

The forgotten importance of impact parameter for understanding correlations and fluctuations

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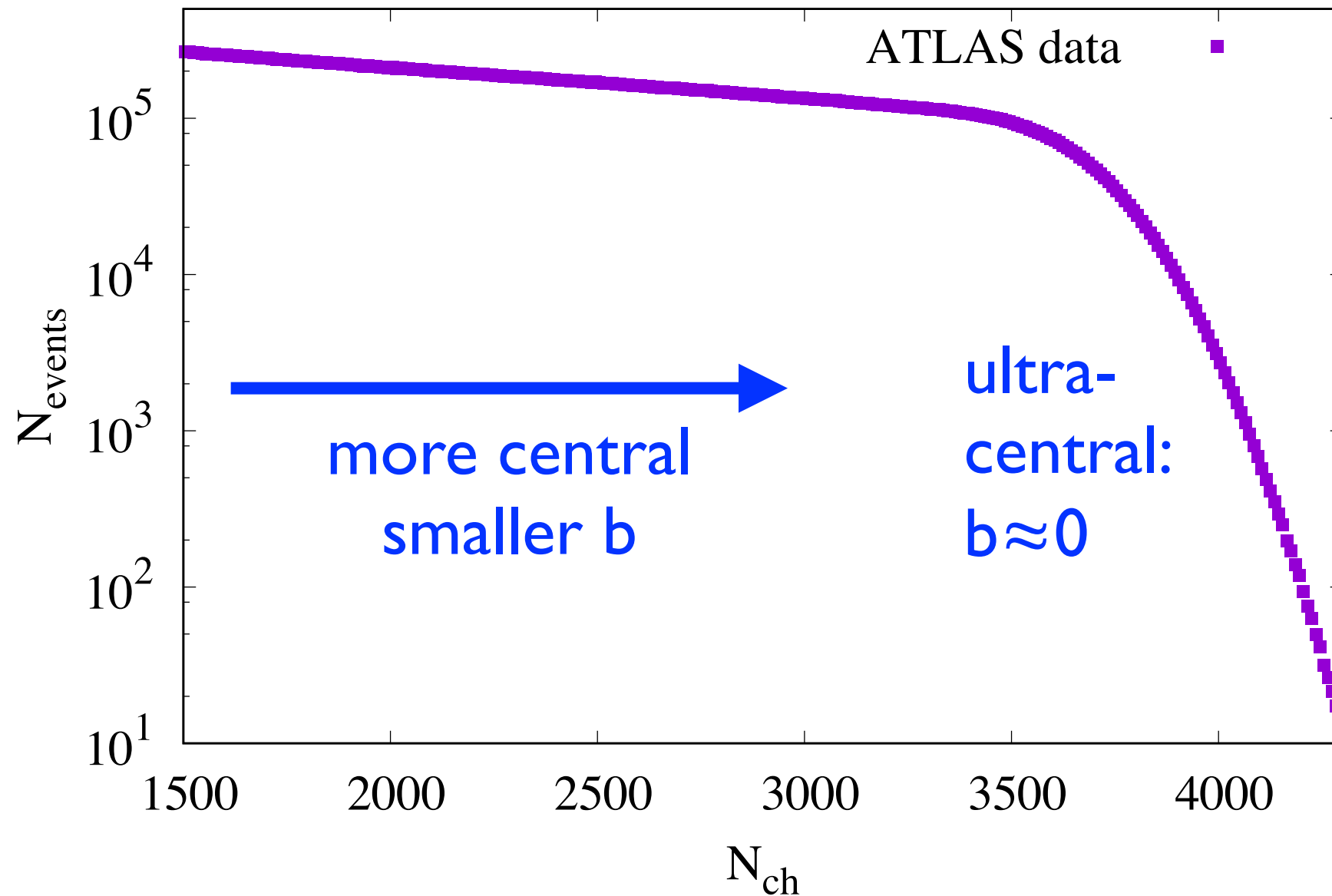
Correlations, fluctuations, and the quark-gluon plasma

- Evidence for the formation of a strongly-coupled **quark-gluon plasma** in collisions at the LHC largely relies on the observation of **correlations** (e.g. azimuthal correlations)
- They are interpreted as **fluctuations** of the single-particle distributions
Alver Roland <https://arxiv.org/abs/1003.0194>
Luzum <https://arxiv.org/abs/1107.0592>
- Where do **fluctuations** come from in collisions at the LHC?

Classical and quantum fluctuations

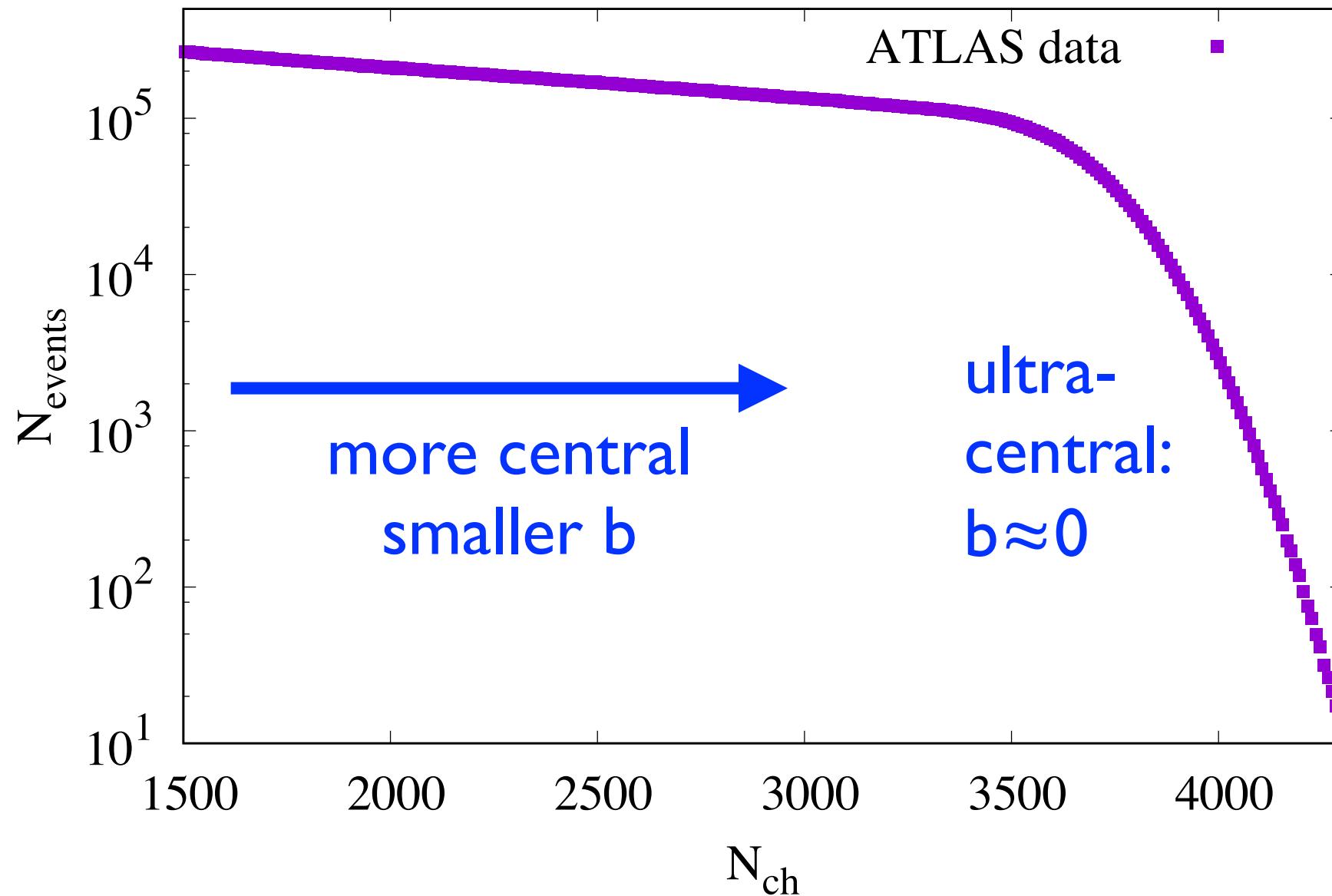
- The **quantum uncertainty** on **impact parameter** is negligible at the LHC:
proton: $\delta b = 3 \times 10^{-5} \text{ fm}$ Pb: $\delta b = 4 \times 10^{-7} \text{ fm}$
- Therefore, event-to-event **fluctuations** of **impact parameter** (either in **magnitude** or **orientation**) are **classical** fluctuations
- At fixed **b**, all remaining fluctuations are **quantum**
*In simulations, we should characterize fluctuations at fixed **b**, which are likely simpler. Is this doable also in pp?*

Centrality in Pb+Pb collisions



Experimentally, one typically estimates the **centrality** using the multiplicity of charged particles, N_{ch} .

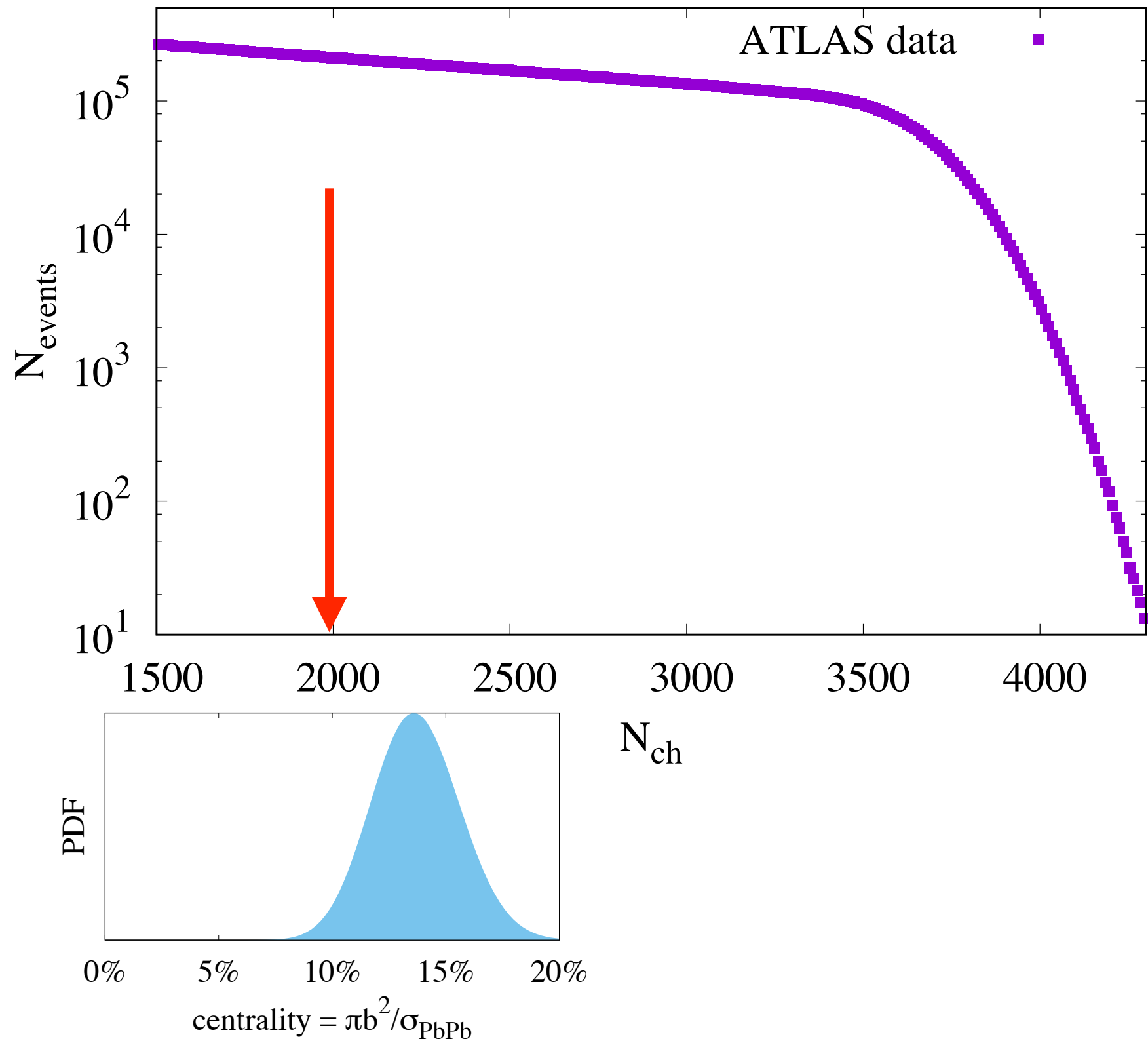
Centrality in Pb+Pb collisions



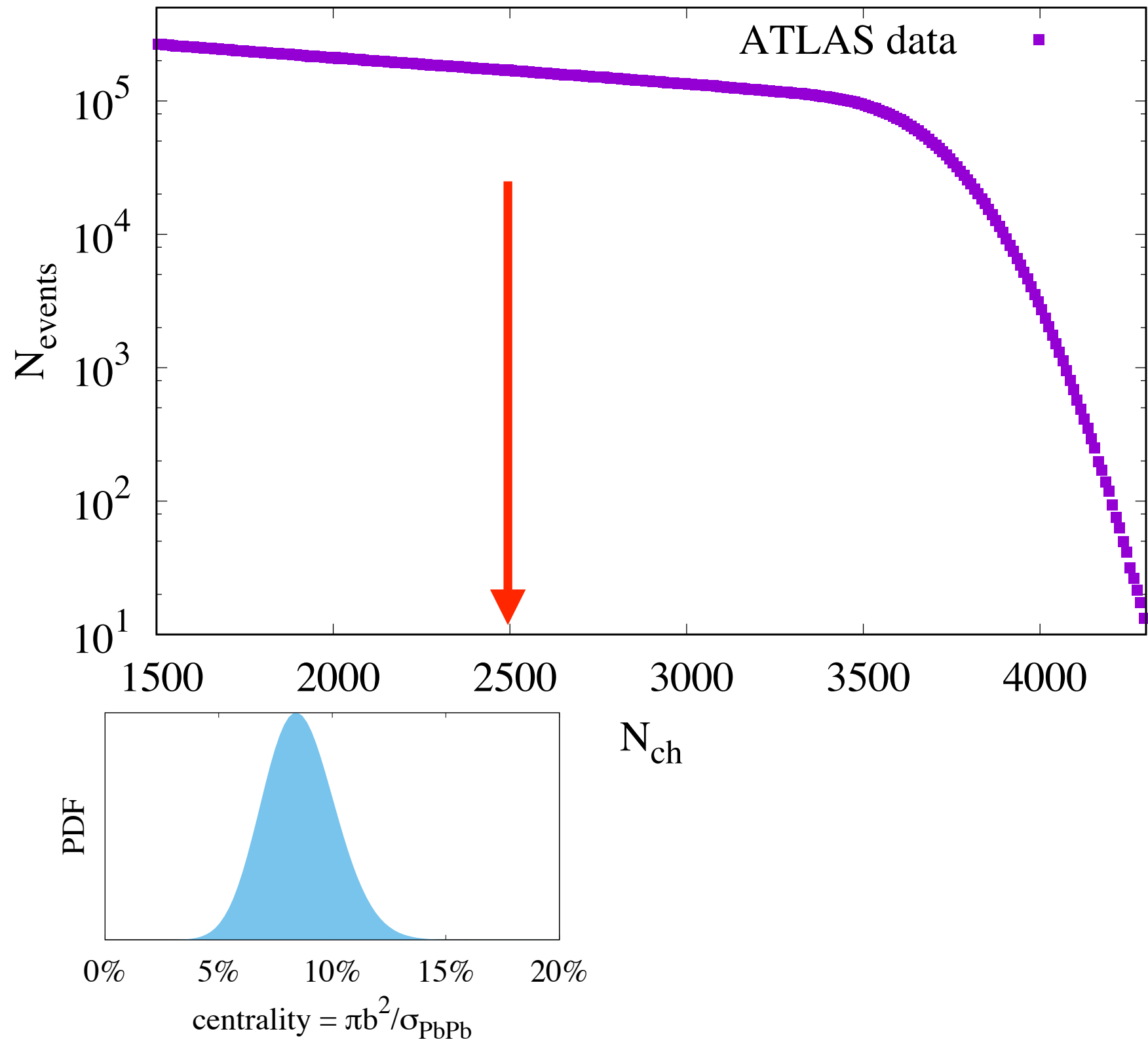
In reality, a fixed N_{ch} corresponds to a range of centrality (or impact parameter)

Das Giacalone Monard JY0 <https://arxiv.org/abs/1708.00081>

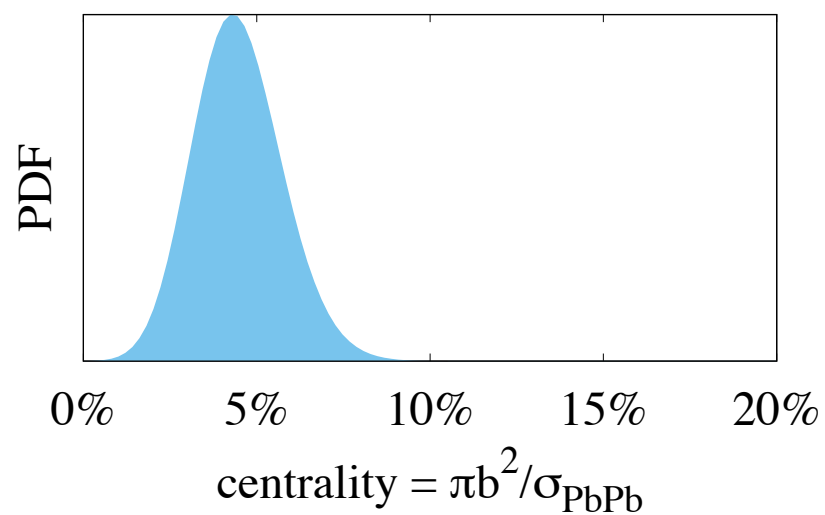
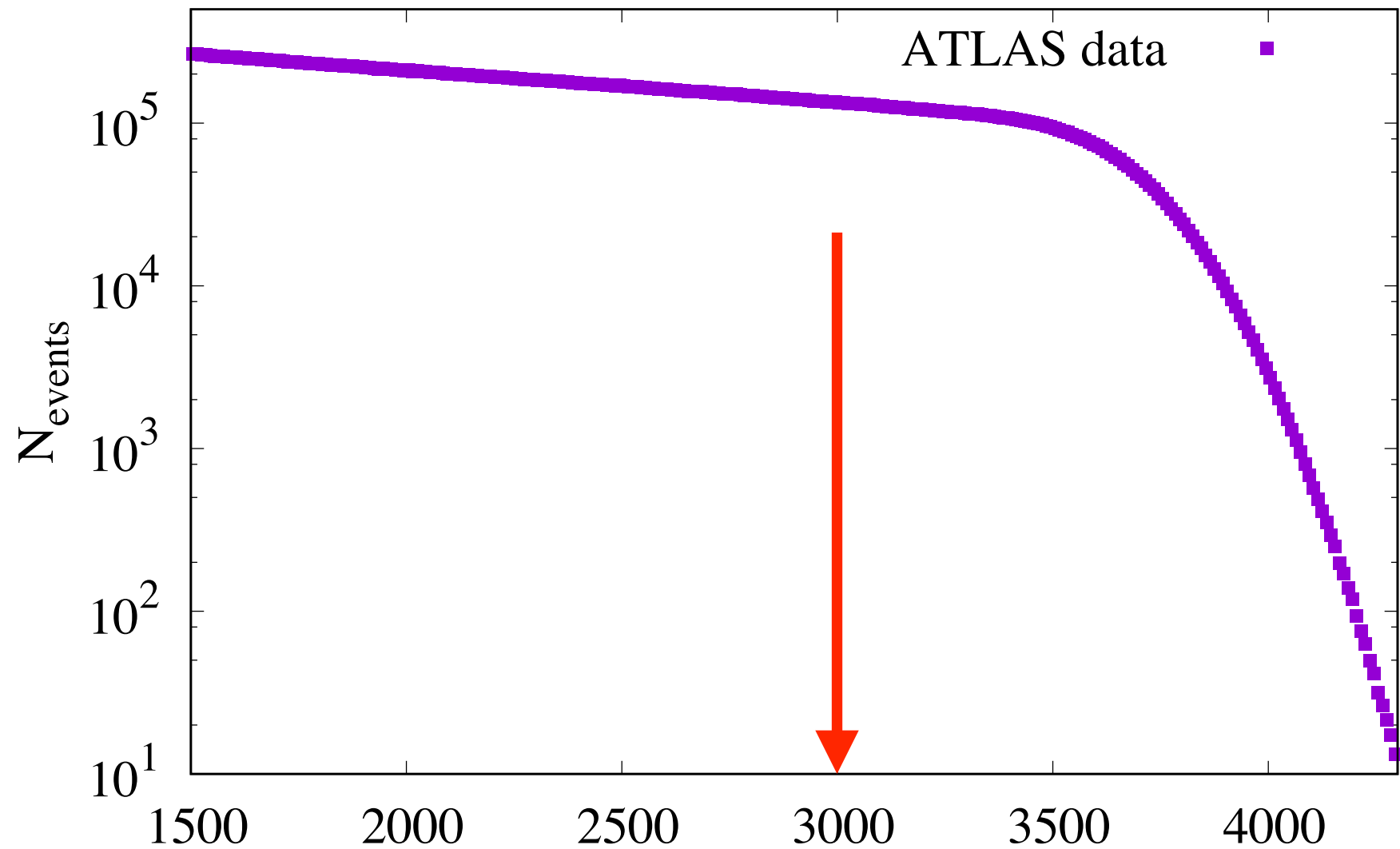
Centrality in Pb+Pb collisions



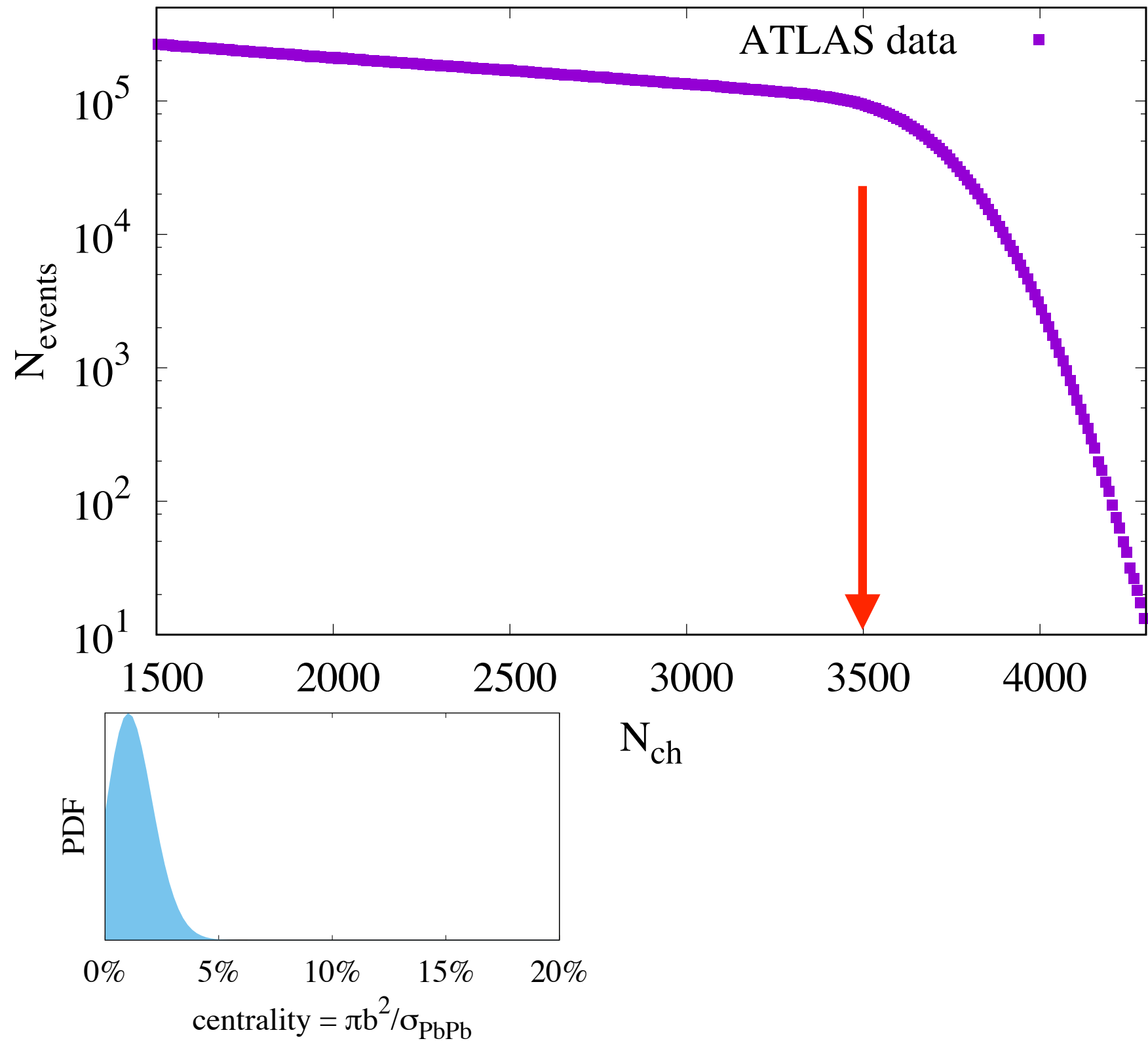
Centrality in Pb+Pb collisions



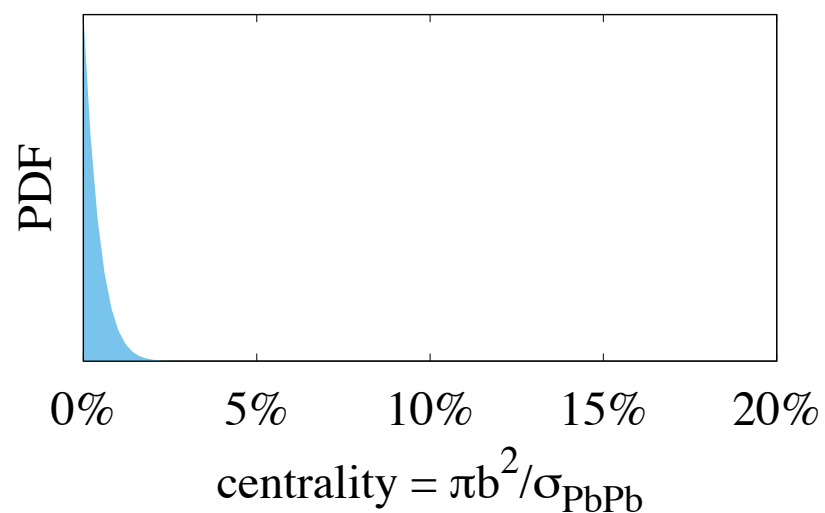
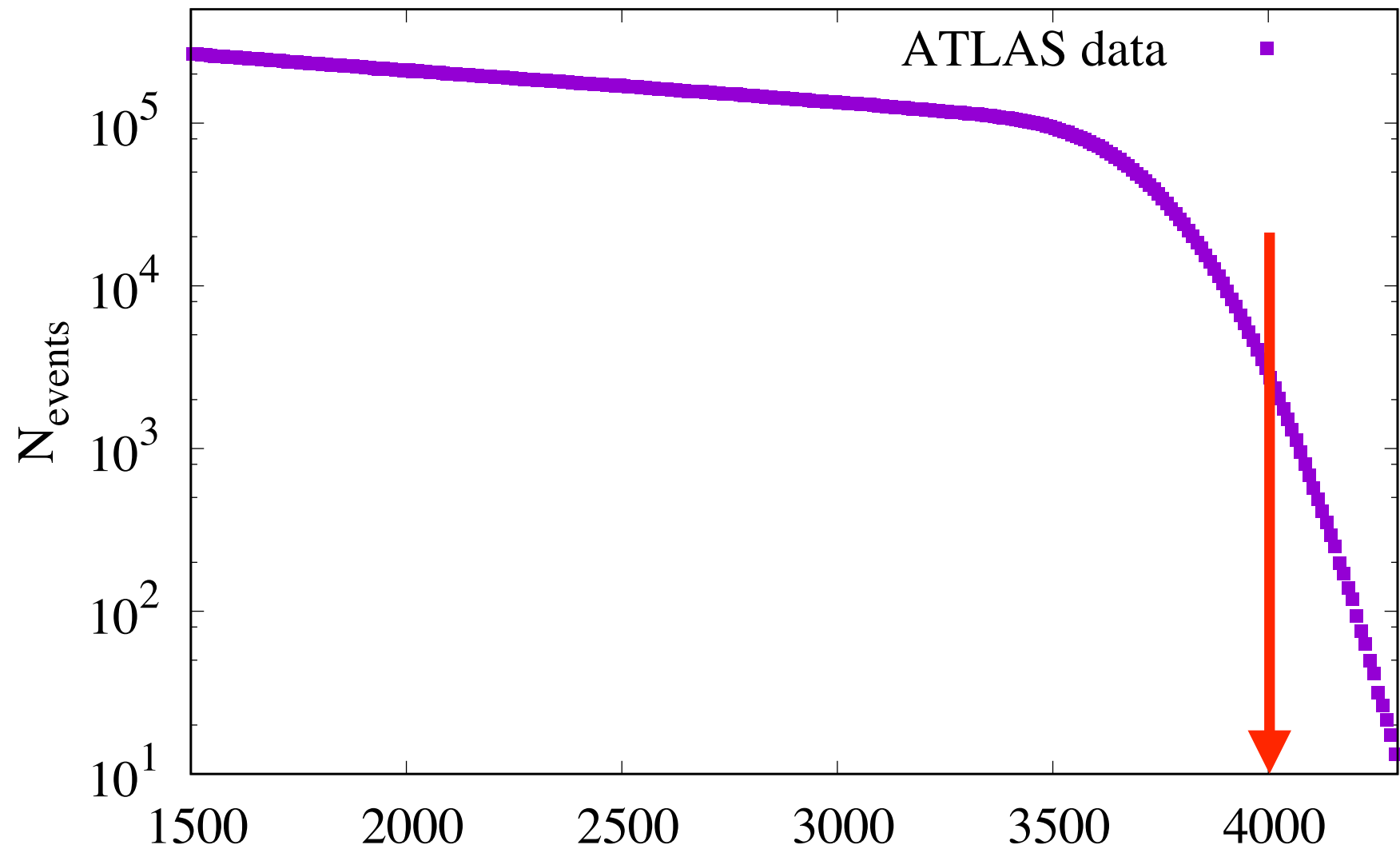
Centrality in Pb+Pb collisions



Centrality in Pb+Pb collisions



Centrality in Pb+Pb collisions



N_{ch}

Ultracentral collisions are special:
b fluctuations much reduced

Observing and modeling collisions at $b=0$

- Correlations and fluctuations in collisions at $b=0$ can be reconstructed from data in a robust way in Pb+Pb and in p+Pb collisions (nobody has tried pp)
- Transparent way of **comparing models to data**.
- **Example 1**: Angantyr overestimates multiplicity fluctuations in p+Pb collisions at $b=0$

Pepin Christiansen Munier JY0 <https://arxiv.org/abs/2208.12175>

- **Example 2**: In Pb+Pb collisions at $b=0$, there is a large correlation between $[p_t]$ and multiplicity in data and in hydro, not in Hijing

Samanta Bhatta Jia Luzum JY0 <https://arxiv.org/abs/2303.15323>

Samanta Luzum JY0 <https://arxiv.org/abs/2306.09294>