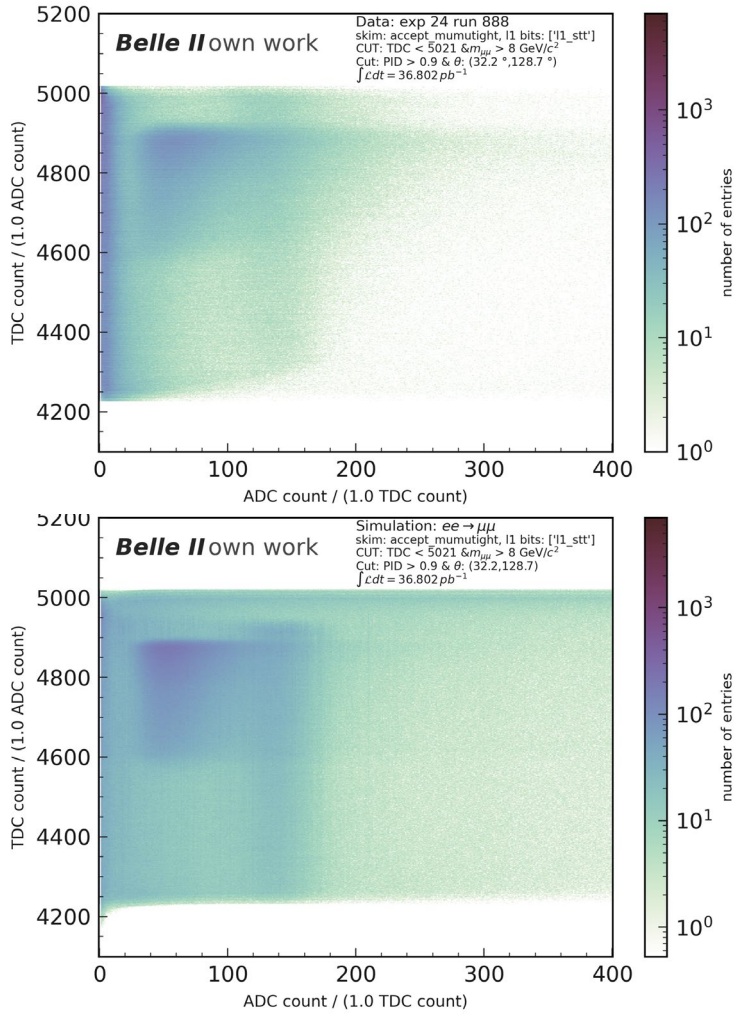


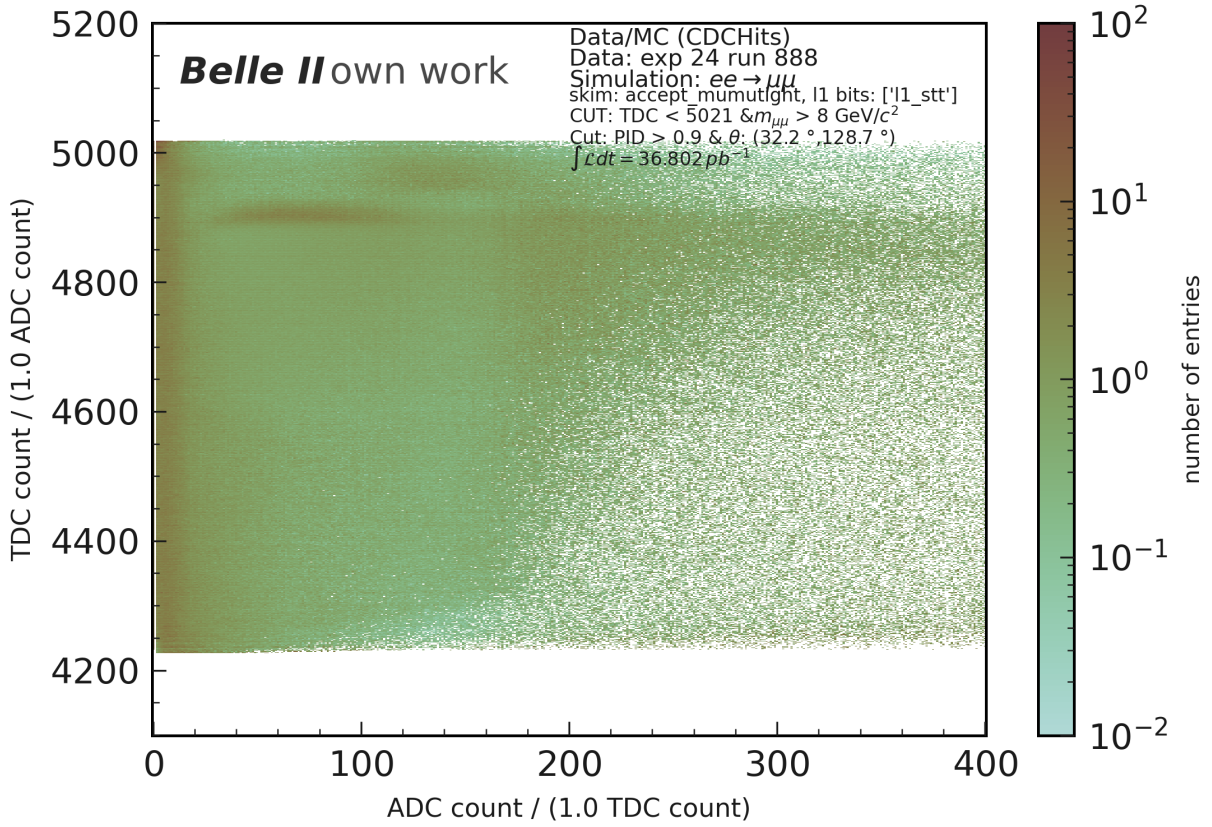


TDC count


Belle II own work
skim: accept_mumutight, l1 bits: ['l1_stt']
CUT: TDC < 5021 &$m_{\mu\mu}$ > 8 GeV/c^2
Cut: PID > 0.9 & θ: (32.2 °,128.7 °)
$\int \mathcal{L} dt = 36.802\, pb^{-1}$
n_{data}/n_{sim} (hits): 0.849
$n_{data,sig}/n_{sim,sig}$ (hits): 1.088
$n_{data,bkg}/n_{sim,bkg}$ (hits): 0.782
n_{data}/n_{sim} (tracks): 1.054
Simulation: $ee \to \mu\mu$, track
Simulation: $ee \to \mu\mu$, bkg
Data: exp 24 run 888, track
Data: exp 24 run 888, bkg
entries / (1.0 TDC count)
data/MC
TDC count

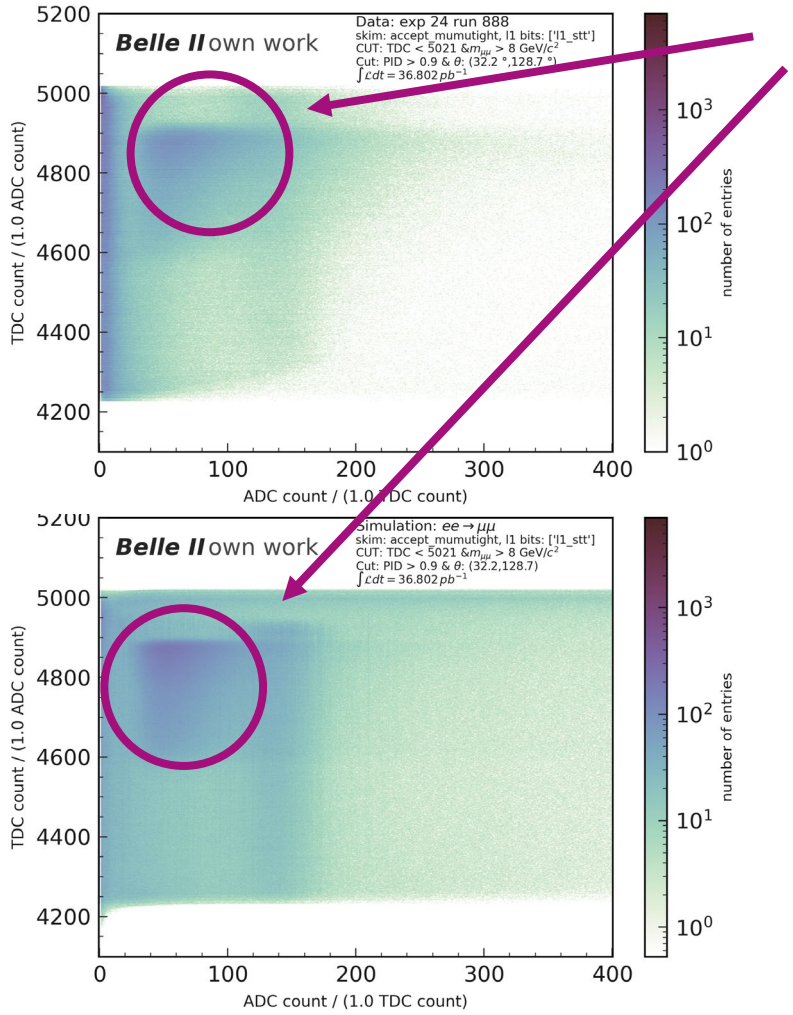
ADC and TDC 2D Comparison

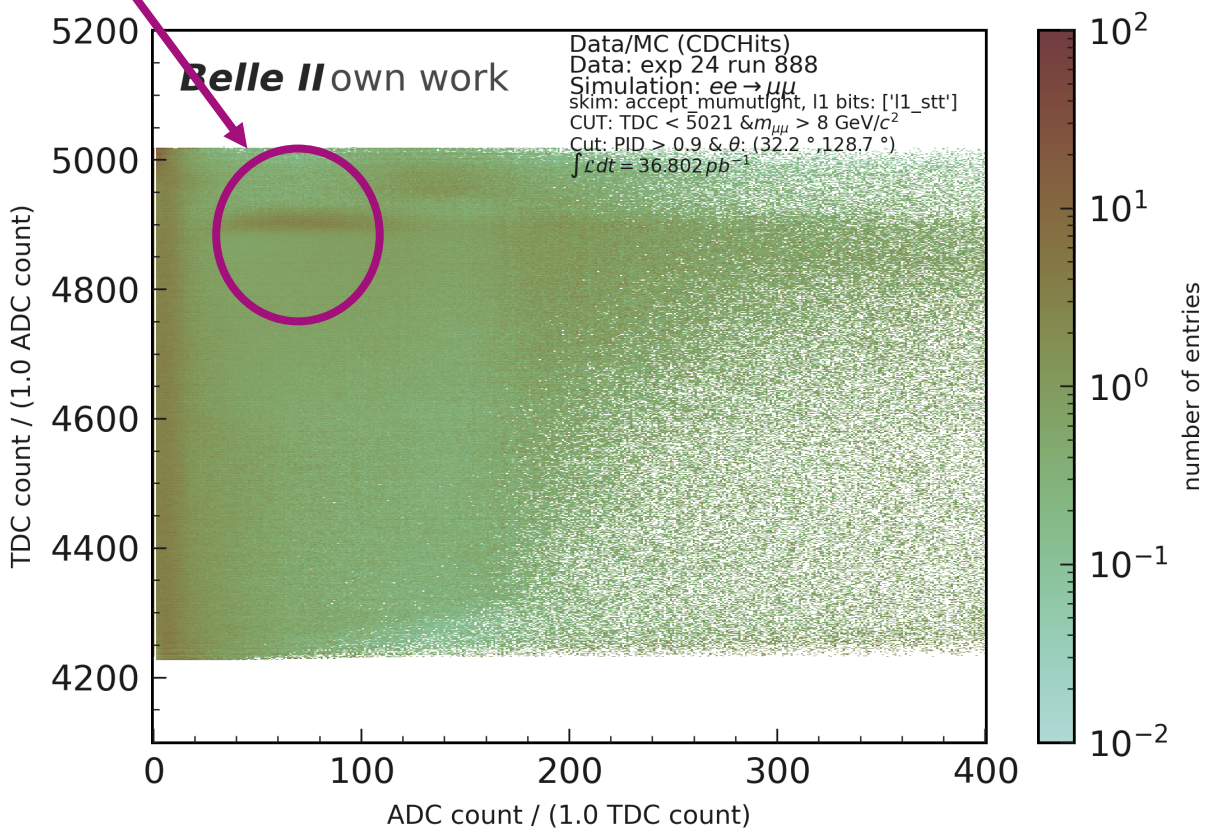




ADC and TDC 2D Comparison

Signal region





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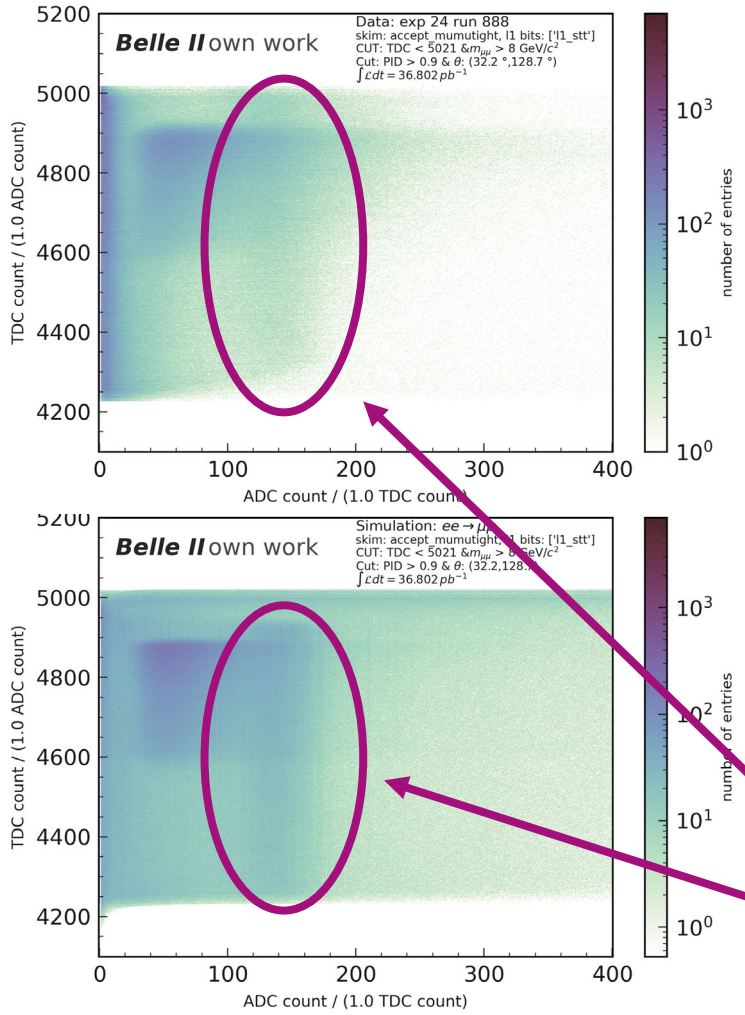
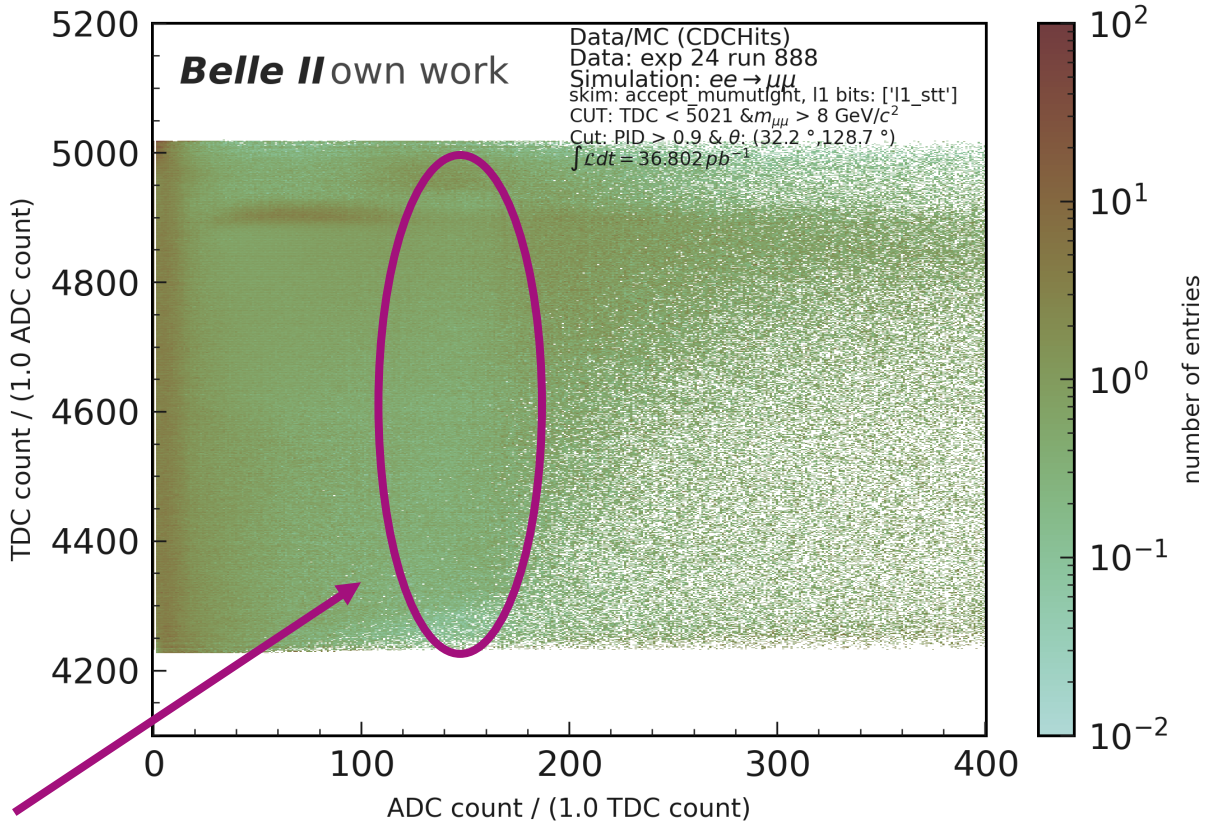




Background region

Outlook and Next Step

Current status

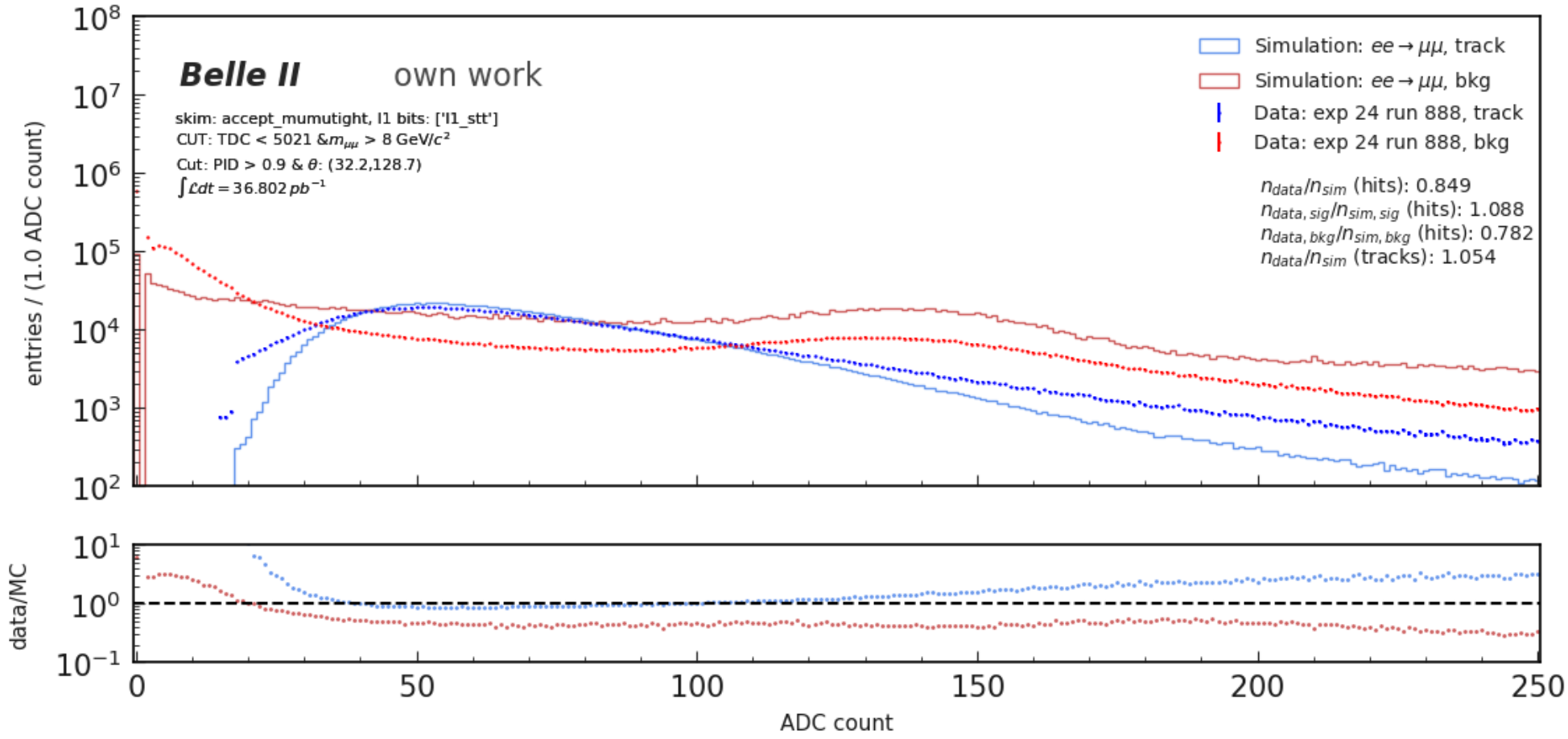
- First Data/MC comparison with a tight selection
- ADC Count and TDC Count are discriminatory and should be used as input features
- Signal track hits are having a ratio close to one and discrepancy comes mainly from non-signal hits

Outlook

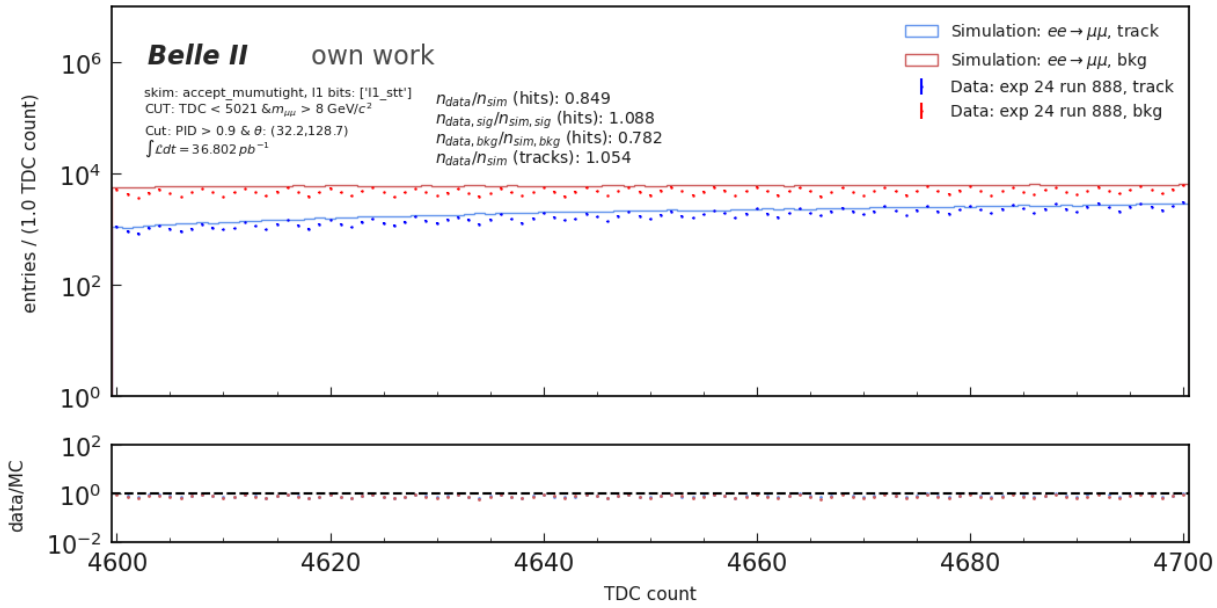
- Understand better non-signal modeling (cross-talk modeling, run-dependent MC)

Backup

ADC zoomed in



Oscillation of TDC count

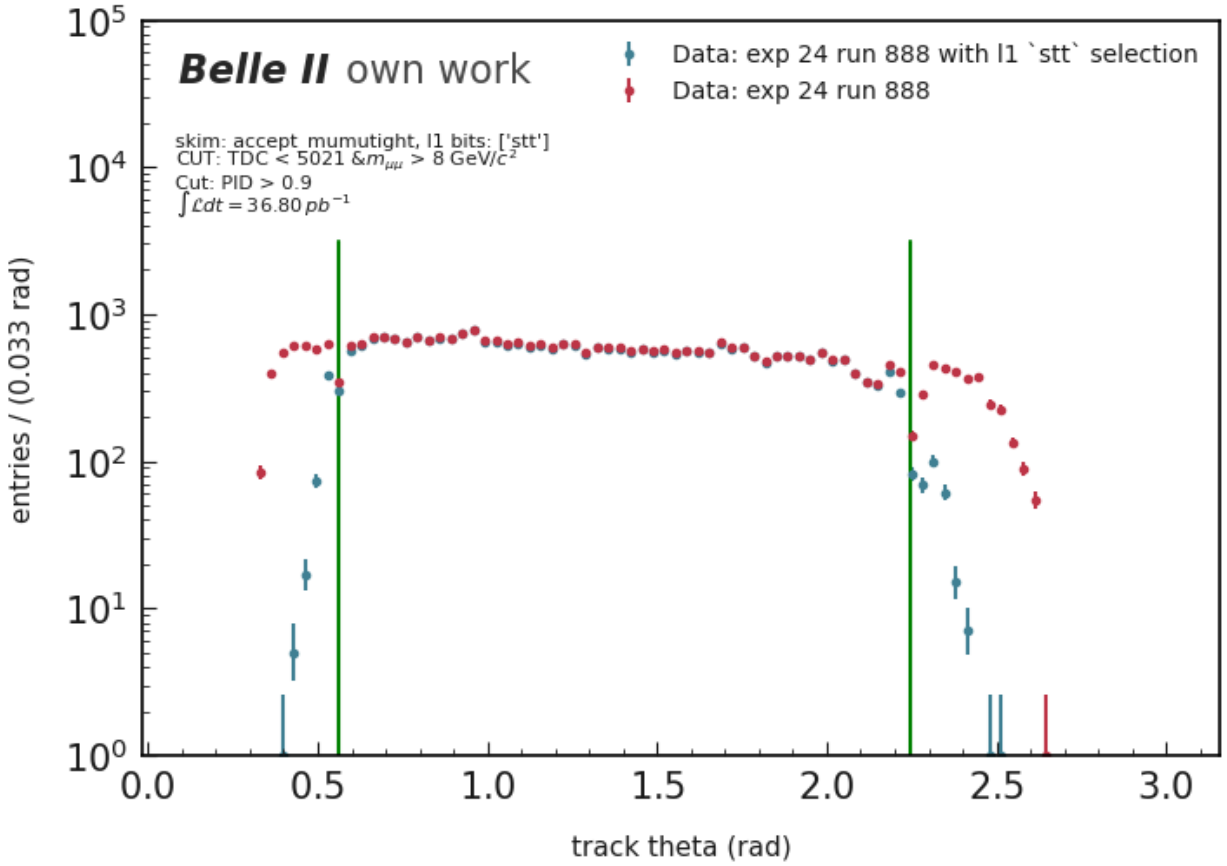


$$c * (TDC\ count) = TDC_{stop} - T_{evt} - T_{tof} - T_{drift} - T_{prop\ \_\ delay} - T_{time\ \_\ walk}$$

- TDC_{stop} : nominal stop time; usually called t0
- T_{evt} : event time; in simulation =0 for signal event, random for background event
- T_{tof} : time-of-flight from the event time to the cell
- T_{drift} : drift time of electrons
- $T_{prop\ \_\ delay}$: signal propagation time along the sense wire
- $T_{time\ \_\ walk}$: time-walk (i.e. pulse-height dependent timing shift)

(https://confluence.desy.de/display/BI/CDC+TDC)

Theta distribution before theta cut with and without l1 selection



Event Displays of exp 24, run 888 and MC