Study of ρ photoproduction with ALICE at the LHC

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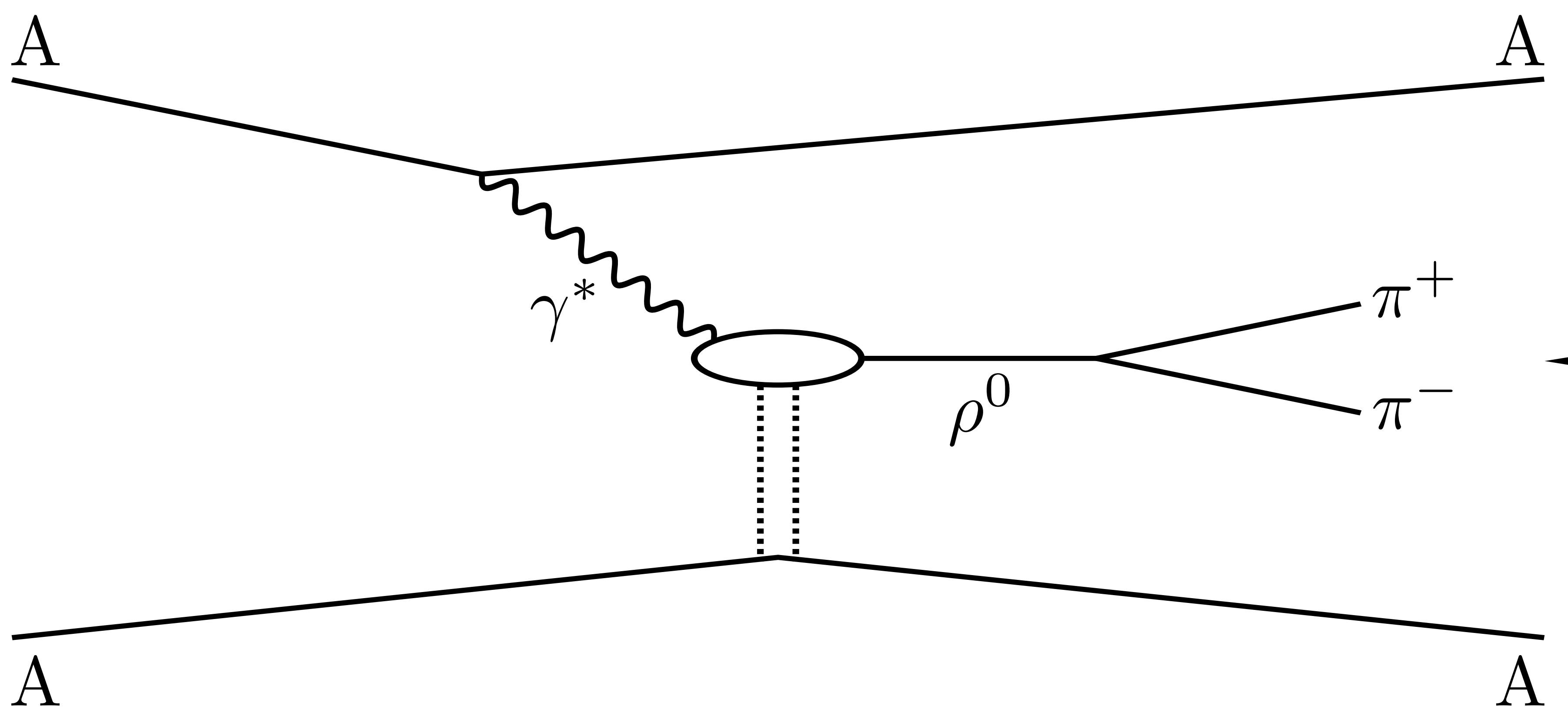
Vector meson photoproduction



only two pions in the event

- studied within heavy-ion UPCs ($b > 2R_\mathrm{A}$)
  - limited hadronic interactions → clean environments for measurements of exclusive events with rapidity gaps
- emitter/target role interchangeable → quantum interference
- cross sections sensitive to nuclear gluon distributions

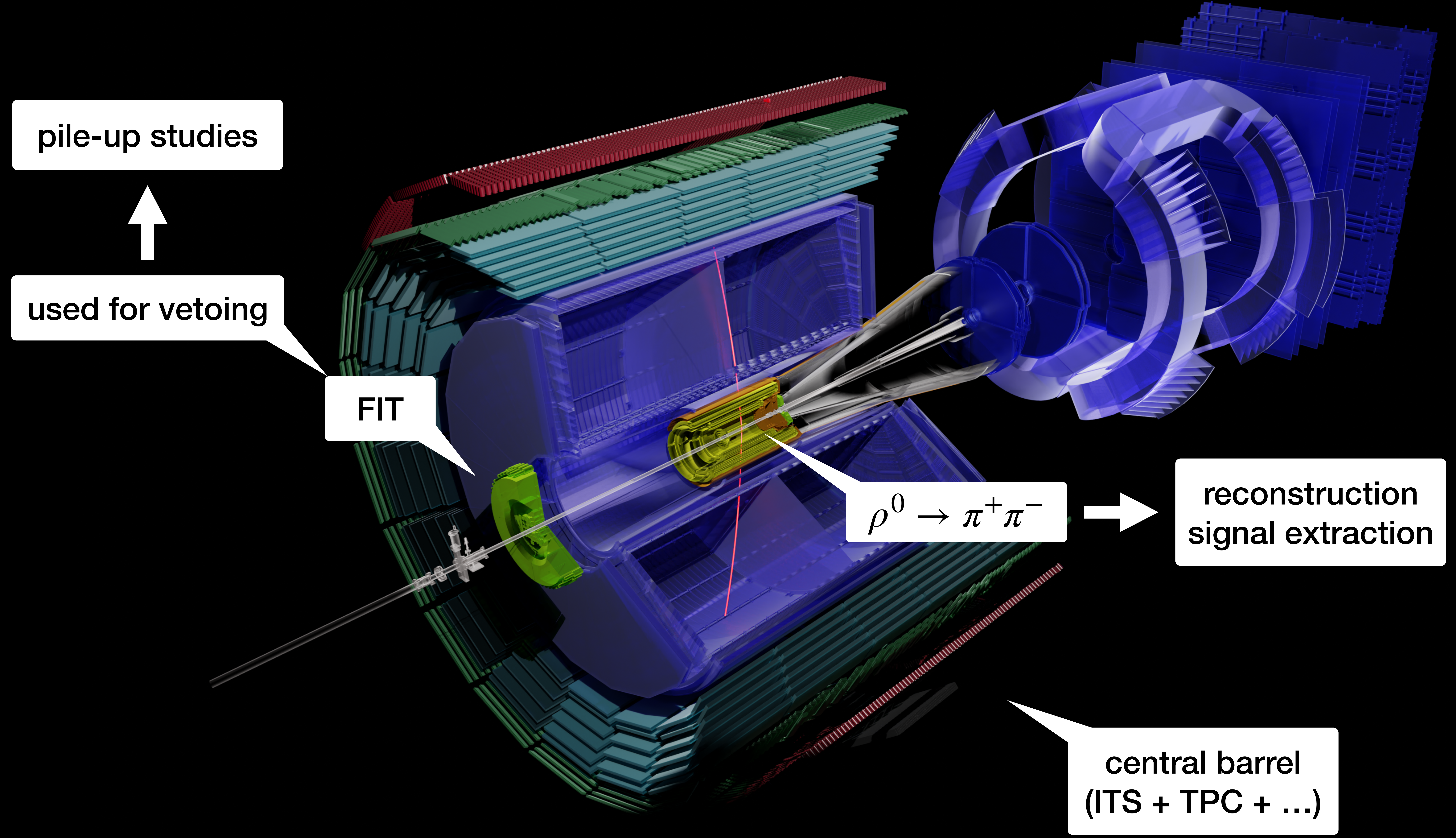
ALICE during Run 3

- in Run 3 ALICE is focusing on measurements of rare events with high signal to noise ratios → requires massive amounts of data
  - switch to continuous readout
  - almost all subdetectors upgraded, overhauled, or completely replaced during LS2
  - introduction of the Online—Offline (O^2) framework

ALICE during Run 3

➡ previously untested environment, many improvements but also novel challenges, e.g.:

- difficult unification of detector readout (differing ROF sizes)
- massive increase in amount of recorded data
  - previous ρ analyses used data samples with O(10^4) events, now O(10^7)
  - significant pile-up, backgrounds from $\gamma\gamma \rightarrow e^+e^-$ events



Dobrigkeit Chinellato: ALICE Ultra-peripheral event display. Zenodo.

Motivation
photoproduction cross section

- ρ^0 photoproduction cross section has been measured several times in the past for Pb—Pb collisions
  - never in the Run 3 paradigm (ALICE 2 detector, O^2 software, large datasets)

ρ^0 signal + yield extraction

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y} = \frac{N_{\rho^0}}{(A \times E) \cdot BR(\rho^0 \to \pi^+\pi^-) \cdot L_{\mathrm{int}} \cdot \Delta y}$$

previous work + pile-up studies

Pile-up studies
in 2022 Pb—Pb data

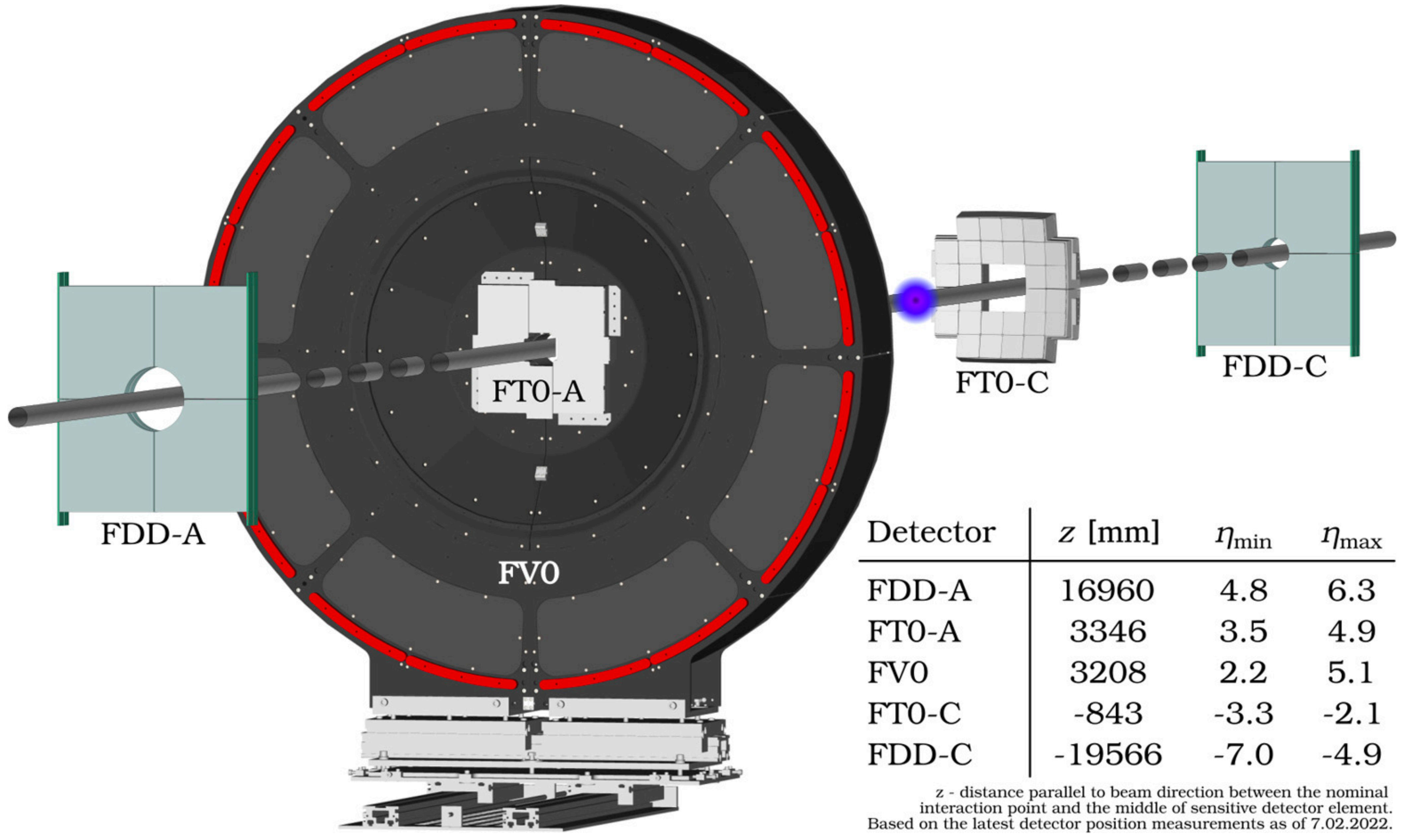
Pile-up effects

- parasitic signals from various physical processes interfering with measurements
  - signatures from overlapping collisions, neighbouring BCs, particle—detector interactions, beam gas events, etc.
- can have profound impact on measurement sensitivity
- especially important for UPC measurements
  - UPC triggers often include vetoes on excessive particle production, pile-up can mimic these signals and cause loss of events

Pile-up in 2022 heavy-ion data

LHC22s Run 529418 apass4

- studied in the context of the FT0 and FDD detectors (part of FIT)
  - collision rate and background monitoring, luminosity estimation, triggering
  - also used in UPC event filtering



Detector	z [mm]	η_{min}	η_{max}
FDD-A	16960	4.8	6.3
FT0-A	3346	3.5	4.9
FV0	3208	2.2	5.1
FT0-C	-843	-3.3	-2.1
FDD-C	-19566	-7.0	-4.9

z - distance parallel to beam direction between the nominal interaction point and the middle of sensitive detector element. Based on the latest detector position measurements as of 7.02.2022.

Slupecki: Nucl.Instrum.Meth.A 1039 (2022) 167021

+

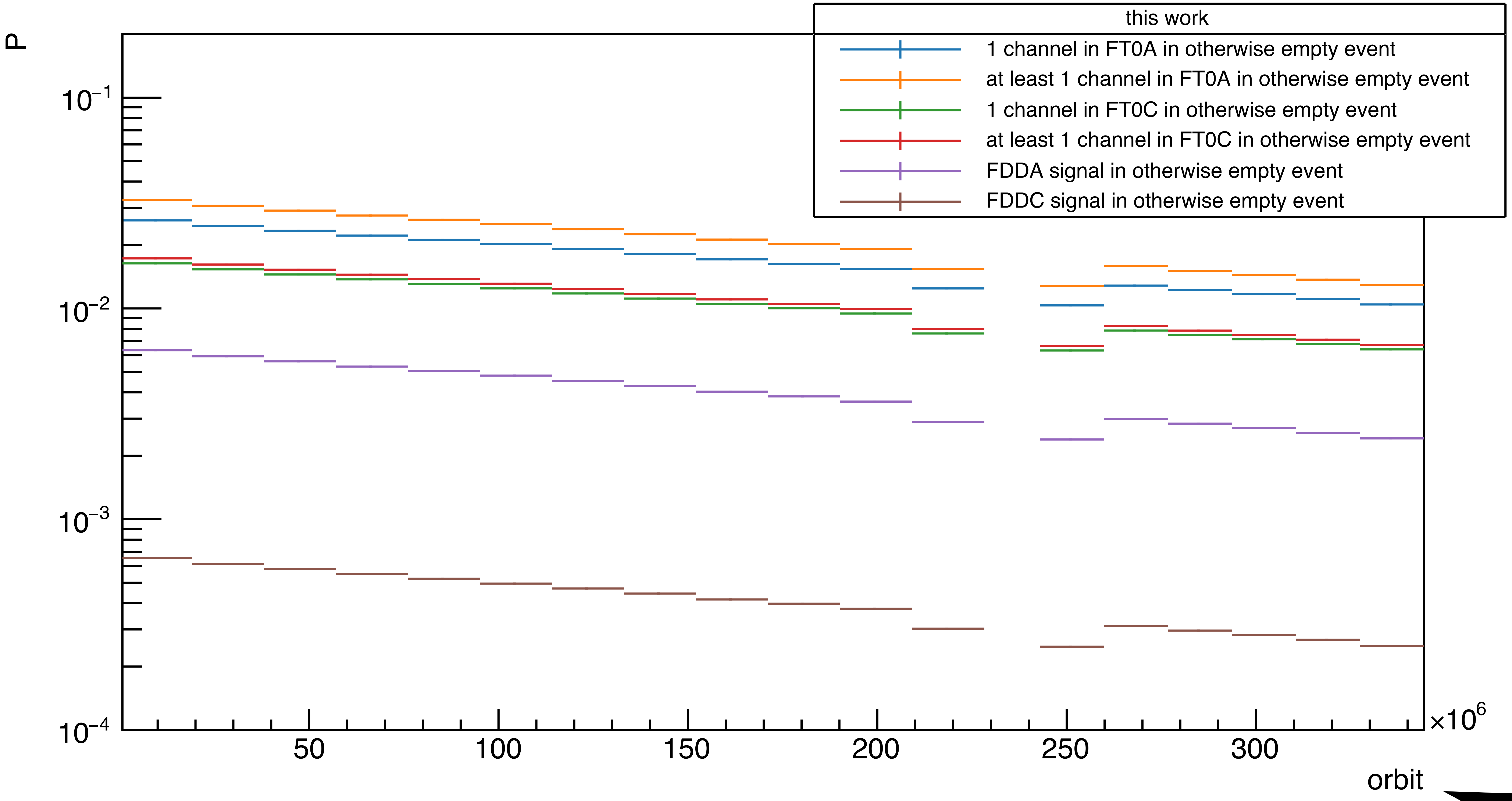
Collected info from FT0 and FDD

- A and C sides of both detectors treated separately
- data grouped by BCs, orbits used for timing purposes
  - saved total amplitude and number of channels in FT0
  - signal in FDD was based on checking charge coincidences within quadrants of the two layers (only a boolean value)
  - also collected FT0 and FDD vertex trigger rates

BC ID	orbit	FT0A/C amplitude	FT0A/C channels	FDDA/C coincidence

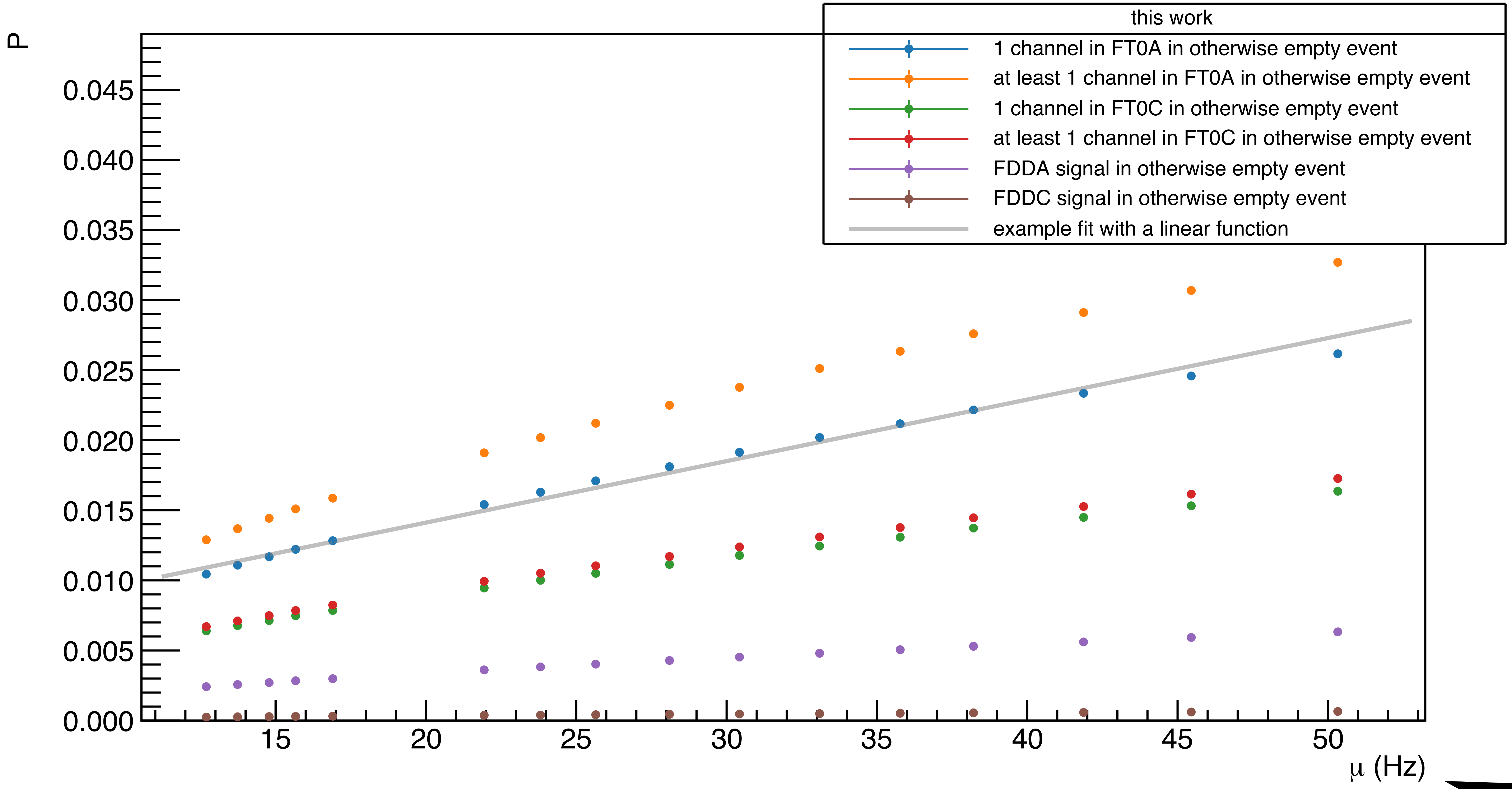
Pile-up probabilities

time evolution



1 orbit = 88.9246 μs

Pile-up probabilities
vs hadronic interaction rate μ



from FT0 vtx rate

ρ photoproduction in 2023 Pb—Pb data

Utilised dataset

- *UD_LHC23_pass2_upc_SingleGap_final* dataset
    - derived from *LHC23zzfghik_pass2_upc* using the Single Gap Candidate producer
    - 2023 ‘Golden Runs’—1/6 of all 2023 data
- analysis run full-scale on Hyperloop

create your own QR code here

Utilised event selections

collision level

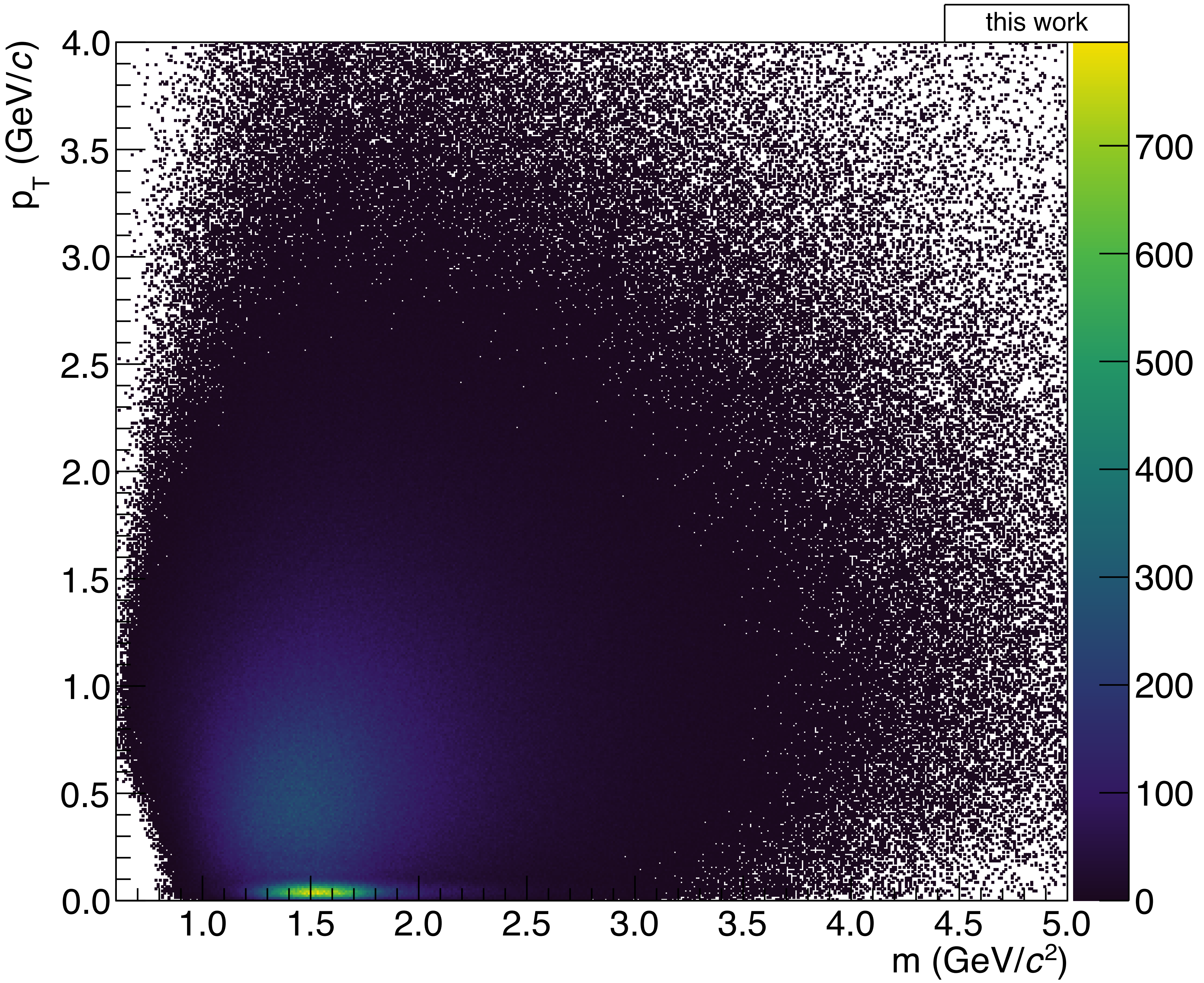
- gap side specification (exclusive photoproduction has rapidity gaps on both sides of the event)
- vertex Z position < 10 cm from IP
- event tagging into neutron classes using the ZNA/C detectors
  - 0n0n, 0nXn, Xn0n, XnXn differentiated from ZN Common Energy and ZN Time

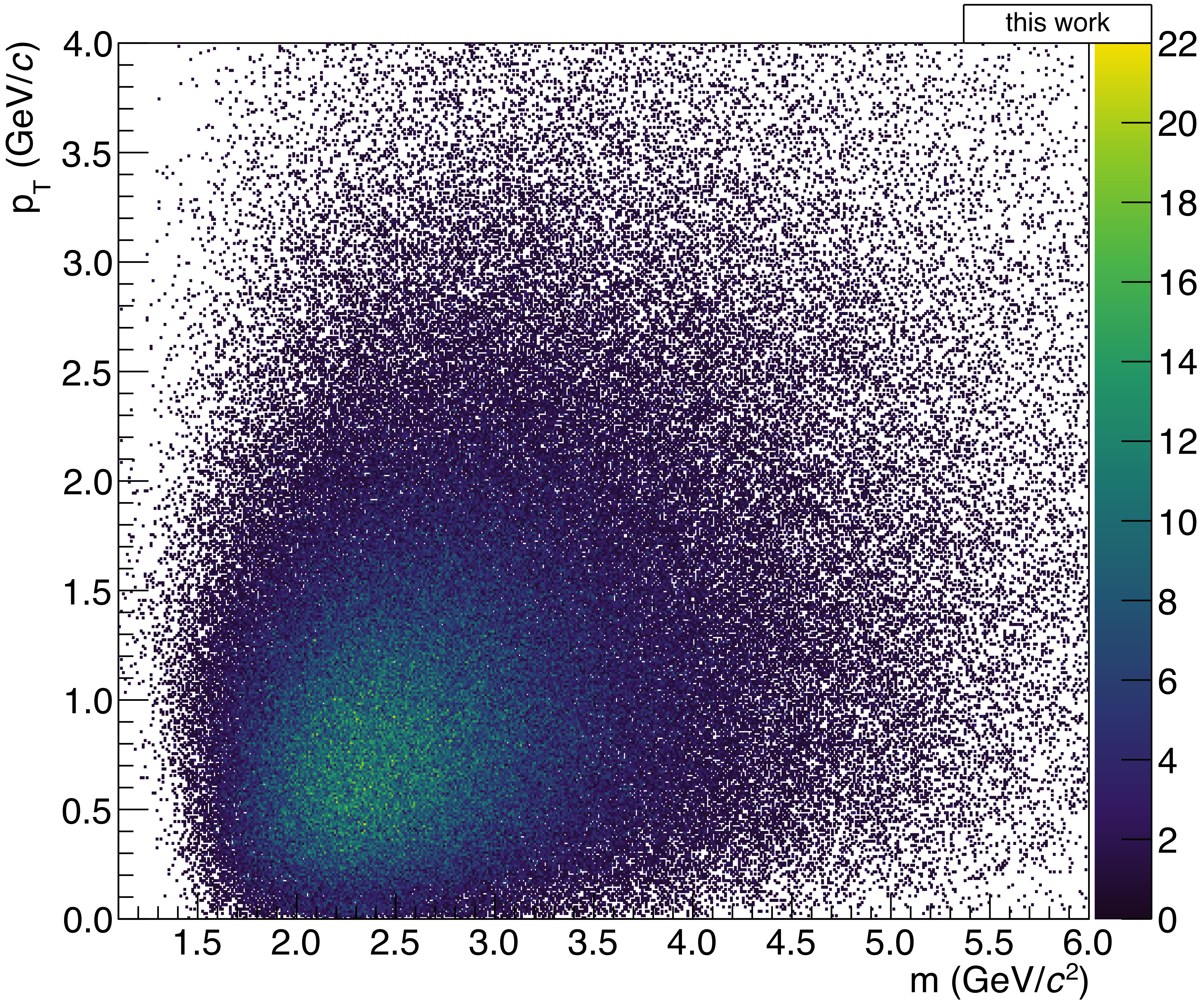
Utilised event selections

track level

- PV contributor requirement
- ITS hit (remove TPC-only tracks)
- DCA < 1 cm from PV in both XY and Z directions
- $|\eta| < 0.9$ (PC directive)
- n-dimensional PID selection within 3 $n\sigma_\pi$

p_T vs m distributions for 4- and 6-pion systems
(Guillermo mentioned these yesterday)



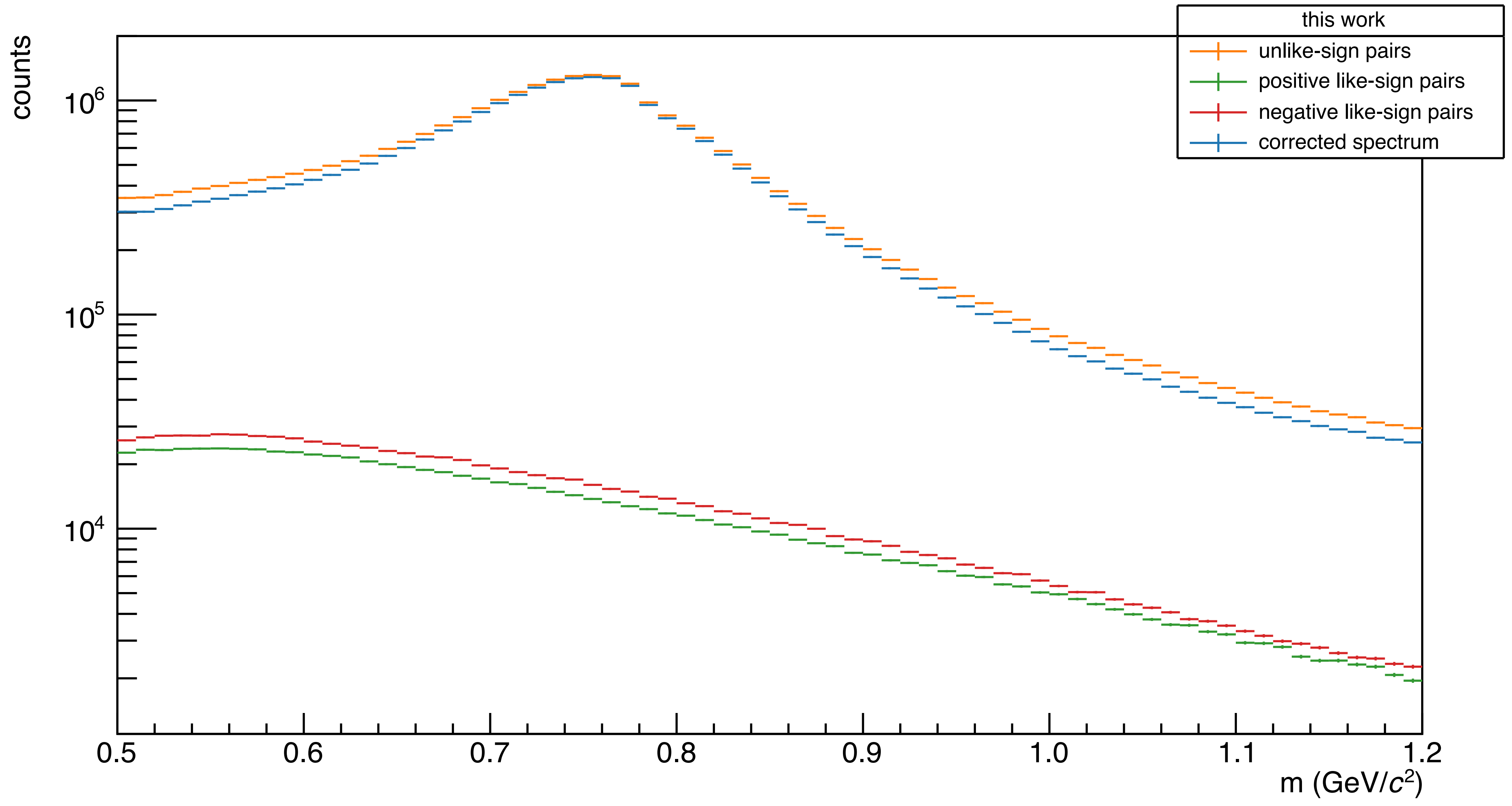


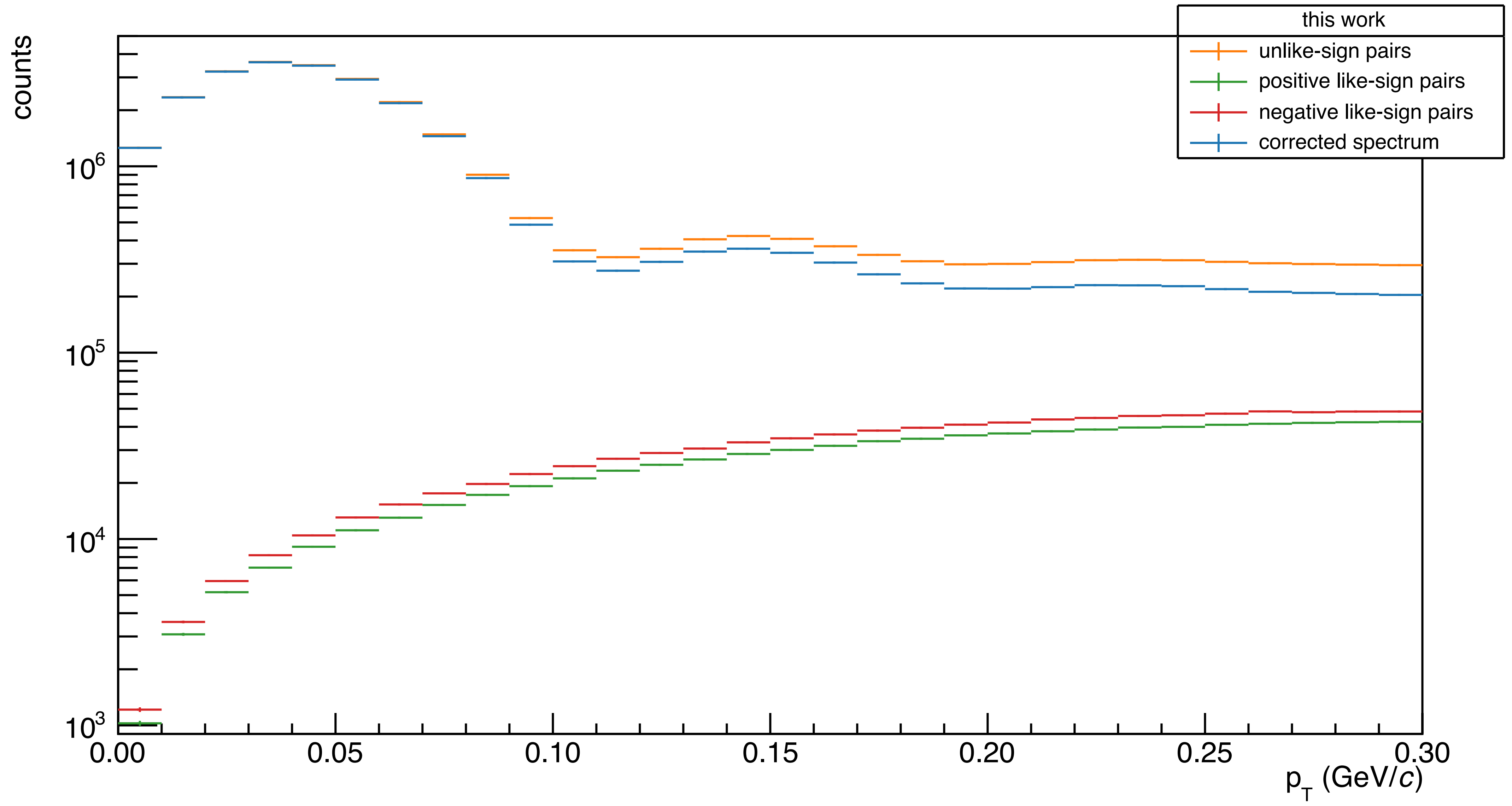
Utilised event selections

pion pair level

- $m \in (0.5, 1.2)$ GeV/c^2
- $p_{\mathrm{T}} < 0.3$ GeV/c
- $|y| < 0.9$

Corrections





- combinatorial background subtraction with $B = 2\sqrt{N_{++}N_{--}}$
- further $A \times E$ corrections necessary, central MC production still unavailable
  - m response assumed as sufficiently flat based on previous work → limited distortion of spectrum shape

Yield extraction

- invariant mass spectra fit using the (extended) Söding model

$$\frac{\mathrm{d}N}{\mathrm{d}m_{\pi\pi}} \propto \left| A_\rho \cdot \frac{\sqrt{m_{\pi\pi} m_\rho \Gamma_\rho}}{m_{\pi\pi}^2 - m_\rho^2 + \mathrm{i} m_\rho \Gamma_\rho} + B_{\pi\pi} + C_\omega \cdot \mathrm{e}^{\mathrm{i}\phi_\omega} \cdot \frac{\sqrt{m_{\pi\pi} m_\omega \Gamma_{\omega\to\pi\pi}}}{m_{\pi\pi}^2 - m_\omega^2 + \mathrm{i} m_\omega \Gamma_\omega} \right|^2 + a \cdot m_{\pi\pi} + b$$

ρ contribution

direct (non-resonant) pion production

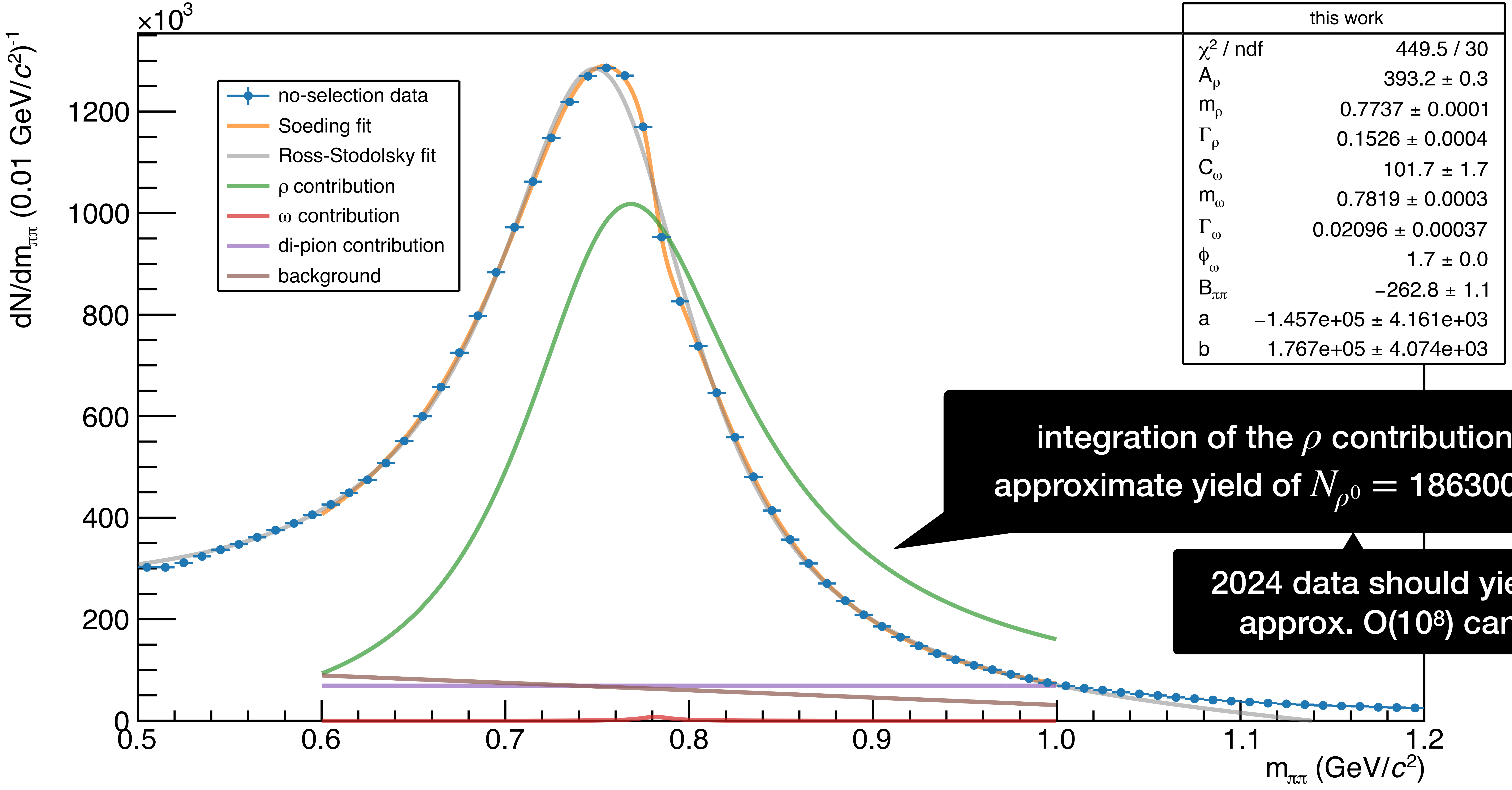
ω contribution

$\omega \to \pi^+\pi^-\pi^0$ & $\omega \to \pi^+\pi^-$

linear background (mostly misidentified $\mu^+\mu^-$)

with $\Gamma_\rho = \Gamma_0 \frac{m_\rho}{m_{\pi\pi}} \left(\frac{m_{\pi\pi}^2 - 4m_\pi^2}{m_\rho^2 - 4m_\pi^2} \right)^{3/2}$ and $\Gamma_{\omega\to\pi\pi} = \mathrm{Br}(\omega \to \pi\pi)\Gamma_0 \frac{M_\omega}{M_{\pi\pi}} \left(\frac{M_{\pi\pi}^2 - 4m_\pi^2}{M_\omega^2 - 4m_\pi^2} \right)^{3/2}$

Yield extraction



integration of the ρ contribution gives an approximate yield of $N_{\rho^0} = 18630000 \pm 30000$

2024 data should yield further approx. O(10^8) candidates

Summary and outlook

- a basic framework to study pile-up effects and perform ρ^0 signal extraction and yield integration in Run 3 heavy-ion data has been set up
    - convenient starting point for further expansions to cover more detailed studies
        - measurement of ρ^0 photoproduction cross section at a new energy, p_{T}- and b-dependence of decay product azimuthal anisotropy, incoherent ρ photoproduction, …

          2025: O—O and p—O data—a completely new collision system
          O(10^4) ρ candidates expected

Backup
Pile-up studies

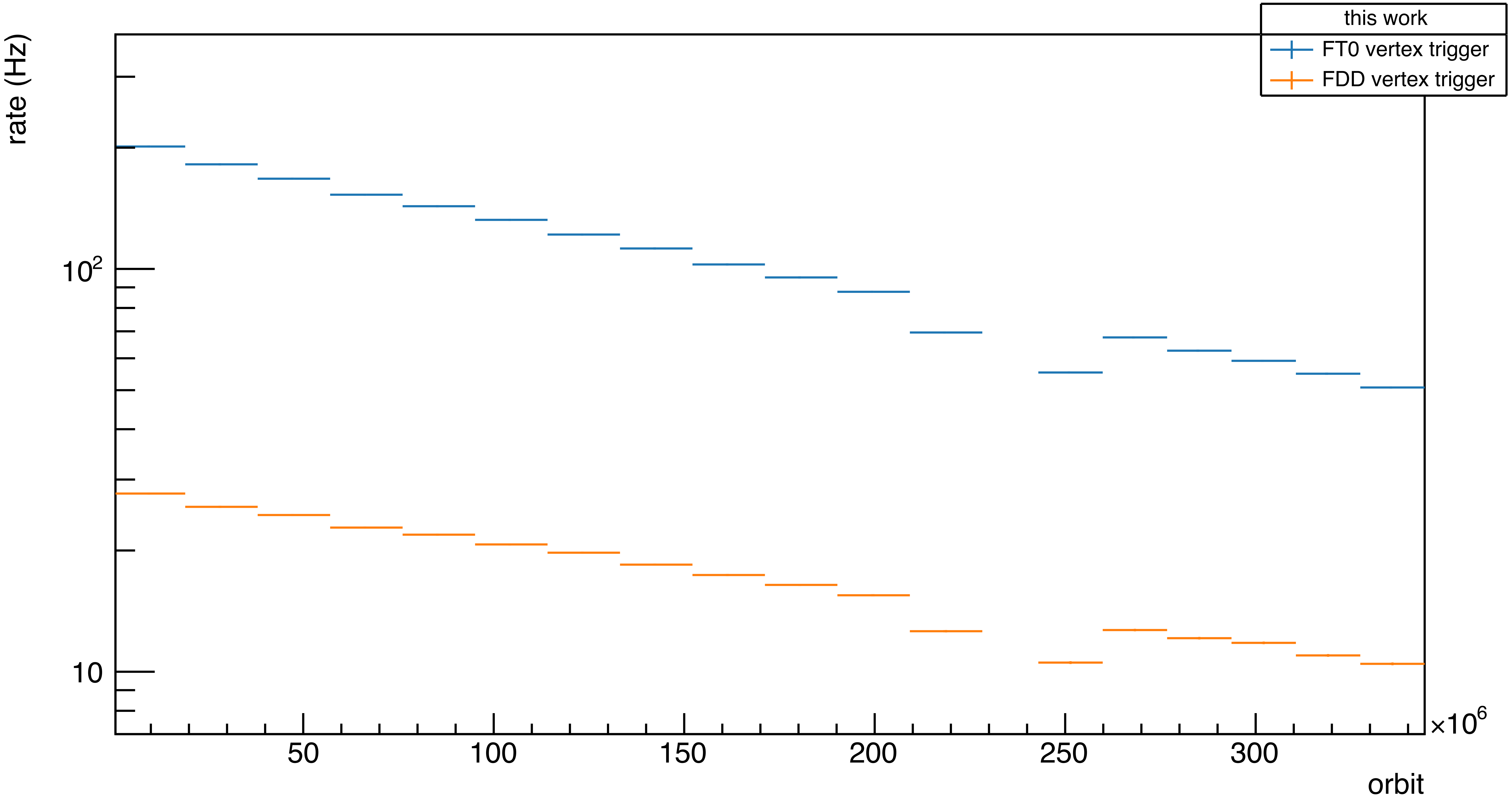
Studied Run

- *LHC22s* *Run 529418* Pb—Pb at 5.36 TeV
  - filling scheme *50ns_24b_8_24_5_8bpi_10inj_PbPbtrains*
  - 18 interacting (B) bunches (360, 795, 1248, 1250, 1252, 1254, 1256, 1258, 1260, 1262, 2139, 2141, 2143, 2145, 2147, 2149, 2151, 2153)
  - 0 A bunches & 1 C bunch (3041)
- apass4 data, no specific production, approx. 400 GB, all tests run locally
- why this run? available at the time, large amount of data

Some analysis details

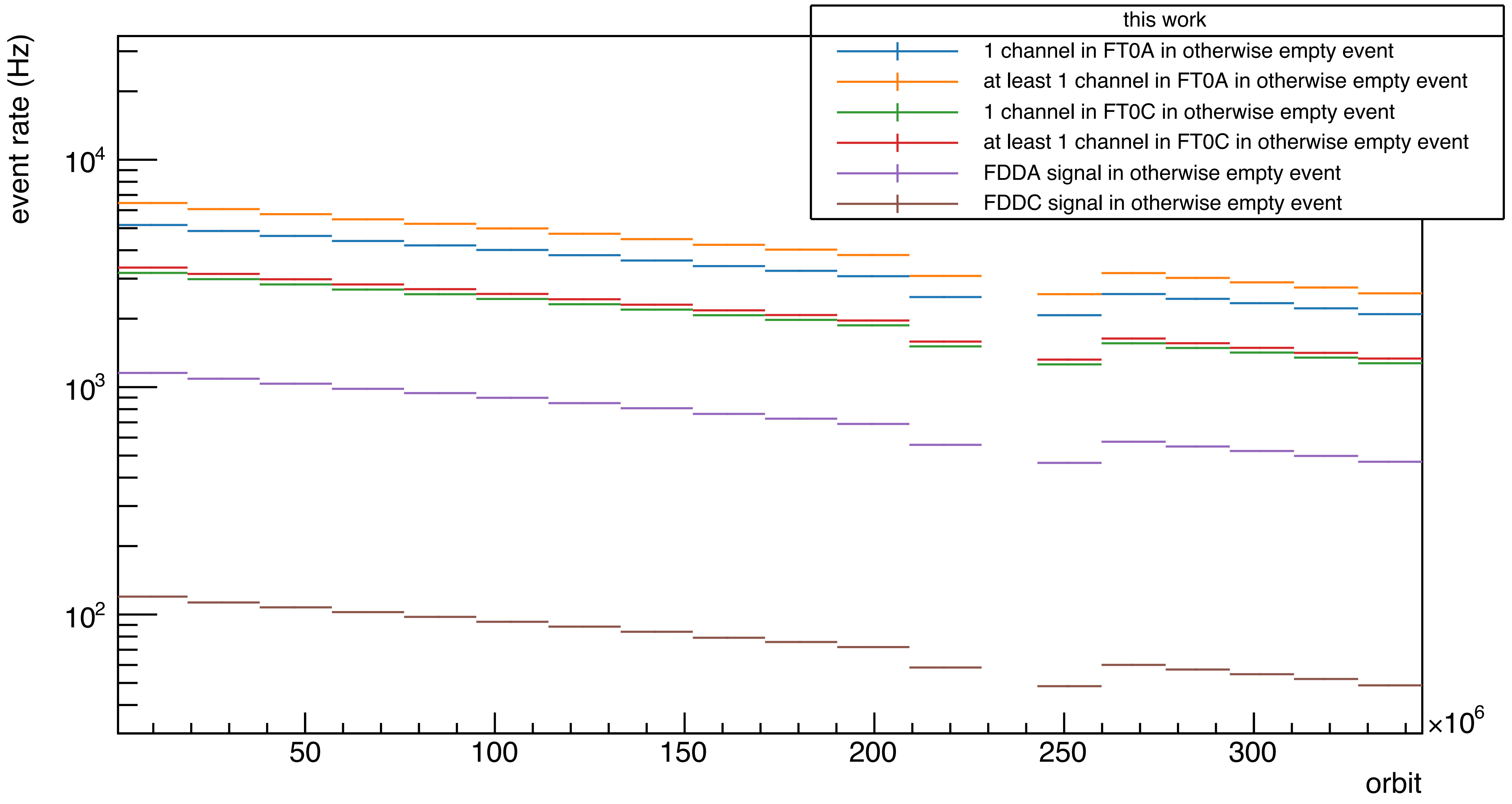
- FT0 and FDD trigger rates obtained from their respective trigger masks (checking o2::fit::Triggers::bitVertex)
- global BC IDs used for grouping, recalculated into local BC IDs and orbits
    - local BC ID used to select only B bunches
    - orbits used as a unit of time (1 orbit = 88.9246 μs)
    - the run encompassed approx. 350 million orbits, i.e. took about 8.5 hours

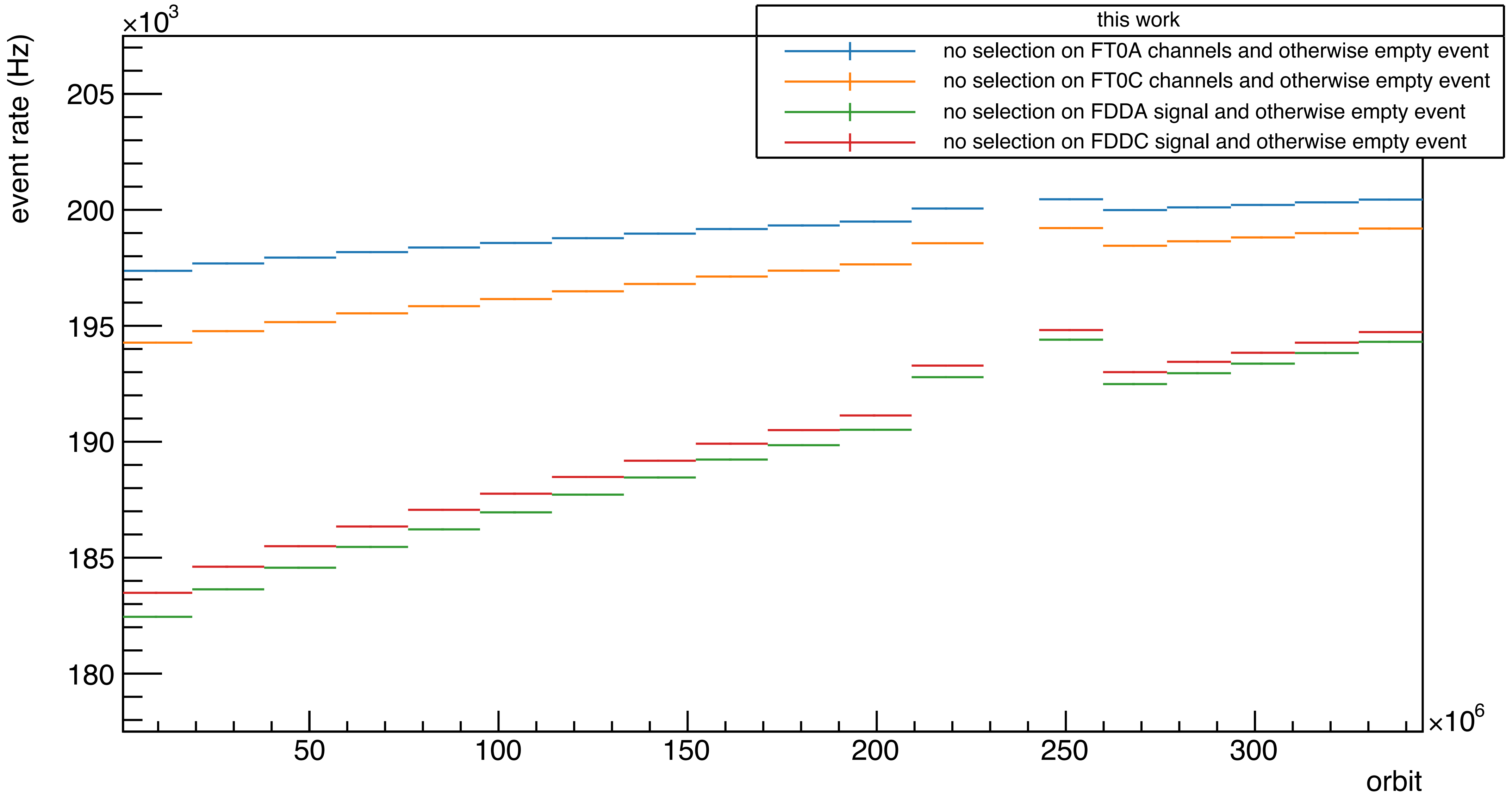
FT0 & FDD vertex trigger rates



Numerators and denominators

P = N/D





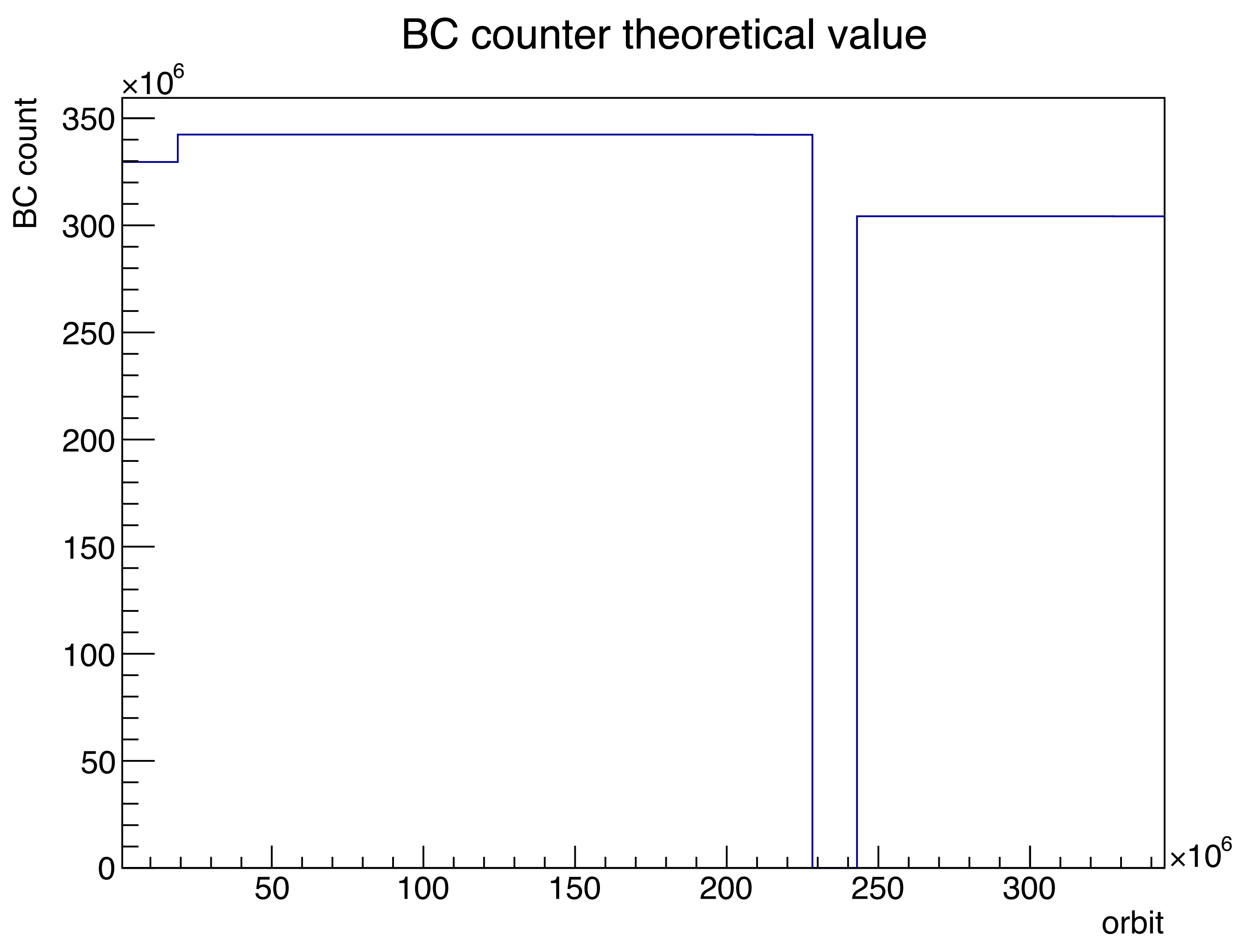
Pile-up probabilities

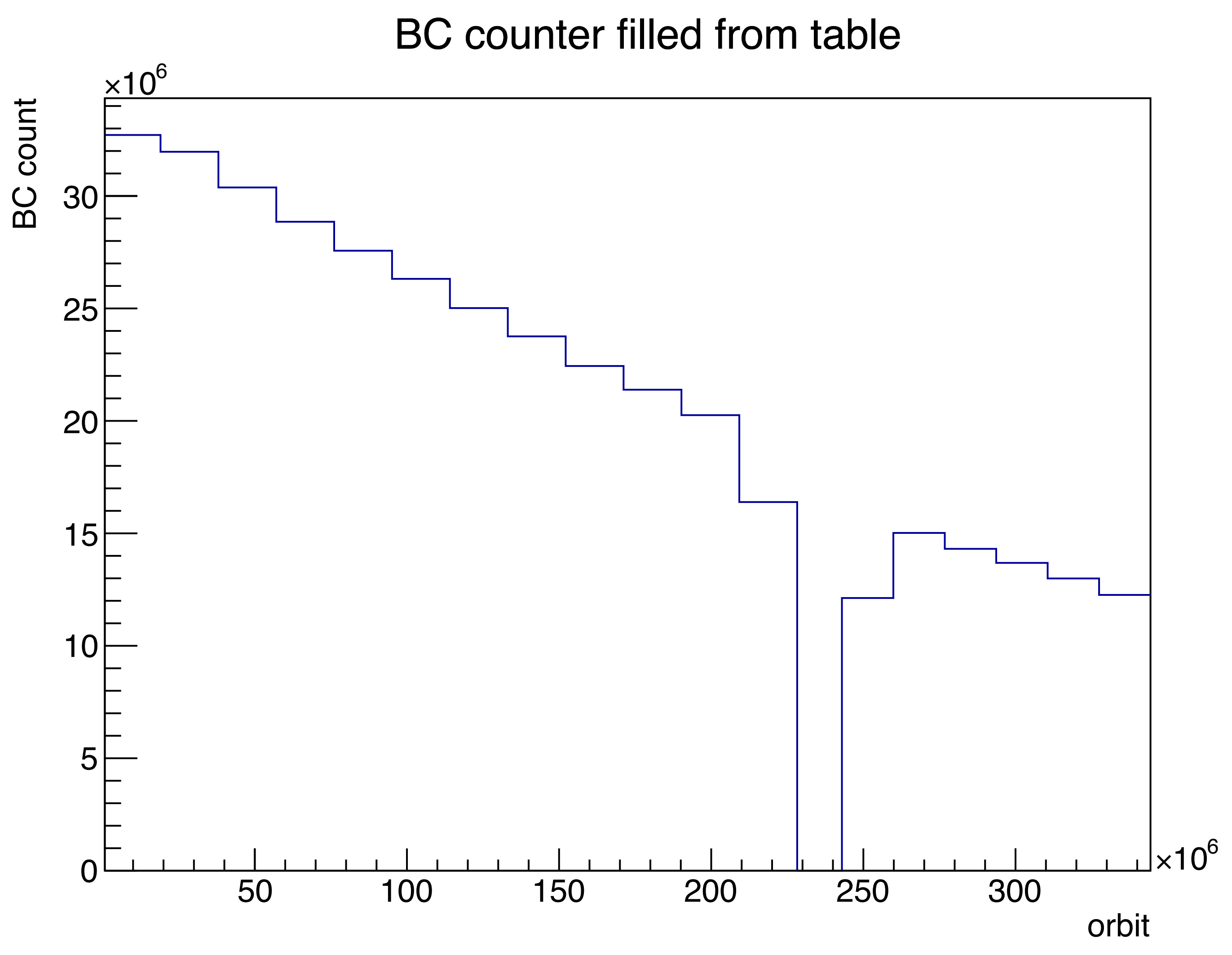
P = N/D

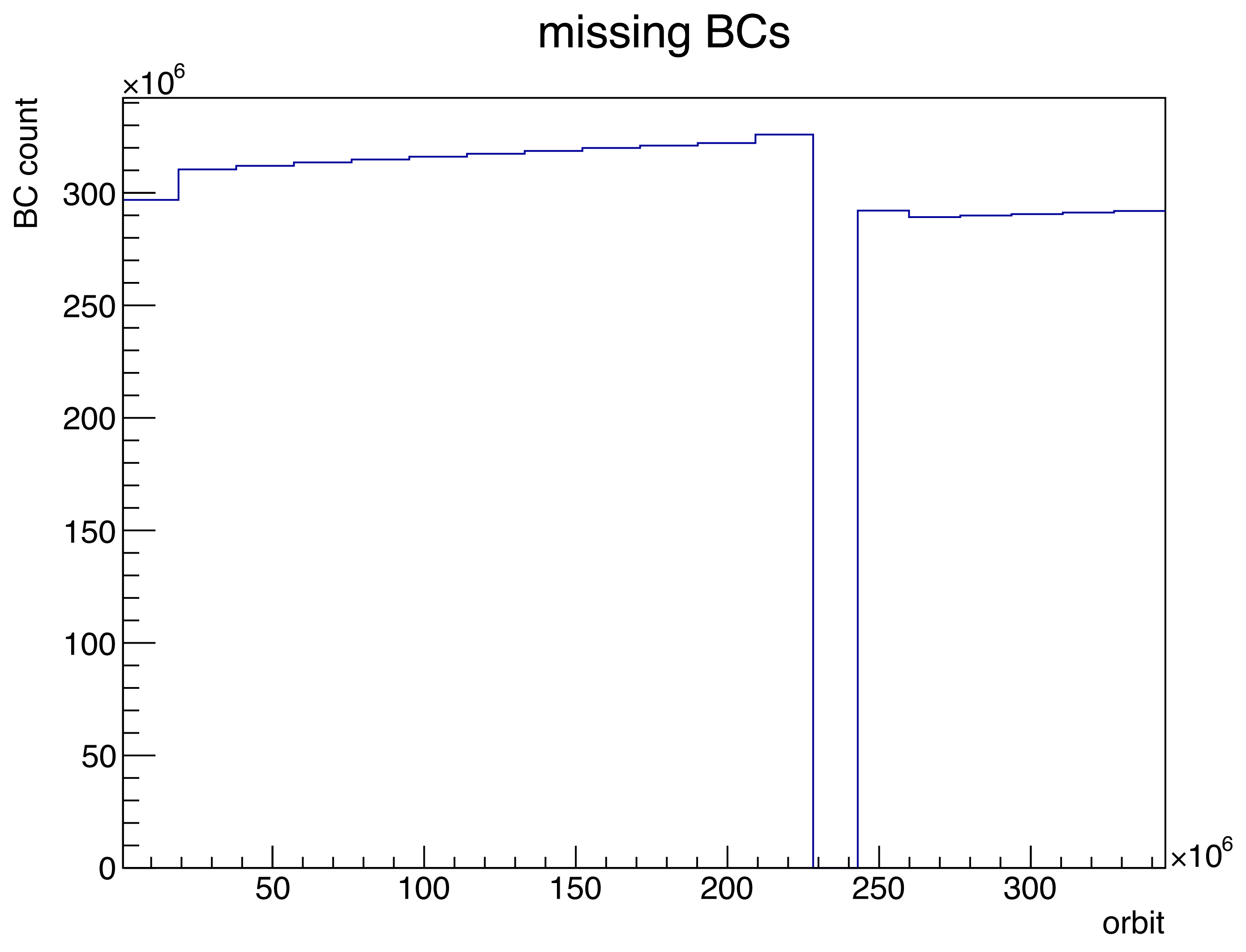
- the numerator is simple to find, but with the denominator one must be more careful
    - if a BC truly has no signal it is not saved in the data, these “missing” BCs need to be accounted for

Missing BCs

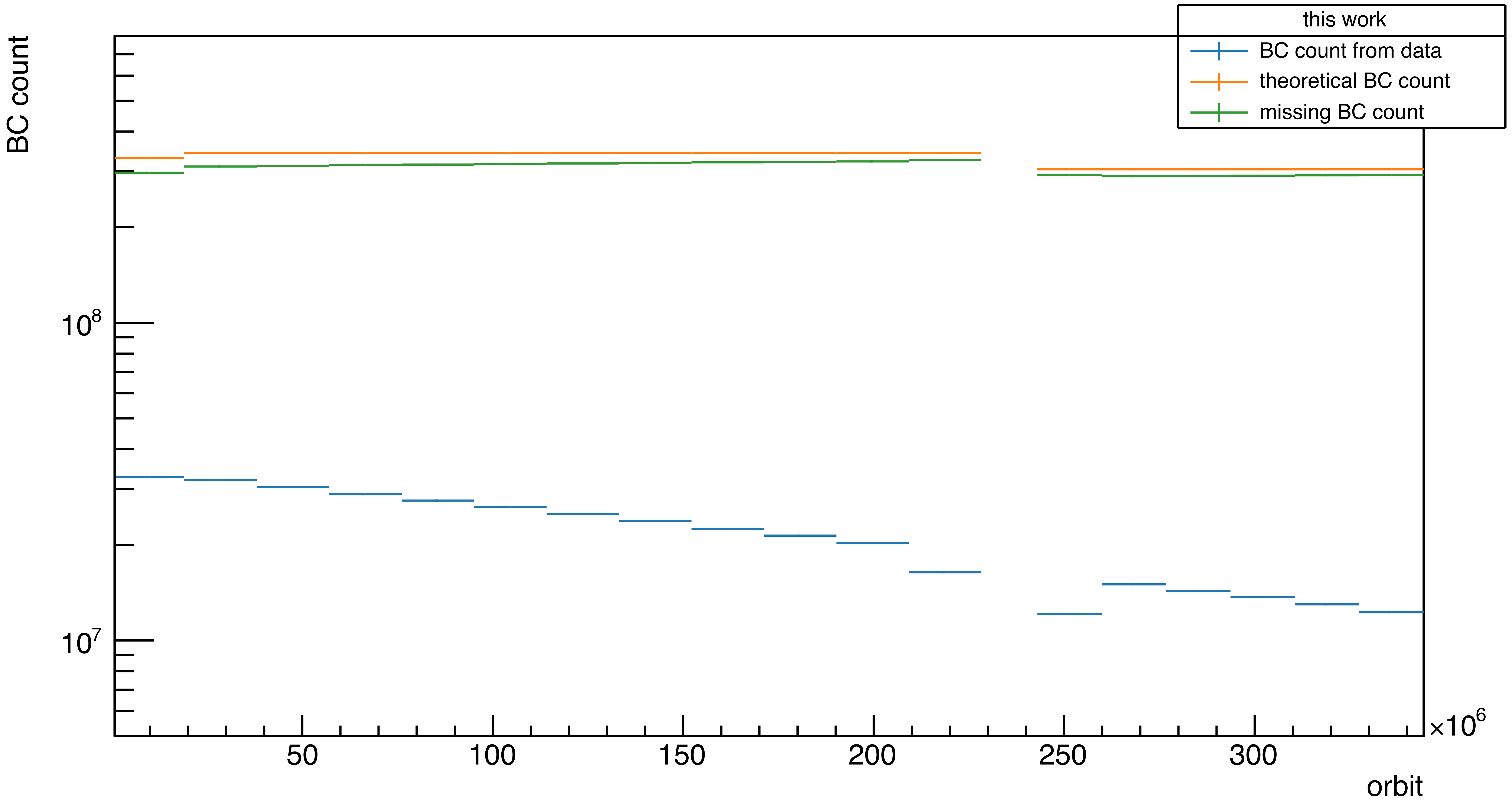
- the theoretical number of BCs within a selected orbit range is easy to calculate if the number of interacting bunches is known, the ones actually present in data can be counted easily
  - the missing ones need to be added to those found by checking BCs for “FT0Cchannels == 0 && !FDDA && !FDDC” (or similar)







Missing BCs

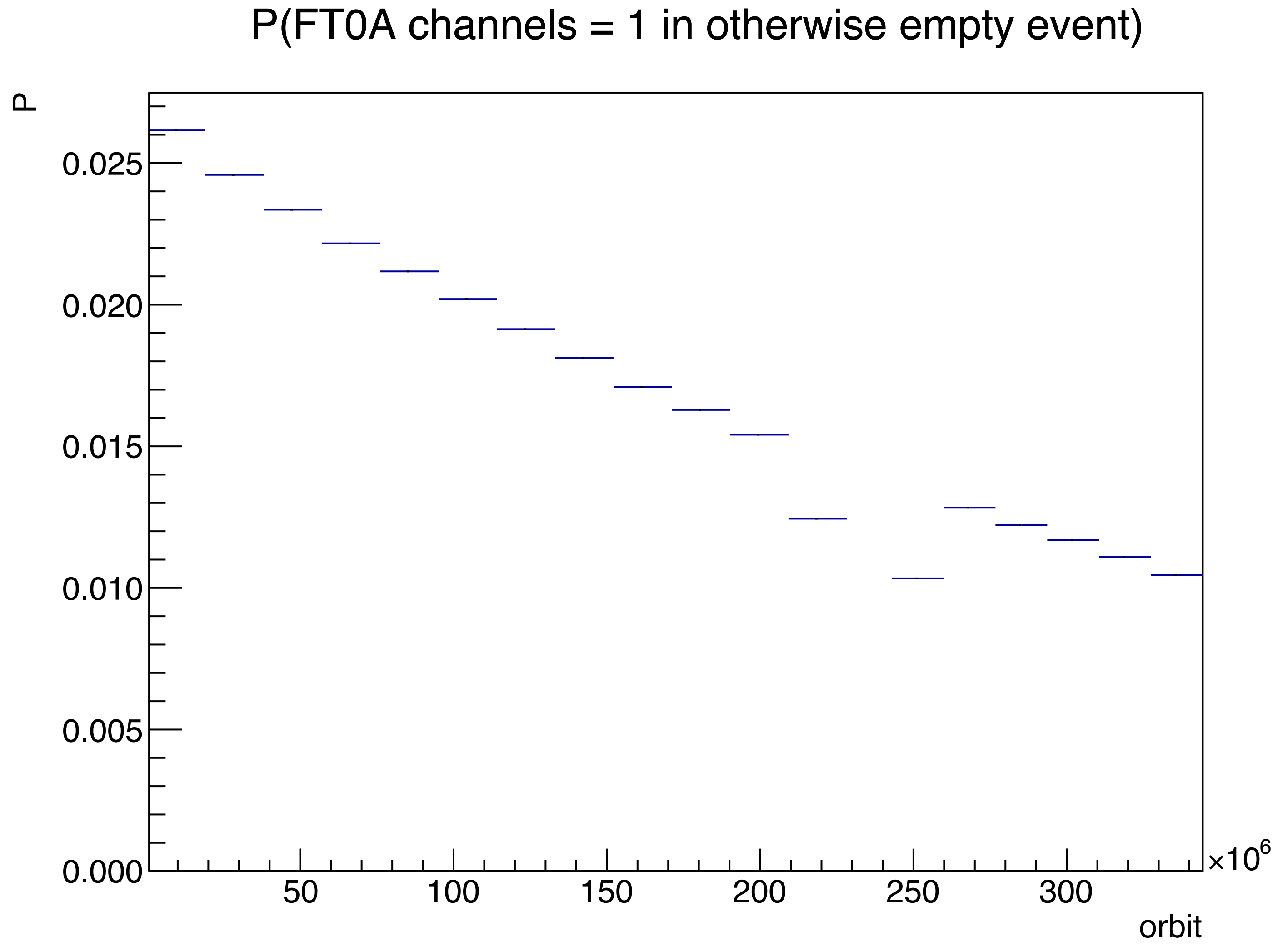


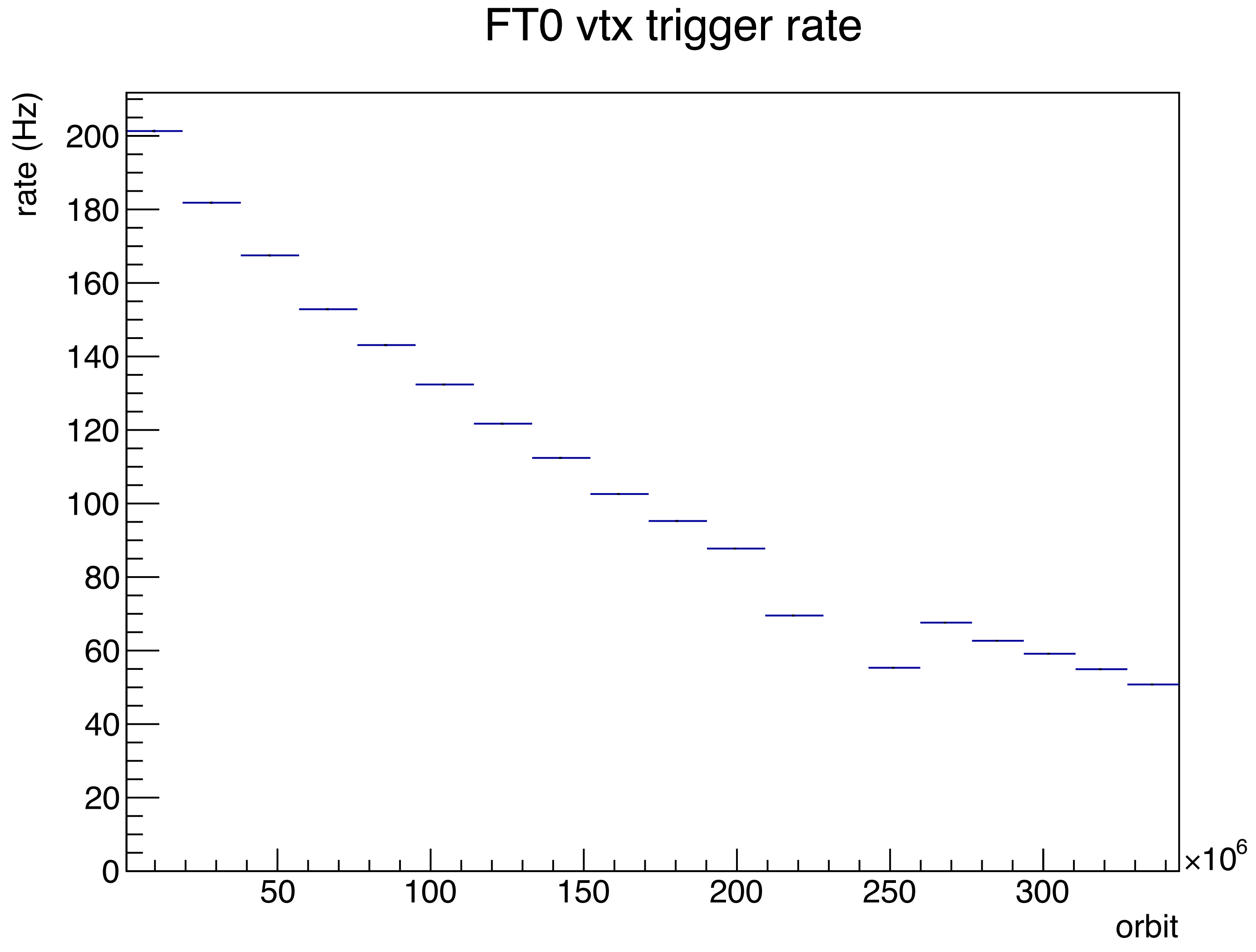
BC count
this work
BC count from data
theoretical BC count
missing BC count
10^8
10^7
50
100
150
200
250
300
×10^6
orbit

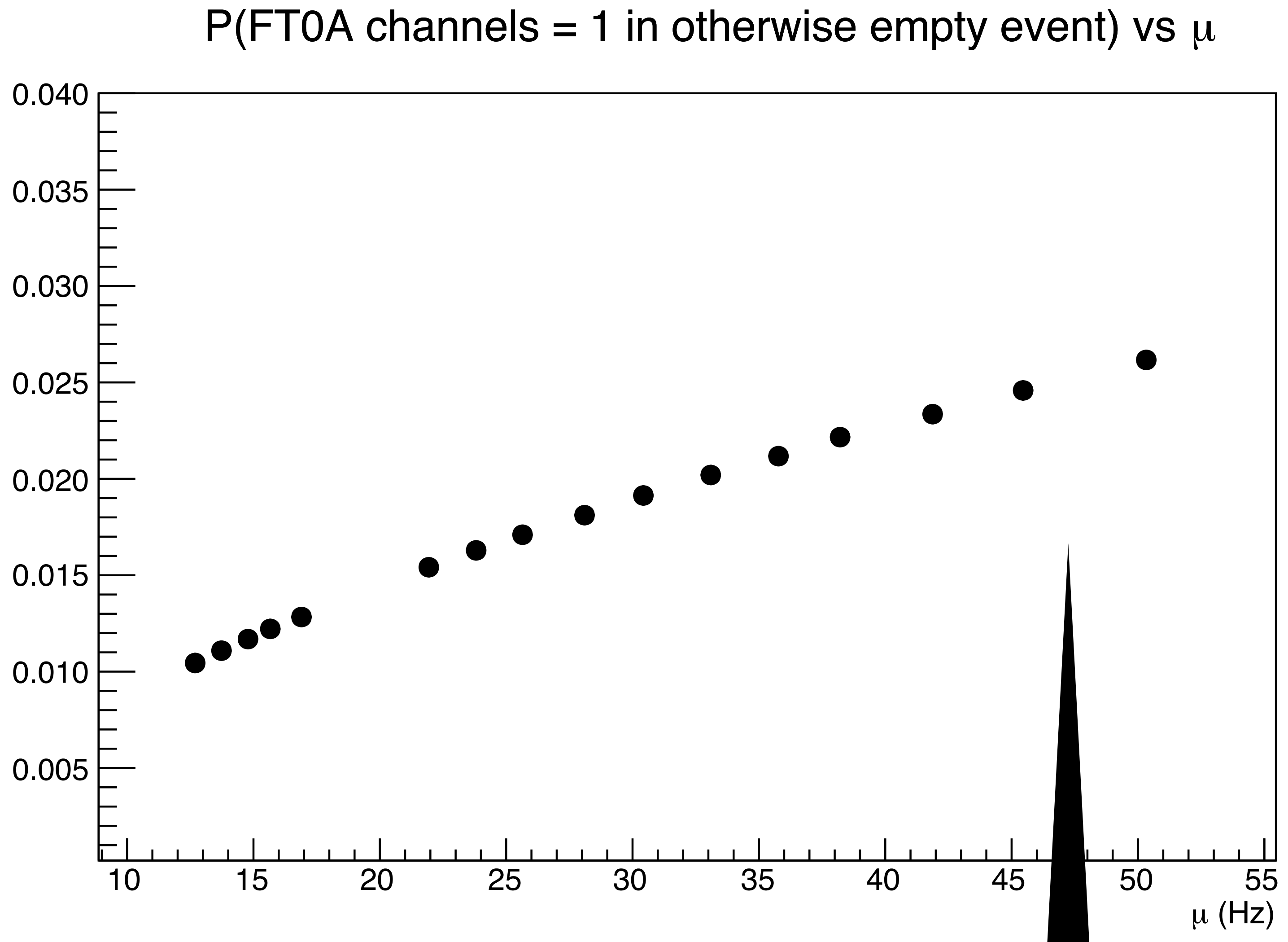
P depending on the interaction rate

- one typically wants to look at the probabilities as a function of the interaction rate, rather than time; this can be obtained by relating values corresponding to the same time range

1/4*FT0vtx rate used as an estimation of the hadronic interaction rate



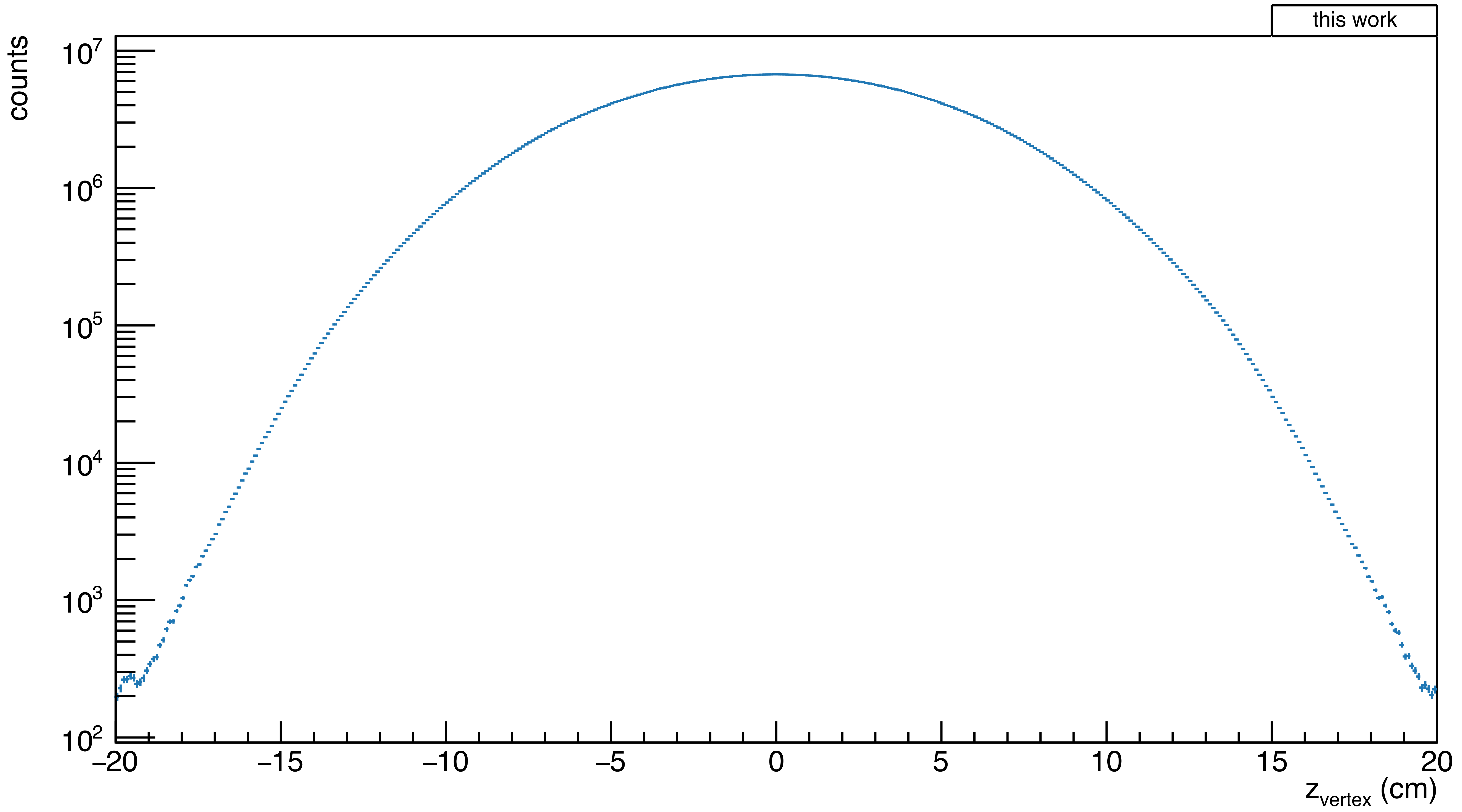




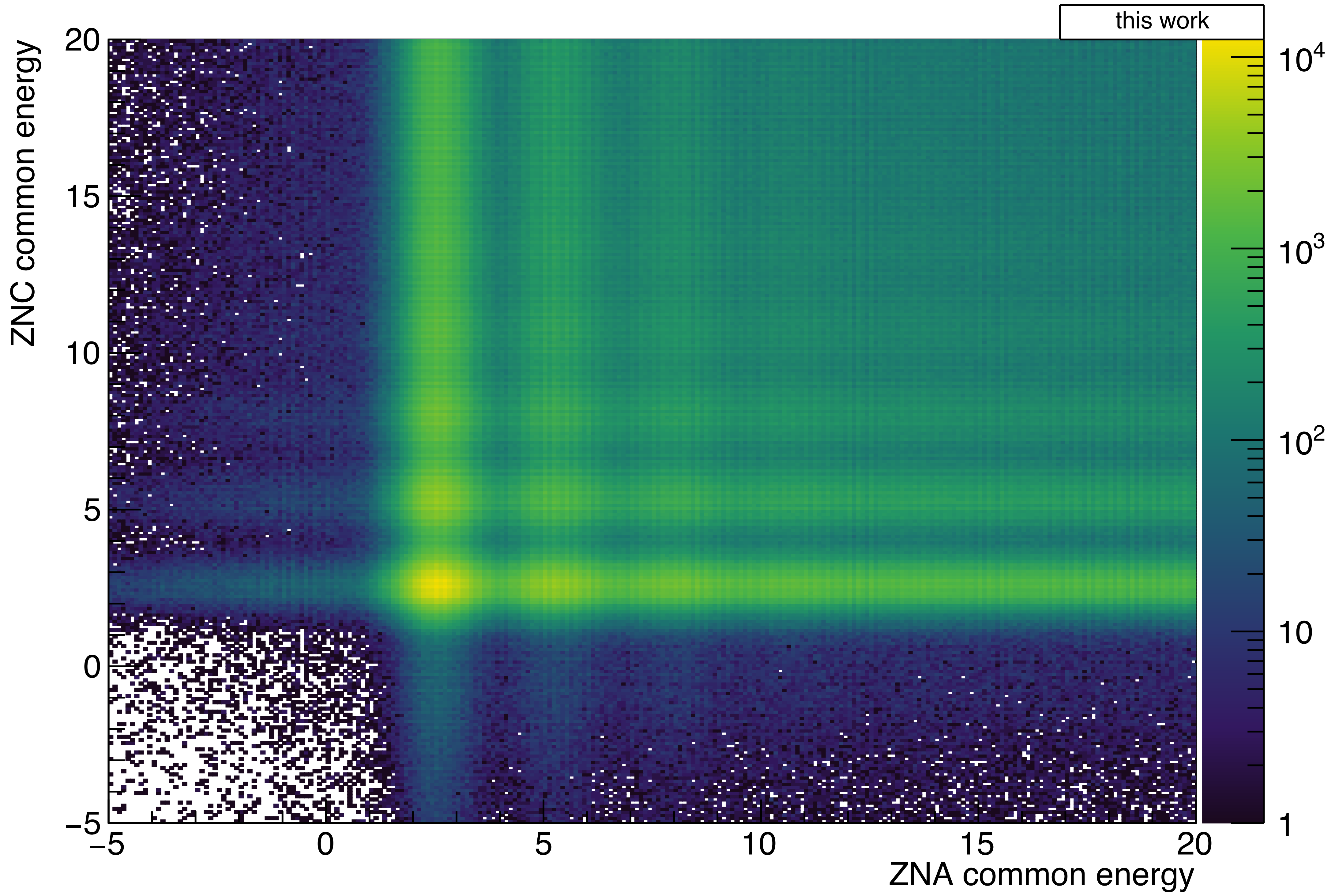
behaviour not linear (unexpected)

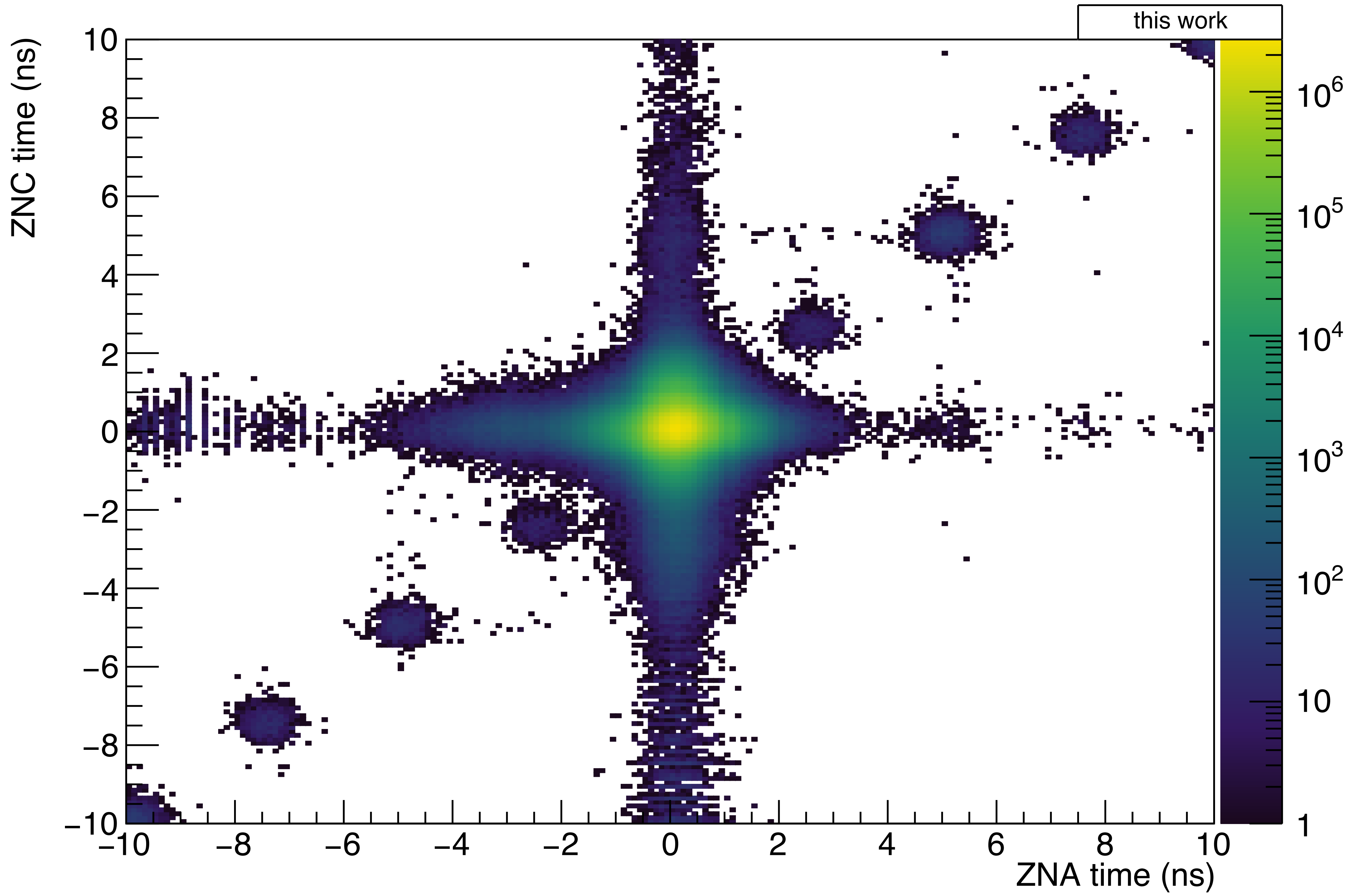
Backup
ρ signal extraction

Vertex Z position distribution

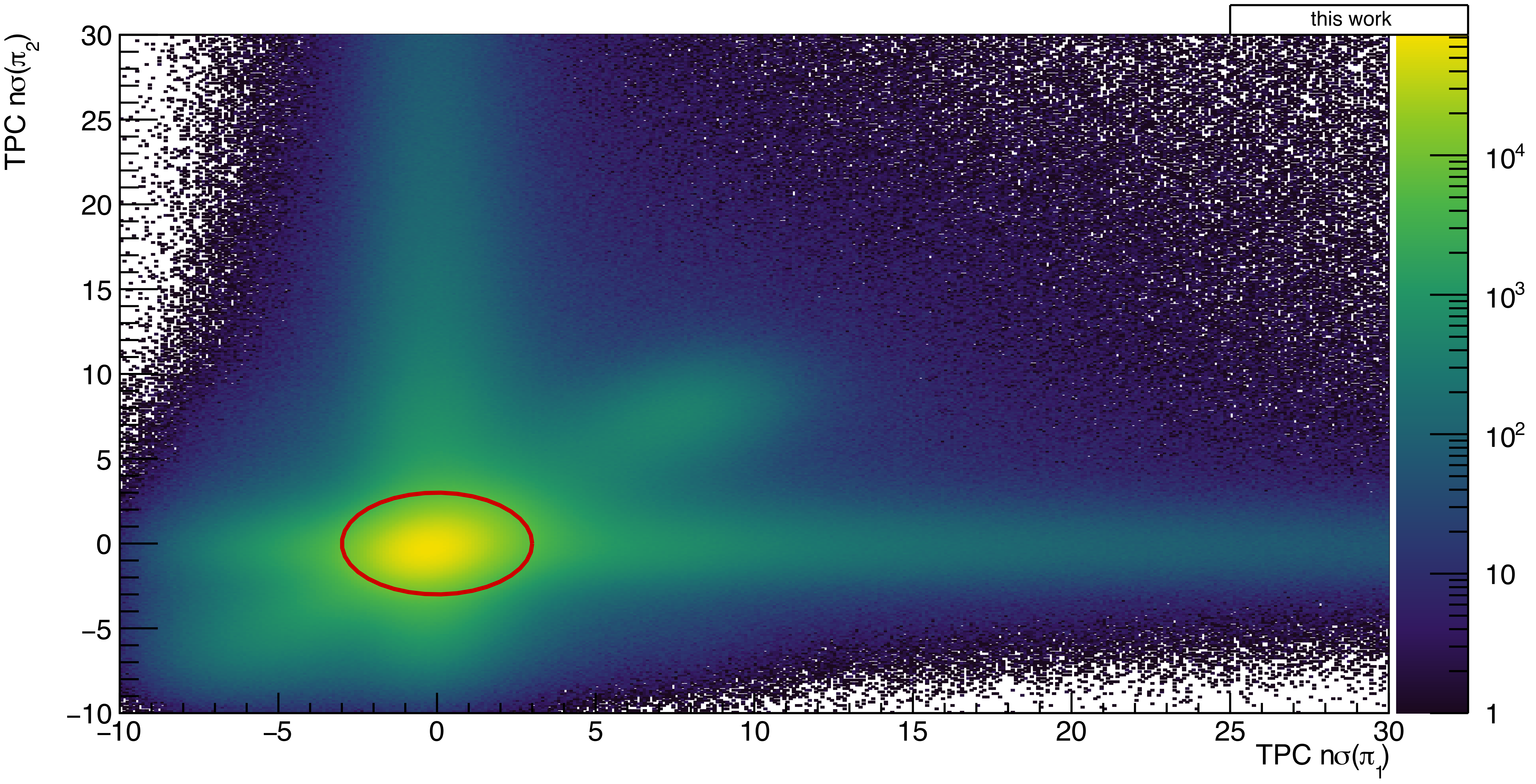


ZN signals


this work
ZNC common energy
ZNA common energy
20
15
10
5
0
−5
−5
0
5
10
15
20
10^4
10^3
10^2
10
1


this work
ZNC time (ns)
ZNA time (ns)
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−8
−6
−4
−2
0
2
4
6
8
10
10^6
10^5
10^4
10^3
10^2
10
1

2D TPC PID



this work
TPC nσ(π2)
TPC nσ(π1)
30
25
20
15
10
5
0
−5
−10
−10 −5 0 5 10 15 20 25 30
10^4
10^3
10^2
10
1

Mass distribution fits

differentiated neutron classes