OAK RIDGE National Laboratory

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Rates at the LFHCal

Aiden Wu

ORNL (NGSI), Farragut High School

U.S. DEPARTMENT of ENERGY

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Overview

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Primary Data Source

April full background simulation data: NC, DIS, 10x275 GeV, $Q^2 > 1$ GeV^2:

- epic:/FULL/26.04.1/epic_craterlake/Bkg_Exact1S_2us/GoldCt/10um/DIS/NC/10x275/minQ2=1/pythia8NCDIS_10x275_minQ2=1_beamEffects_xAngle=-0.025_hiDiv_1.0000.edm4hep.root

Used the first 500 files, approximately 19k events.

GeneratorStatus mapping

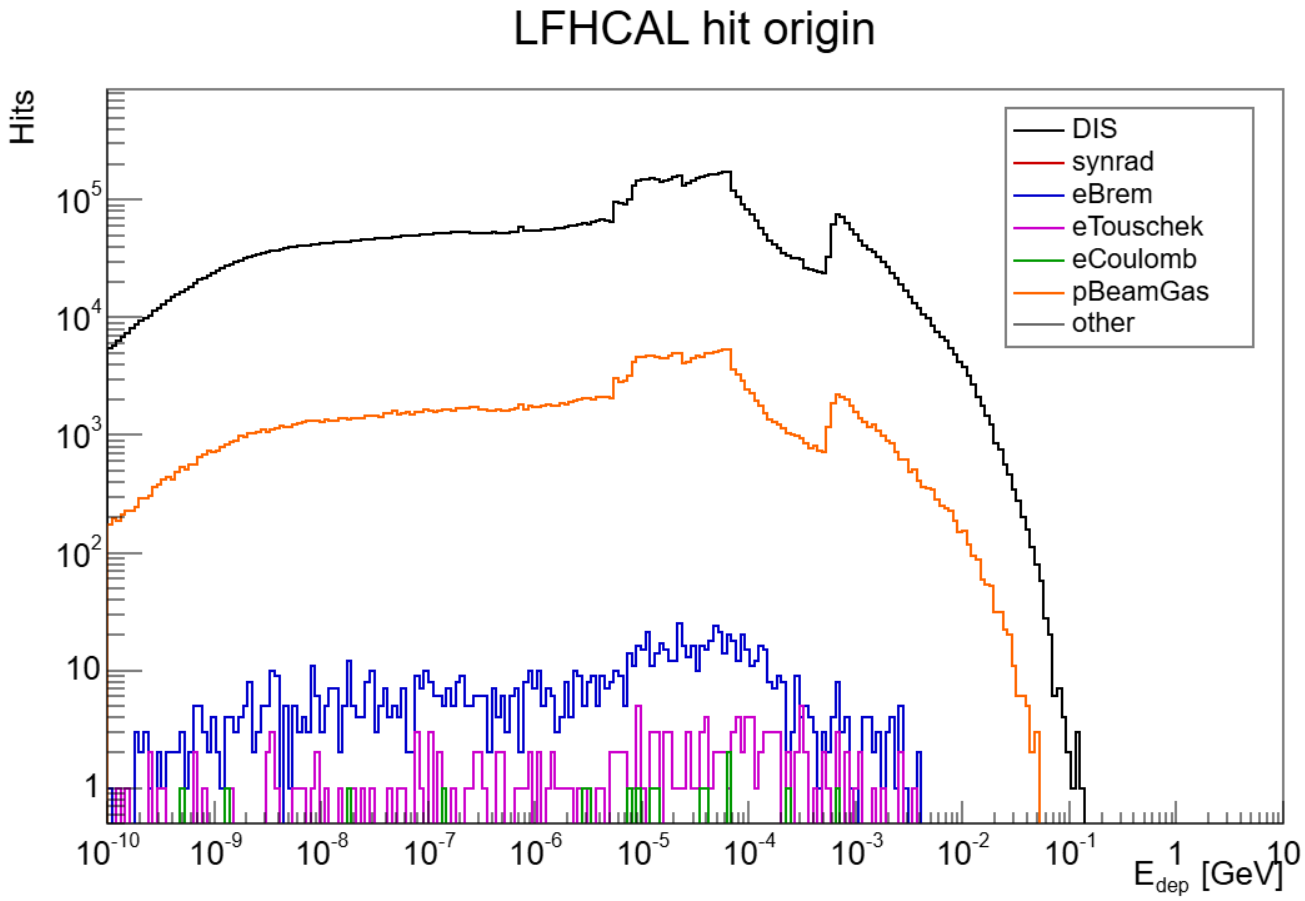
Symbol	Process	Description	Status Code Shift
	signal	DIS NC 18x275 $Q^2>1$ (Deep inelastic scattering neutral current)	0
	synrad	Synchrotron Radiation	2000
	ebrems	Electron bremsstrahlung radiation	3000
	etouschek	Electron Touschek scattering (intrabeam scattering)	4000
	ecoulomb	Electron Coulomb scattering processes	5000
	p.b.gas	Proton beam gas interactions	6000

Background composition at the LFHCal

Sum all hit contributions from the same GeneratorStatus family per hit.

DIS will drive all rate numbers.

The rest are nonexistent/negligible.



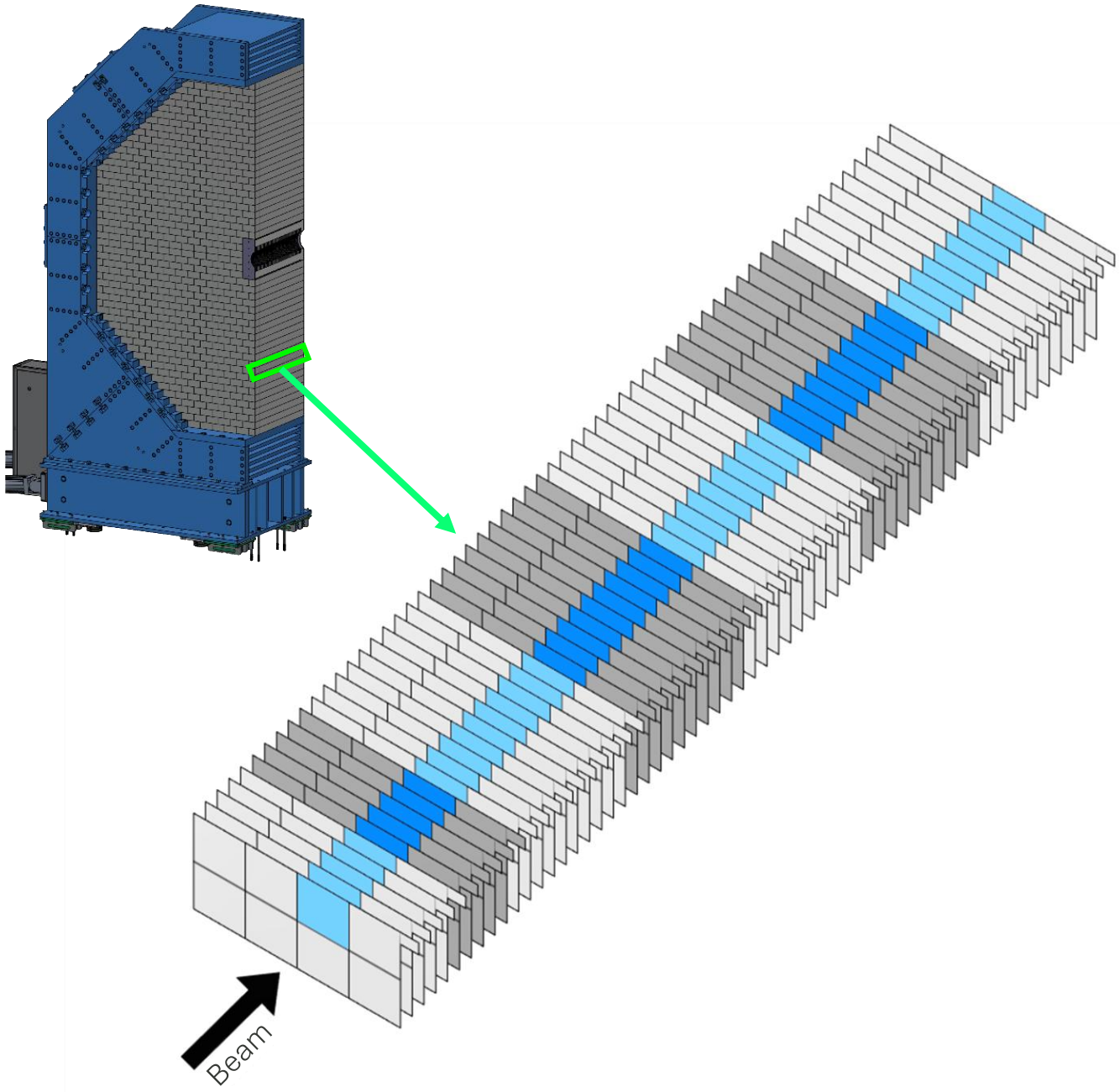
LFHCal readout

The LFHCal has ~1200 modules:

- 8M modules (shown on the right)
- 4M modules

Inside an 8M module:

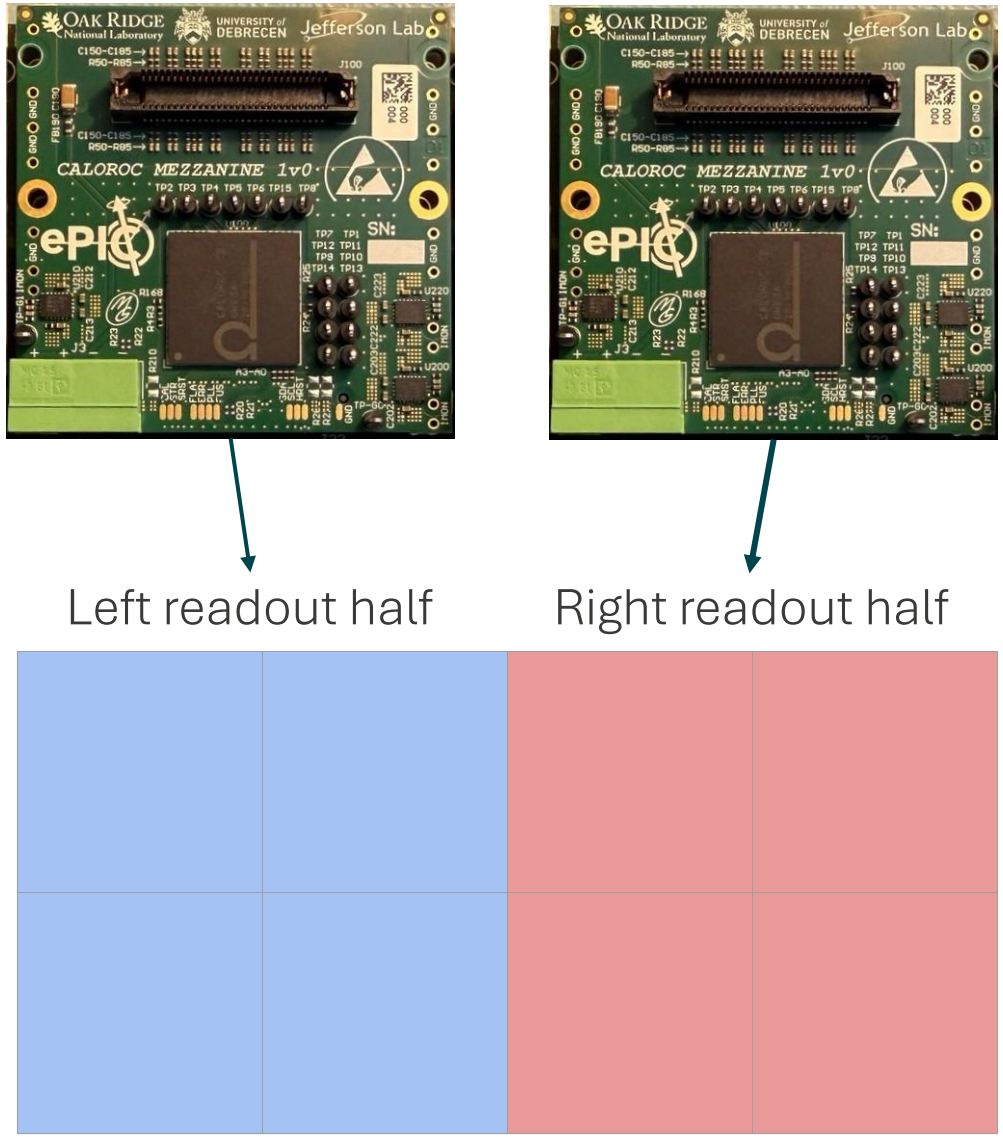
- 8 towers
- 7 longitudinal readout segments
- 56 total readout channels
- 2 CALOROC chips



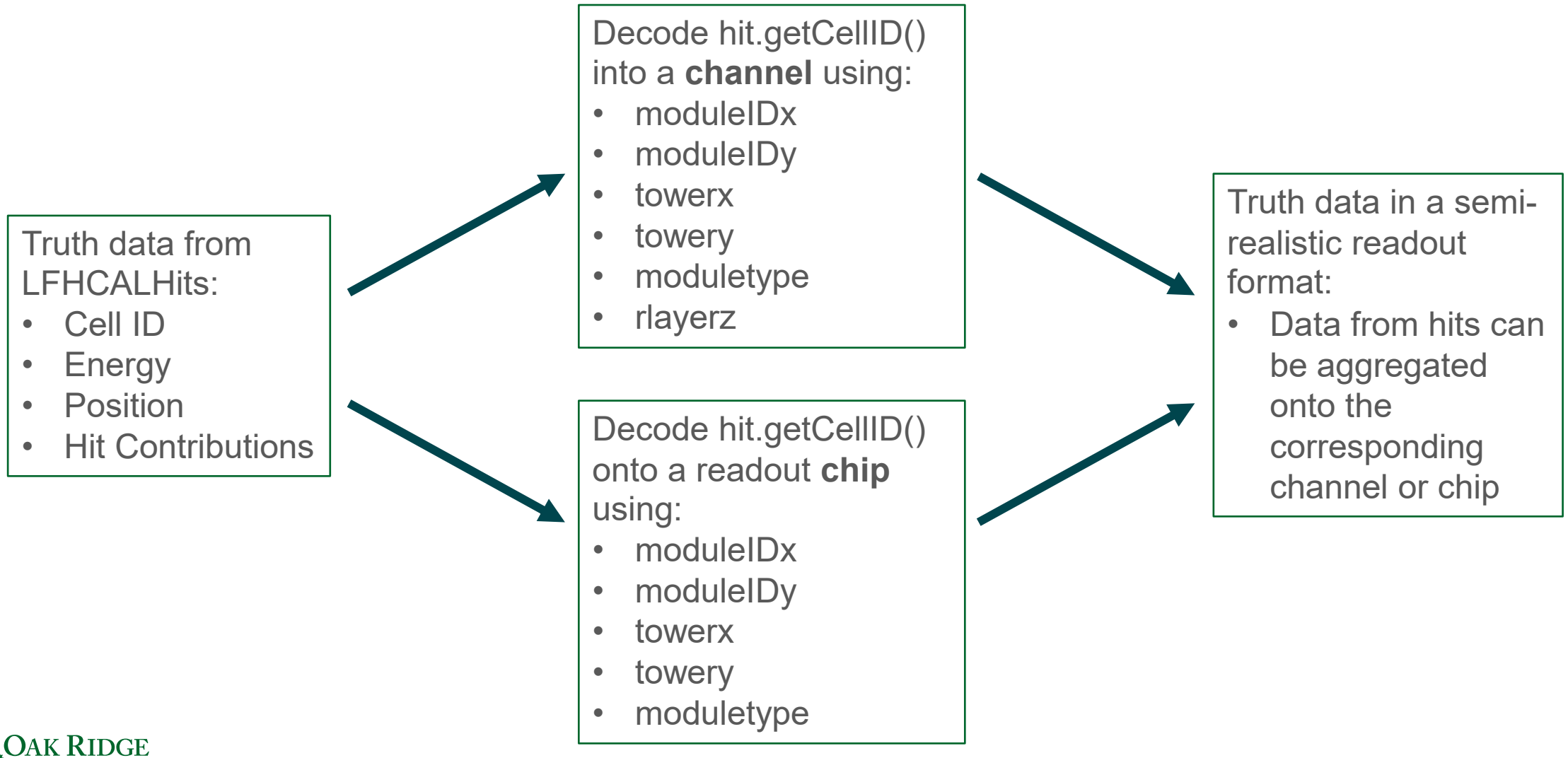
Readout chips

CALOROC readout chips:

- 36 channels max
- 28 used in practice
- Module mapping:
  - 1 chip = 28 channels = 4M module
  - 2 chips = 56 channels = 8M module
- Readout bandwidth per chip
  - 2 output links × 1.28 Gb/s = 2.56 Gb/s



Conversion from simulation data



Threshold definition

Thresholds are enforced per-channel.

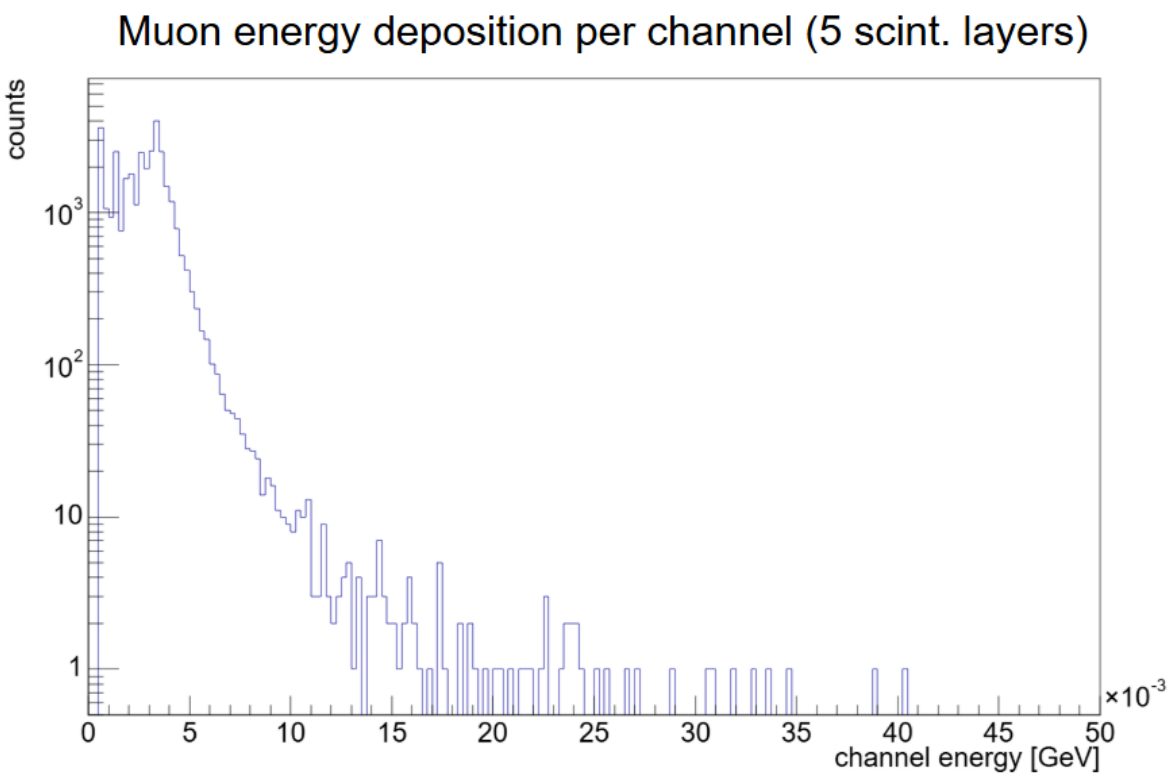
MIP-based threshold with a simple ddsim particle gun:

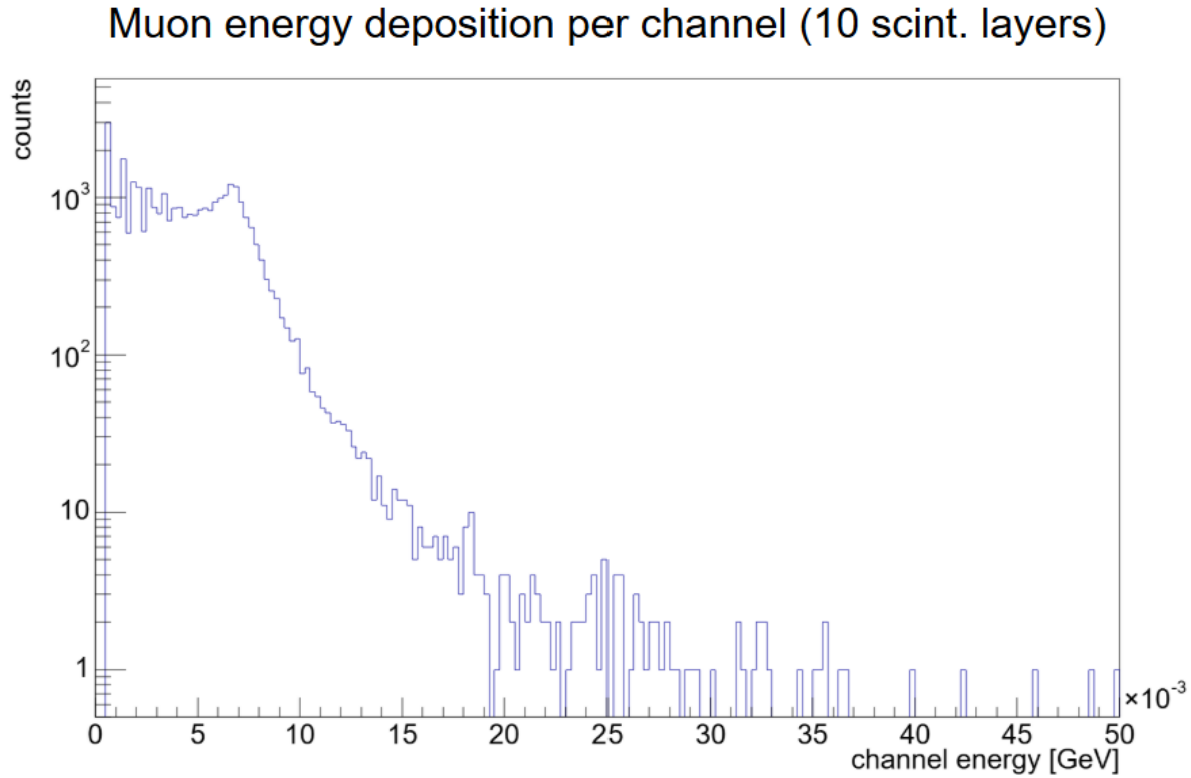
- 10 GeV muons
- Sprayed into the LFHCal from (0,0,0)
- 100k events
- Histogram per-channel energy deposition and extract peaks

MIP energy deposits

Readout channels with five scintillator layers peak around 3.5 MeV,

Readout channels with ten scintillator layers peak around 7.0 MeV.





MIP-based channel thresholds

For channels with 5 scintillator layers: MIP = 3.5 MeV

For channels with 10 scintillator layers: MIP = 7.0 MeV

Energy thresholds per channel will be expressed as some multiple of the corresponding MIP value.

- 0.1 MIP, 0.2 MIP, 0.3 MIP, etc..

Plots use 0.5 MIP as the threshold unless otherwise specified.

Rate definitions

For a channel

A channel is counted as fired when its summed hit energy in an event exceeds its MIP-based threshold.

Rate:

$$\frac{\text{Channel fire count}}{\text{Total events} \times 2 \text{ microseconds}}$$

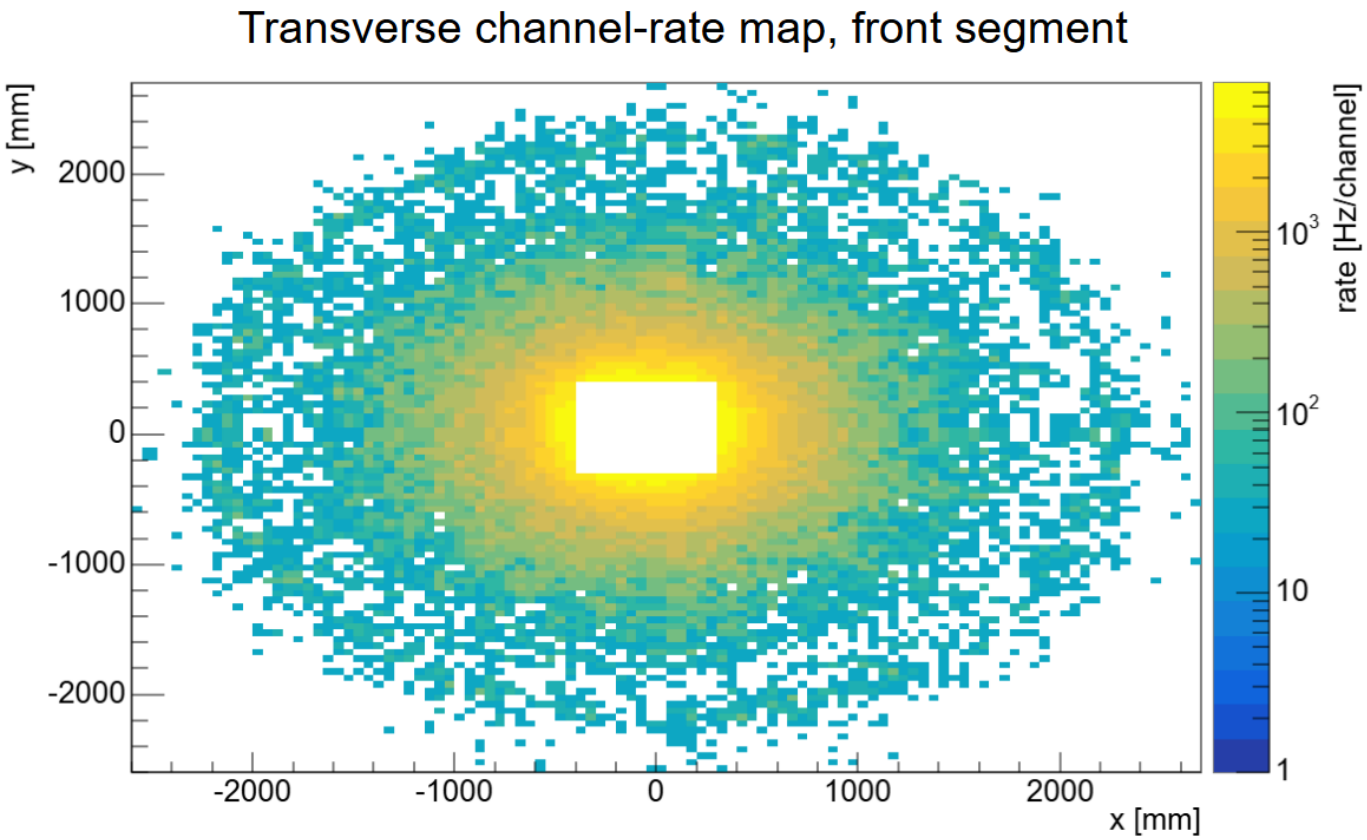
For a readout chip

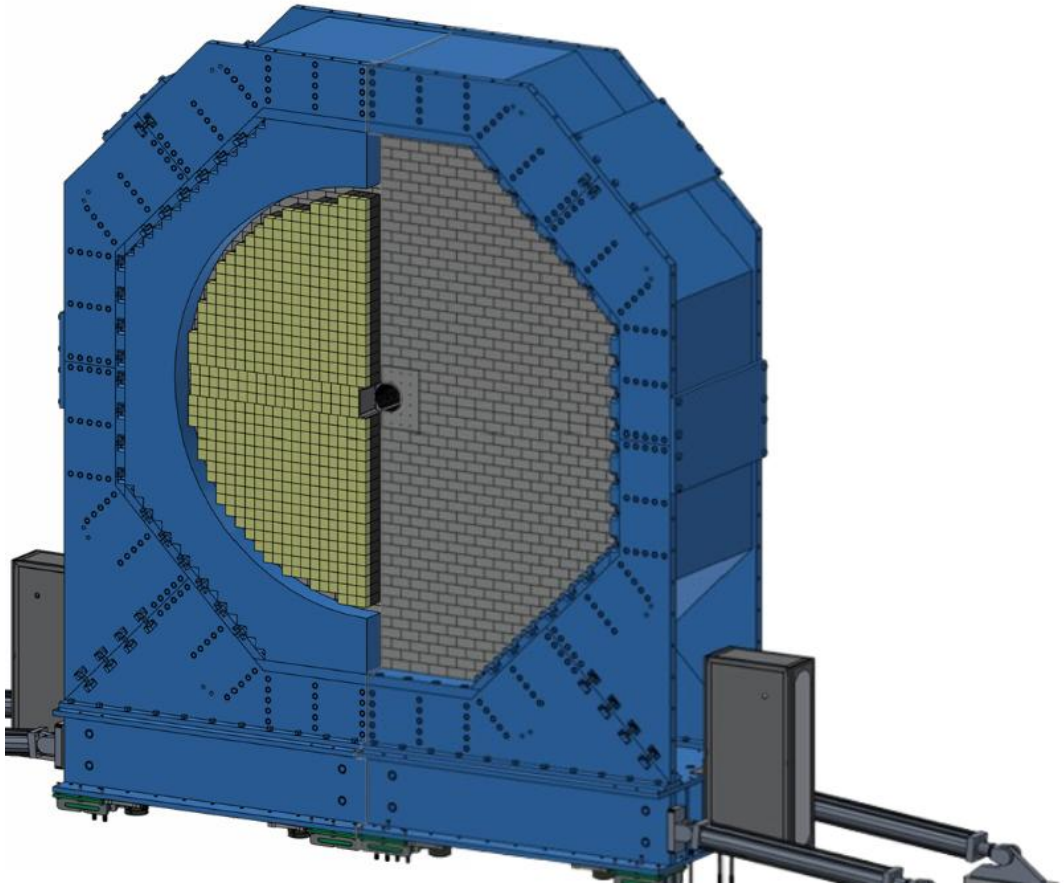
A chip is counted as fired when any channel on that chip fires in that event.

Rate:

$$\frac{\text{Chip fire count}}{\text{Total events} \times 2 \text{ microseconds}}$$

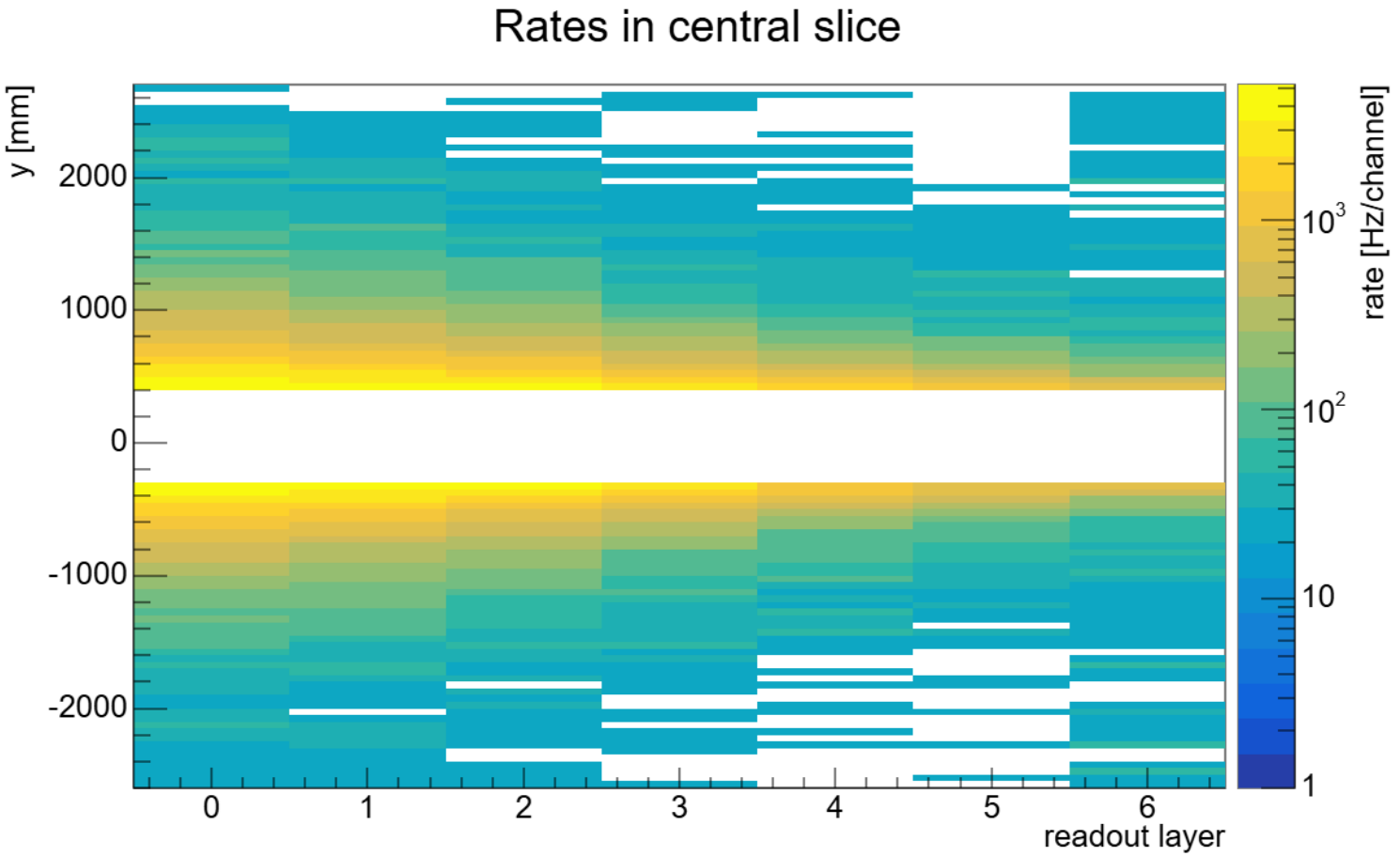
Channel rates for DIS at 0.5 MIP





Longitudinal view for DIS channel rates at 0.5 MIP

Average rate of channels in a central vertical slice of the LFHCal for all longitudinal segments.



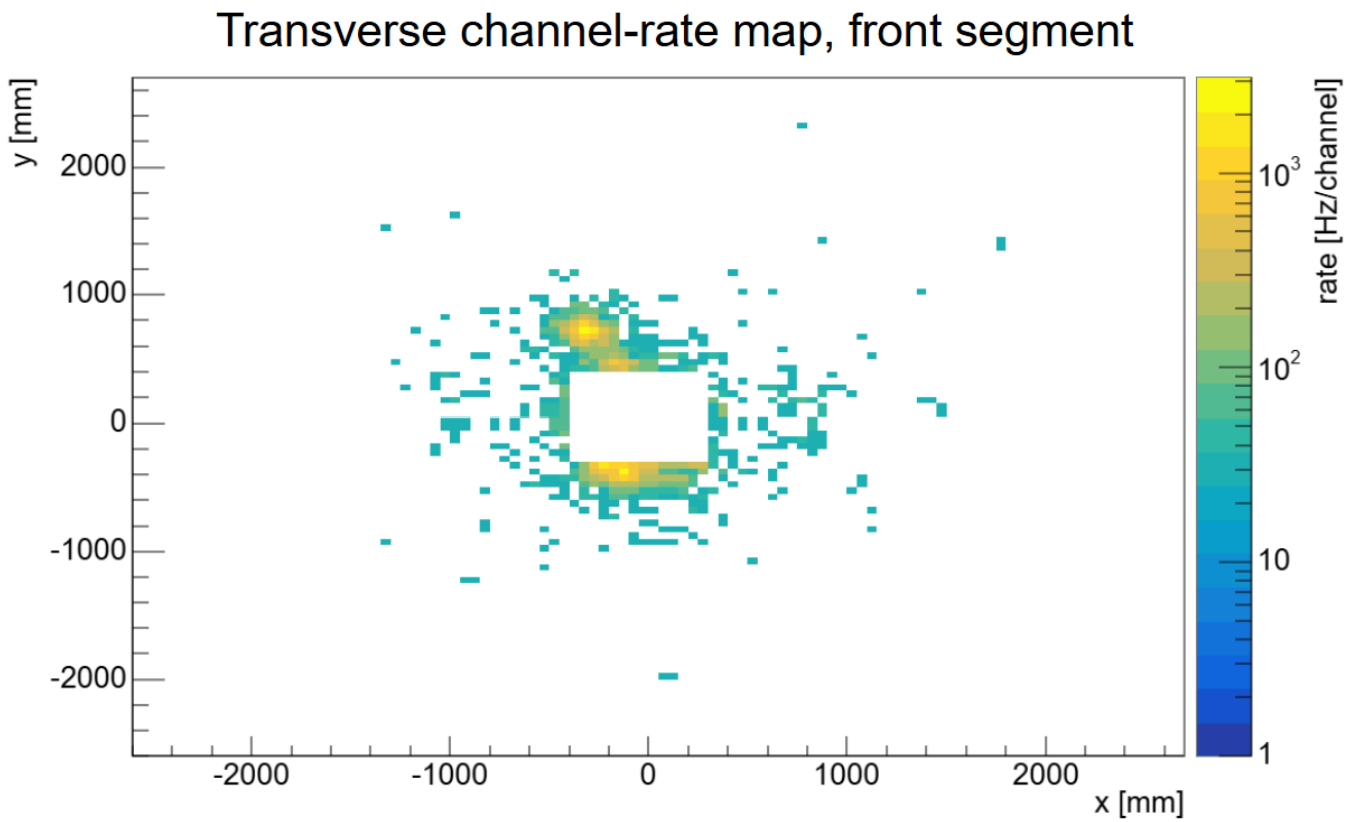
Anisotropic pBeamGas events

For each MCParticle:

1. Trace to the earliest parent
2. Hash the parent's 4 vector, vertex, and PDG
3. 14 unique pBeamGas ancestors across 19k events

No meaningful impact on rate quantities within current data sample.

- pBeamGas contributes to ~1% total rate



Recently resolved at https://github.com/eic/HEPMC_Merger/issues/24

Channel rate summary

	Full rate	DIS rate
99th percentile of all channel rates at 0.5 MIP	3.11 kHz	3.05 kHz
95th percentile of all channel rates at 0.5 MIP	1.08 kHz	1.05 kHz

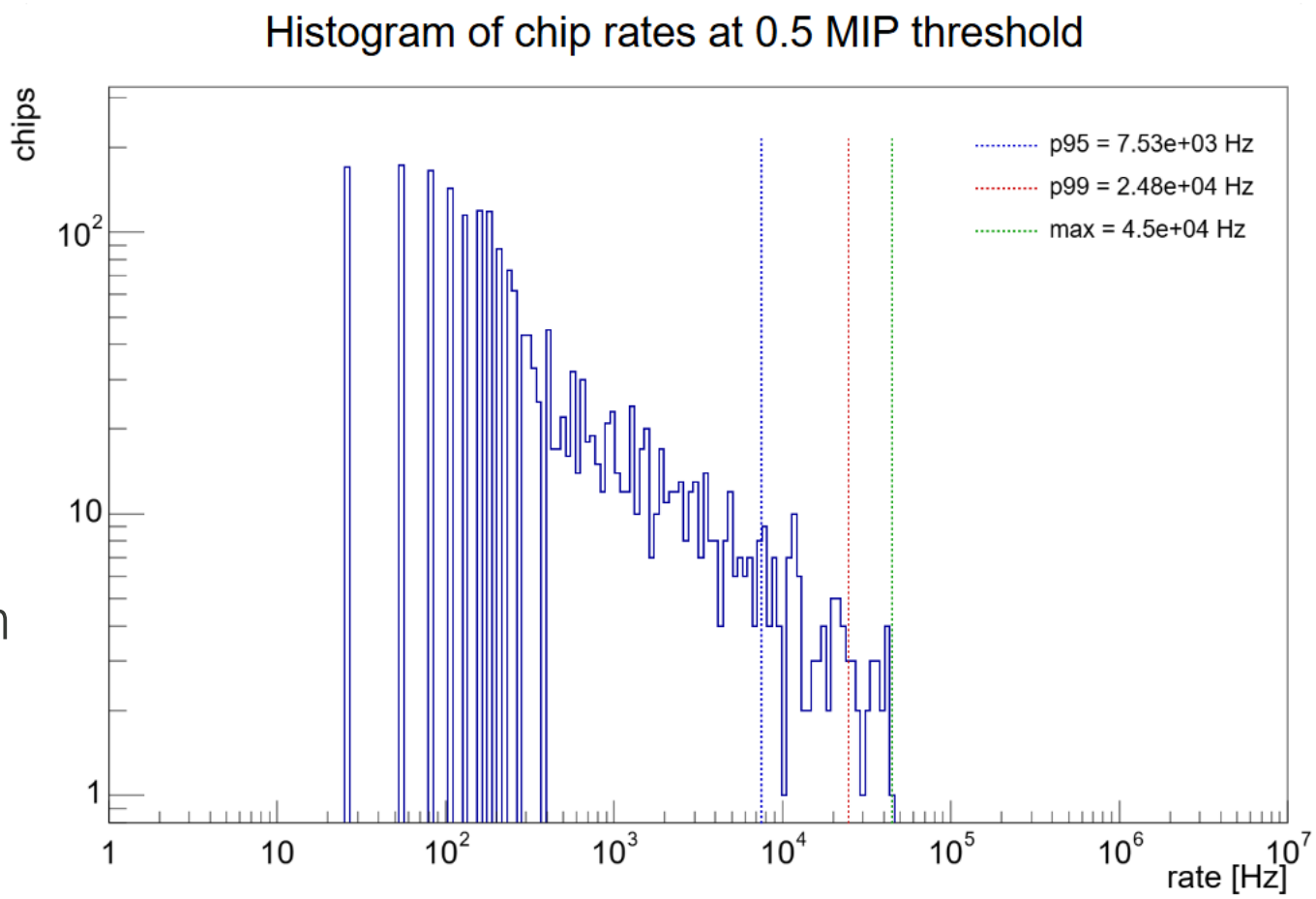
Hardware implications

What do hit rates look like for readout chips?

- Electronics need to accommodate the highest possible chip-level rates

With finite statistics, percentiles of rates provide a more stable basis for rate interpretation than the observed maximum rate.

- 95th and 99th percentiles to estimate upper extrema



Tail rates for readout chips

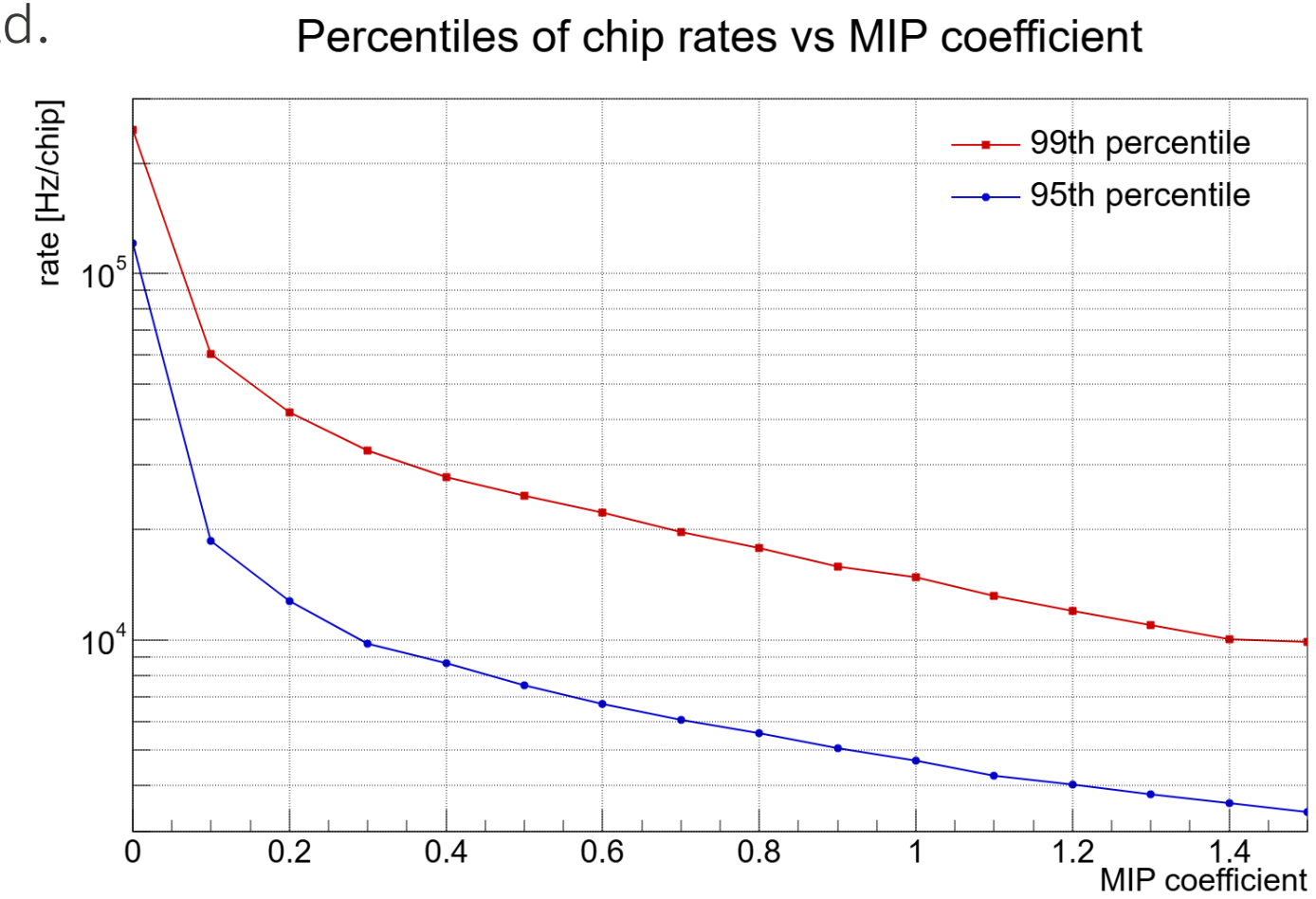
95th and 99th percentiles of readout-chip rates as a function of MIP threshold.

p95:

- 19 kHz at 0.1 MIP
- 6 kHz at 0.5 MIP
- 3.4 kHz at 1.5 MIP

p99:

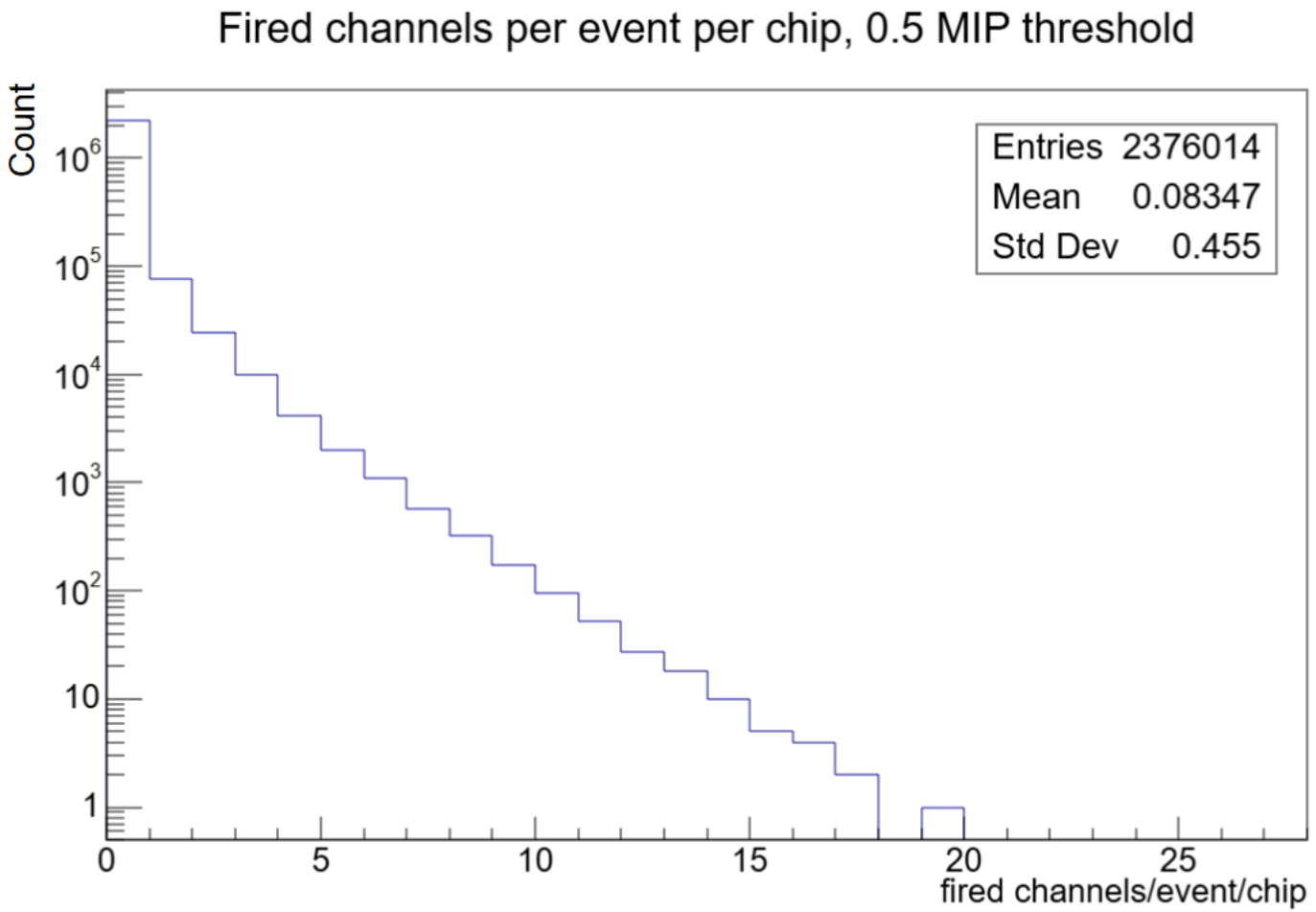
- 60 kHz at 0.1 MIP
- 20 kHz at 0.5 MIP
- 10 kHz at 1.5 MIP



Fired channels per chip at 0.5 MIP

Histogram of the number of channels exceeding the 0.5 MIP threshold in each chip for each event.

Average of 2.165 channels per event excluding the zero bin.



Chip data model

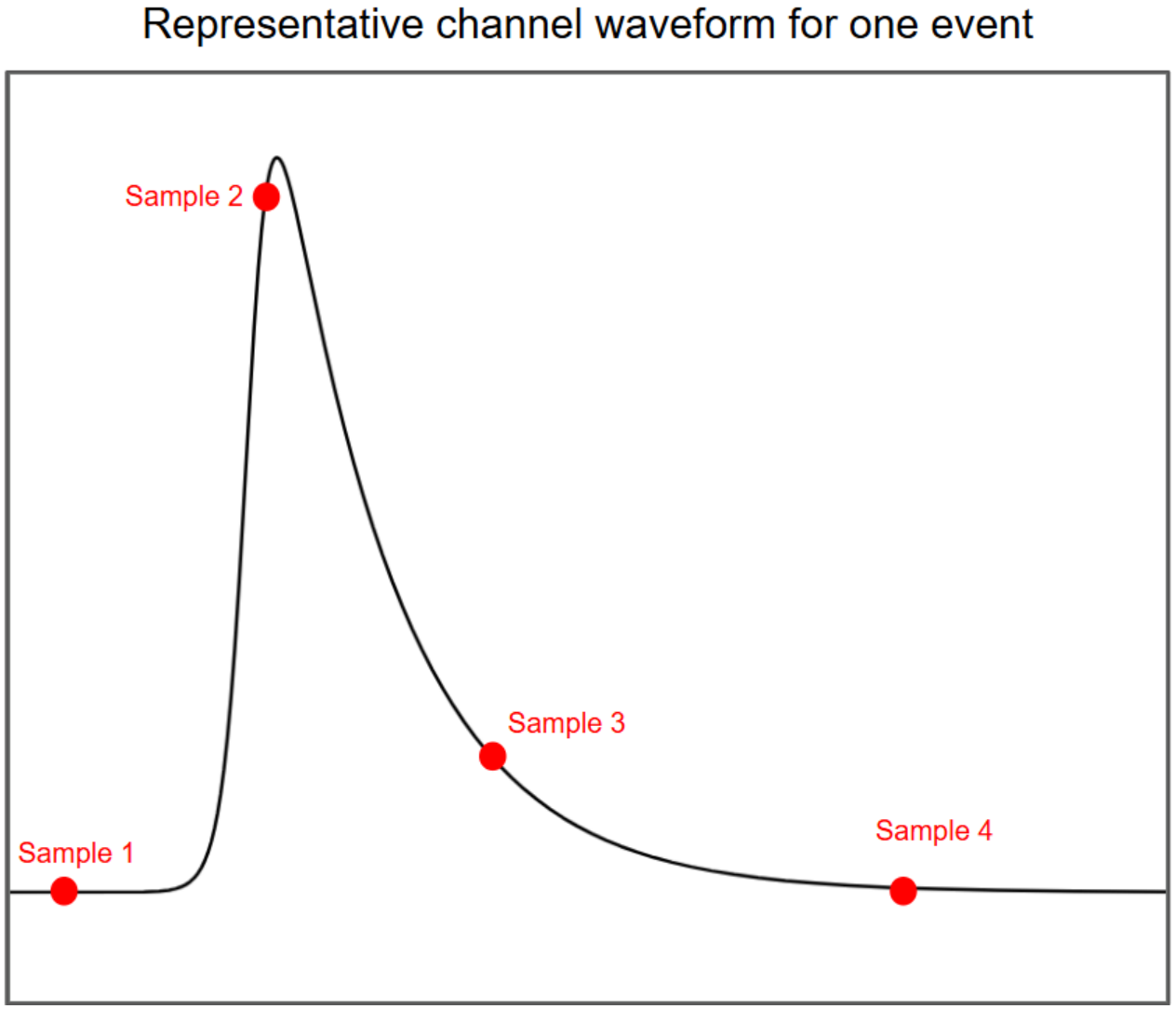
Assume each active event reads out 4 samples per chip.

Each sample contains:

- 128 bits overhead
- N × 32 bits, where N is the number of channels above threshold

So the total data per active event is:

- [128 bits + (channels above threshold) × 32 bits] × 4 samples



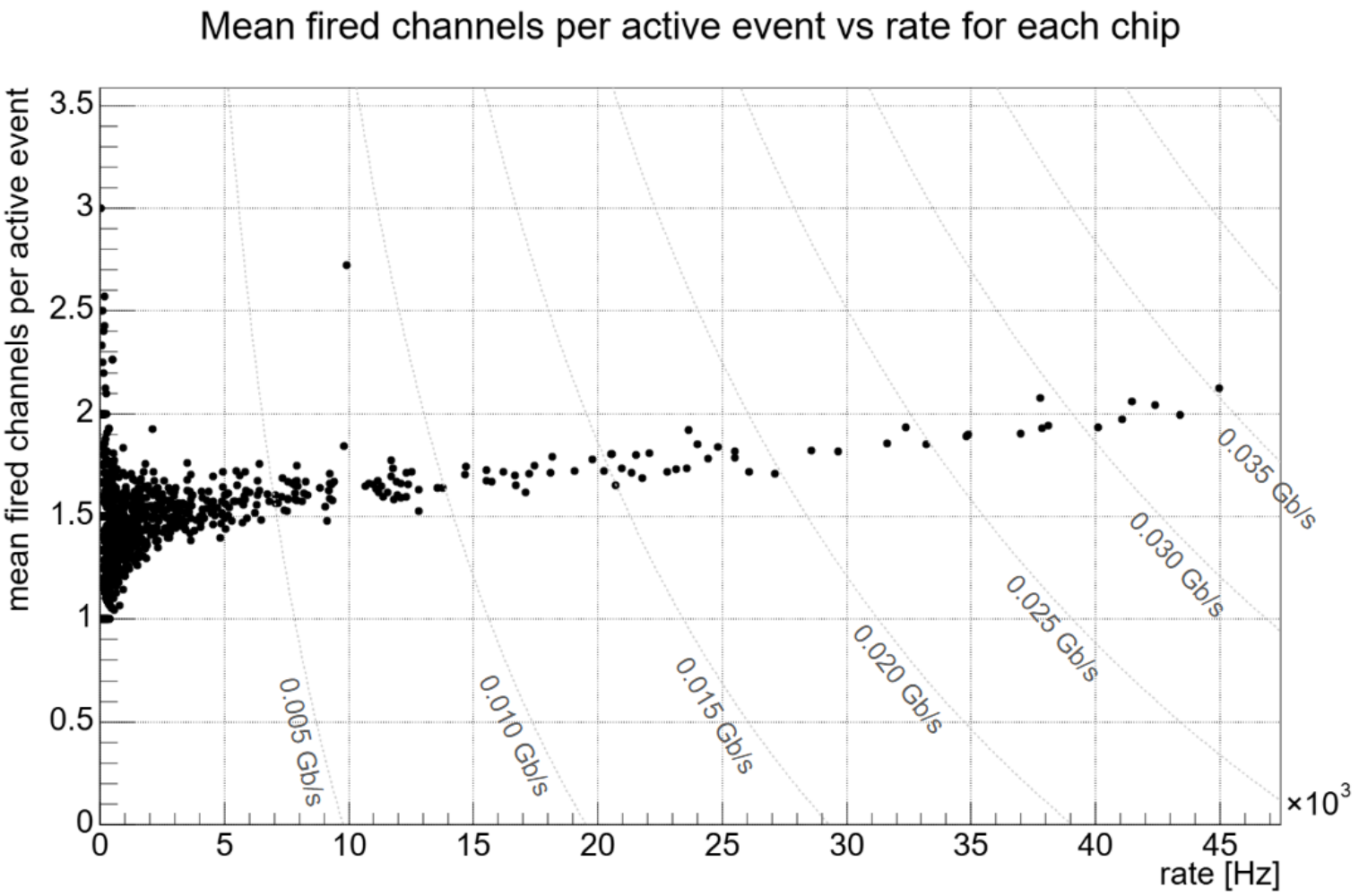
Fired-channel rate per chip vs overall rate per chip

Chip firing rate versus the average number of channels above 0.5 MIP in active events.

Contours show constant data rate, calculated with:

Rate (Gb/s) =

x × (128 + 32y) × 4 / 1e9



Data rate distributions

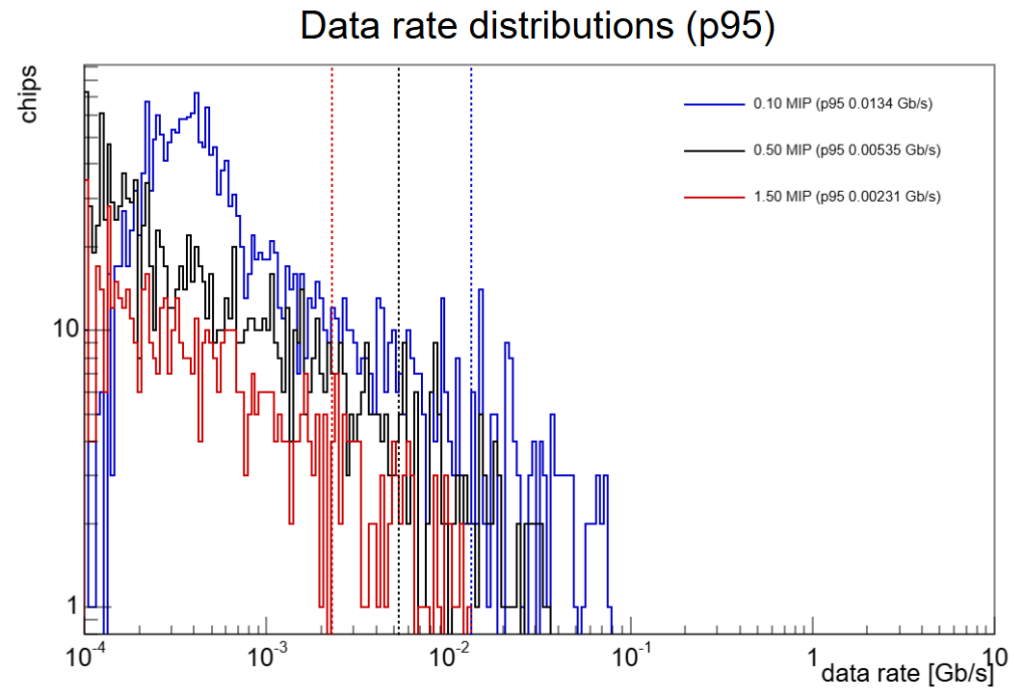
Histogram for the data rate of all chips in the LFHCal at different MIP thresholds.

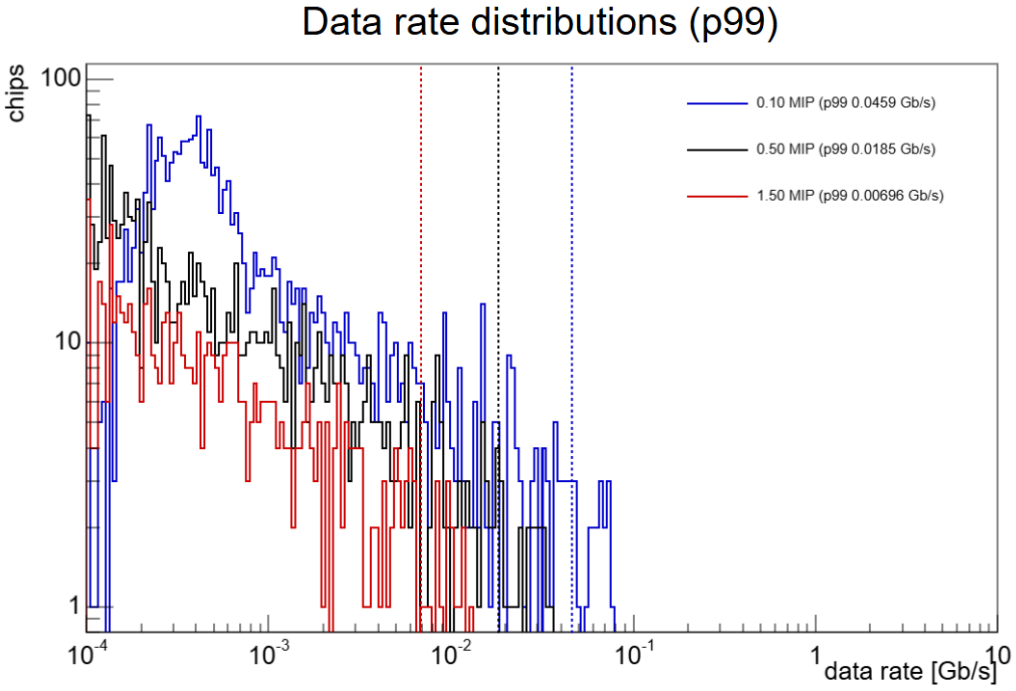
95th percentile:

- 0.0134 Gb/s at 0.1 MIP
- 0.00535 Gb/s at 0.5 MIP
- 0.00231 Gb/s at 1.5 MIP

99th percentile:

- 0.0459 Gb/s at 0.1 MIP
- 0.0185 Gb/s at 0.5 MIP
- 0.00696 Gb/s at 1.5 MIP

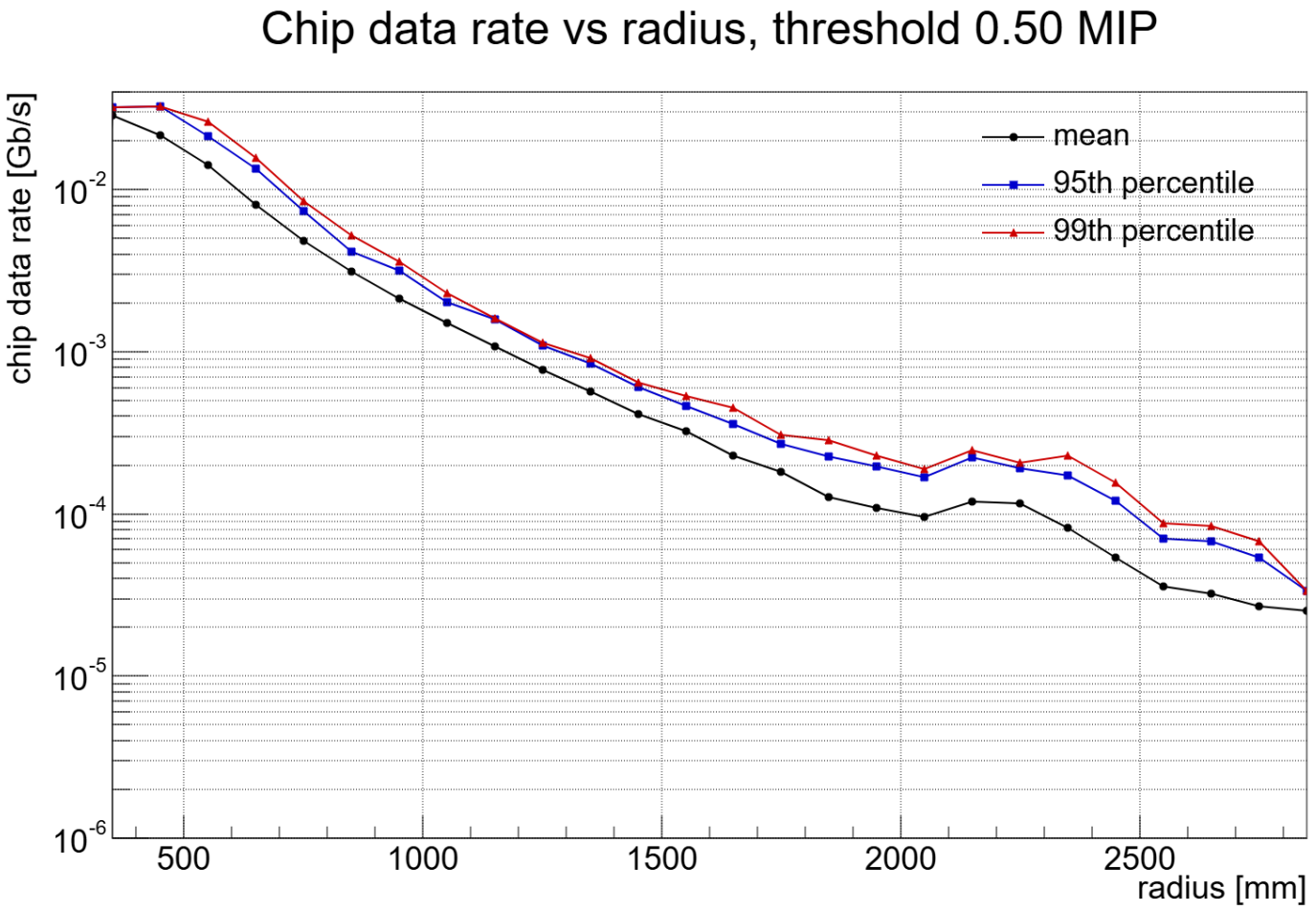




Average data rate vs radius

Average and tail values of all chips' data rates binned by distance from (0,0).

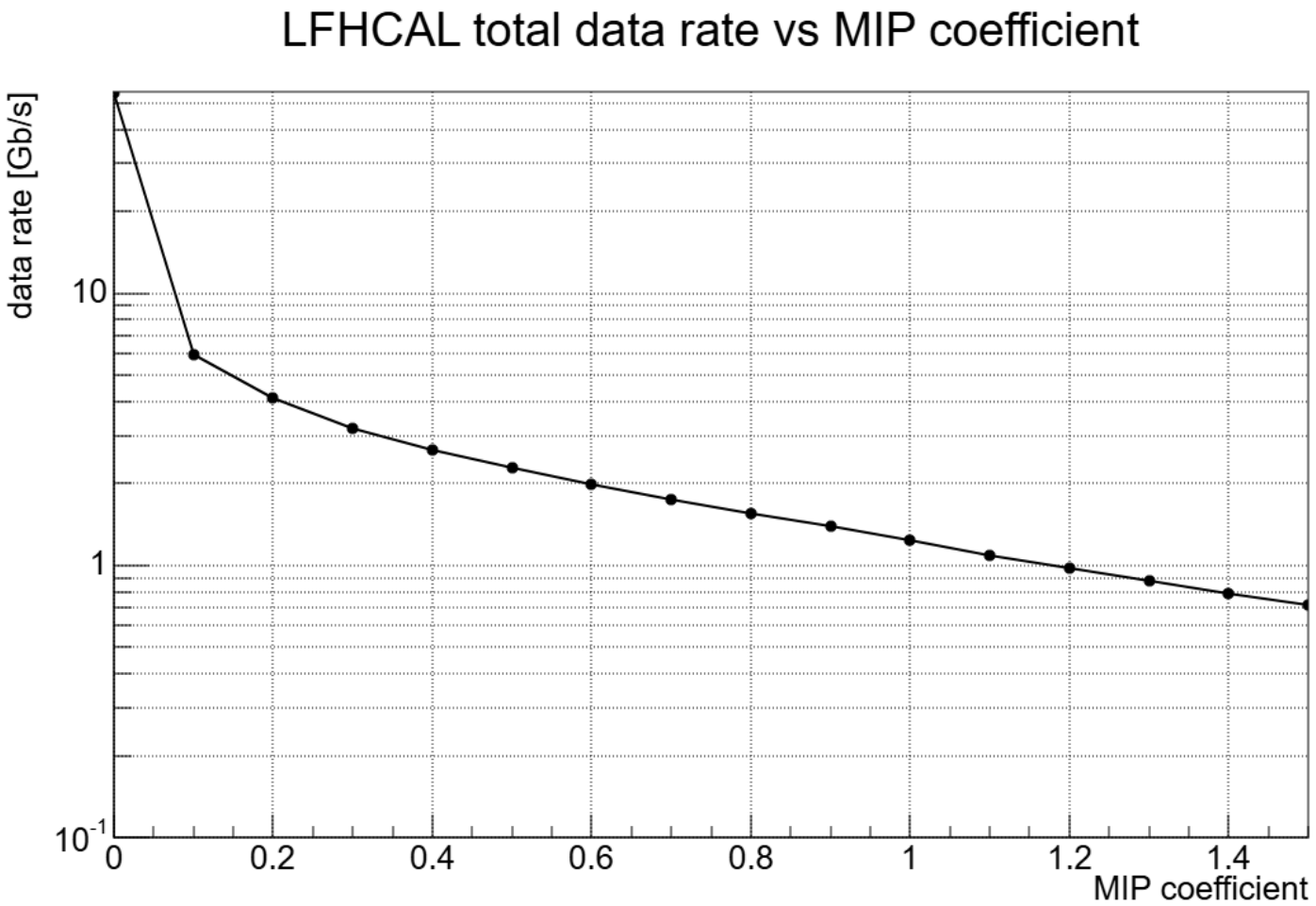
- average 0.022 Gb/s at ~500 mm
- average 1.2e-4 Gb/s at ~2000 mm
- average 2.7e-5 Gb/s at ~2700 mm



Data readout rate for the LFHCal

The sum of all rates from each readout chip as a function of MIP threshold.

- 55 Gb/s no threshold.
- 6 Gb/s at 0.1 MIP
- 1.8 Gb/s at 0.5 MIP
- 0.7 Gb/s at 1.5 MIP



Conclusion

Anisotropic data samples

- At least February and April campaigns affected
- Repeat the study with July simulation campaign

Upper tail of simulation-derived data rate well below max capacity

- Peak at ~0.035 Gb/s << 2.56 Gb/s per chip
- ~1-6 Gb/s for the entire LFHCal

Repeat the study for the HCal Insert