Exploring charged-particle multiplicity distribution in p-O at ALICE

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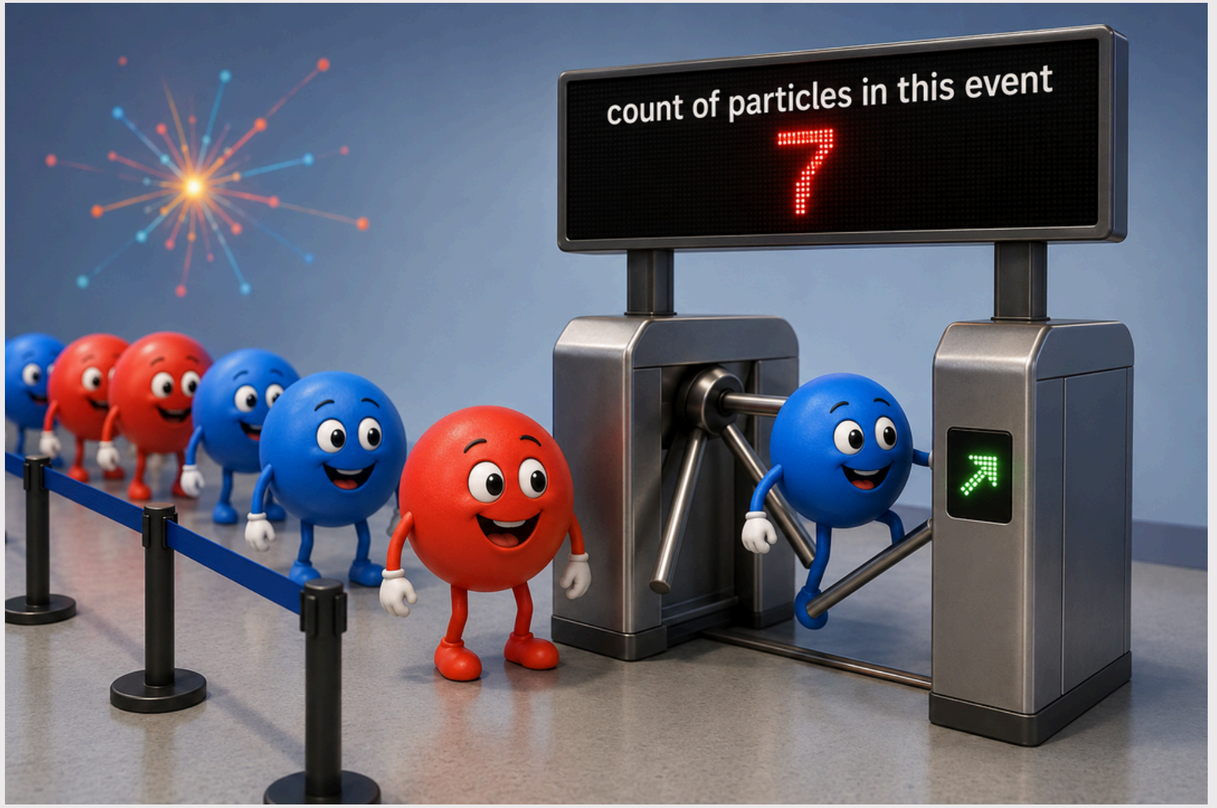
July 17th, 2026

What is multiplicity?

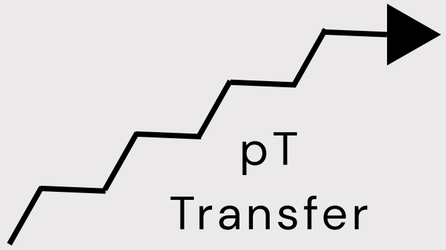
- **Multiplicity distribution *P(N)*** is among the most fundamental observables in hadronic collisions. It describes the probability of observing a specific number N of charged particles produced within a particular space phase
- The probability is determined completely by a **frequentist formalism**



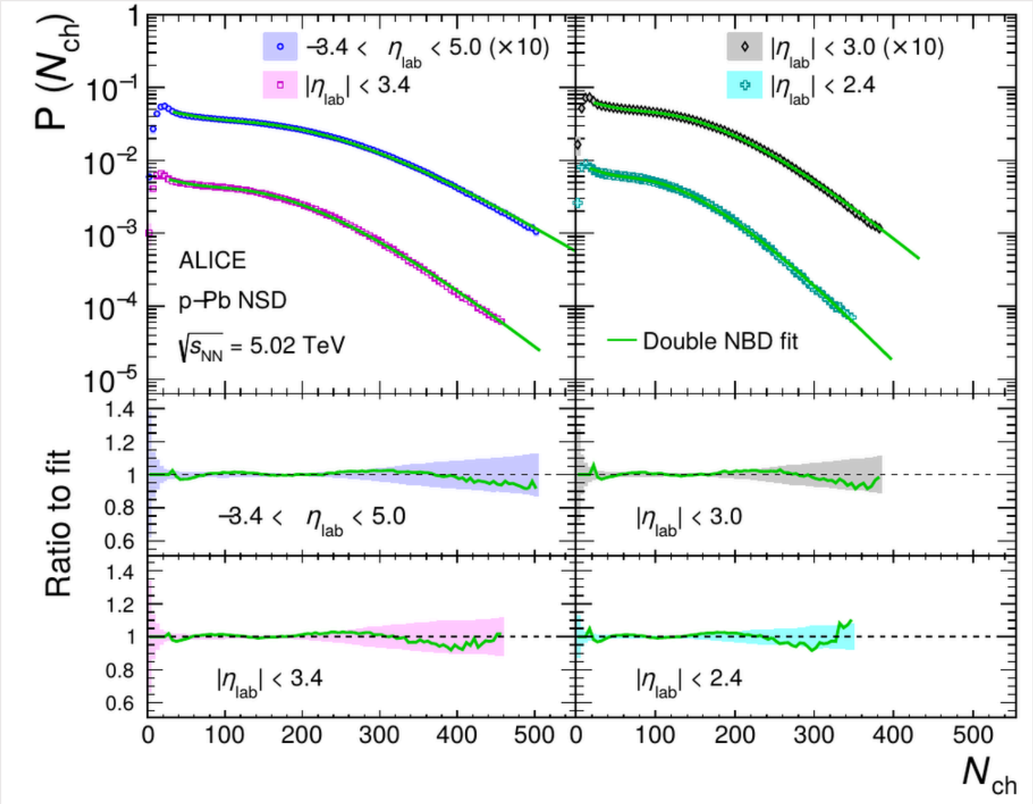
Why still study multiplicity?

- Provides a valuable probe of particle production mechanisms

Soft processes
(low pT transfer)
non perturbative description



Semi-hard processes
Increase in pT transfer
perturbative description



p-Pb multiplicity distribution for a wide range of η

$$P_{NBD}(n, \langle n \rangle, k) = \frac{\Gamma(n+k)}{\Gamma(k)\Gamma(n+1)} \frac{(\langle n \rangle / k)^n}{(1+\langle n \rangle / k)^{n+k}}$$

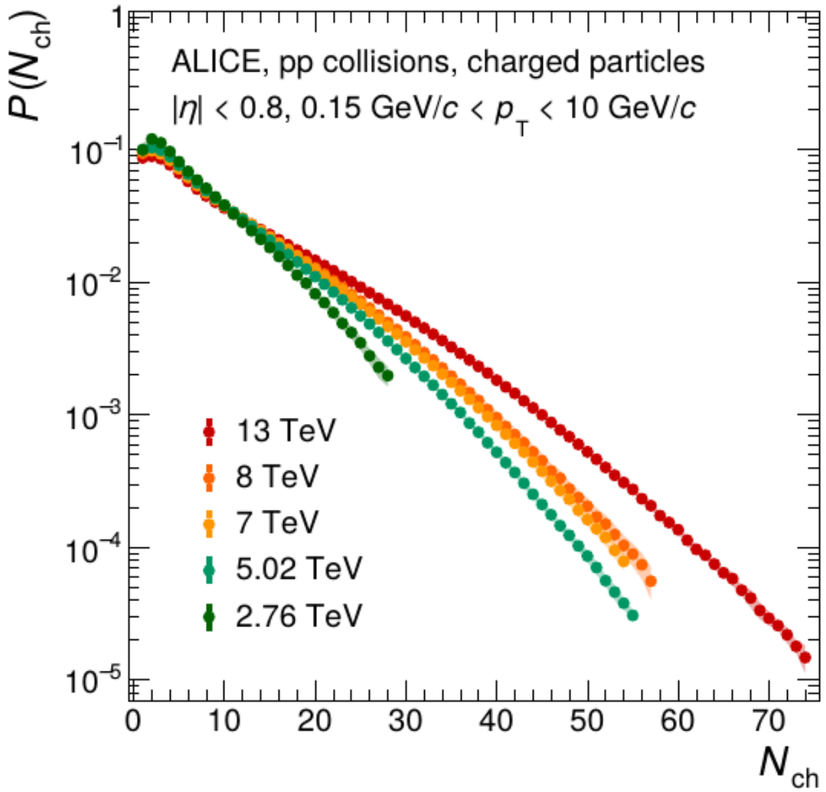
$$P_{dNBD} = [\alpha P_{NBD}(n, \langle n_1 \rangle, k_1) + (1-\alpha) P_{NBD}(n, \langle n_2 \rangle, k_2)]$$

Particle production insights from parametrization:

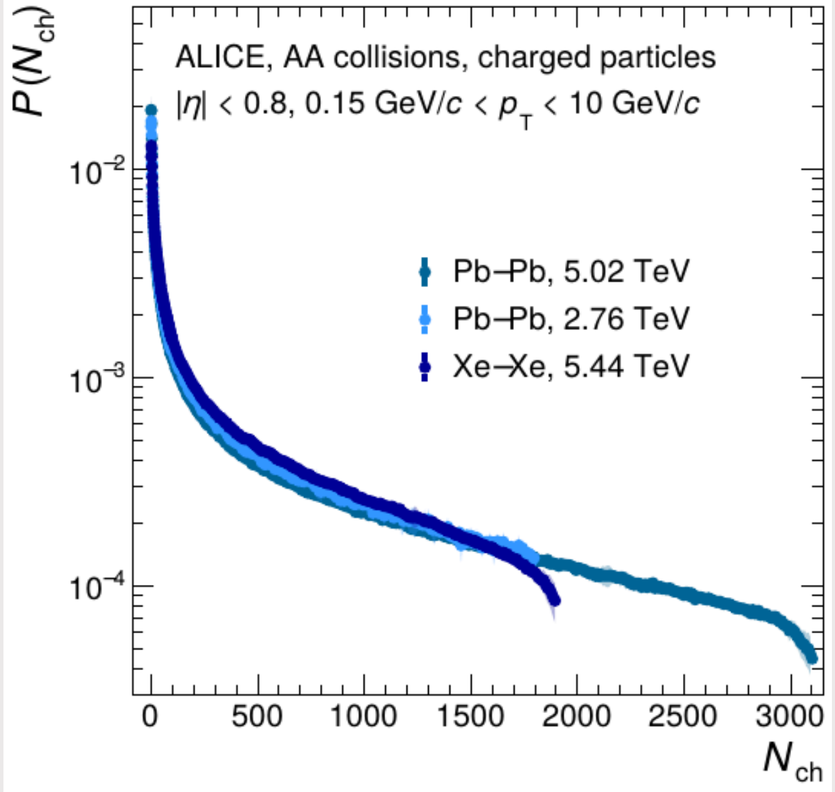
- $soft > semi - hard$
- $\langle n_1 \rangle \alpha \langle n_2 \rangle$

Why still study multiplicity?

- It has been a very studied observable considering different systems, energies and ranges
  - In HEP → p-p, p-Pb, Xe-Xe and Pb-Pb
  - Energies: from 900 GeV to 13 TeV



Multiplicity distribution of p-p collisions at central pseudorapidity for different energy ranges

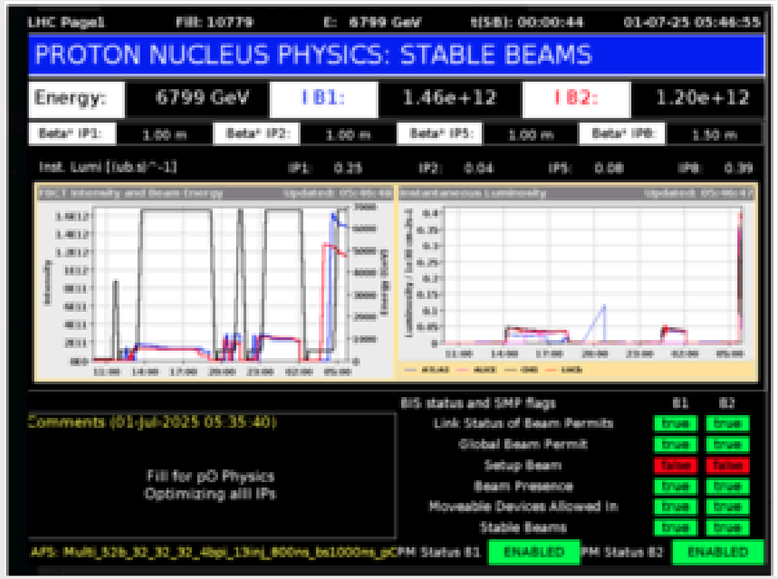


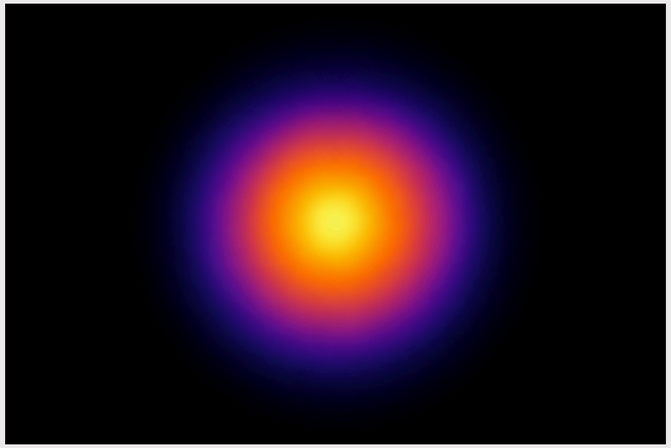
Multiplicity distribution of heavy-ion collisions at central pseudorapidity for different energy ranges (especially for Pb-Pb)

Why oxygen collisions?

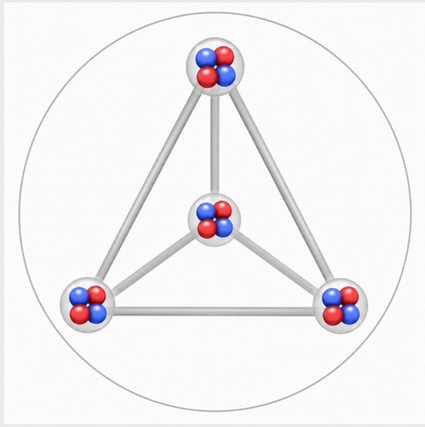
- The Large Hadron Collider (LHC) performed **light-ion collisions** for the first time in 2025
- Oxygen collisions represent an **intermediate system** between p-p and heavy-ion collisions
- Observables may describe open questions from both the created environment and the nucleus, such as the **inner structure**

First time on July 1st 2025





Woods-Saxon Distribution



Alpha Cluster Distribution

Objectives

- Study the multiplicity distribution in p-O collisions
  - Simulation & Data (ALICE Collaboration)
- Evaluate if multiplicity is sensitive to the oxygen initial state and its nuclear distribution

Methodology

- Data analysis → Work in progress
- MC Simulation:
  - Pythia/Angantyr vs kT-factorization

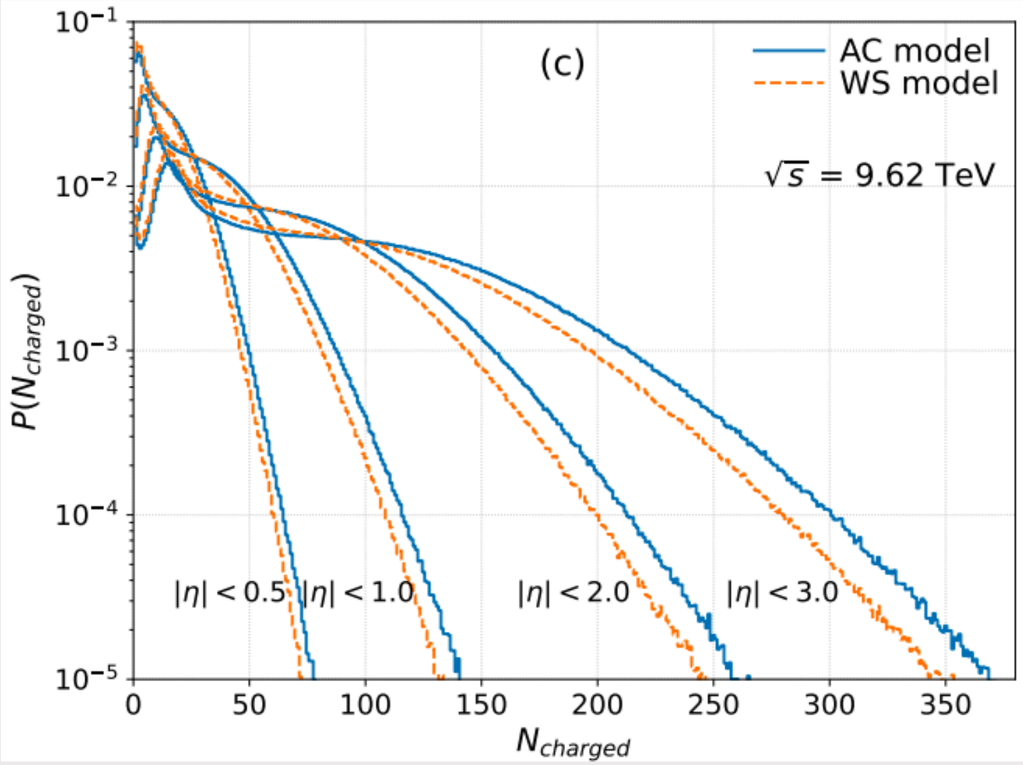
Based on collinear factorization with phenomenological increments

kT Factorization

It generalizes collinear factorization to small x-regions (high energies) → transverse momentum of the partons cannot be neglected

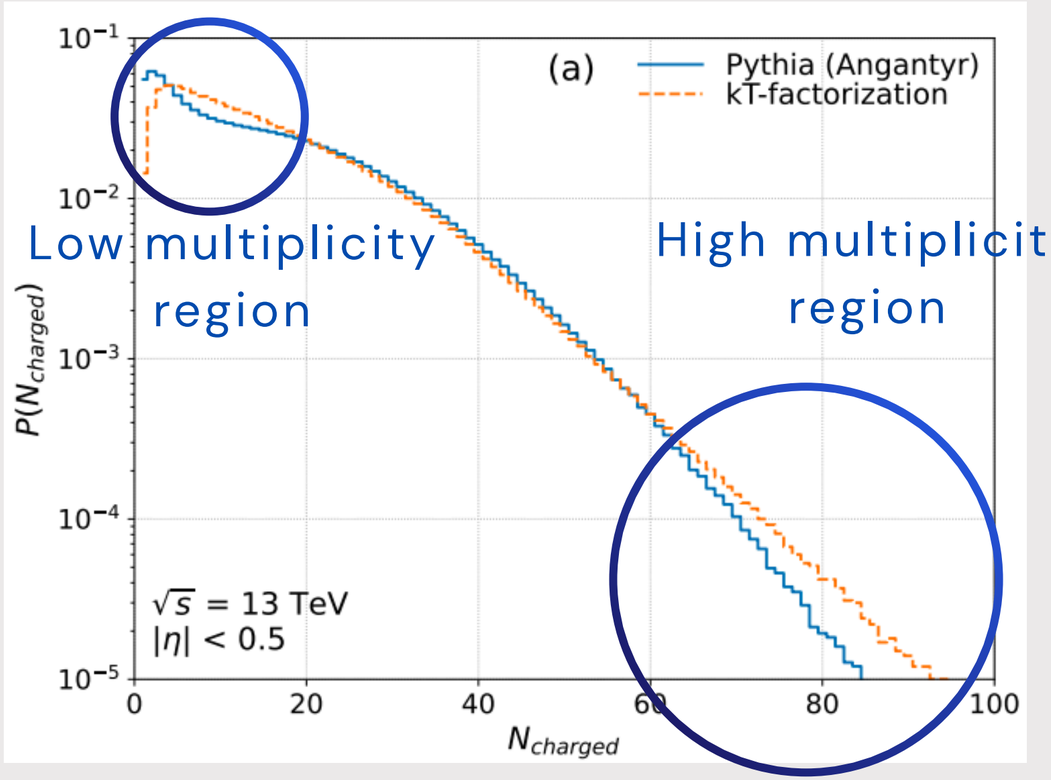
Approved phenomenological results

Comparison between the **Alpha Cluster Model** and the **Woods-Saxon Model**



- There is a significant difference between the models across the entire spectrum. This behaviour **increases with N and pseudorapidity**.

Comparison between the **two phenomenological tools**



Reasons for discrepancies :

- **Low multiplicity** → differences in modeling
- **High multiplicity** → particle production formalisms (influence of gluons?)

Outcome and next steps

- Can we compare particle production mechanisms in p-O with the already known systems?
  - YES!

- Is the Oxygen nucleus really composed of 4 alpha particles?
  - Maybe, who knows?
  - Multiplicity is sensitive to the initial geometry

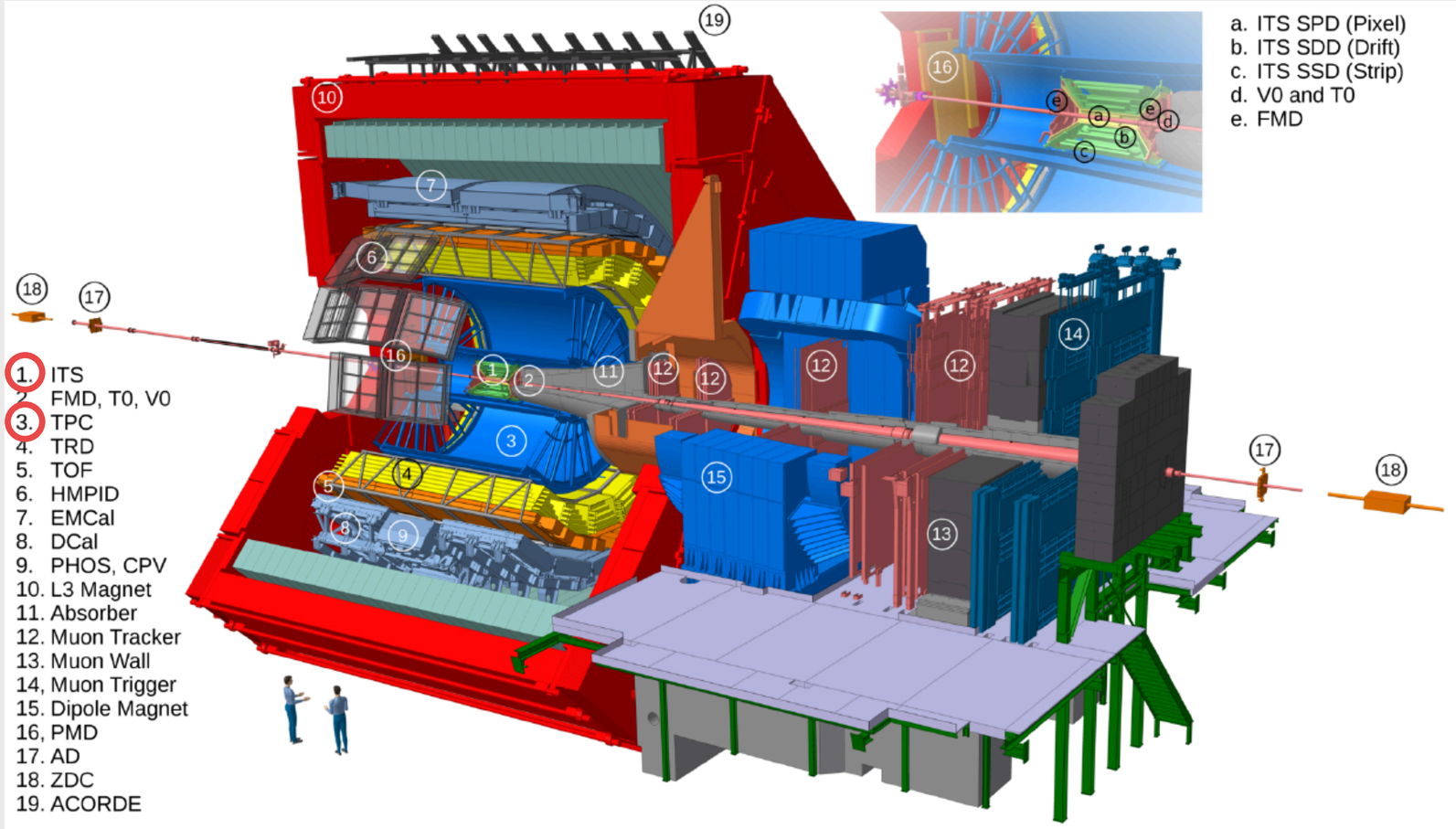
- Does real data prove the alpha cluster model?
  - We are still working on the best way to make this comparison based only on the MD
  - 🤐 (we are optimistic with the results so far)

- What's left to be done?
  - Analysis procedure and analysis bureaucracy
  - Evaluate the real-life effects and how this is reflected (or not) in data.

Thank you!

Backup

Detectors in ALICE experiment



Track Selection:

- Global Tracks → ITS + TPC Tracks
- ITS-only Tracks

*TPC-only Tracks → limited pseudorapidity range and low pointing resolution due to distance from collision vertex

Event Selections

The selection of events is done by considering different triggers and different criteria:

- Select the best bunch crossing, based on the timing of the arriving signals, by evaluating the presence of coincident signals in the forward detectors FTO-A and FTO-C
- Rejection of ITS ReadOut Frame Border due to distance from bunch crossing
- Rejection of pileup collisions in the same bunch crossing
- INEL > 0 → requires the reconstruction of at least one charged particle within $|\eta < 1.0|$
- Vertex *z*-position within 10 cm from the nominal interaction point

Analysis procedure

$$O_{data}^{Corrected} = O_{data}^{unfolded} \times \frac{f_{evt}}{f_{sig}}$$

Raw Distribution

Distribution without correction effects

Unfolding correction

Corrections due to detector effects

Event Loss and Signal Loss correction

Corrections in lower bins due to biases in vertex or trigger evaluation

Systematic Uncertainties

Evaluation of all sources of uncertainty in the analysis

Corrected and adjsuted distribution

Systematic Uncertainties

Source	Variation
Track Selection	One hit on first 3 ITS layers
Vertex cut	$\lvert v_z \rvert < 5$ cm $\lvert v_z \rvert < 7$ cm
Unfolding iterations	2 iterations, 8 iterations
Run-by-Run fluctuations	3 different groupings
ϕ Selection	$0 < \phi < \pi/2$, $\pi/2 < \phi < \pi$, $\pi < \phi < 3\pi/2$, $3\pi/2 < \phi < 2\pi$,
Low pT generated particles	$2 - 10 \times p_t^{gen}$ $0.5 + 5 \times p_t^{gen}$

Alpha cluster parametrization

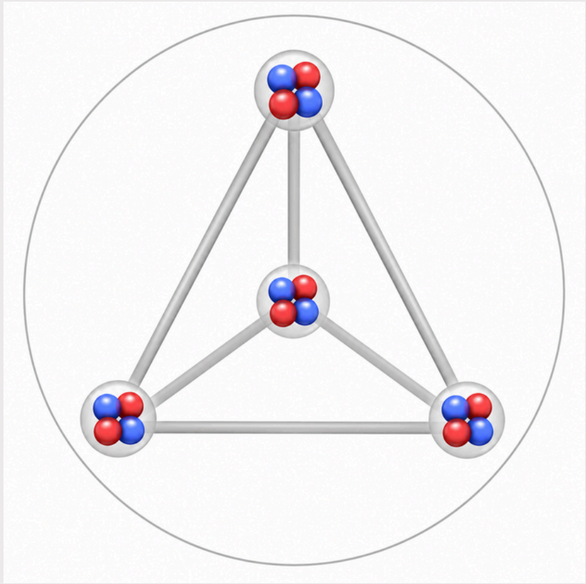
Nuclear charge density is considered at a radial distance r from the center of nucleus, via the 3pF distribution:

$$\rho(r) = \frac{\rho_0[1 + w(r/R)]}{1 + \exp[(r - R)/a]}$$

R → nuclear radius = 0.964 fm

a → diffuseness parameter = 0.322 fm

w → skin thickness parameter = 0.517



- For each cluster, the positions of the nucleons are randomized by applying three successive Euler rotations
- The parameter w is the main difference between the models. If it is 0, we revert to the Woods-Saxon model