Leprince Ringuet laboratory (LLR)

Intern Presentation

Application of new techniques for the luminosity measurements in the LHCb

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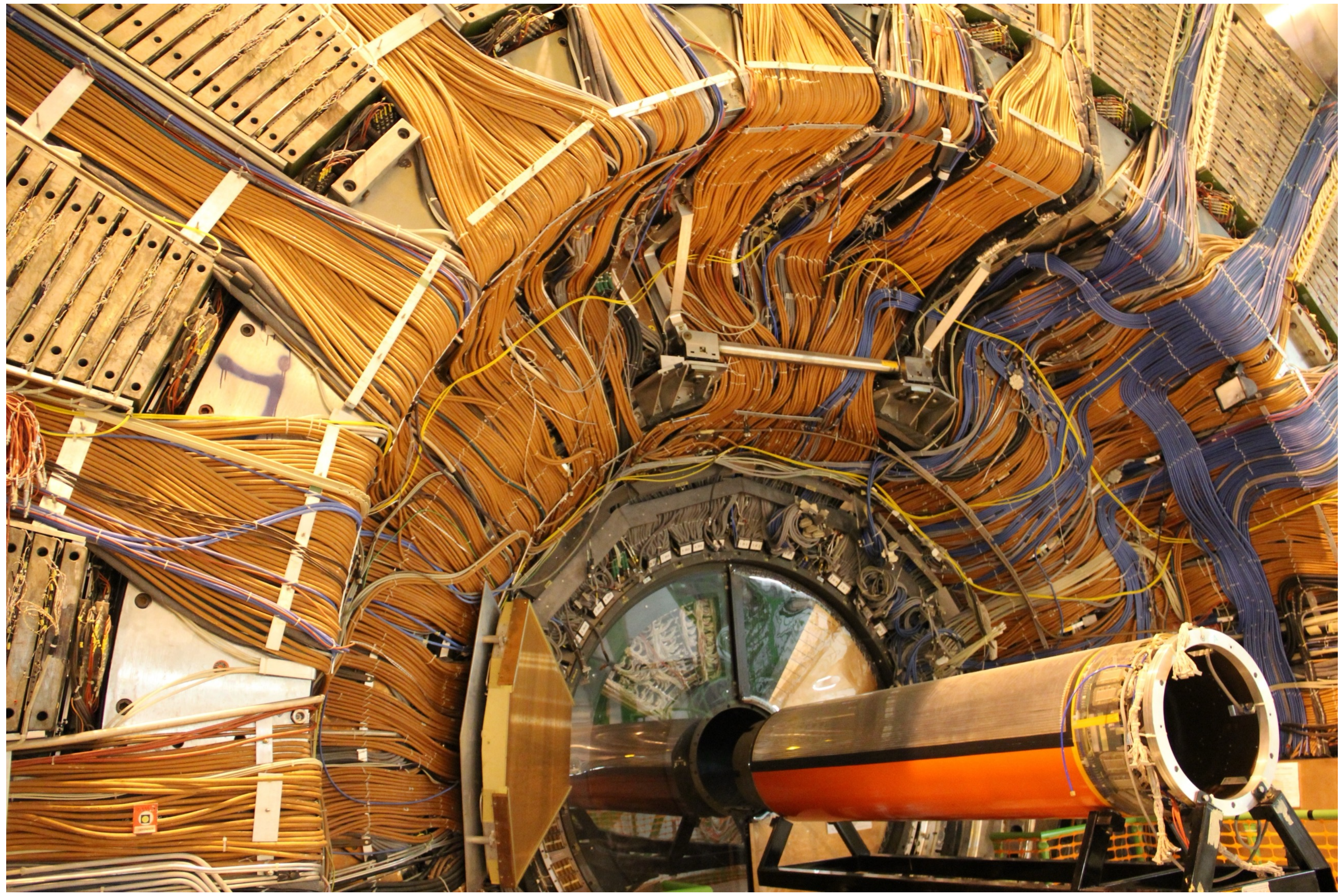
What is LHCb?

- Single-arm forward spectrometer
- Optimized for b- and c- hadron physics
- Key subsystems: VELO, RICH, Calorimeters, etc.



- VELO: Vertex Locator
  - Responsible of the reconstruction of proton-proton collision, etc.

Key parameters

Log-zero method

Key considerations:
- Bias from high-μ events
- Limitation from low-μ events

Average method

- μ: Number of interactions per events
- Number of tracks per event

Comparison between the estimation techniques

Log-zero method	Average method
$\mu = -\ln(P(0))$	$\mu \propto \langle \text{number of hits/tracks} \rangle$
Pros: Insensitive to reconstruction inefficiencies in “busy” events—once there is at least one interaction, it is simply counted as “non-zero.” Straightforward to implement and calibrate when μ is small. **Cons**: At high μ, the fraction of zero-interaction events becomes extremely small (e^{-}^μ), making this method statistically unstable and highly sensitive to fluctuations or tiny inefficiencies. **Summary**: Great for relatively low pile-up (i.e. low average number of interactions per bunch crossing), but not reliable for higher μ.	**Pros**: Conceptually simple and linear in the low-to-moderate μ regime. Often used when the detector response is well-understood across the full range of μ. **Cons**: Biased by reconstruction failures in the busiest events: If an event has many simultaneous interactions, and the detector undercounts them (due to saturation or inefficiencies), the average can be mis-measured. Assumes that the calibration constant remains stable over time and that the device is linear (i.e. no “saturation”) at the highest interaction counts. **Summary**: Straightforward but requires careful handling of detector nonlinearities, especially as μ grows larger.

Proposed solution

Application of the **PGF method**:

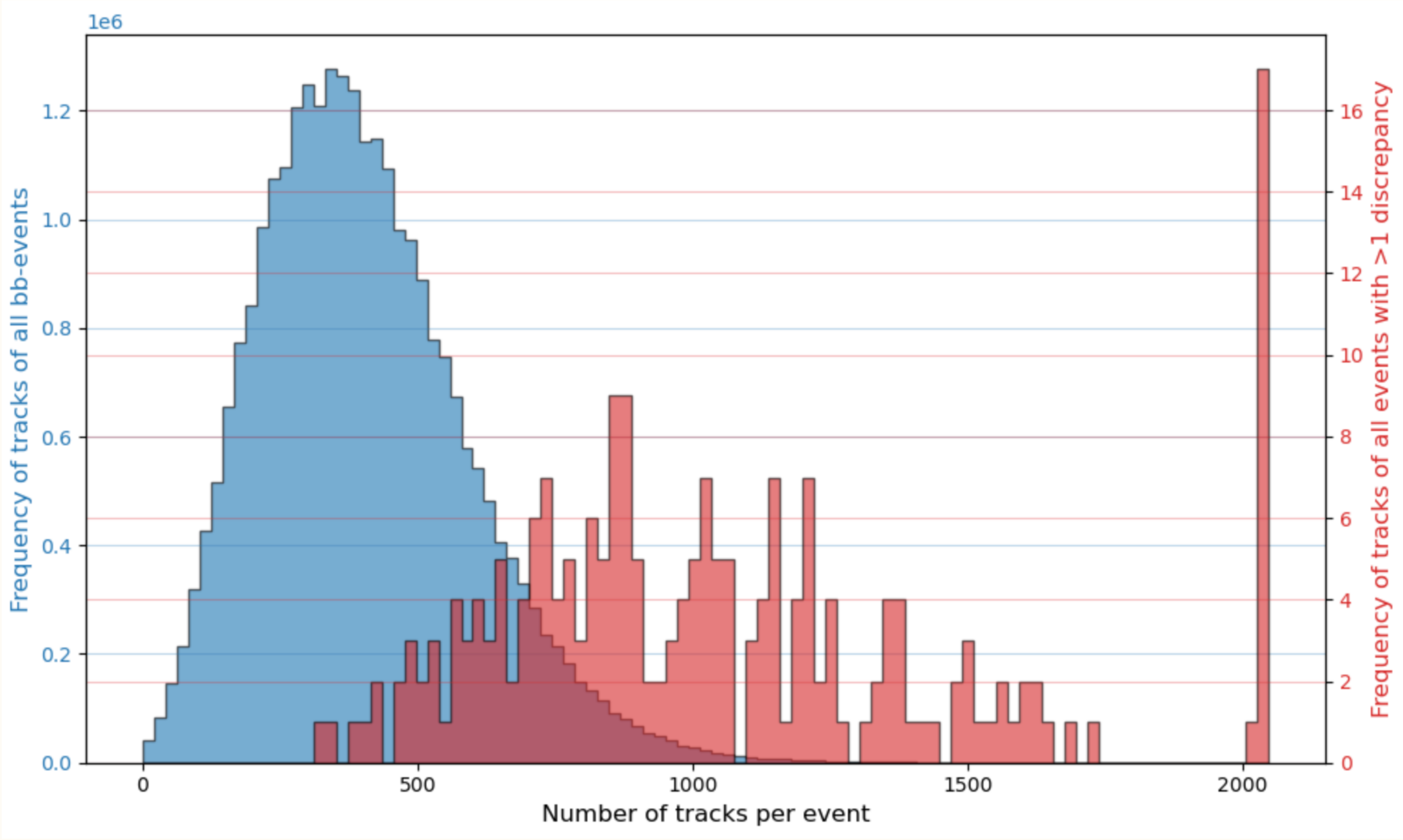
For a parameter $0 < z < 1$, and $N =$ the number of observed tracks:
$G_{poisson}(z) = e^{-\mu\left(G_p(z)-1\right)}$ and $G_p(z) = \sum_N p(N) z^N$,
One fits μ from the measure $\langle z^N \rangle$.

Overview

- PGF = Probability Generating Function
- By comparing the average to the known form of the generating function for Poisson-distribution interactions

Objectives

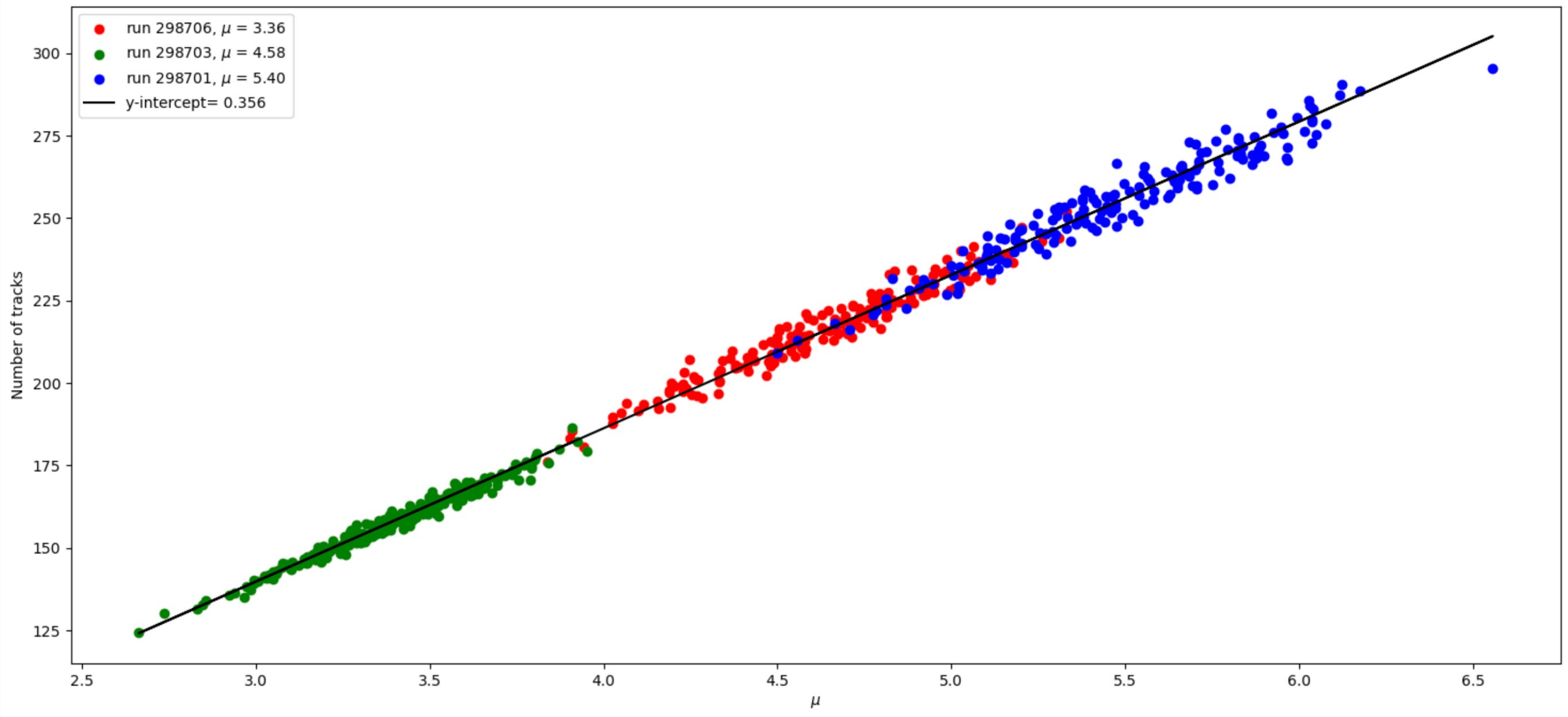
- Less bias
- Good trade-off between the pros and cons of the other two methods



Key Result 1:

Validation of high track counts

- Goal: Check if VELO track counts are uniform across rapidity bins
- Method: Compare integrated Track counts with sum over all rapidity-bins
- Result:
  - Some of the tracks not captured in the busy events by the rapidity bins
  - Some of the busy events exceed detector limits



Key Result 2:

Linearity of μ with respect to tracks

- Goal: Check if the μ is linear with respect to the number of tracks.
- Method: Work on low-μ events. Bin the distribution of tracks to have sufficient statistics in each bin. Then calculate the μ using log-zero for the events corresponding to each bin. Fit a linear curve to see whether the curve goes through zero very well.
- Result:
  - y-intercept goes through 0 within 3σ.
  - Negligible quadratic term

Next steps

Implement PGF method and repeat the same linearity analysis but for high-μ events

- This will be a validation for the PGF method

Validating the scope of PGF

- PGF method assumes all interactions produce an identical track flow. We can validate this assumption by considering calculating μ's for beam-gas vs beam-beam interactions. If they differ, $p(N)$ would be different for one interaction.

Validity of μ over time

- Check whether for a certain run, μ remains fairly stable over time.

Summary and Conclusion

The discrepancy observed at $\mu \approx 5$ indicates that the traditional log-zero method underestimates multiplicity in very busy events. This has implications for real-time luminosity measurements – for Run 3, LHCb might benefit from incorporating PGF-based algorithms when instantaneous μ gets large. Our demonstration attempts to validate that PGF works on real data and could be integrated into the luminosity calculation workflow.

The new filtering procedure and visualization scheme developed in this project can improve how LHCb analyzes beam-gas data, contributing to more reliable luminosity measurements. The successful application of the PGF method provides a foundation for its use in regular LHCb operations.

These techniques could be applied to other datasets or integrated into the real-time data monitoring at LHCb.

Questions?

Thank you for listening!