Searches for pion condensation in pp and Xe-Xe collisions with ALICE experiment at the LHC

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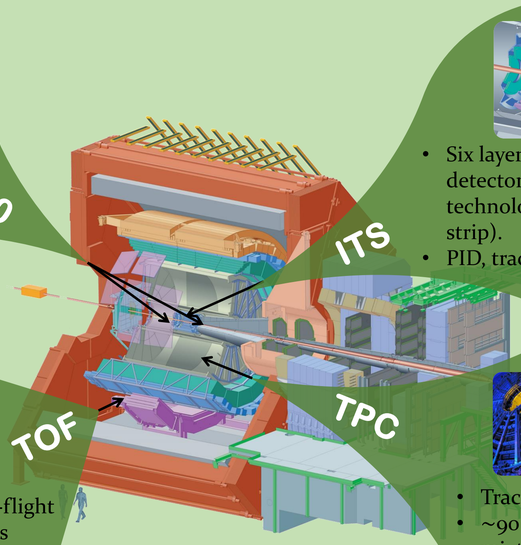
Two arrays of scintillator counters
- **V0A** ($2.8 > \eta > 5.1$)
- **V0C** ($-3.7 < \eta < -1.7$)

→ Trigger and centrality determination

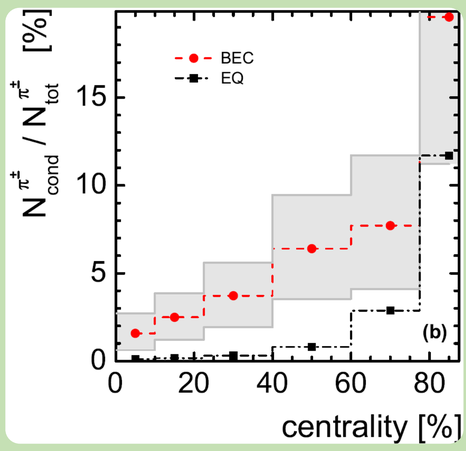


- Six layers of silicon detectors of three different technologies (pixel, drift, strip).
- PID, tracking and vertexing

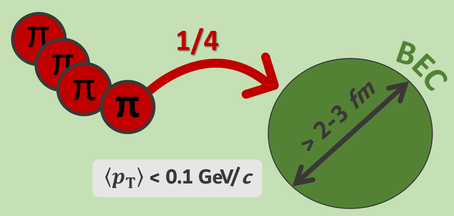
- PID by means of time-of-flight
- A time resolution of 80 ps provides a **3σ π/K and K/p separation up to p = 2.2 GeV/c** and **4 GeV/c, respectively**

- Tracking and PID through dE/dx
- ~90 m^3 cylinder filled with a mixture of gases
- Coverage (full tracks): $|\eta| < 0.9$

- Most of the hydrodynamic calculations have problems with the prediction of very low-p_T spectra of pions (for example ALICE results in Pb-Pb 2.76 TeV [1]).
  - **Possible solution**: the matter produced in heavy-ion collisions at LHC energies is formed out of chemical equilibrium [2].
- Chemical non-equilibrium model predicts that the pion abundances are characterized by a **non-zero value of the chemical potential (μ)** that is close to the **critical value for the Bose-Einstein Condensation** (BEC) [2].
  - Almost 5 % of the pions are expected to be in the condensate



- NA44 experiment: ratio of π^+ spectra in Pb-Pb and S-S shows an enhancement at low p_T correctly reproduced assuming non-zero μ_π (60, 80 or 100 MeV) [3].
- At **LHC energies** the fit **without** chemical equilibrium and with $\mu_\pi \neq 0$ describes better the low-p_T pion spectra [3].
  - The fit gives $\mu_\pi \approx m_\pi$ → **BEC reached**?
- From 2-3-pion correlations in ALICE [4], the fraction of coherent pions is **23% ± 8%.**



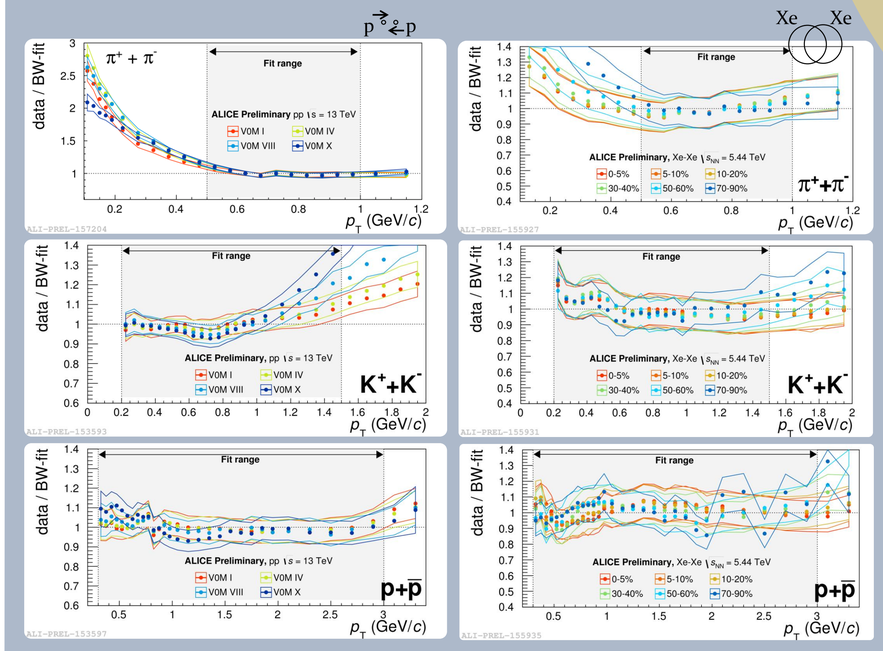
- **Boltzmann-Gibbs blast-wave fit** [5] → A three parameters simplified hydrodynamical model
- The **resulting spectrum is a superposition of the individual thermal sources**, each boosted with the boost angle ρ.

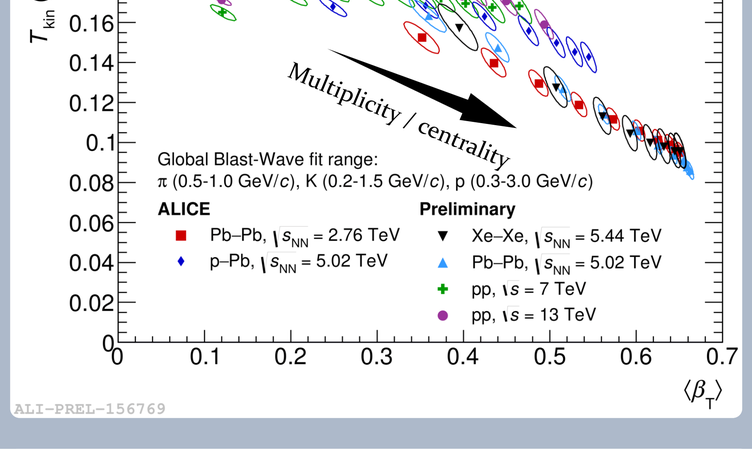
$$E\frac{d^3N}{dp^3} \propto \int_0^R m_T I_0\left(\frac{p_T \sinh(\rho)}{T_{kin}}\right) K_1\left(\frac{m_T \cosh(\rho)}{\beta_T}\right) r\, dr$$

$$\rightarrow m_T = \sqrt{m^2 + p_T^2} \quad \rho = \tanh^{-1}(\beta_T) \quad \beta_T(r) = \beta_s \left(\frac{r}{R}\right)^n$$

n: velocity profile ↔ profile form
T_{kin}: kinetic freeze-out temperature
$\beta_T(r)$: transverse velocity distribution
m_T: transverse mass
β_s: surface velocity
ρ: boost angle
I_0, K_1: Bessel functions

- BW model doesn't describe low-p_T pion production in pp and Xe-Xe. In general, π, K and p are well described within the fit range.
- **T_{kin} and $\langle\beta_T\rangle$ evolve with multiplicity**
  - comparable T_{kin} and $\langle\beta_T\rangle$ in pp & p-Pb, Xe-Xe & Pb-Pb at similar multiplicities
  - The most central AA collisions have the highest T at the early stages and so, the lowest T_{kin} at the end.





Conclusions

Pion production can be studied at very low p_T (0.1 GeV/c) with the ALICE experiment. Pions show an enhancement in high multiplicity pp collisions with respect to MB collisions. In Xe-Xe, pions are not suppressed as kaons and protons in central collisions. The excess of pions at low p_T is not fully described by Blast-Wave model. We observe the thermal spectrum modified which, however, could also be caused by resonance decays. The question if BEC is reached remains open.

Future perspectives

Study of very low p_T pions (< 0.1 GeV/c) with the ALICE ITS and inclusion of model with chemical and non-chemical equilibrium.

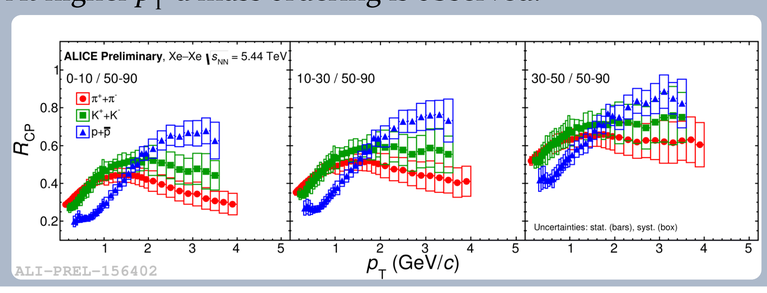
ALICE ◎ Pion condensation ◎ Pion spectra ◎ Ratios ◎ Blast-wave fits ◎

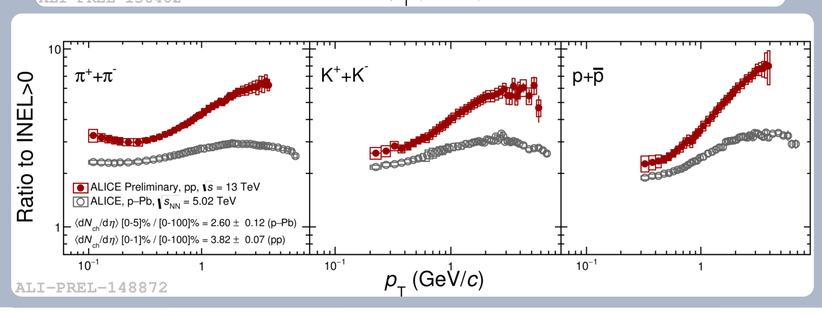
- **Ratio central-to-peripheral in Xe-Xe**

$$R_{CP} = \frac{1/\langle T_{AA}^{cent}\rangle \cdot (d^2N^{cent}/(dp_T dy))}{1/\langle T_{AA}^{periph}\rangle \cdot (d^2N^{periph}/(dp_T dy))}$$

T_{AA} : nuclear overlap function

- Pions are less suppressed than kaons and protons at low p_T in most central collisions. Pure radial flow or pion condensation contribution?
- At higher p_T a mass ordering is observed.

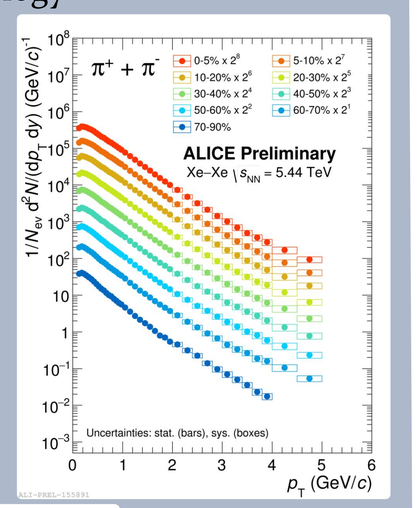


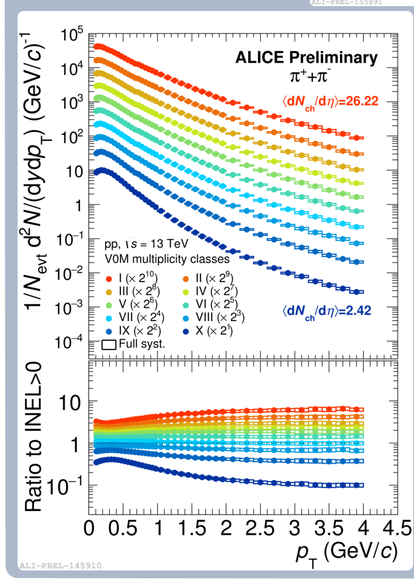


- **Centrality estimation with V0 amplitudes**
- Combination of **ITS, TPC and TOF particle identification** capabilities including kaons from kink decay topology

Pion spectra in Xe-Xe collisions vs multiplicity

- Collisions at a lower magnetic field in ALICE (**0.2 T**)
- Higher reconstruction efficiency with respect to nominal field (0.5 T)
- The low-p_T (down to 50 MeV/c) pion production will be better studied in Xe-Xe with the ALICE ITS with unfolding method to minimize p_T resolution biases.





Pion spectra in pp collisions vs multiplicity

- In high multiplicity collisions, pion ratio to [0-100] % INEL>0 shows an enhancement at low p_T

Ratio to [0-100] % at high multiplicity

- In high multiplicity pp collisions a low-p_T enhancement for pions is observed. Not observed in p-Pb.
- The low-p_T enhancement is not observed for kaons and protons neither in pp nor in p-Pb at high multiplicity

[1] ALICE Collaboration, *Phys. Rev. C 88, 044910 (2013)*
[2]V. Begun, W. Florkowski, *Phys. Rev. C 91, 054909 (2015)*
[3] E. Shuryak, *C. M. Hung, Phys. Rev. C 57 1891 (1998), Rev. Mod. Phys. 89, 35001 (2017)*
[4] ALICE Collaboration, *Phys. Rev. C 89 (2014) 024911*
[5] E. Schnedermann, J. Sollfrank, U. Heinz, *Phys. Rev. C 48 (1993) 2462*

References