High Background Conditions

FSP Slow Pion Workshop
09 November 2021

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Introduction

Injection background in Belle II detector

- Noisy injected bunch produces additional background when they cross Belle II detector
- Belle II trigger veto prevents excessive data rate, but only partially effective for PXD
- Unclear how it develops in the future at high luminosity

Injection background in PXD

- Very high occupancy in the first ~500μs but decays relatively quickly in O(ms) → almost covered by trigger veto
- Currently issues related to injection background (missing event, data truncation) is still at low level O(1/1000)
  (offline performance study in progress)
  → some concerns that a large event may cause loss of subsequent “good” events (?)
- Physics analyses can in any case choose to simply veto for a slightly extended time period
  → injection timing variable now in mDST since release-06!

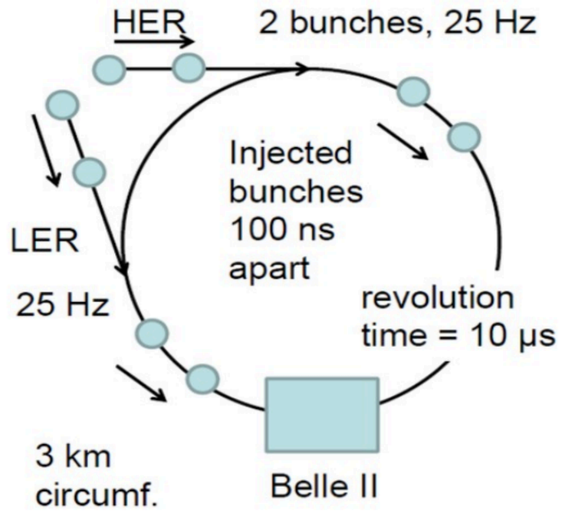
In this presentation

- Plain views over injection background as seen by Belle II and PXD
- Mention of some efforts in progress to understand injection background and impact on performance

SuperKEKB and Continuous Beam Injection

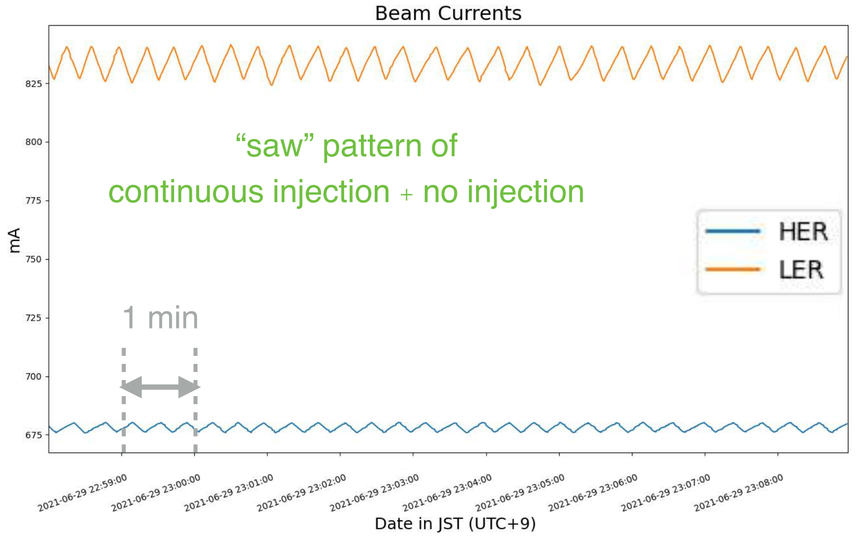
SuperKEKB with a nominal instantaneous luminosity of 10^{36} cm^{-2}s^{-1}

- Need to reach and sustain high beam currents
  (nominal HER/LER currents 2.6A/3.6A, up to ~625mA/~850mA during 2021b)
- Higher the beam currents, faster the decay time
  → frequent "top-up" = continuous injection of new e± bunches

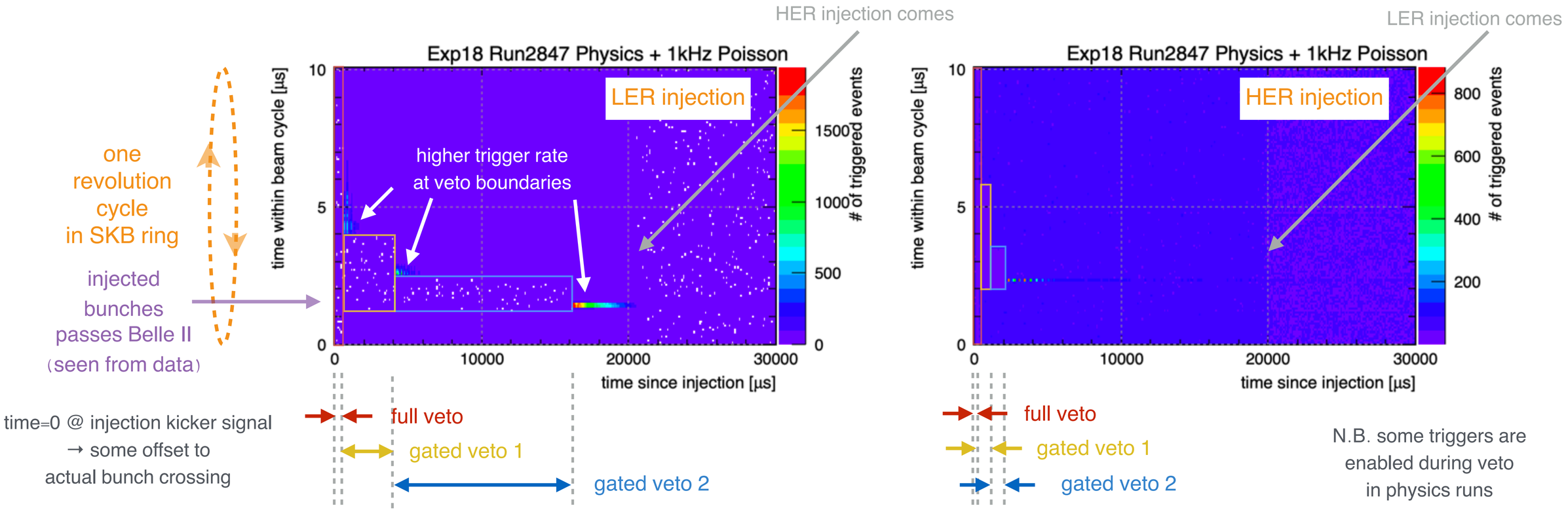


Some relevant constants / parameters (for this talk)

- Beam revolution time = 10 μs
- Bunch spacing = O(10) ns
  (separation of two consecutive Level-1 triggers > 500 ns)
- Injection frequency nominally @25Hz per HER/LER beam
  (injection timing for HER and LER shifted by 20ms)
- Two-bunch injection = 2 bunches separated by 100 ns per injection cycle
  (used for LER injection above ~700mA in 2021b)
- Level of injection background depends on several beam/injection parameters
  (injection background modelling by B. Schwenker [ref @last B2GM])



Physics Run and Trigger Veto



Physics trigger preferentially fires at injected bunch crossing timing

- Trigger veto timing is tuned based on trigger rates observed on online oscilloscope while minimising dead time (= veto'ed area in the plots)
  → currently length of the gated veto2 period is adjusted automatically [refs by T. Koga @ Background meeting, June B2GM]
- High rate x high occupancy may cause dead time of the sub-detector readout electronics and/or truncation of the data

Triggered Events (2020c – current picture may be different)

Event rate vs time since injection

- Rate ~ constant in this time scale
- Step structure due to gated trigger veto

Time since previous Level-1 trigger

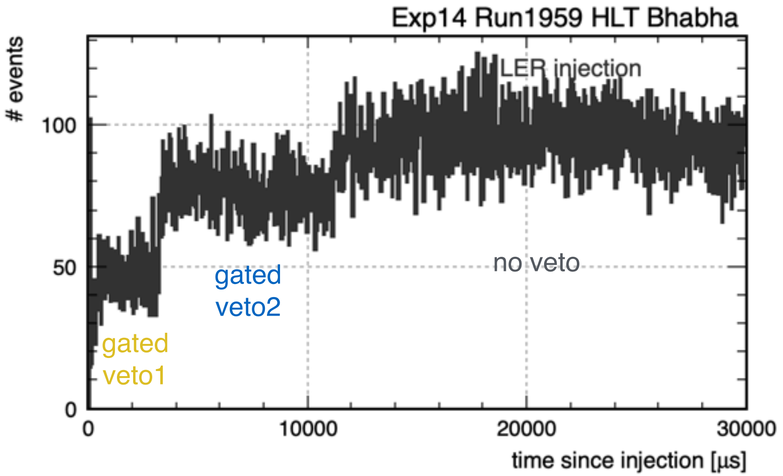
- Minimum requirement = 0.5 μs

Bhabha vs Hadron (HLT skim)

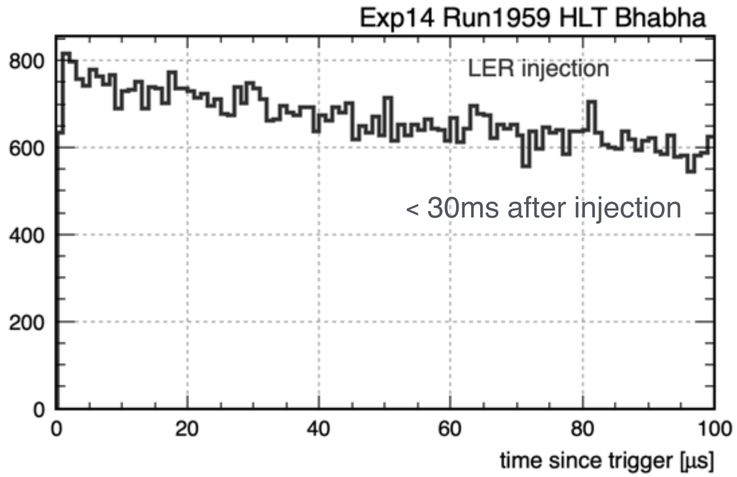
- Hadron selection preferentially triggers on injected bunch
- Bhabha (& other triggers based on ECL, μμ) seem to be insensitive

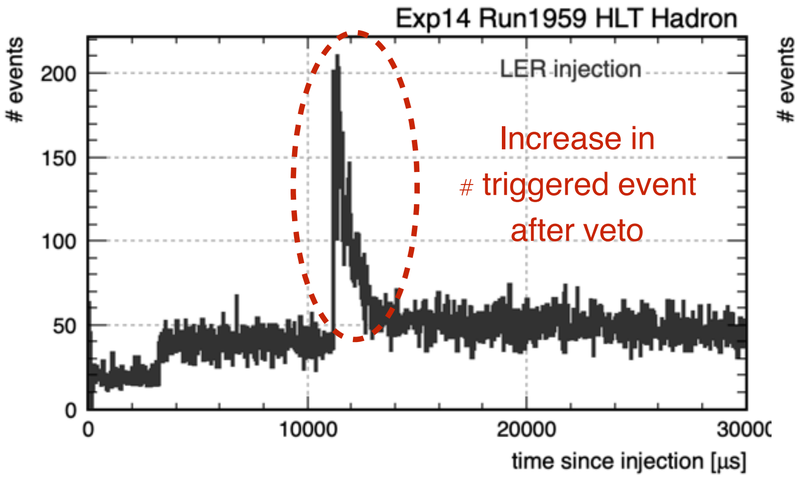
Fake trigger from CDCTRG at high lumi discussed by T. Koga @June B2GM

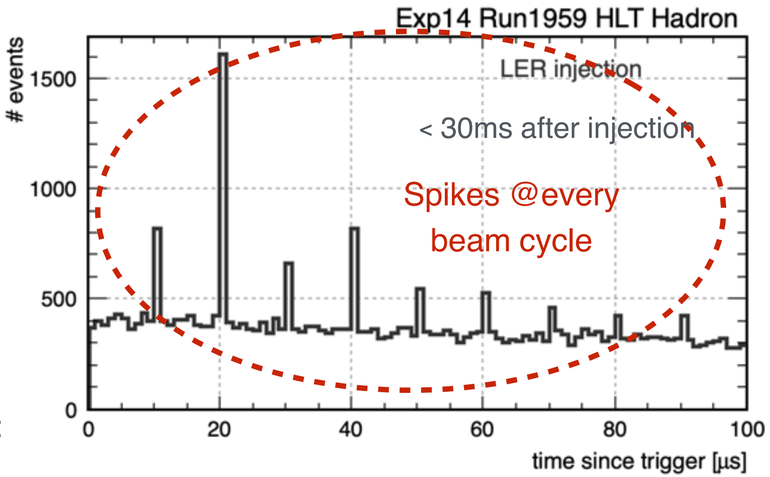
Time since injection (LER only)



Time since previous trigger (LER only)







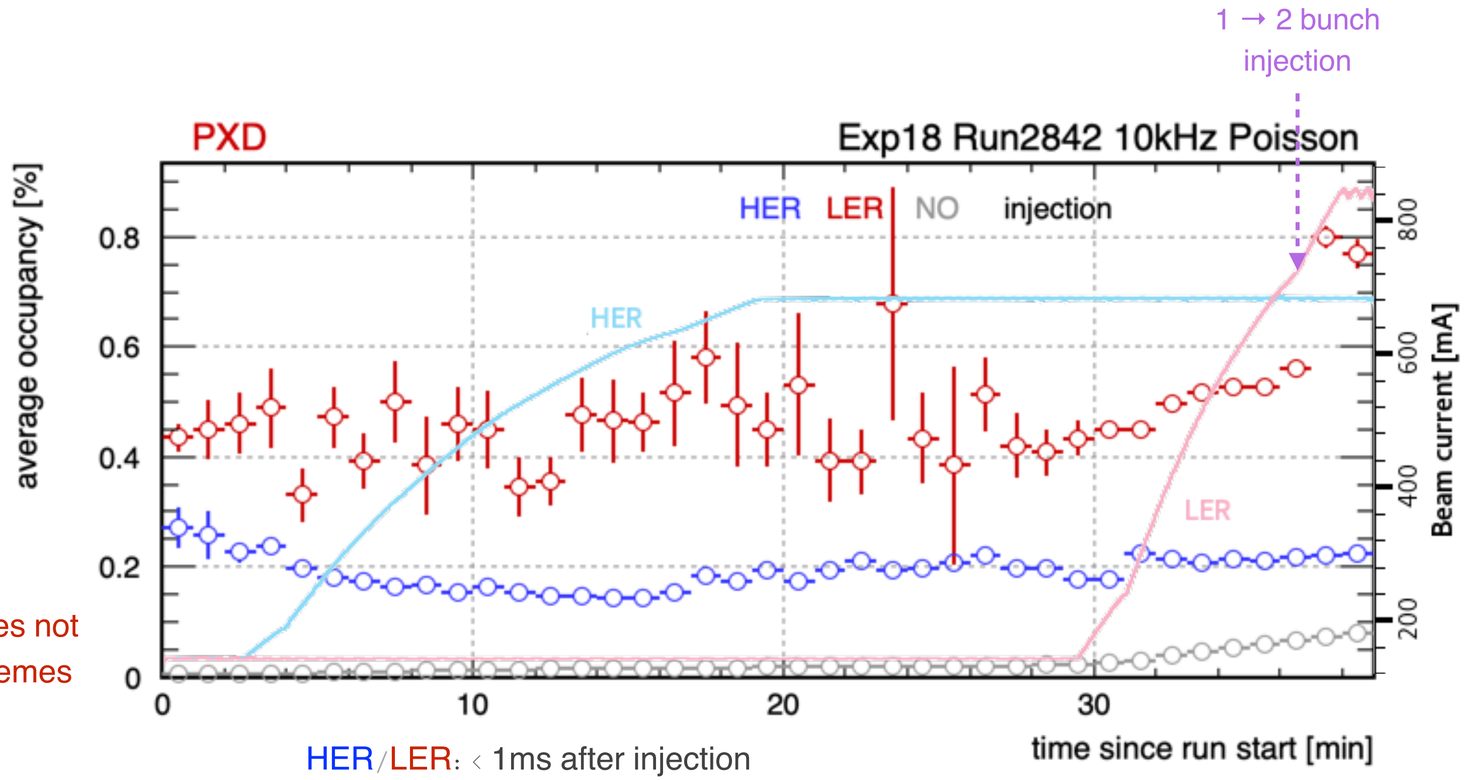
Injection Background Study with Veto-Free Runs

Special trigger veto free runs with Poisson trigger to study injection background

- Allows for unbiased view inside the normally vetoed time slices just after injection
- Following studies cover mixture of data-taking period (2020c and 2021b), but qualitative picture should be the same

Topics covered so far

- Injection background behaviour during ramp-up and steady currents
- Time & spatial structure of the background in PXD just after injection
- Correlation across sub-detectors



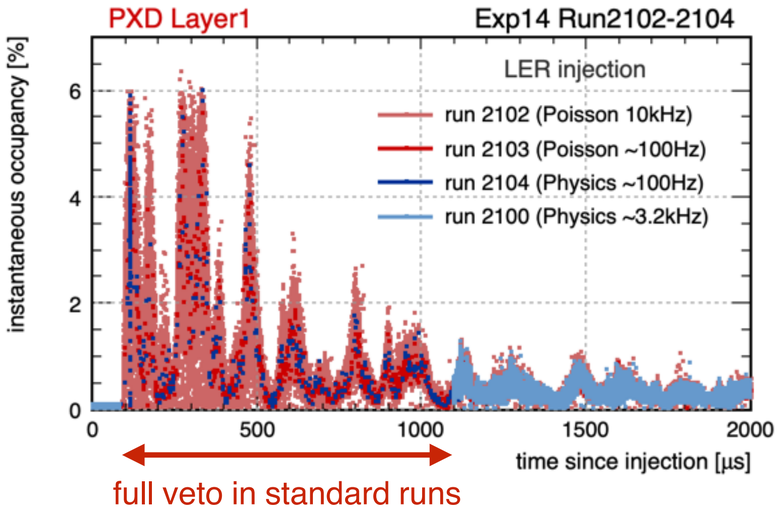
N.B. “average” does not represent the extremes

HER/LER: < 1ms after injection

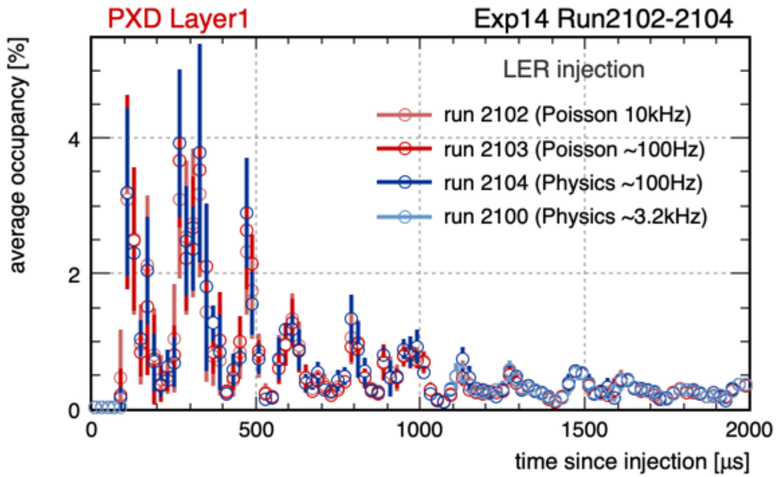
NO: > 30ms after injection

PXD Occupancy Evolution < 2ms after Injection (2020c)

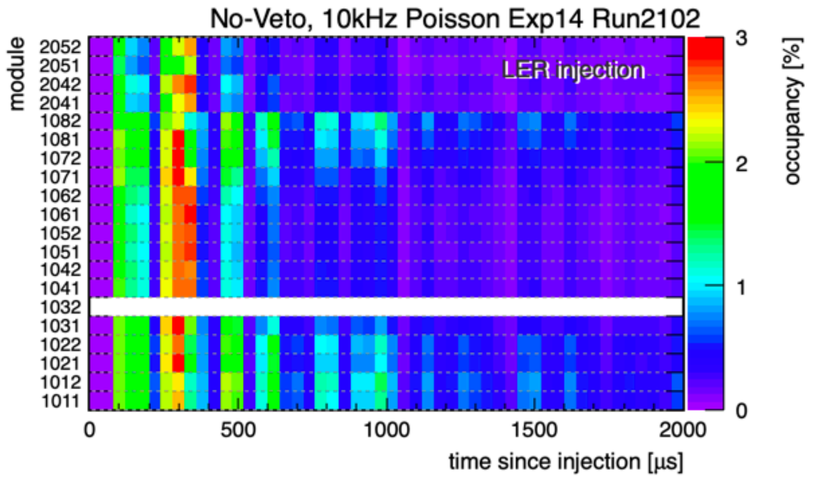
PXD occupancy per event
(LER only)



PXD occupancy per 50μs bin
(LER only)



Module occupancy per 40μs bin
(LER only)



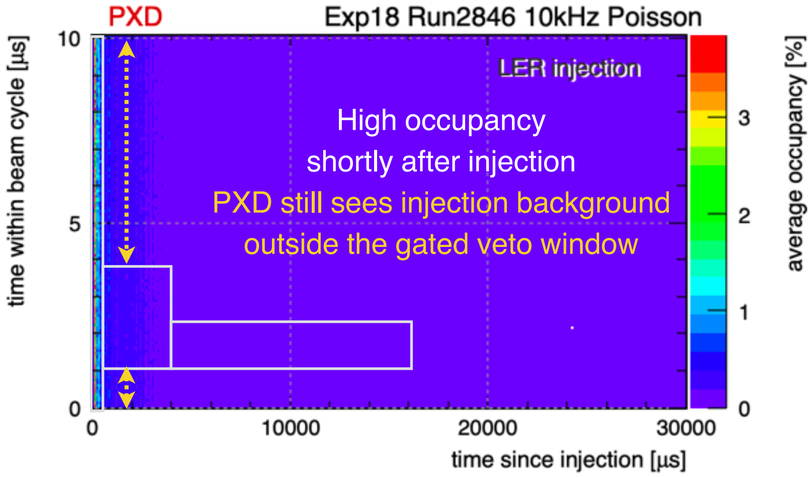
Particular temporal & spatial structure

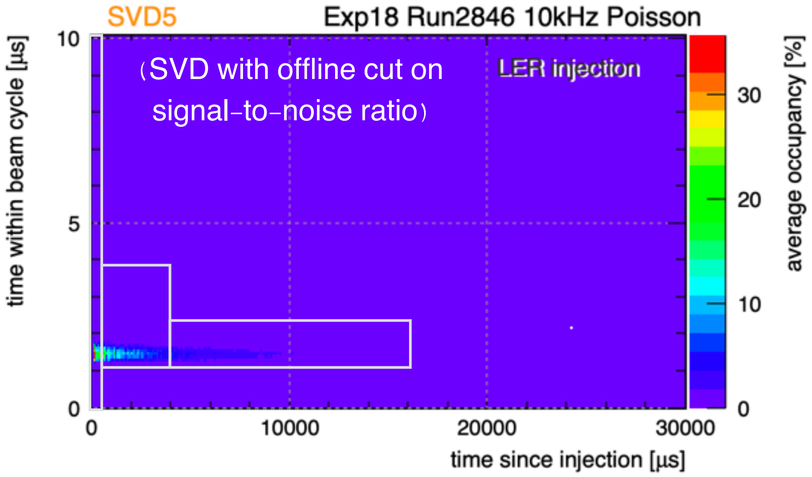
- Oscillation of the occupancy due to Betatron oscillation of the beam
- Max occupancy up to 7% (readout limit), average occupancy >3% (at peak of oscillation) in the first ~5ms
- Variation of local occupancy and damping time over different module in ϕ

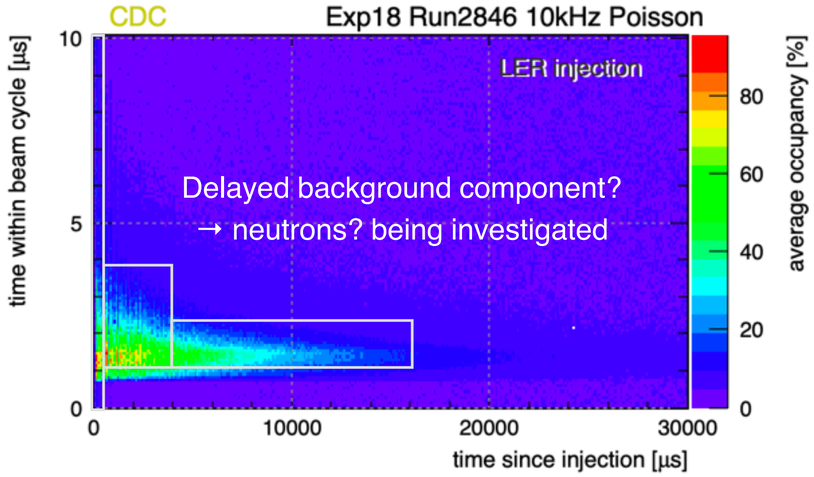
Further characterisation of temporal & spatial distribution and cluster properties on todo list

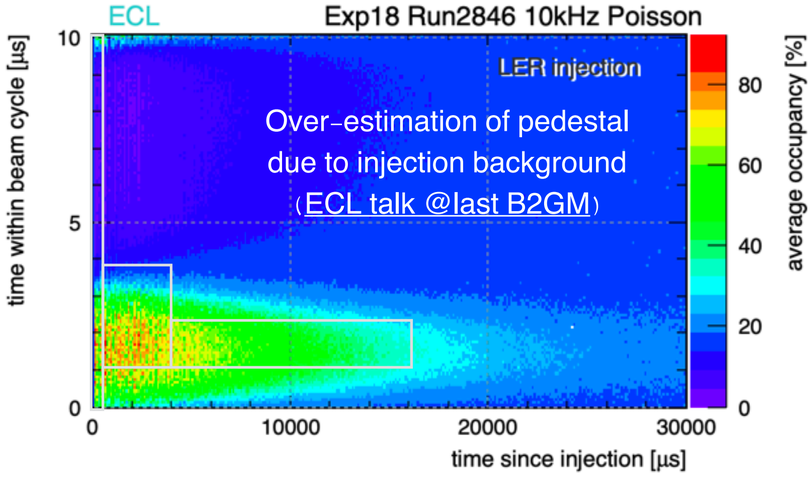
Sub-Detector Occupancies after Injection (LER)

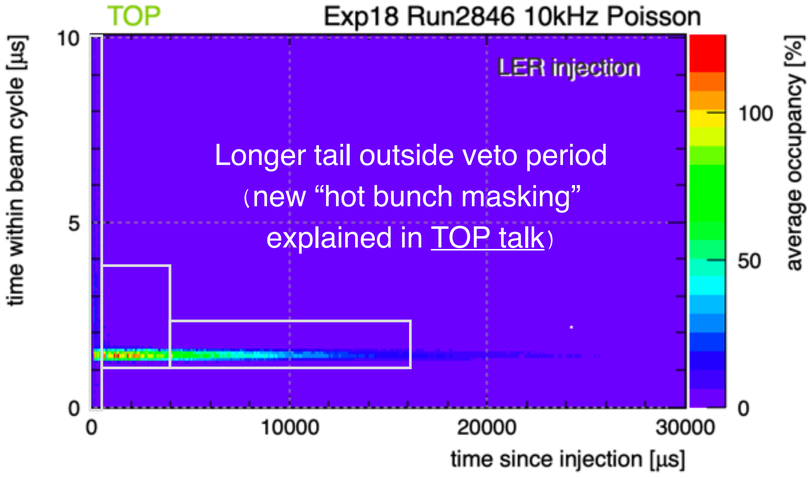
N.B. free z-scale

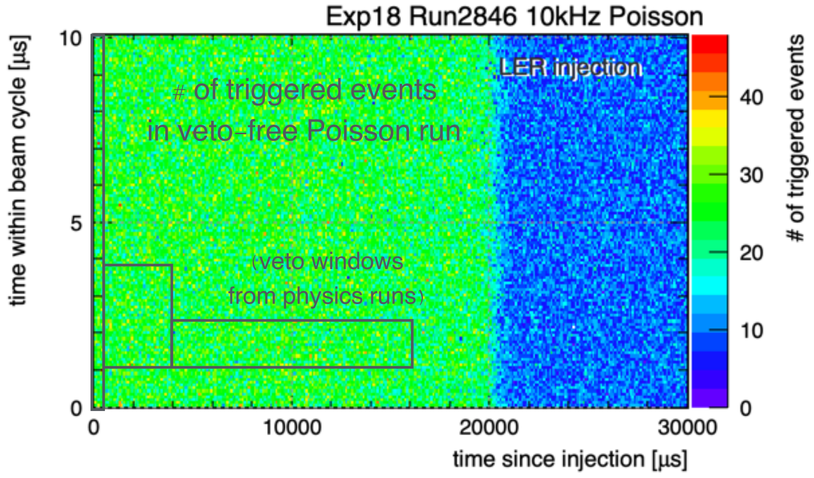












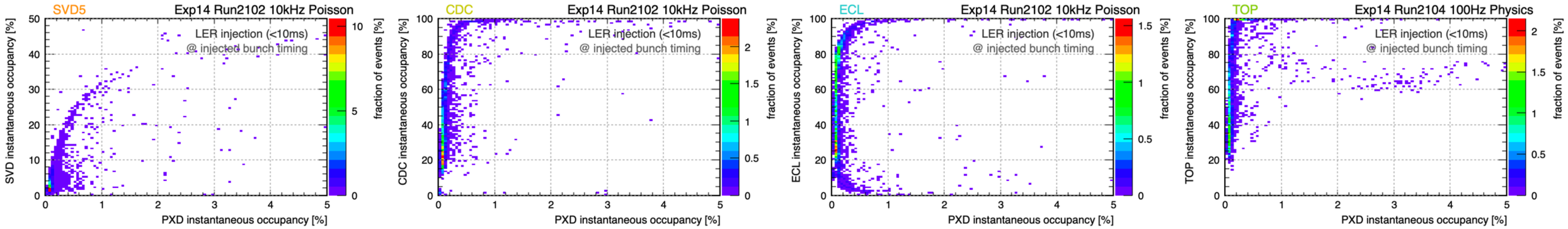
Timing cut removes out-of-time pile-up
in ECL (see back-up)

Veto windows shaped by CDC & ECL → how will it develop in the future?

Sub-Detector Correlation @Injected Bunch Crossing (2020c)

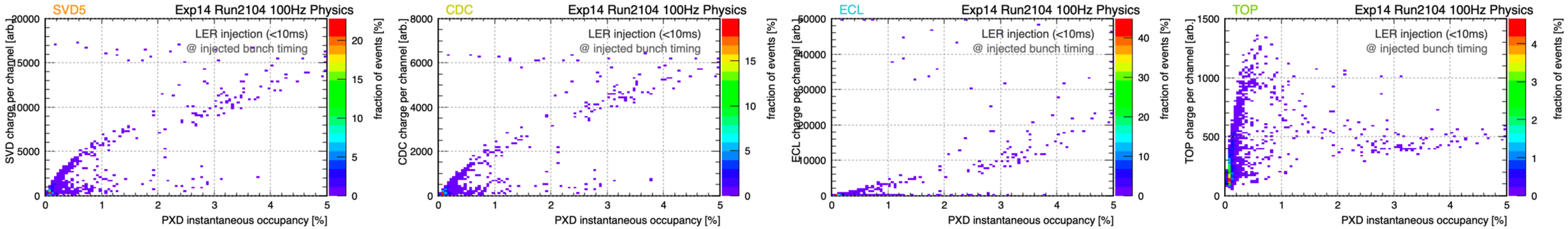
Sub-detector occupancy vs PXD occupancy

Sub-detector occupancies quickly reach 100%



Sub-detector total charge vs PXD occupancy

Total charge show no obvious cut-off but other features



Bunch crossing timing determined using physics trigger rate (window size ~1.5μs)

Further understanding of the correlation to other sub-detectors would help estimating the future situation of trigger veto & PXD occupancy

Reconstruction Performance in High Occupancy

Important to understand reconstruction performance in high occupancy

- Early simulation studies indicated that PXD without Layer 2 would degrade vertex resolution at nominal background
- Preliminary study on injection background events show ~20% fake rate in simple geometrical track-PXD matching at 3% occupancy
- There is room for improvement as e.g. cluster properties are not fully exploited in the current matching algorithm

Studies from other tracking detectors

- Limits on SVD occupancy for good tracking performance by J. Wiechczyński @last tracking meeting
- CDC performance at higher background by A. Glazov @June B2GM

Existing efforts and plans for PXD

- Understanding of the current performance at high occupancy
- Evaluation of Layer 2 contribution at nominal background condition
- Characterisation of signal & background clusters (e.g. earlier study on cluster angle by J. Nierman & B. Schwenker @mini-workshop)
- Better matching in PXD CKF needs discussion with the tracking group

Mini-workshop to discuss these points planned in December

Summary & Outlook

Impact of injection background on Belle II and PXD

- Trigger rate, event size, dead time (through veto as well as readout limit), degradation of reconstruction performance etc
- PXD is not fully protected by Belle II trigger veto because of the long integration time
- Injection background show up different in sub-detectors, but some level of correlation exist

Further understanding of injection background and implications to PXD in the future

- Sub-detector correlation may give some hint on how the PXD background may develop w.r.t. veto conditions
- On-going studies within the background group to model injection background and to identify the responsible machine parameters and mechanisms to help controlling the background level

Studies & developments in progress / in plan to improve offline performance at high occupancy

More Info

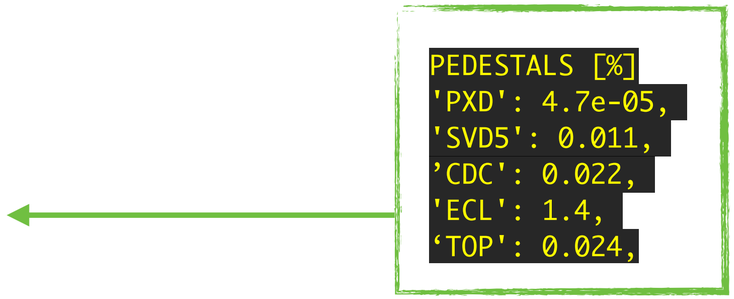
Sub-Detector Occupancies

Sub-detector occupancies using almost “raw” hits stored offline (divided by # of channels)

- PXDDigits / 3648k pixels (19 modules) → hot pixel mask applied offline
- SVDShaperDigits / 223744 strips → SNR>5 cut additionally applied offline as recommended
- CDCHits / 14336 wires
- ECLDigits / 8736 crystals
- TOPDigits / 8192 channels

No pedestal subtraction

- Not significant but can do next time

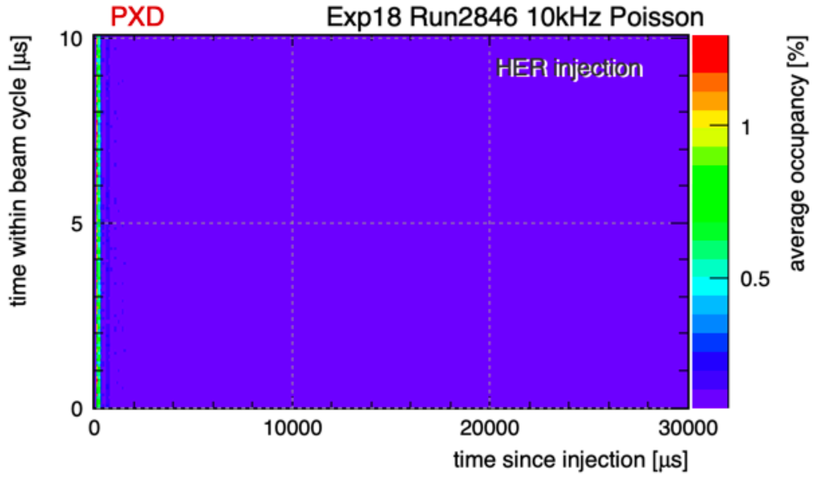


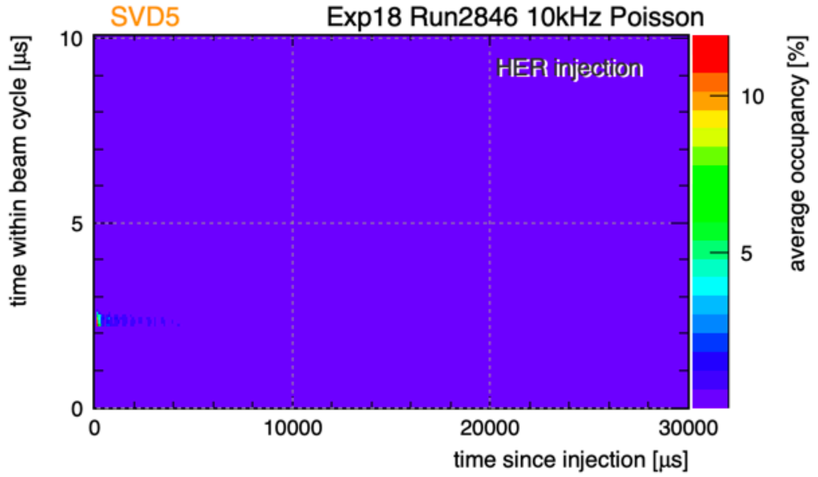
Definition of background types

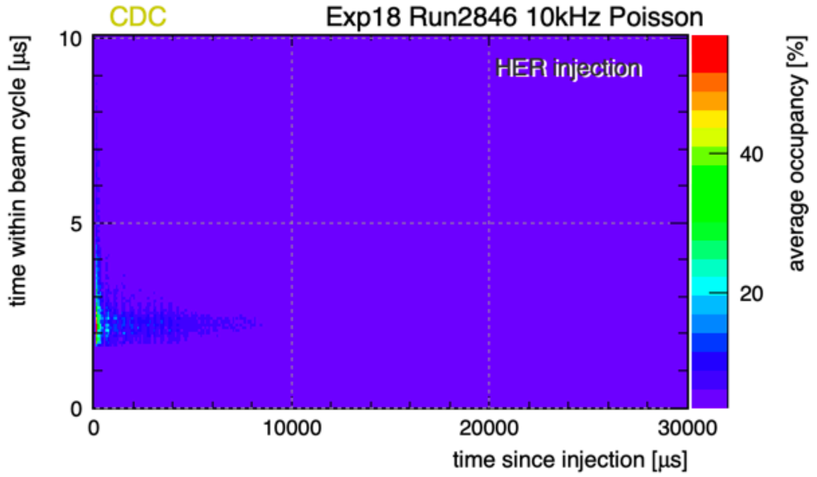
- Non-injection (storage) background: time since injection > 30ms after any injection
- Injection background (see more in the next slide):
  - PXD: time since injection < 1ms
  - Other sub-detectors: time since injection < 20ms and within bunch crossing timing (see back-up)
    → This selection is used for the time evolution (time since run start) plots, but I don’t actually have them in slides, only in the liked web page

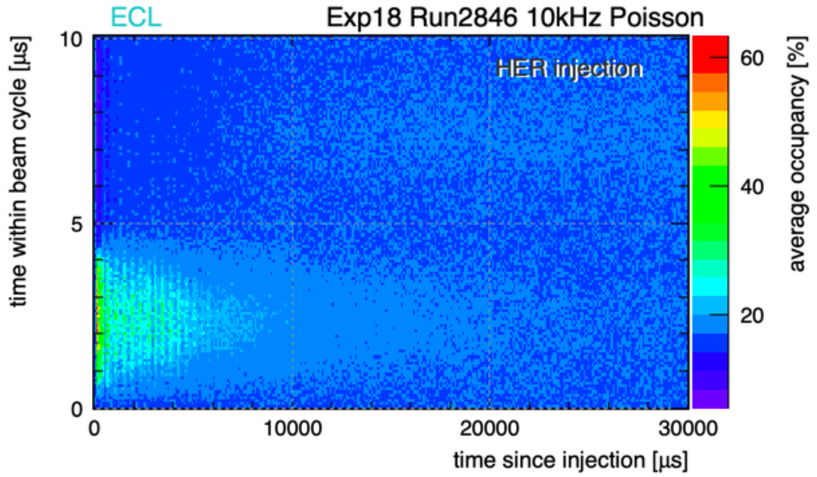
Sub-Detector Occupancies after HER Injection with Poisson

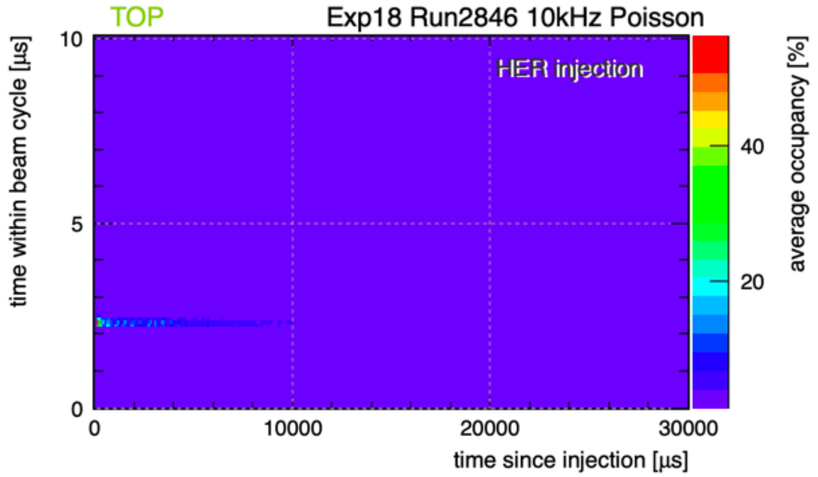
N.B. free z-scale











Injected Bunch Crossing Timing（From 2020c Runs）

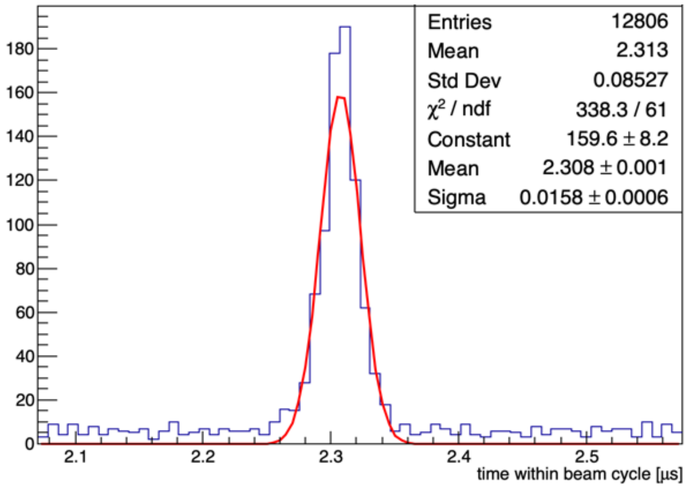
Most of sub-detectors see injection background only at the timing when injected bunch cross Belle II detector

- Best time resolution by TOP（least contamination in raw data）
- Physics triggers are very sensitive to injected bunch

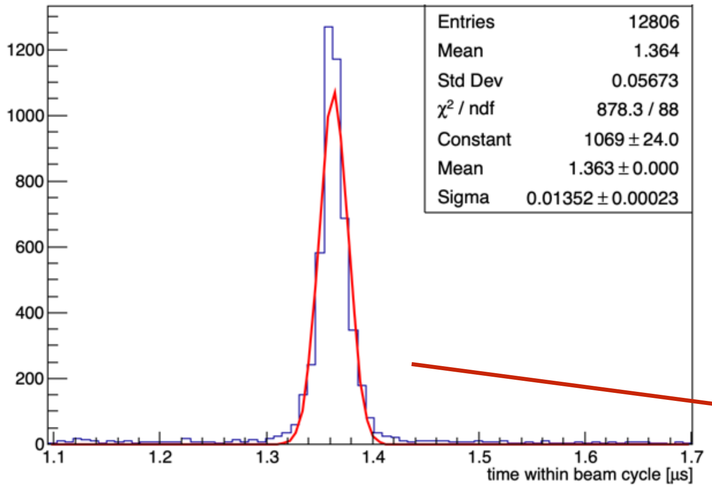
Define bunch crossing timing windows

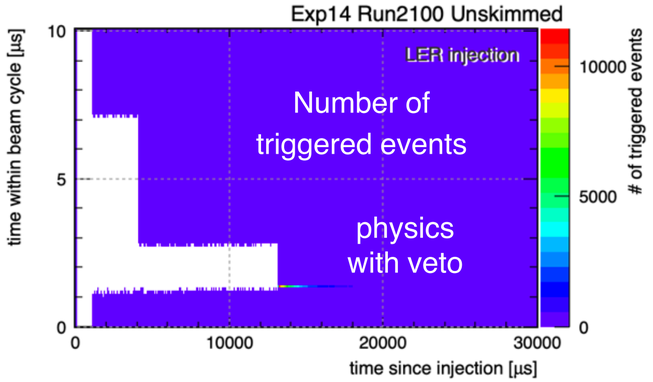
- Fit the triggered event rate in physics run without veto（2020c）and take 2 σ
- Different timing（offset）for HER and LER injection

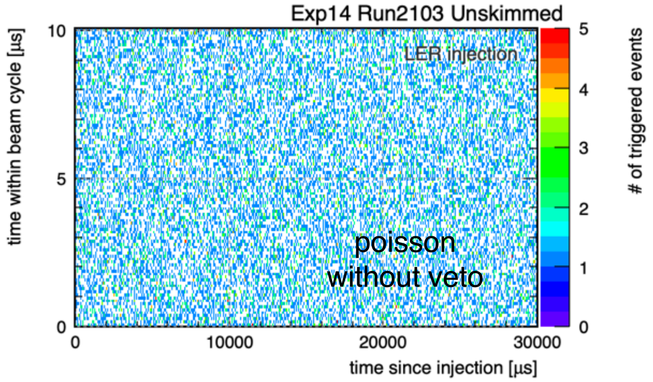
HER injected bunch timing

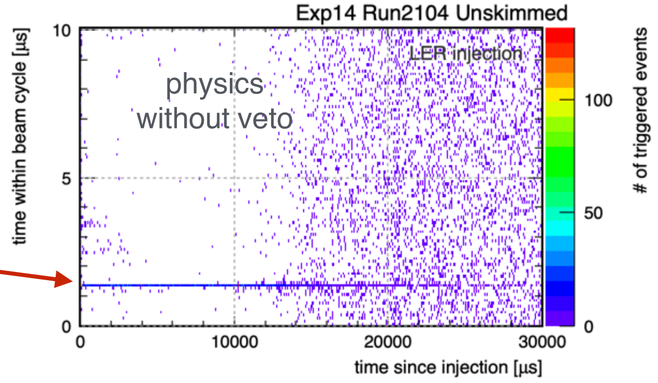


LER injected bunch timing

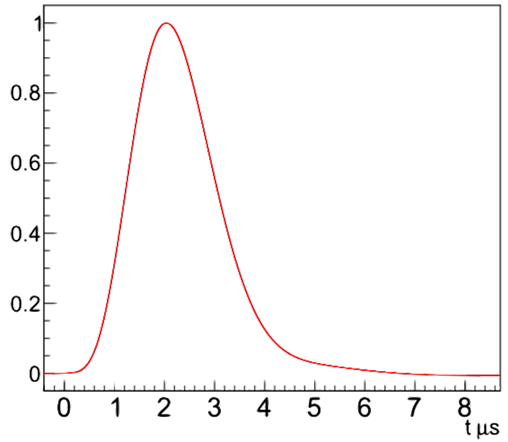






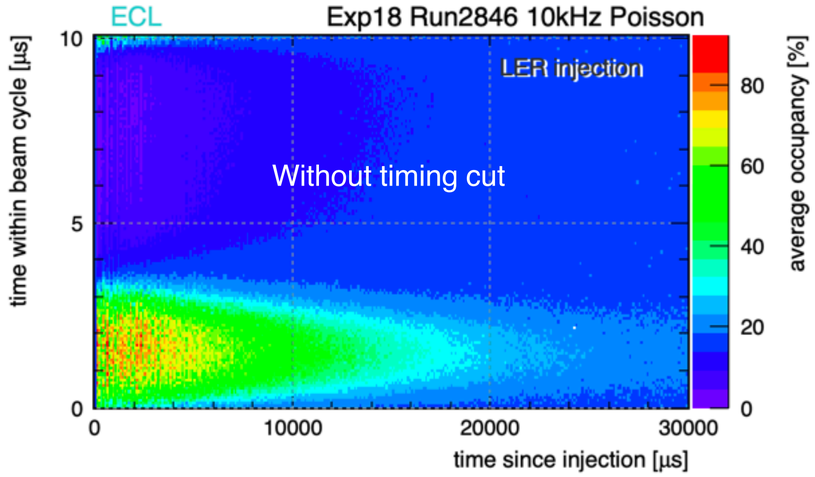


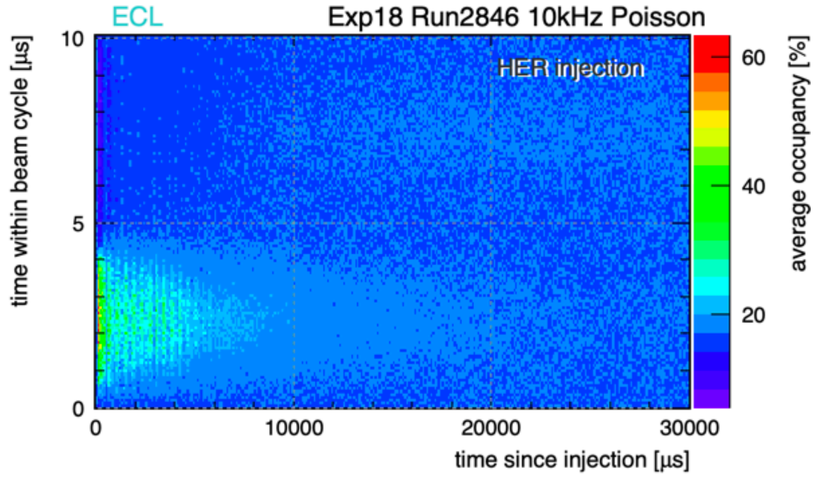
ECL Occupancy with Timing Cut

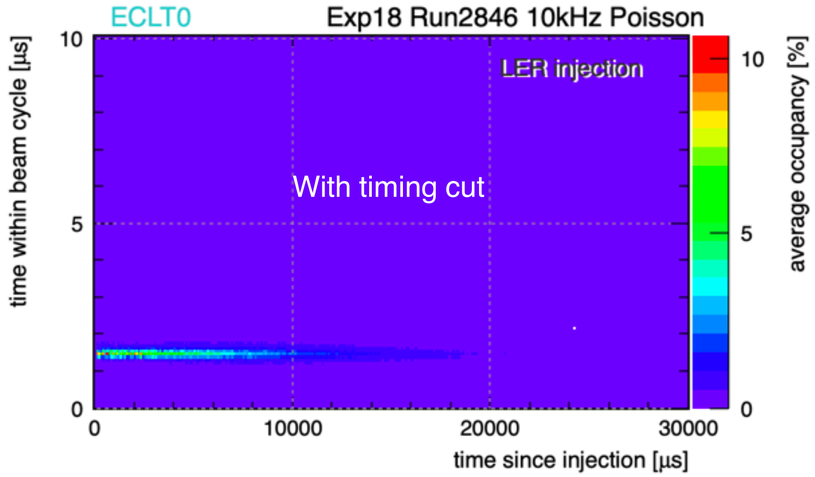


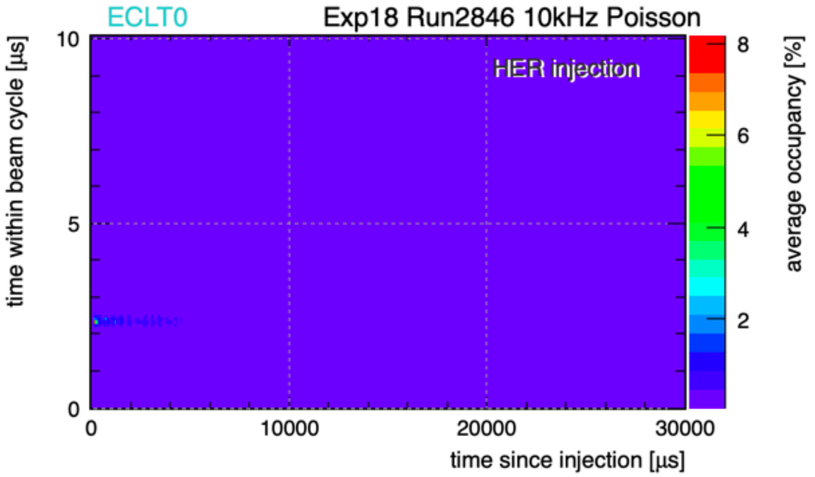
ECL waveform stretch over ~5μs
but fitted time resolution ~O(ns)

N.B. free z-scale





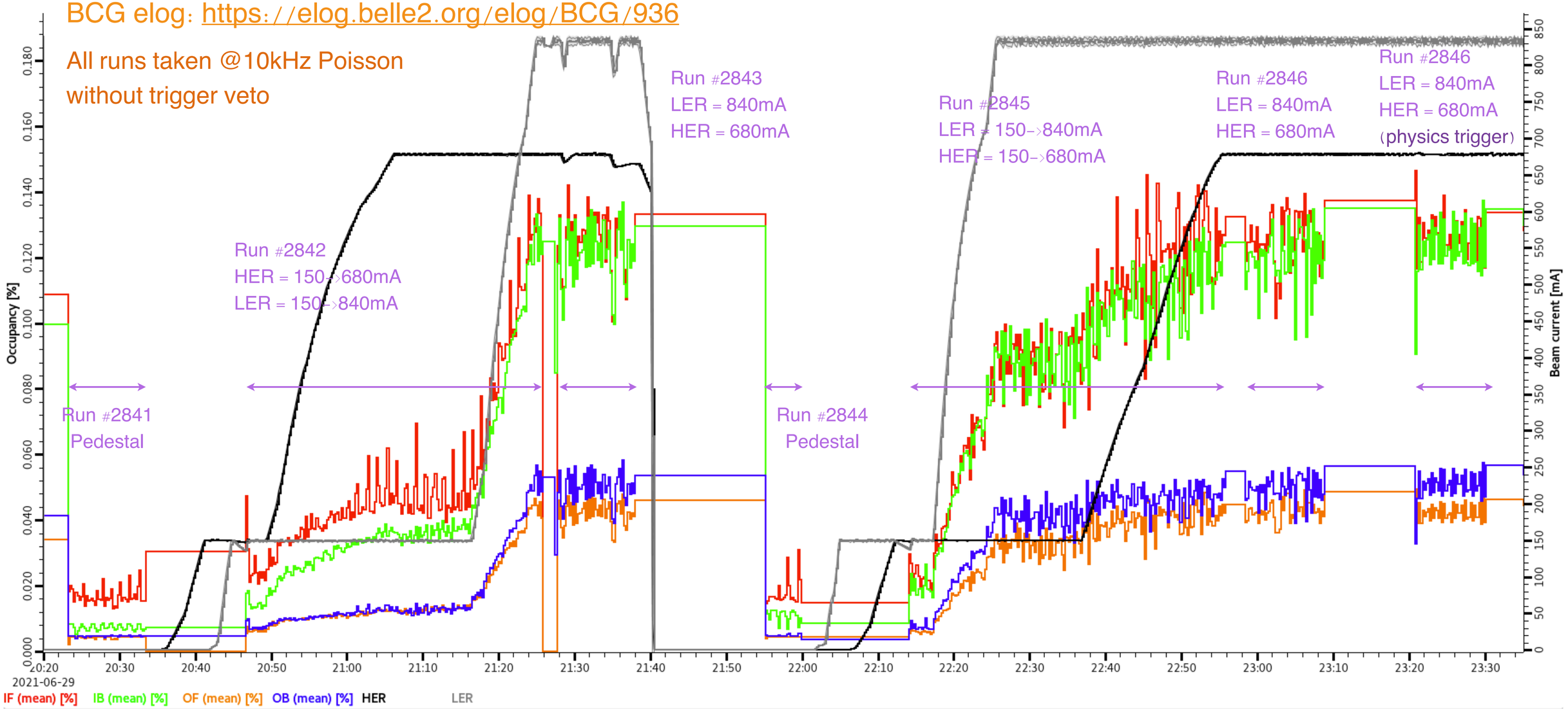




Injection Background Study Runs on 29 June

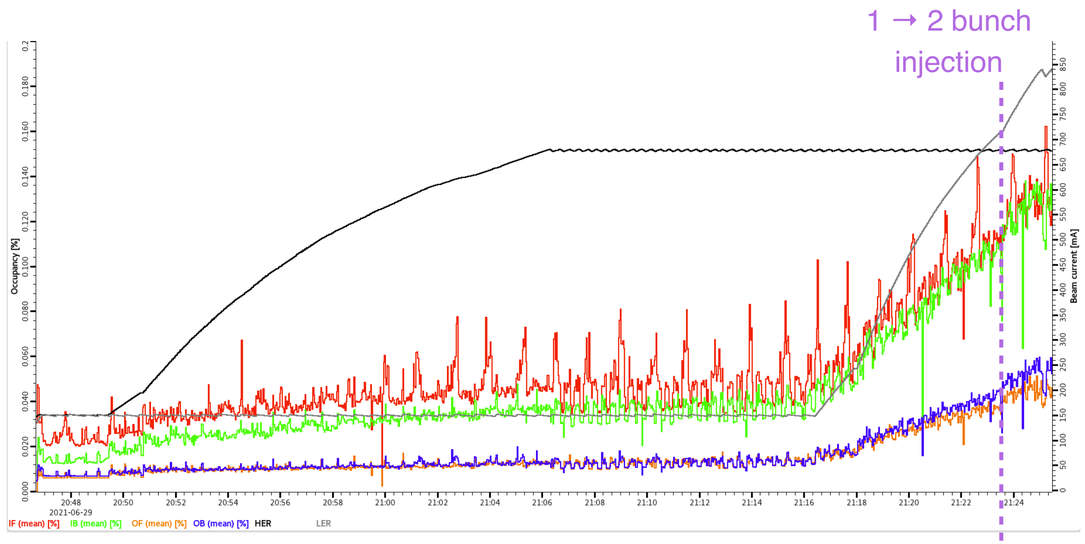
BCG elog: https://elog.belle2.org/elog/BCG/936

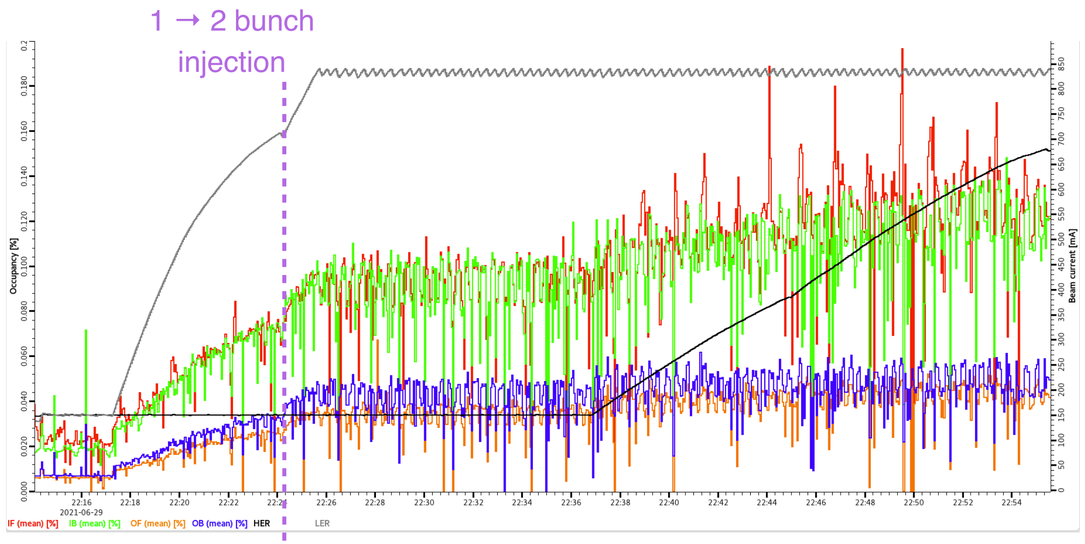
All runs taken @10kHz Poisson
without trigger veto

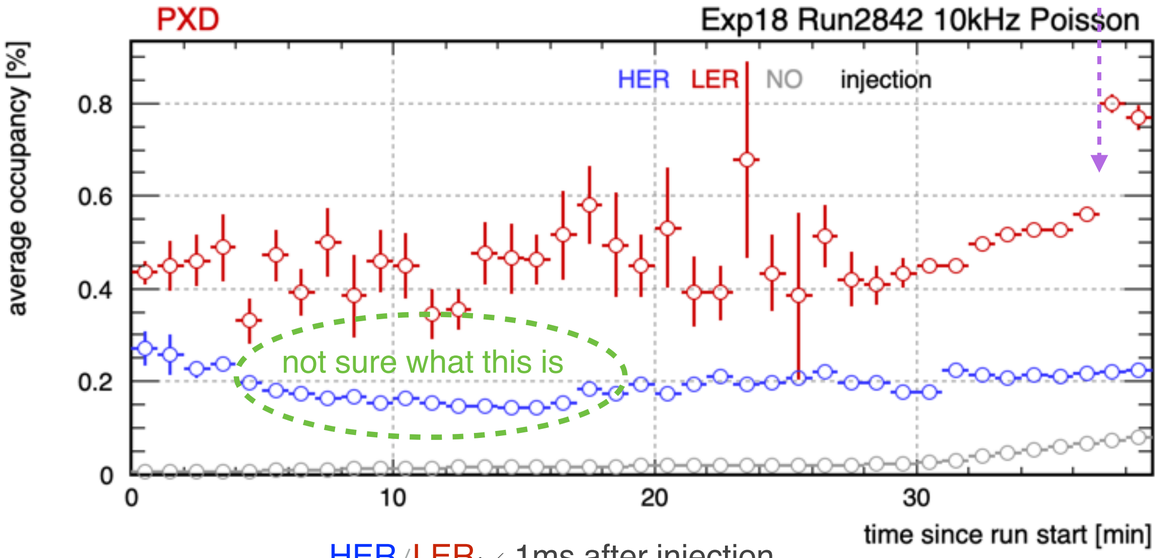


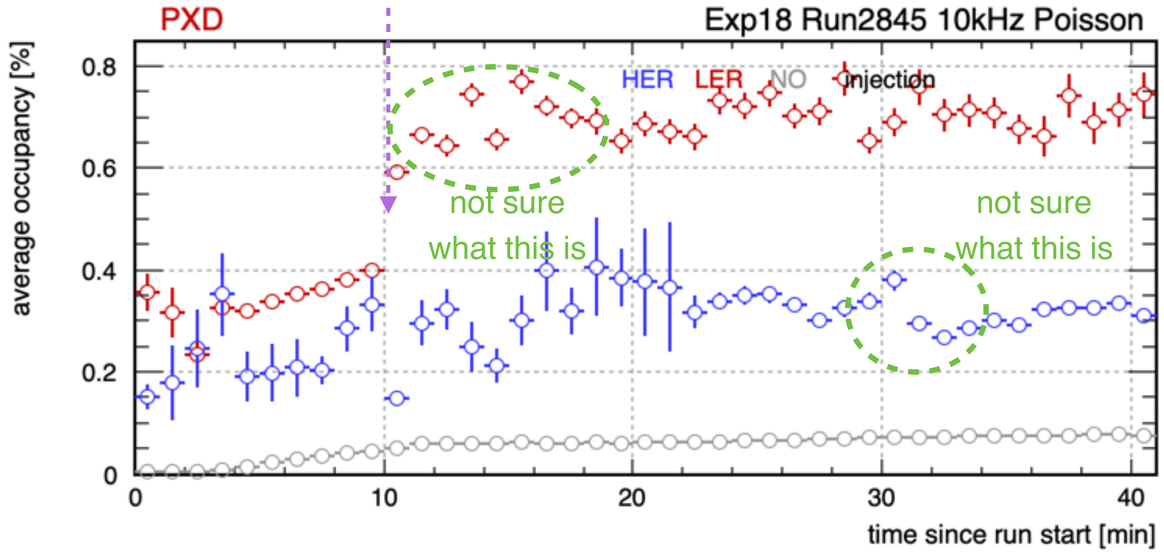
In Colour: PXD online occupancies in Inner/Outer-Forward/Backward modules (note: some known hot pixels/regions after beam incident damage)

Veto Free – Increasing Beam Currents







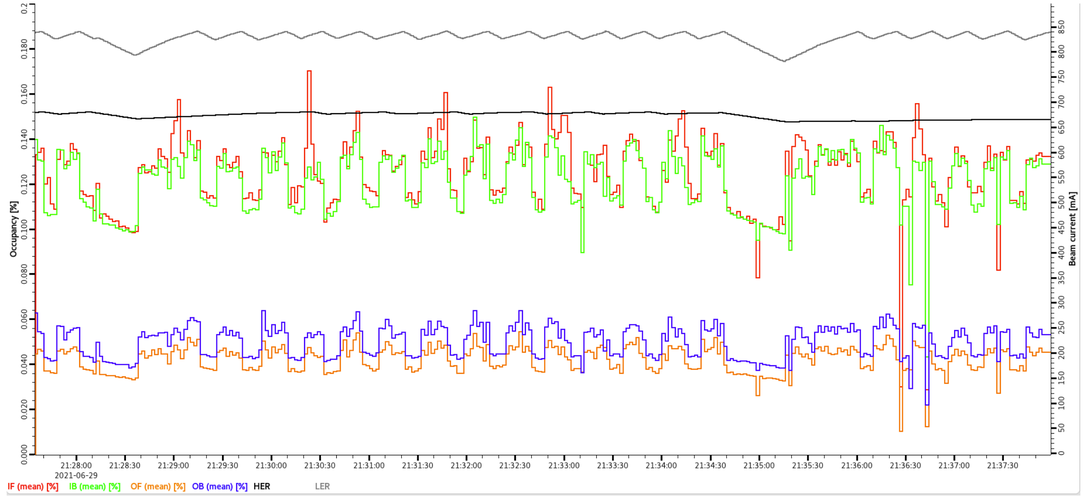


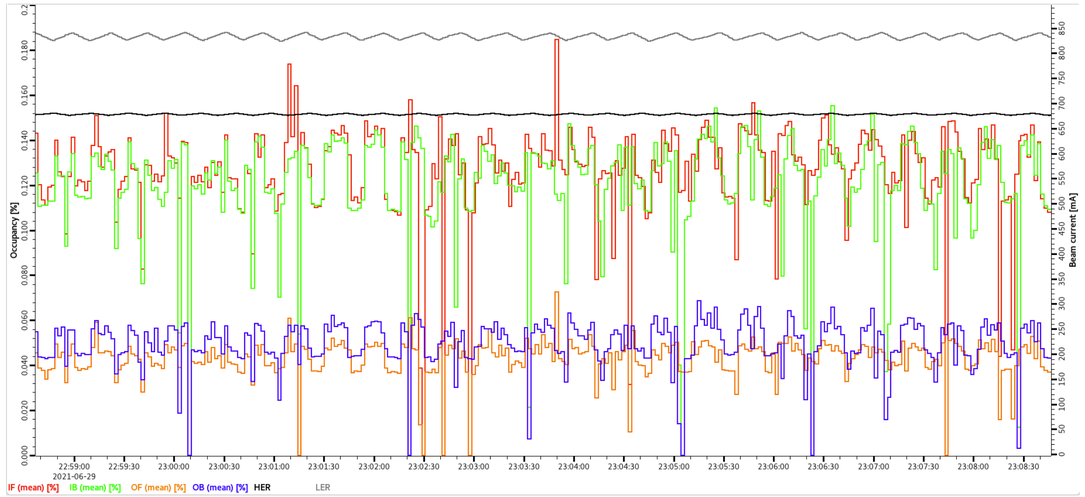
HER/LER: < 1ms after injection

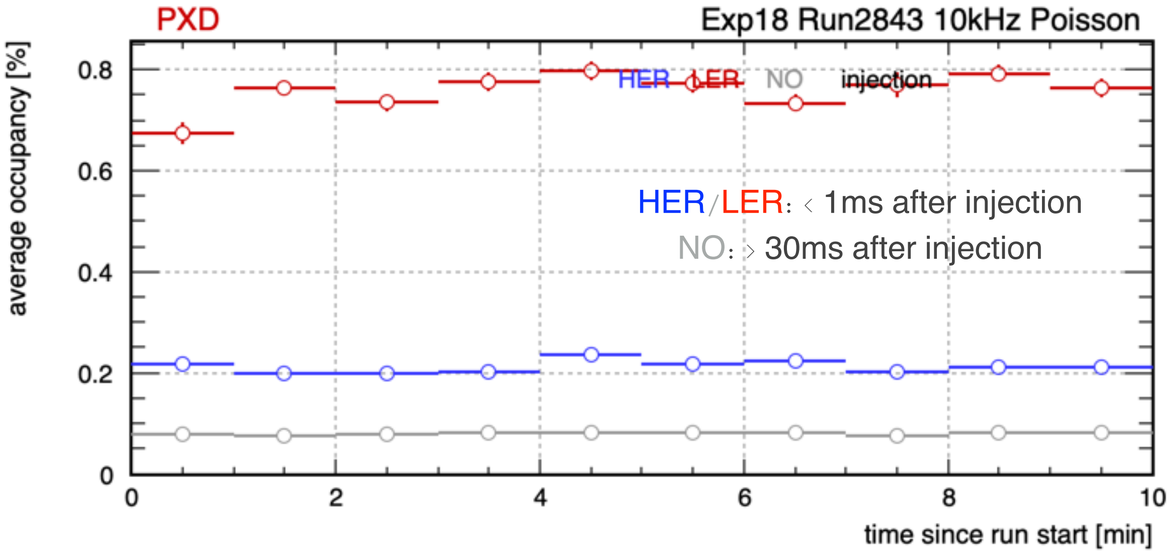
NO: > 30ms after injection

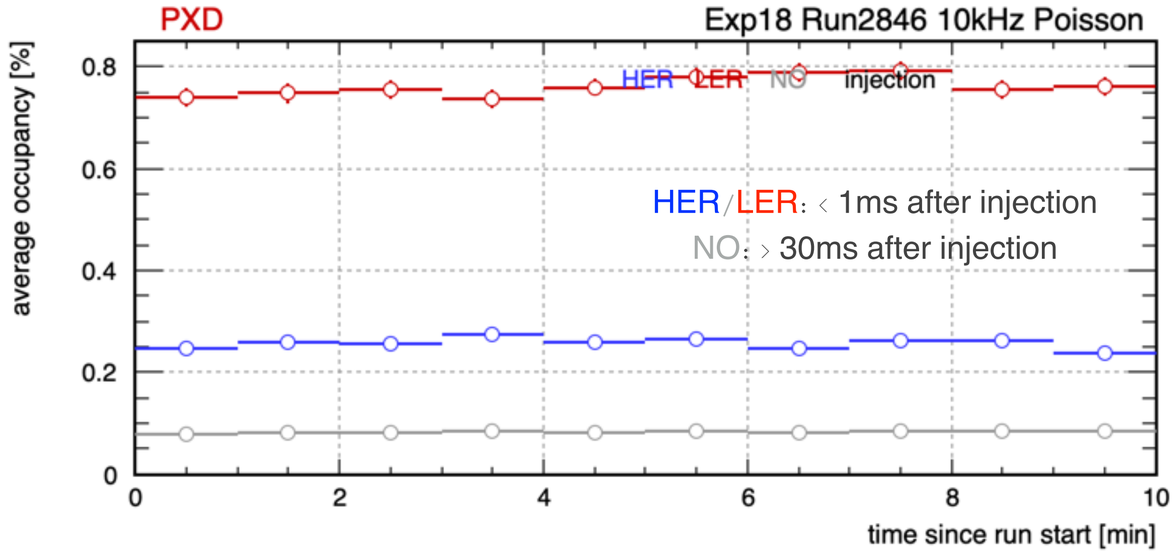
Other sub-detector plots can be found HERE

Veto Free – “Constant” Beam Currents









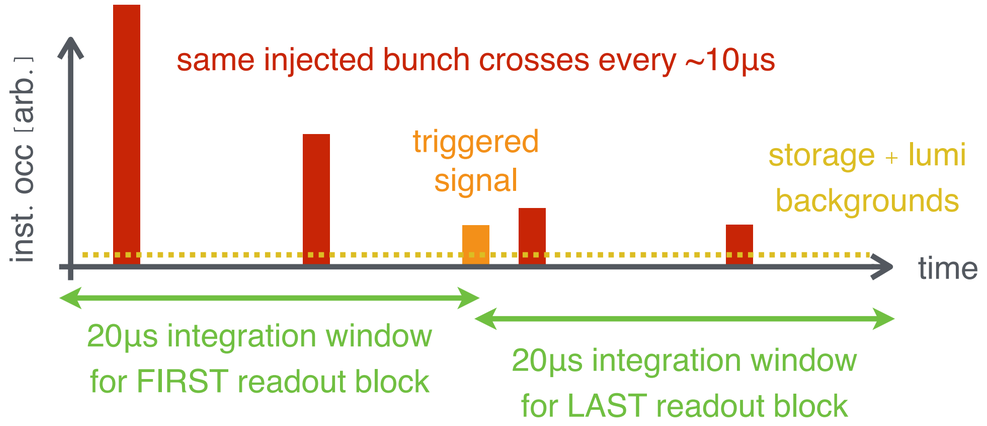
Some difference in HER occupancy?

Other sub-detector plots can be found HERE

PXD Specifics

Rolling shutter readout and integration time

- Pixels are readout in sequence of blocks over 20μs
- Each pixel accumulates charge from traversing particles over 20μs



Readout limits

- PXD is designed to tolerate 3% “average” occupancy
- Readout limit set to ~7% per instance
- Data truncation (and dead time) may occur when consecutive triggers have high enough occupancies → currently truncation occur @ << 1/1000

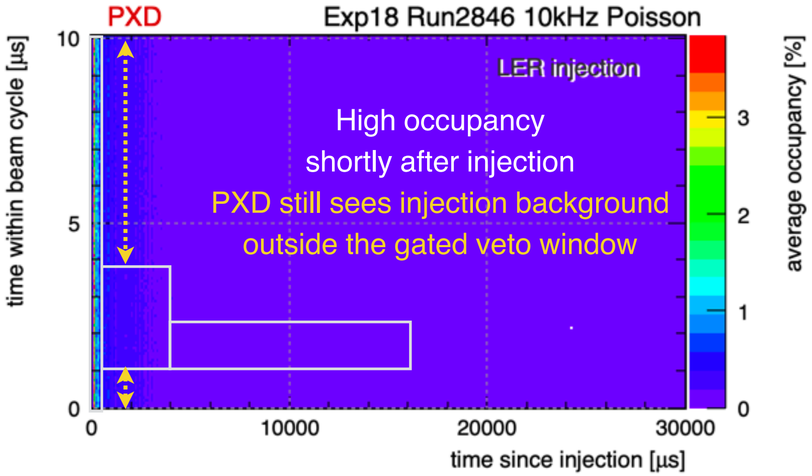
PXD “Gated Mode” operation

⟹ CURRENTLY NO PLAN TO BE USED

[see report by B. Spruck]

Future concerns for injection background?

- Would PXD face more readout issues when injection background increases?
  → background seen in PXD and other sub-detectors do correlate to some level and full veto may still be sufficient to protect PXD readout
- Offline reconstruction needs to be re-optimised for high occupancy
  → studies to characterise signal and background using more recent background knowledge in plan



Standard Physics Runs

Need to also study standard physics runs to understand things that change over longer time span

- Correlation to machine parameters being studied by Benjamin using online data (see next talk)
- Occupancy and dose rate studied by Sally using 2Hz Poisson offline data

Something in pipeline – will the global Belle II trigger veto protect PXD in the future?

- Look at correlation of PXD occupancy just after injection and trigger rate and other sub-detector occupancies outside veto, and length of the gated veto windows over a longer period of time (e.g. entire exp 18)
- Predict evolution of “visible” injection background in PXD vs other detectors