Challenges and highlights in heavy ions physics

Based on the lecture “Monte Carlo Event Generators” by Klaus WERNER, given at the summer school “Heavy Ion Collisions in the QCD phase diagram” , June 27 - July 08, 2022, Nantes, France.

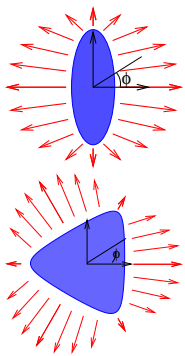
Since 2 decades we know: Colliding heavy ions at relativistic energies

behave like an expanding fluid, with huge transverse flow

(observables: pt spectra)

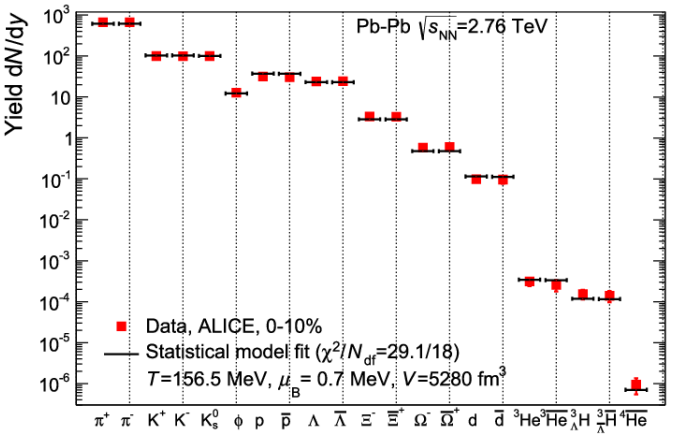
being in particular asymmetric: elliptical / triangular ...

(observables: flow harmonics v2, v3 etc)



We see "statistical particle production"

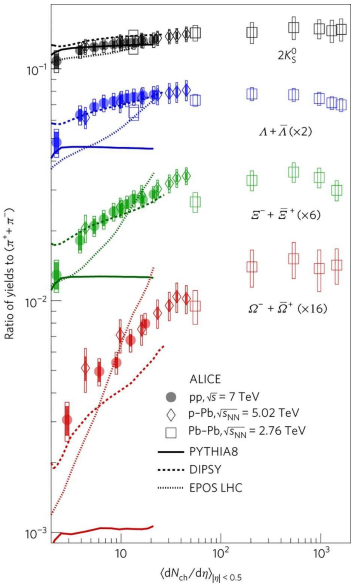
(observables: particle yields or ratios)



A Andronic et al 2017 J. Phys.: Conf. Ser. 779 012012

Very different compared to particle production from string decay

But similar features show up in small systems, at low energies, and as well for heavy flavor particles.



Yields/pions vs multiplicity, for pp, pPb, PbPb
(ALICE, in nature physics 2017)

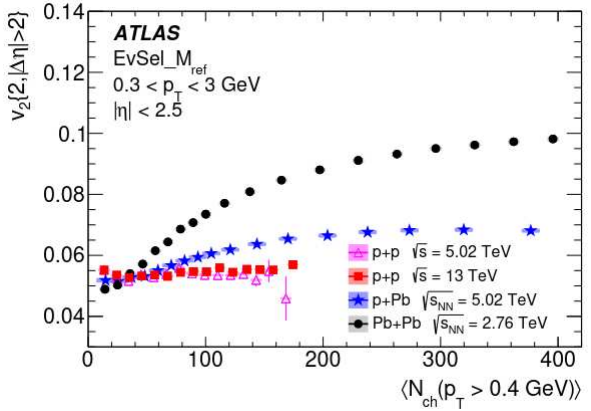
Central PbPb understood as due to "statistical particle production"

But it seems that pp and pPb are at least partly also showing this behavior

The event generators ... clearly need to be improved

v2 vs multiplicity for pp, pPb, PbPb

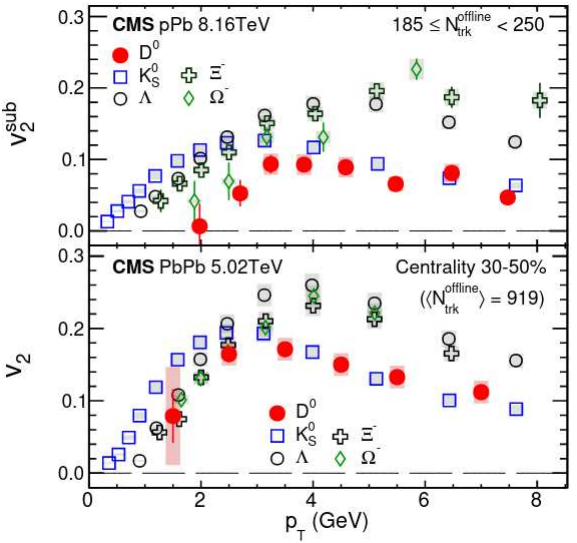
(Eur. Phys. J. C 77 (2017) 428)



Large v2 values (flow) for all systems, but different N_ch dependence

Small energy dependence

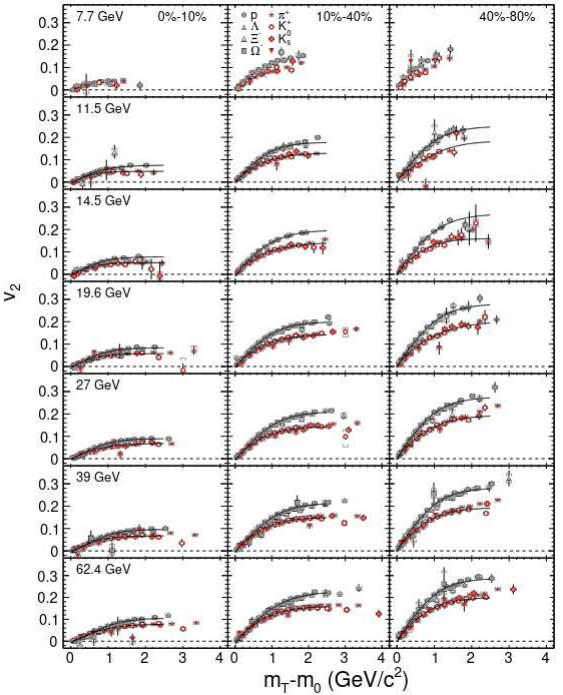
small N_ch dependence in pp



v2 vs pt
for pPb at 8.16TeV
and PbPb at 5.02TeV
(Phys. Rev. Lett. 121, 082301)

Large v2 values in pPb even for D mesons

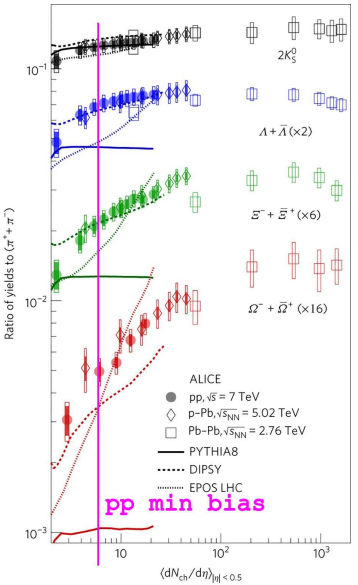
Similar to K_s at large pt ("usual" meson behavior)



v2 vs m_T
for AuAu at 7-62 GeV
(Phys.Rev.C 93 (2016) 1, 014907)

Similar behavior down to low energies (where no QGP is expected)

Actually flow / statistical decay issues are relevant even for min bias pp!



elementary pp models
(particle production simply based on string decay)

do not produce enough Ω baryons even for min bias pp

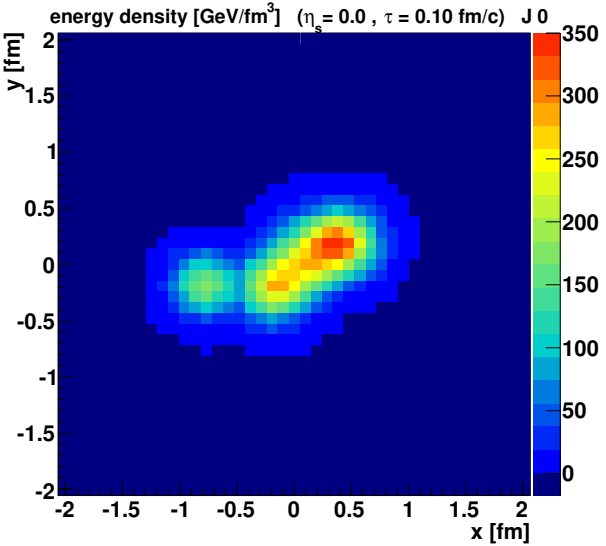
so some "new input" is needed ... compatible with the "normal" pp behavior (jets etc)

So these "features" (flow, stat. hadronizaton,...)**, usually referred to as "QGP signals", expected in high energy heavy ion collisions,**

- ☐ **show up in pp scattering, even min bias**
- ☐ **show up in "low energy" collisions**
- ☐ **concern even charmed hadrons**

In particular the "small systems" (pp, pA) are very interesting...

EPOS simu pp 7TeV



Energy density vs x,y

Tiny

Very short lived (<2fm/c)

Very energetic here 350 GeV/fm3

(nuclear matter: 0.16 GeV/fm3)

Very strongly interacting

(fluid-like)

We better understand all that in a quantitative fashion ... and not to forget high pt features happening at the same time! We have

- **these "mini-plasmas" producing low pt particles**
  (soft domain)
- **and very high pt particles**
  (from pQCD processes, hard domain)

=> we need general purpose Monte Carlo Event Generators which allow to incorporate and test these "features"