MPI@LHC 2023 University of Manchester

EPOS4 overview

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Outline:

- **EPOS4 in the context of 50 years of pQCD**
- **New features**
- **Results on ratios vs multiplicity**

Some history

Before QCD

- **Gribov-Regge (GR) approach, for pp, pA, AA**
  V. A. Abramovsky, V. N. Gribov, O. V. Kancheli, L. N. Lipatov **(1967-1973)**
- **S-matrix theory, parallel scattering scheme**
- **Exchanged "objects" are called Pomerons**
- **AGK theorem** ($\sigma^{AB}_{\text{incl}} = AB \times \sigma^{\text{single Pom}}_{\text{incl}}$)
- **Infinite energy limit**
  (problematic...)
- **Still used (Glauber MC ...)**
  not necessarily correctly

Perturbative QCD for pp

- **Asymptotic freedom**
  D. Gross, F. Wilczek,H. Politzer **(1973)**
- **DGLAP (linear) evolution**
  V. N. Gribov, L. N. Lipatov **(1973)**
  G. Altarelli, G. Parisi **(1977)**, Y. L. Dokshitzer **(1977)**
- **Factorization** J. Collins, D. Soper, G. Sterman **(1989)**
- **Covers only a small fraction of events**
  High multiplicity events are not covered

Saturation (CGC, low-x physics,...)

- **Nonlinear evolution**
  L. V. Gribov, E. M. Levin, and M. G. Ryskin **(1984)**
  L. D. McLerran and R. Venugopalan **(1994)**, Y. V. Kovchegov **(1996)**, ...

An attempt to couple GR and pQCD

- **NEXUS model, earlier EPOS versions**
  Drescher, H. J. and Hladik, M. and Ostapchenko, S. and Pierog, T. and Werner, K. **(2001)**
- **Using: Pomeron = pQCD parton ladder**
- **With energy sharing! (GR^+)**
  crucial for MC applications
- **Problem: violates AGK (and binary scaling)**

Solution: EPOS4 = GR^+ & pQCD & saturation

- **Implement saturation based on theory constraints**
- **Redefine link Pomeron <-> pQCD parton ladder**
- **Fully recovers AGK (and geometric properties which follow)**

EPOS4

- **Oct. 2022 EPOS4.0.0 release** (no "official" EPOS3 release)
  https://klaus.pages.in2p3.fr/epos4/
  thanks Laurent Aphecetche for explaining gitlab pages, nextjs etc
  thanks Damien Vintache for managing installation/technical issues

- **Papers** (https://klaus.pages.in2p3.fr/epos4/physics/papers)

  - **https://arxiv.org/pdf/2301.12517.pdf** (EPOS4 Overview)
  - **https://arxiv.org/pdf/2306.02396.pdf** (pQCD in EPOS4)
  - **https://arxiv.org/pdf/2310.09380.pdf**
    (46 pages, systematic and complete presentation of the theoretical basis,
    combining S-matrix theory, pQCD, saturation,
    many proven statements)
  - **https://arxiv.org/pdf/2306.10277.pdf**
    (Microcanonical hadronization, core-corona in EPOS4)

□ **EPOS4 general structure** (Possible at "high energies")

▷ **Primary scatterings (at t = 0)**
parallel scattering approach based on S-matrix theory
(Major changes)

▷ **Secondary scatterings (at t > 0)**
- core-corona procedure (New methods)
- hydro evolution [1]
- microcanonical decay (New)
- hadronic rescattering [2]

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[1]) I. Karpenko et al, Computer Physics Communications 185, 3016 (2014), K. Werner, B. Guiot, I. Karpenko, and T. Pierog, Phys. Rev. C 89, 064903 (2014), 1312.1233,

[2]) S. A. Bass et al., Prog. Part. Nucl. Phys. 41, 225 (1998), M. Bleicher et al., J. Phys. G25, 1859 (1999)

EPOS4: From Pomerons to prehadrons

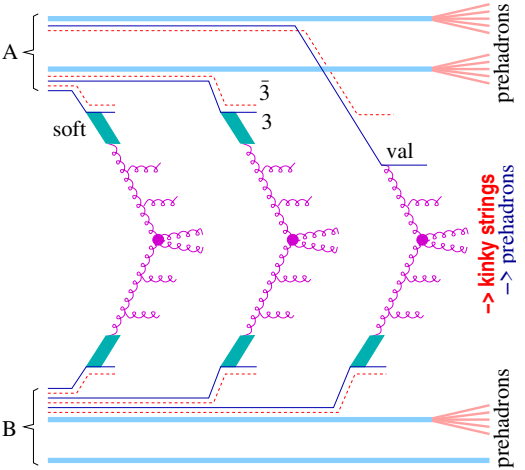
Very compact summary (details: arXiv:2306.02396)

From multiple Pomeron configurations, after making the link with pQCD, we get
partonic configurations

=> color flow diagrams
=> parton chains
=>kinky strings
=> prehadrons

also: remnants
=> prehadrons

At the end: many prehadrons



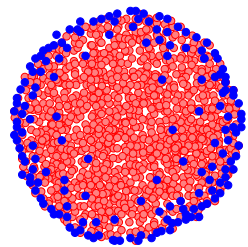
EPOS4: Core-corona separation

(details: arXiv:2306.10277)

We consider all prehadrons (at given τ)

For each one, we estimate its energy loss if it would move out of this system

- **If the energy loss is bigger than the energy of the prehadron, it is considered to be a "core prehadron"**
- **If the energy loss is smaller than the energy, the prehadron escapes, it is called "corona prehadron"**



The core prehadrons constitute "bulk matter", which will be treated via hydrodynamics and decays eventually microcanonically (NEW)

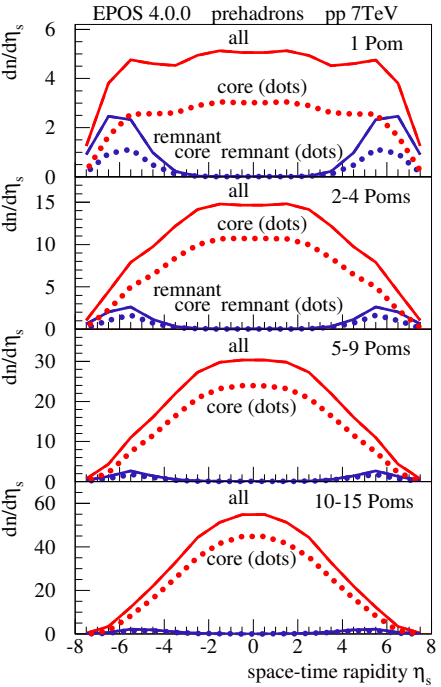
The corona prehadrons become simply hadrons and propagate with reduced energy

The prehadron yield as a function of space-time rapidity,

for different Pomeron numbers in proton-proton collisions at 7 TeV.

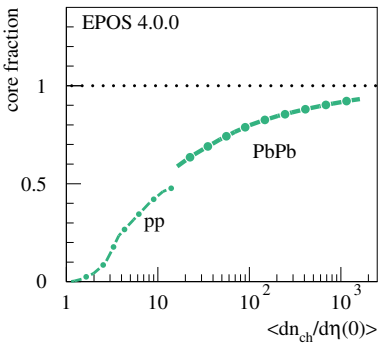
prehadrons:
all (red full),
core (red dotted)
remnant (blue full)
core remnant (blue dotted)

For core: compute $T^{\mu\nu}$ and flavor flow vector, then hydro evolution.



Core + corona results - multiplicity dependencies

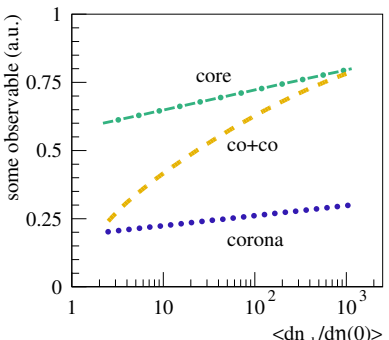
Core fraction



Almost continuous!

see DCCI2, Y. Kanakubo et al
Phys. Rev. C 105 (2022) 2, 024905

Core + corona (co+co) results (sketch)

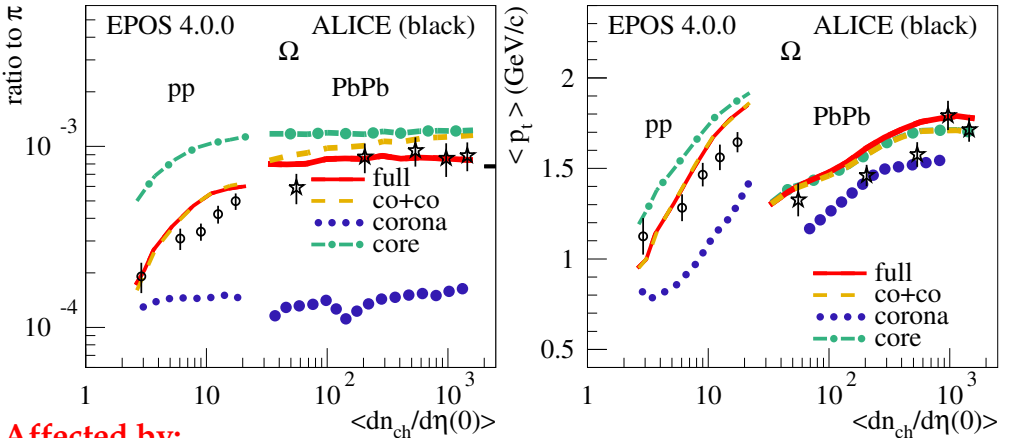


Transition from corona core

Attention ! Core and corona curve continuous ... or not (depends on variable)

On top: effects from hadronic cascade (UrQMD, S. A. Bass et al., Prog. Part. Nucl. Phys. 41, 225 (1998), M. Bleicher et al., J. Phys. G25, 1859 (1999))
aaa

continuous curve **jump**



Affected by:

core-corona

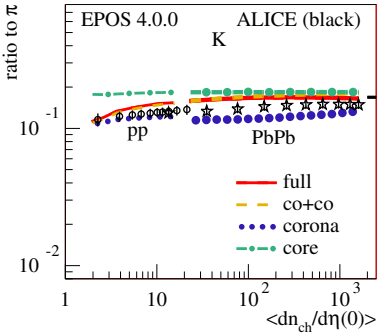
microcanonical

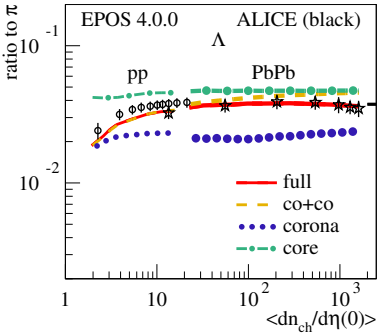
hadronic cascade (UrQMD)

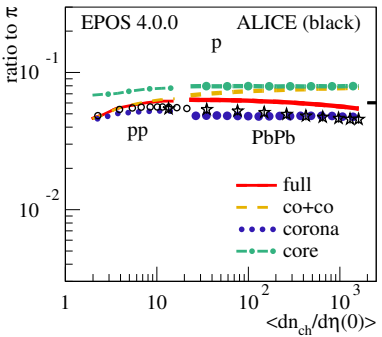
saturation

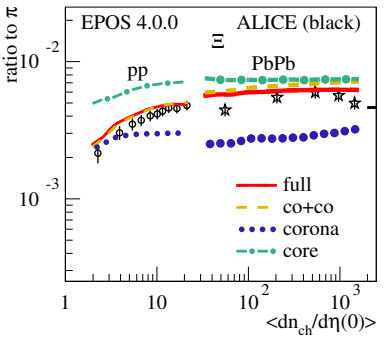
flow

core-corona









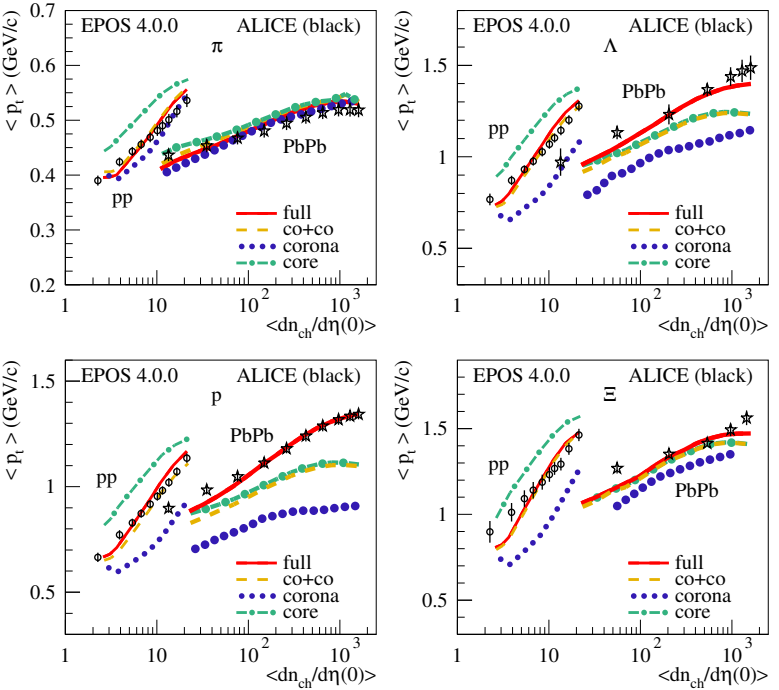
continuous curves

Affected by:

core-corona

microcanonical

hadronic cascade



discontinuities

curves affected by:

saturation

flow

core-corona

hadronic cascade

To summarize the EPOS4 approach

- **Primary interactions: one combines in a particular way**
  (finally free of contradictions)
  - **S-matrix approach with energy sharing (GR^+)**
  - **and pQCD** (specifying the Pomeron in terms of pQCD)
  - **by introducing saturation (driven by theory constraints)**
- **Secondary interactions** (using prehadrons from primary interactions)
  - **core-corona, hydro evolution**
  - **microcanonical decay** (new)
- **Looking at multiplicity dependencies**
  - **Ratios (continuous), mean pt (discontinuous curves)**
  - **both understood in terms of core (flow, stat. decay) and corona (saturation)**