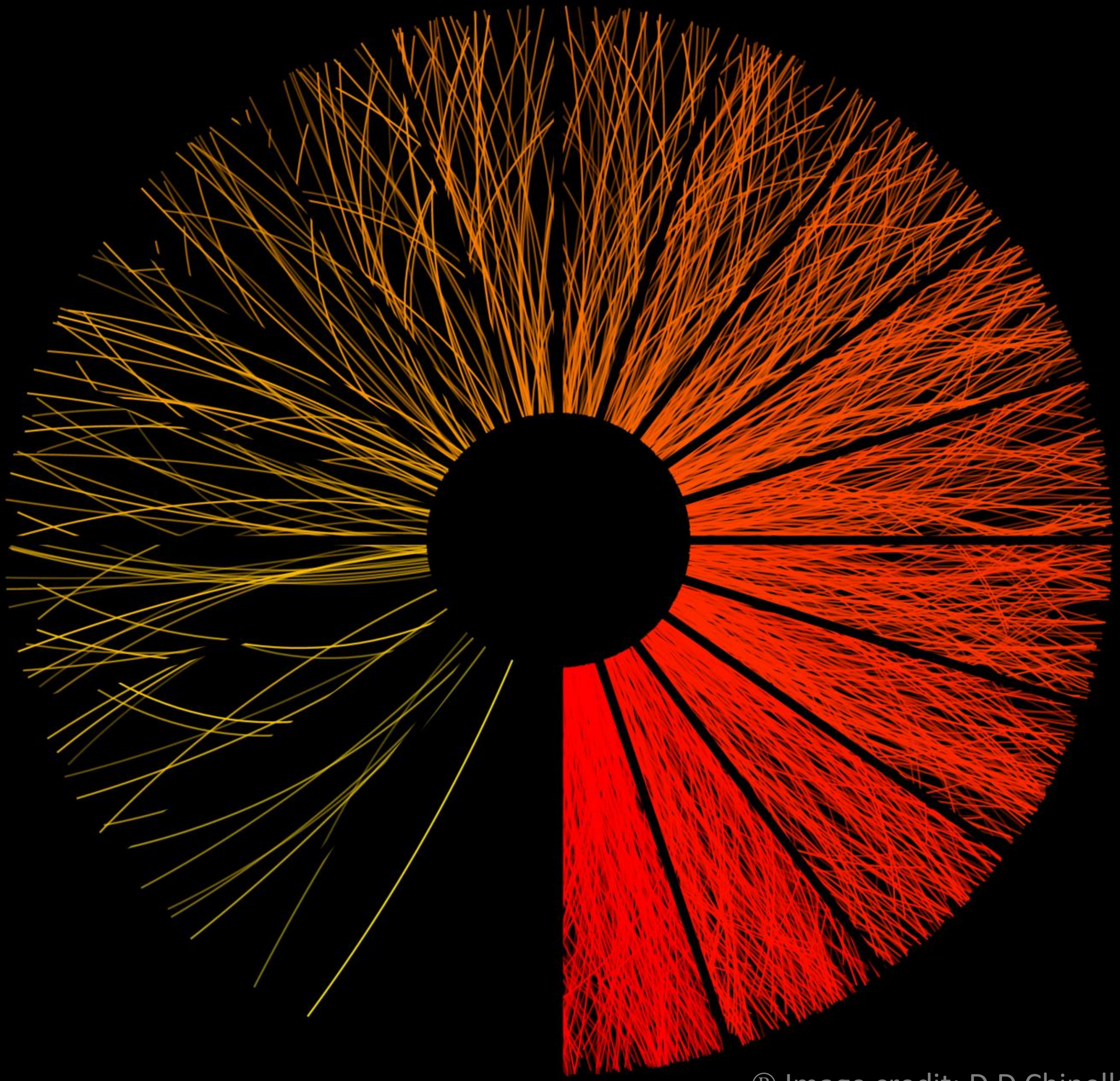
Small Systems

Livio Bianchi
QM 2018 – Venice
Students day

Livio.Bianchi@cern.ch



® Image credit: D.D.Chinellato

Overview

Warm-up

- What does “small” mean
- Multiplicity
- The Standard Model of HI

Collectivity

Hadrochemistry

Hard Probes

Final considerations

Ciao ciao

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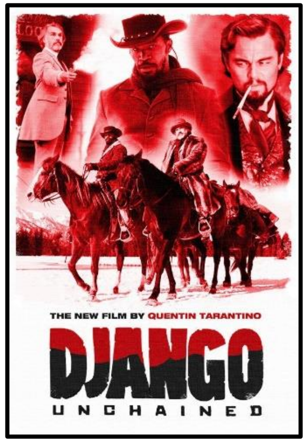
<u>Legend:</u>

Traditional view

Modern view



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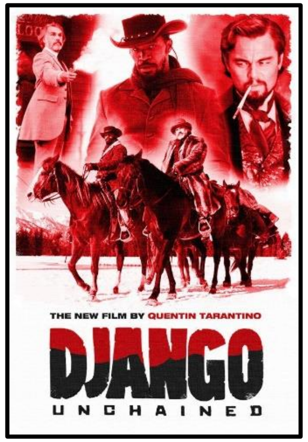
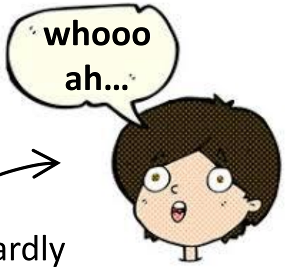


Modern view



Guy awkwardly amazed by physics

TAKE HOME

← **This guy has problems**

Warm-up

Small systems: in which sense?

The attribute “small” normally refers to two different things:

- Size of colliding objects
  - Common way of thinking
  - (ee <) pp < p-A < A-A
- Size of created medium
  - The correspondence to the previous is ~ true only on average
  - N_{part} , N_{coll}
  - Multiplicity

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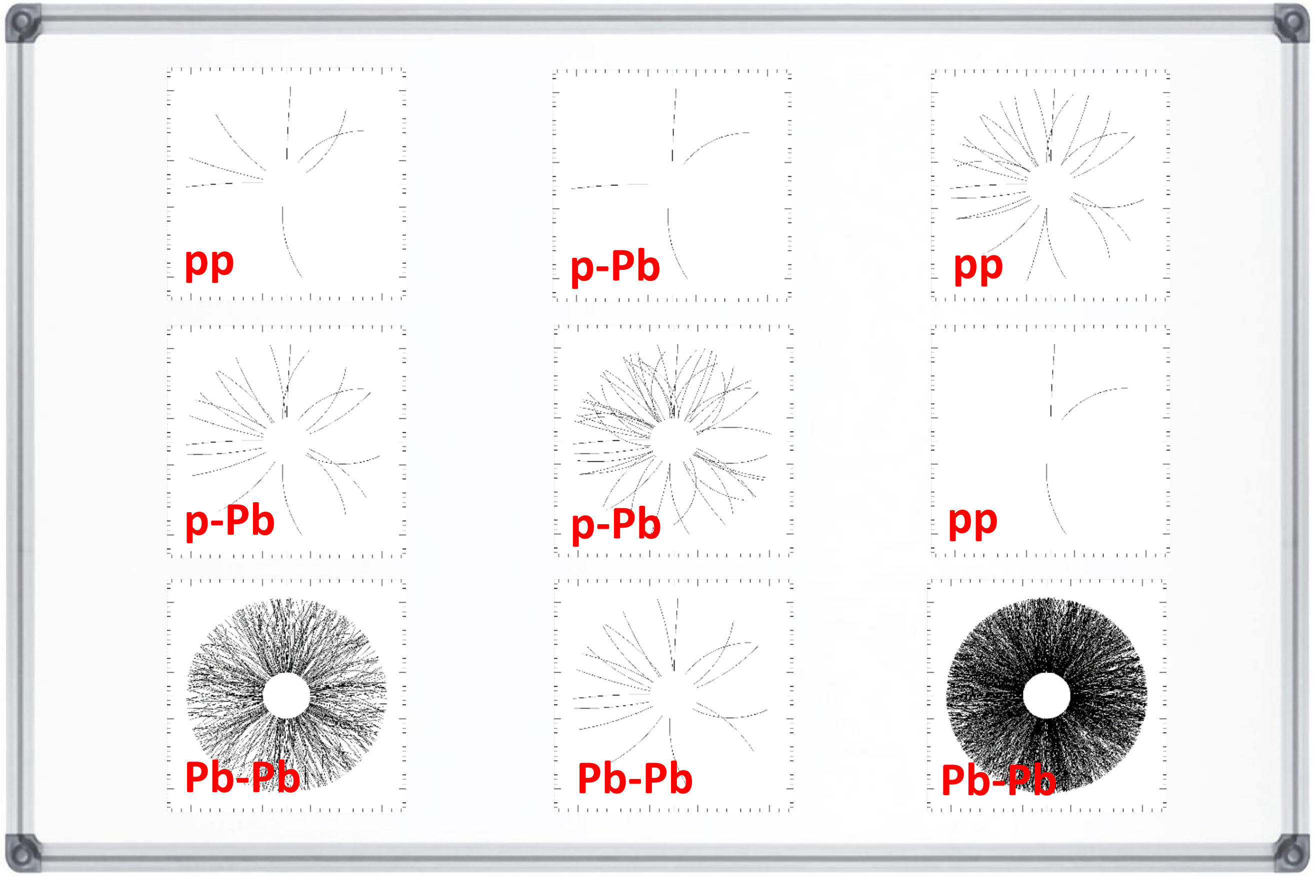

Multiplicity

Multiplicity is a very simple concept:

- Number of particles produced in a defined kinematic region
- HEP experiments have very good performance in reconstructing tracks

But:

- We are mostly interested in primary particles! Need to remove secondaries
- Important concept of MULTIPLICITY ESTIMATOR

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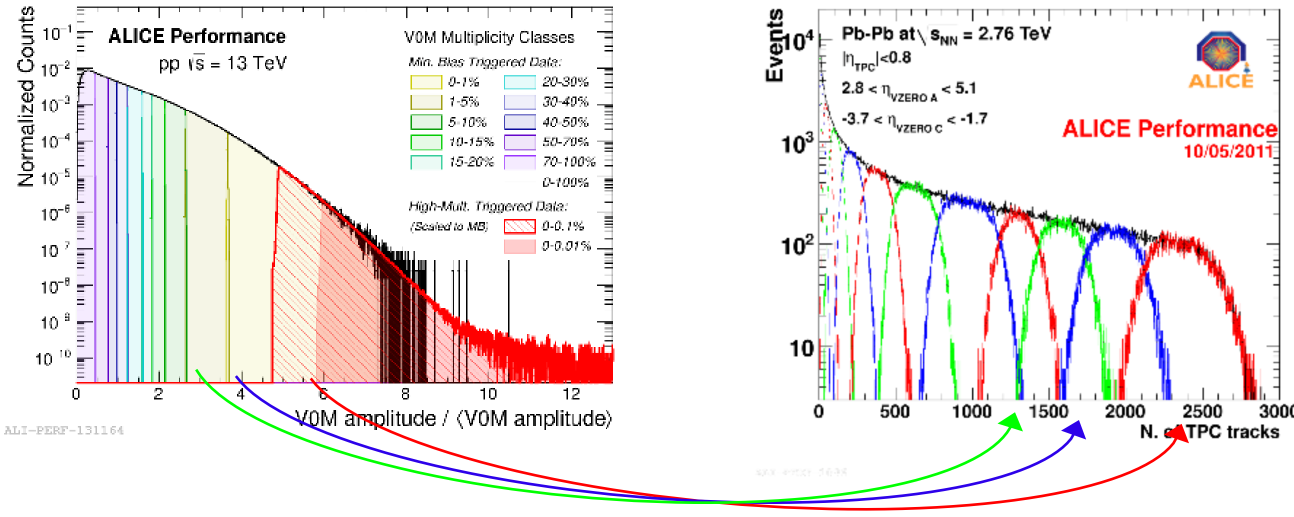
Multiplicity estimator:

- Tool to categorize each event according to its multiplicity
- η gap: important trick to avoid bias in the multiplicity estimation!*
- Comparison among different colliding systems should always be done using unbiased multiplicity estimators



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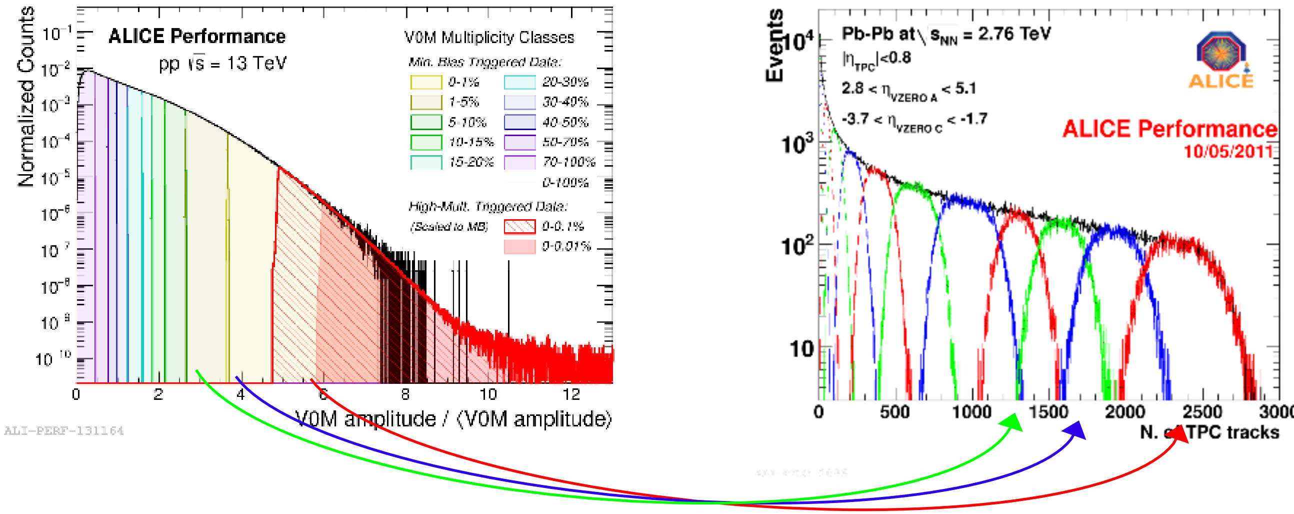

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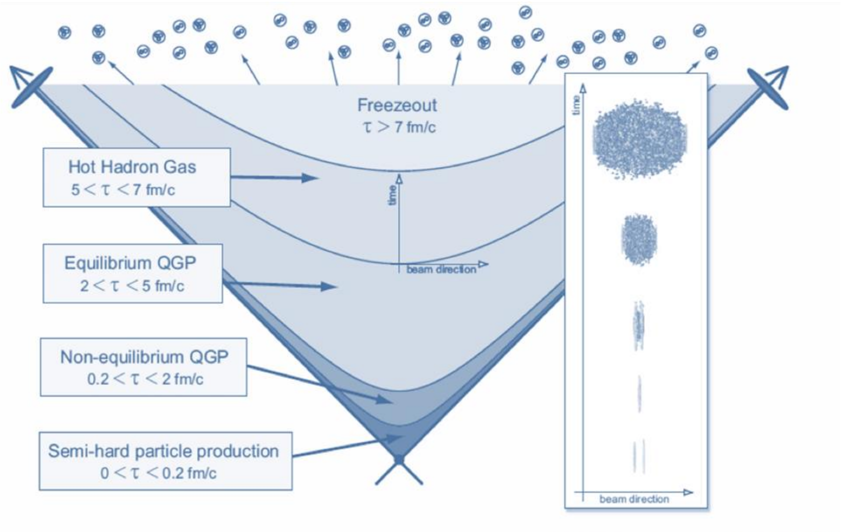
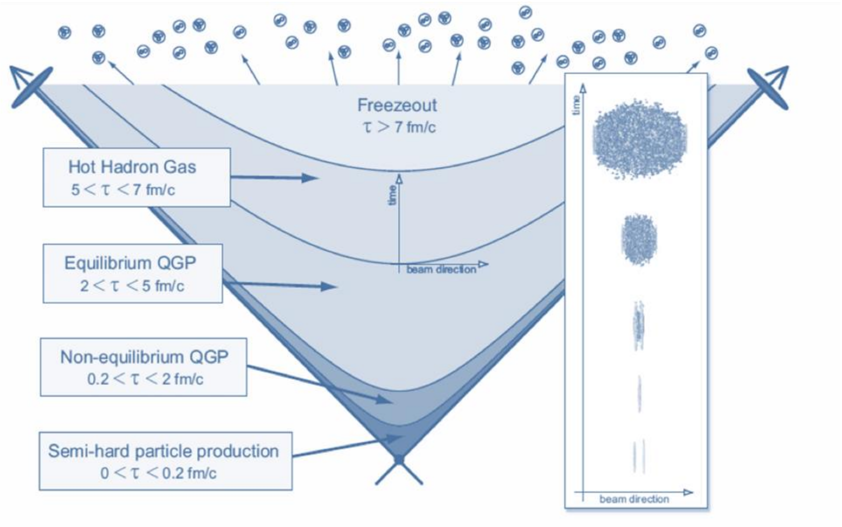
The Standard Model of Heavy-Ion collisions (HISM)



*1 fm/c $\simeq 3 \times 10^{-24}$ seconds

Collectivity:

- flow: correlation between space and momentum (particles close in space → similar velocity in magnitude and direction)
- In contrast to random thermal motion
- Radial and anisotropic flow
- Model: hydro



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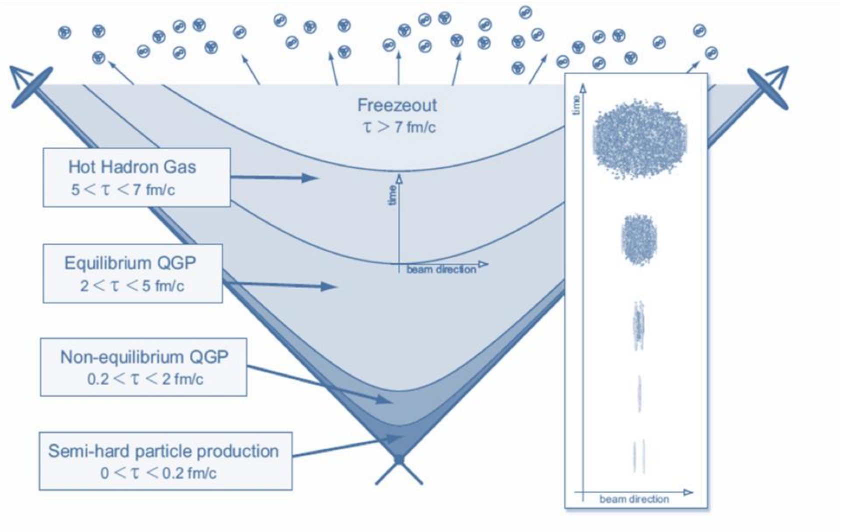

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Hadrochemistry:

- Significantly modified when comparing to elementary collisions
- Relative yields of particles studied
- Model: Statistical (thermal)

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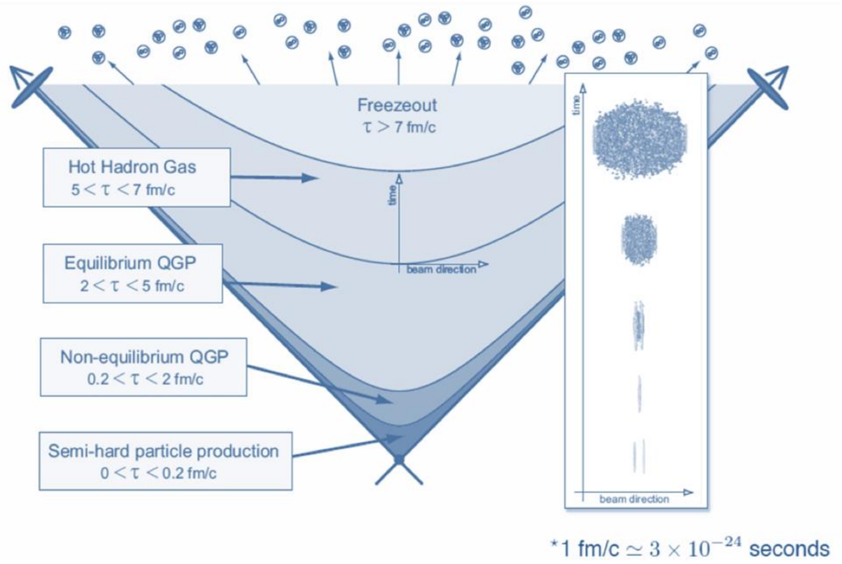

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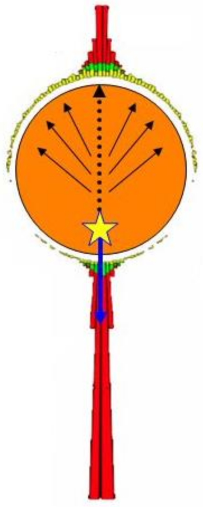
Partonic energy loss:

- Opaque fluid: absorbs energy of partons travelling through it
- Jet quenching
- Can be exploited to measure physical properties (e.g. density)



Quarkonium suppression:

- Debye screening of colour brakes-up qq states
- Sequential suppression of progressively tighter-bound states
- Measures medium's temperature

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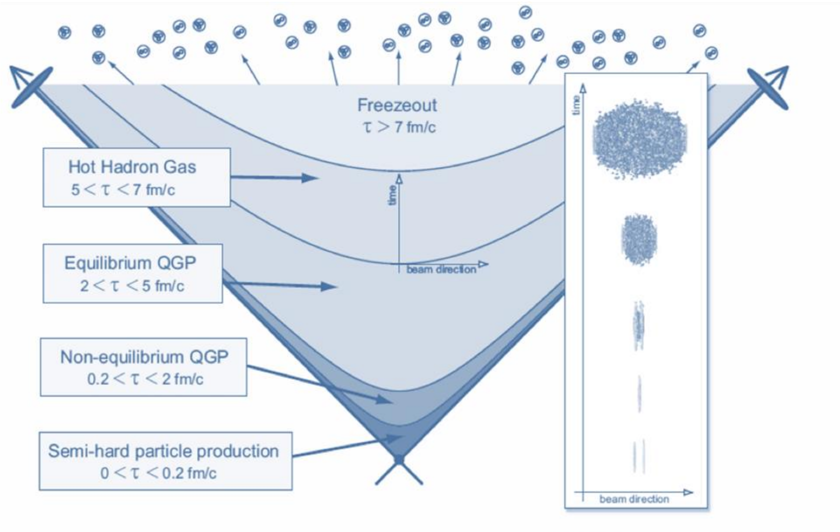

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TAKE HOME

Smoking guns do not survive long.

Compelling evidence of QGP formation in HI comes from several coherent observations

Partonic energy loss:

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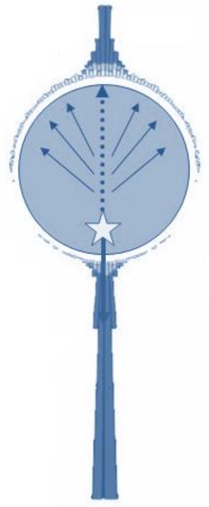
- Can be exploited to measure physical properties (e.g. density)



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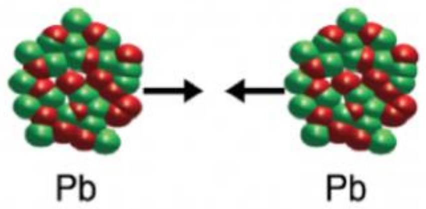
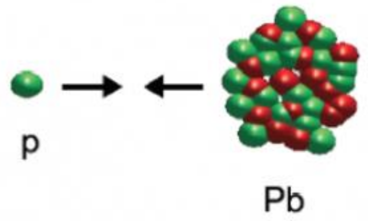
What are we searching for

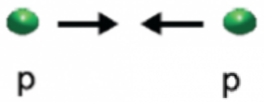
pp e p-A traditionally studied as “control experiments” to highlight the formation of QGP in A-A collisions



QGP



Initial state effects (e.g. shadowing)



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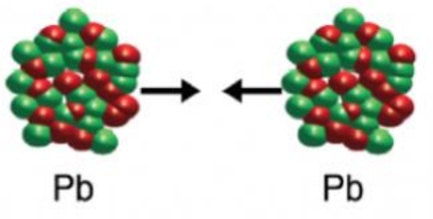

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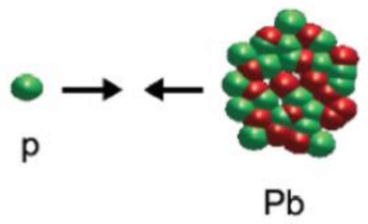

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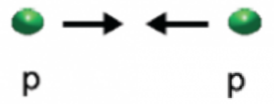

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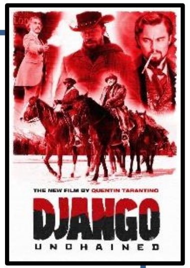
Change of perspective:



QGP production in small systems?

We are searching for:

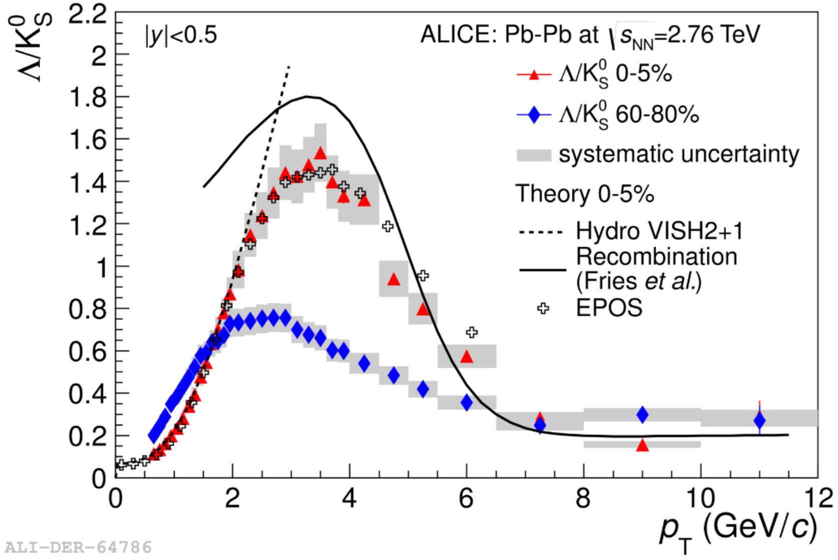
- **Collectivity**
  (flow, common freeze-out)
- **Chemical properties**
  (hadronic abundancies compatible with a QGP phase before hadronization)
- **Physical properties**
  (jet quenching, high-p_T particles - or quarkonia - suppression, ecc..)

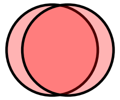
Collectivity

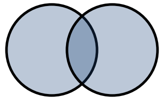
Collectivity in a nutshell (I)

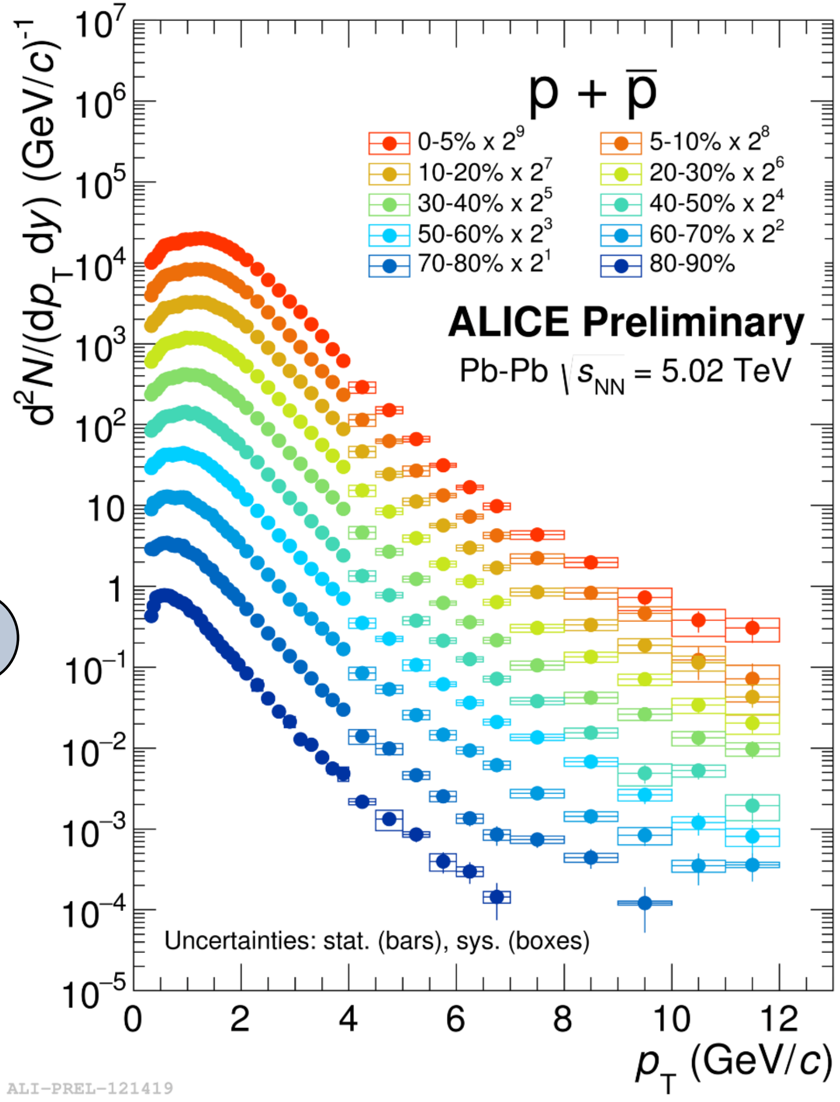
According to the hydro picture, the strongly interacting medium is expected to develop:

- **Radial flow** (important in central collisions):
  - Common expansion velocity of partons
  - Translates into spectral shape modification
  - Baryon/meson anomaly







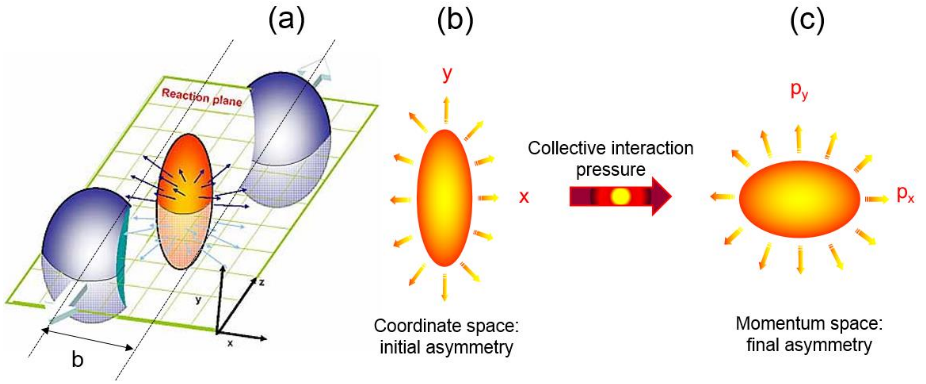


Collectivity in a nutshell (II)

According to the hydro picture, the strongly interacting medium is expected to develop:

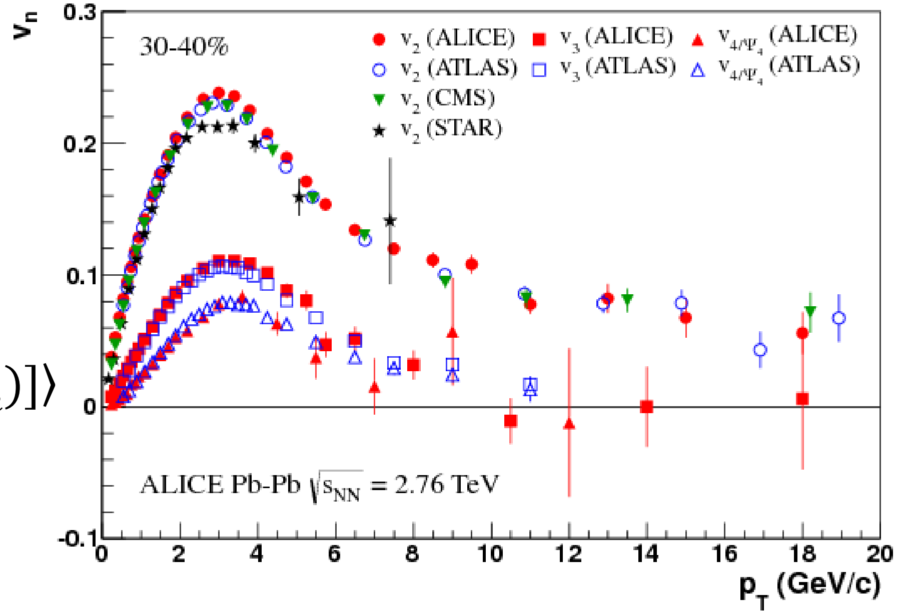
- **Radial flow** (important in central collisions):
  - Common expansion velocity of partons
  - Translates into spectral shape modification
  - Baryon/meson anomaly

- **Anisotropic flow** (important in semi-peripheral collisions):
  - Initial spatial anisotropy translates into final momentum anisotropy (pressure gradients)
  - Measured through angular anisotropies in the momentum distribution

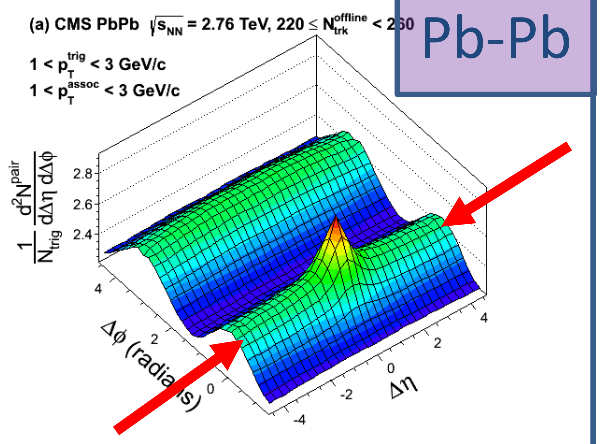


$$v_n = \langle \cos[n(\phi - \Psi_n)] \rangle$$

$$E\frac{d^3N}{dp^3} \approx \frac{1}{2\pi}\frac{d^2N}{p_T\,dp_T\,d\eta}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\phi - \Psi_n)]\right]$$



JHEP 07 (2011) 076



Pb-Pb

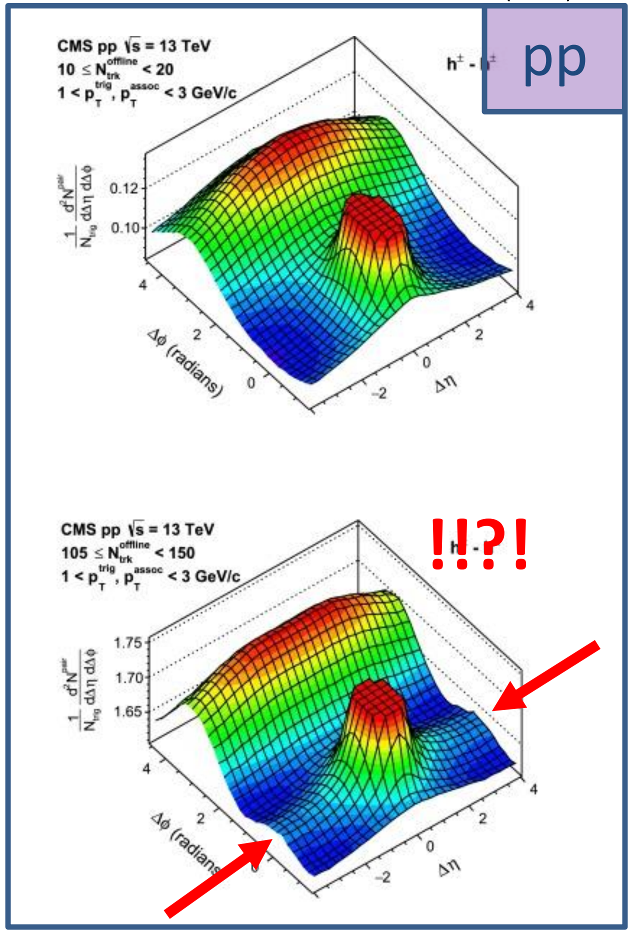
2-particle correlations.

Ridge at $\Delta\phi$=0 in a wide range of $\Delta\eta$.

Attributed to hydrodynamic collective flow of a strongly interacting expanding medium (QGP)

The ridge: collectivity in a hazelnutshell

PLB 765 (2017) 193



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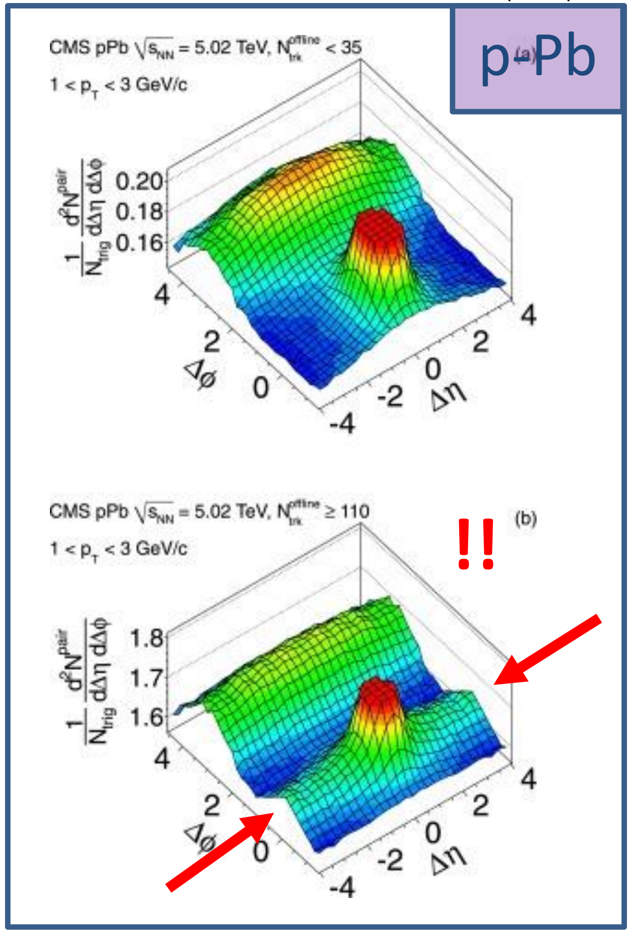

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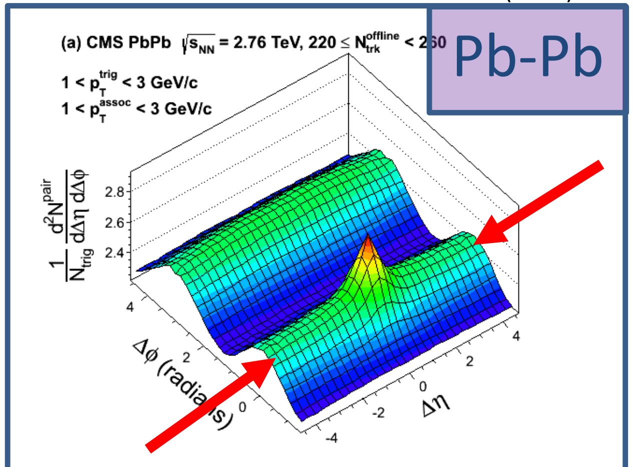

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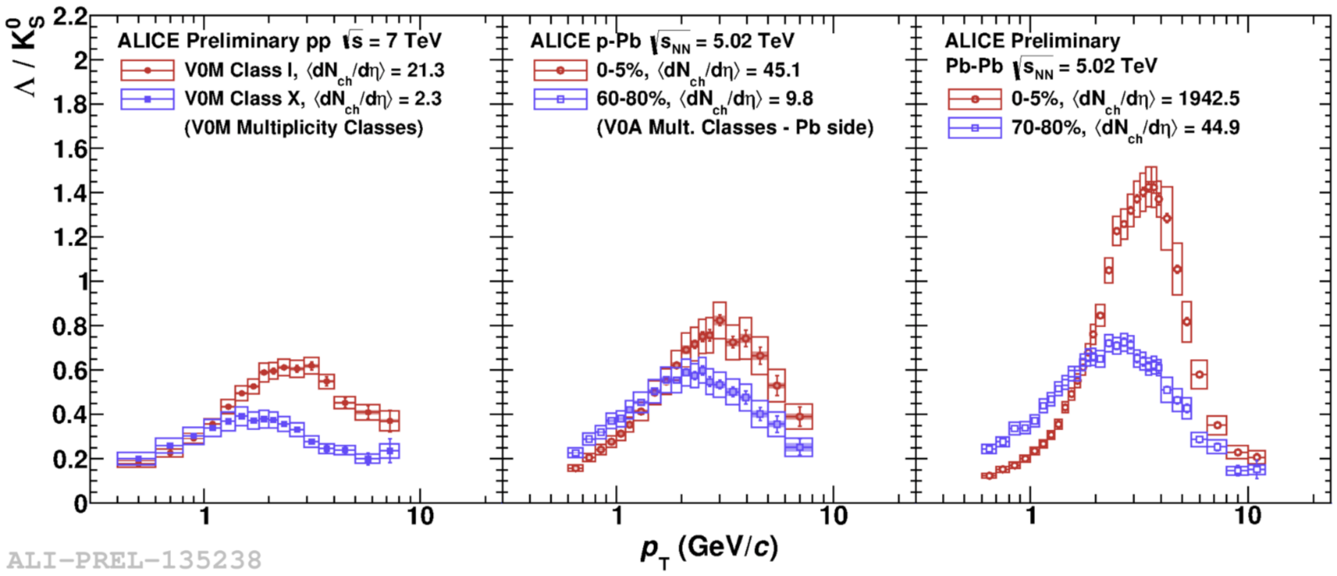
What is the reason for observing a ridge structure in small systems? QGP? Strong initial state momentum correlations?

Need to be more quantitative and study radial and anisotropic flow in small systems!

↓

Collectivity in small systems: radial flow (I)



Same pattern in the Λ/K^0_S measured in small systems, with different magnitude…

…but…

MIND THE MULTIPLICITY SPAN!

In order to make proper comparison, one can select p_T ranges and look at multiplicity dependence

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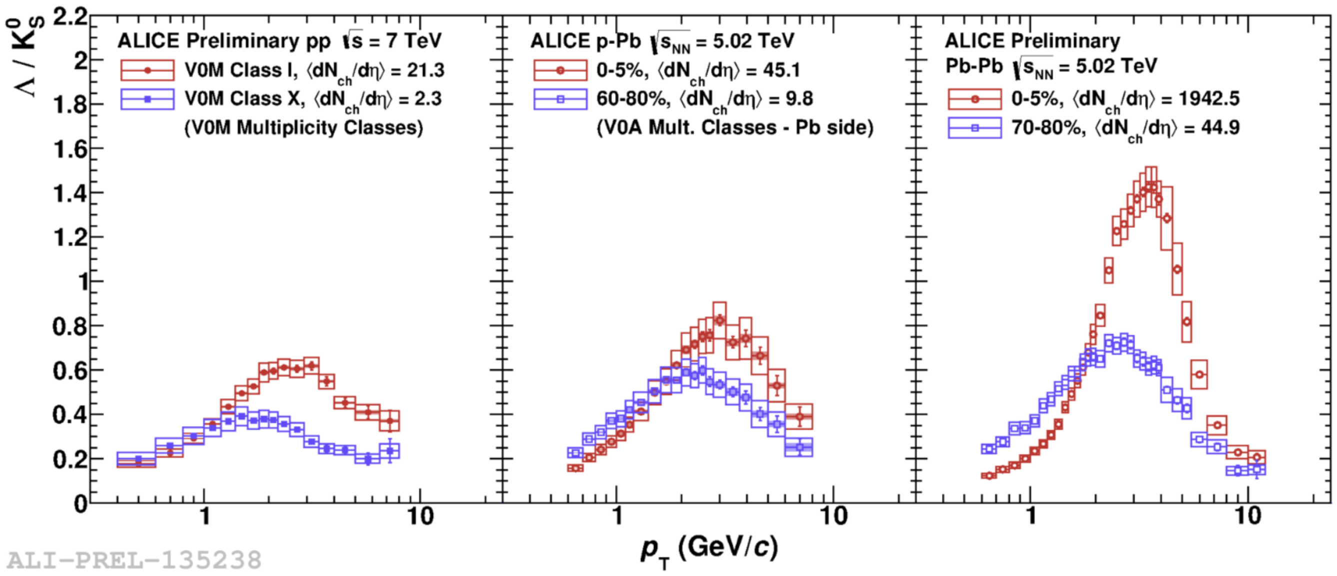

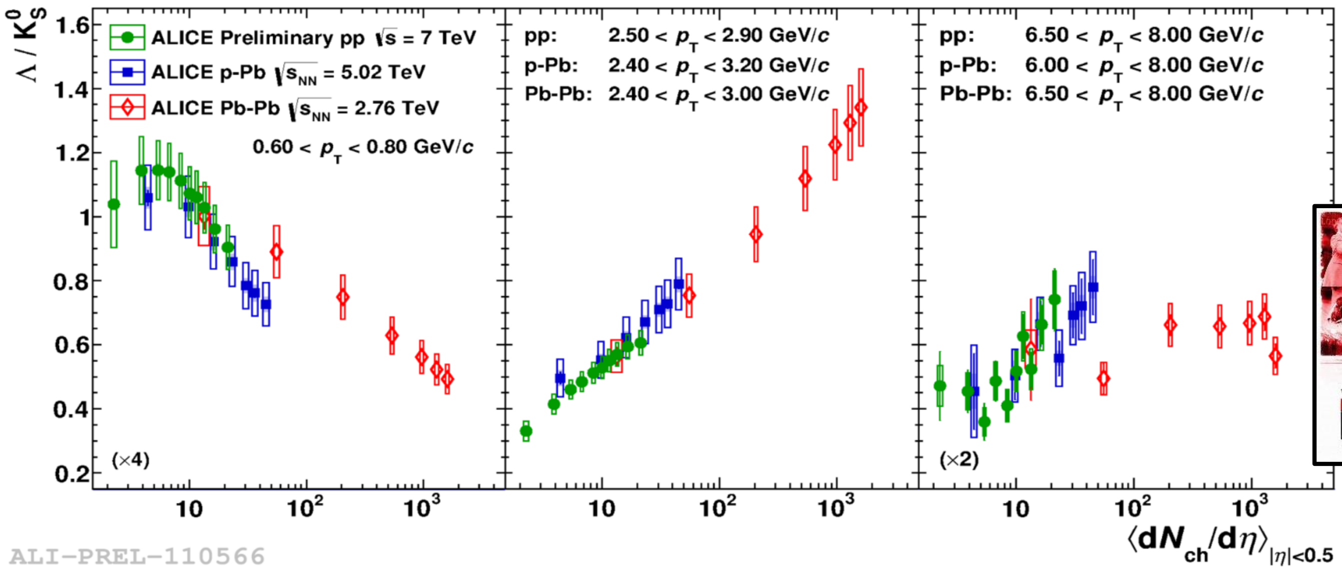

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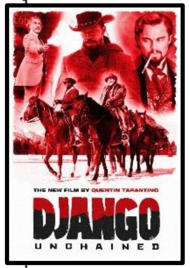
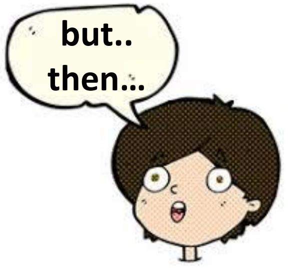
Clear continuity among different systems!

Is the underlying mechanism the same here?

Need to compare to hydro

↓





Blast wave: simplified hydro model:

- Assumes common particle expansion with β_T and T_{kin}
- If assumption ok: fit (e.g.) π,K,p $\rightarrow$ predict pT shape of other particles

- Assumption ~ok for all collision systems
- pp and p-Pb: similar T_{kin}-β_T progression
- Considering corresponding multiplicity:
  less "violent" expansion in Pb-Pb,
  but T_{kin} common for all systems

Collectivity in small systems: radial flow (II)

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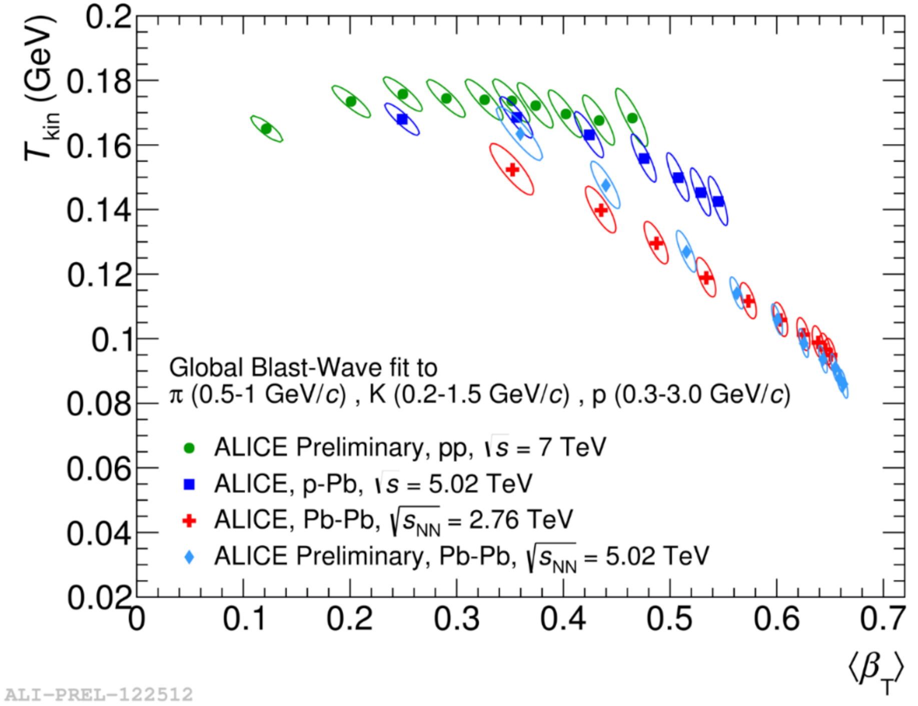
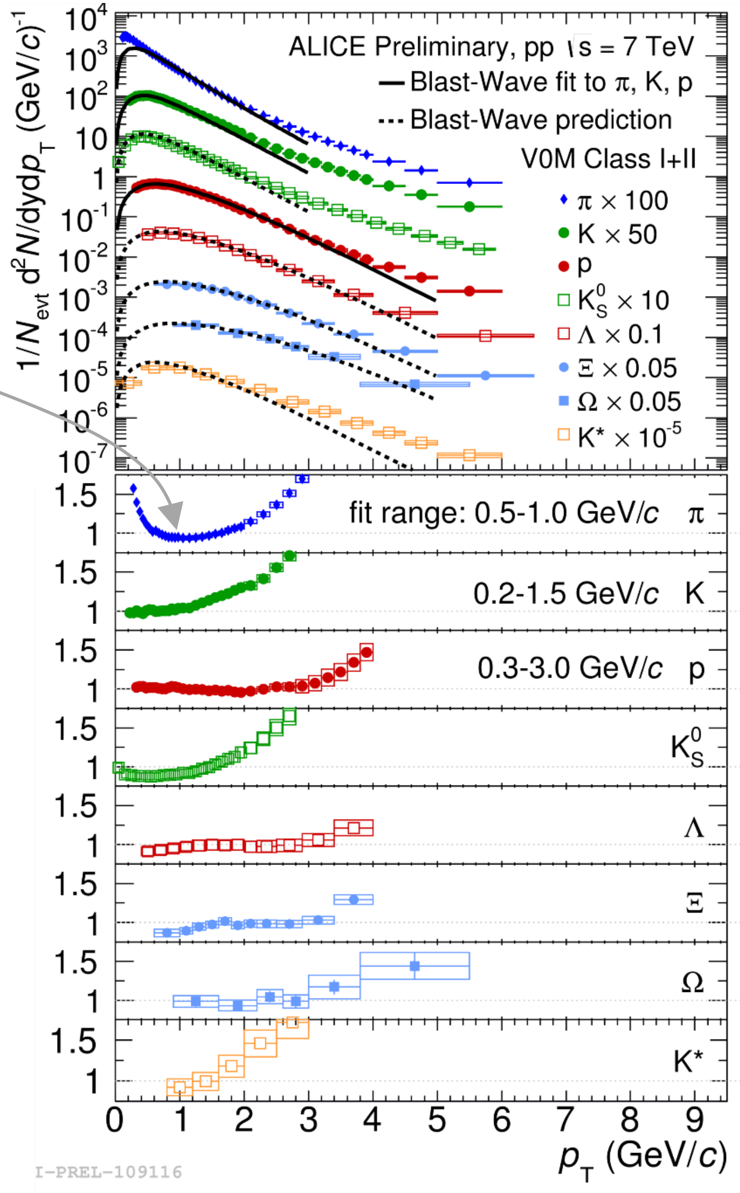
CAVEAT: limited p_T range of validity. Resonance decays at low-p_T, perturbative production at high-p_T





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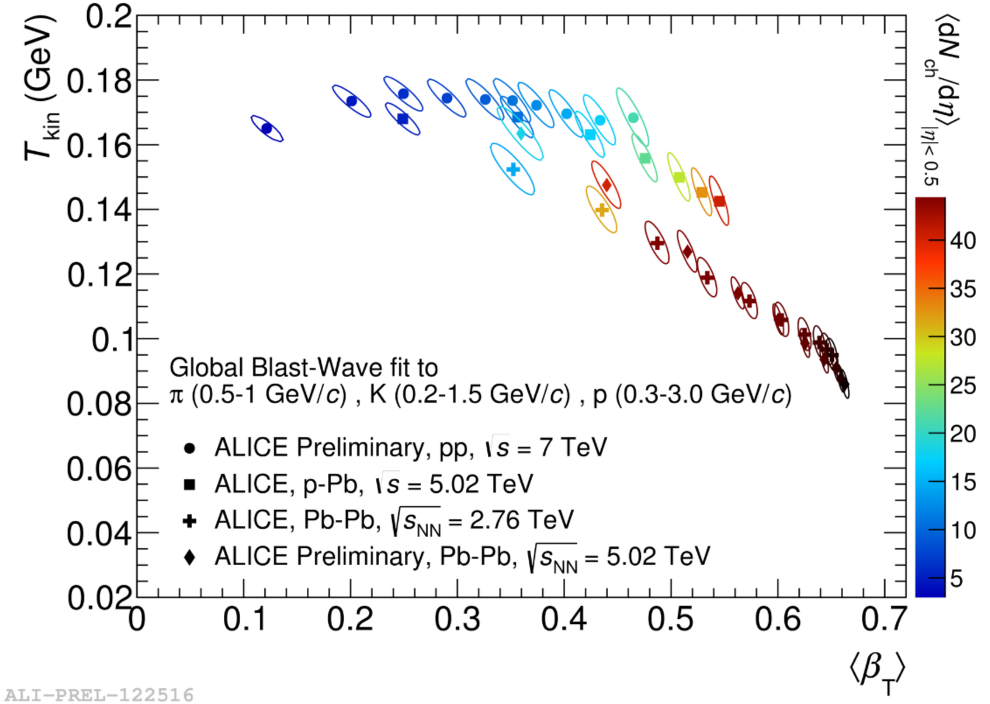
TAKE HOME

Simple hydro model seems to describe p_T spectra evolution with multiplicity across different collision systems



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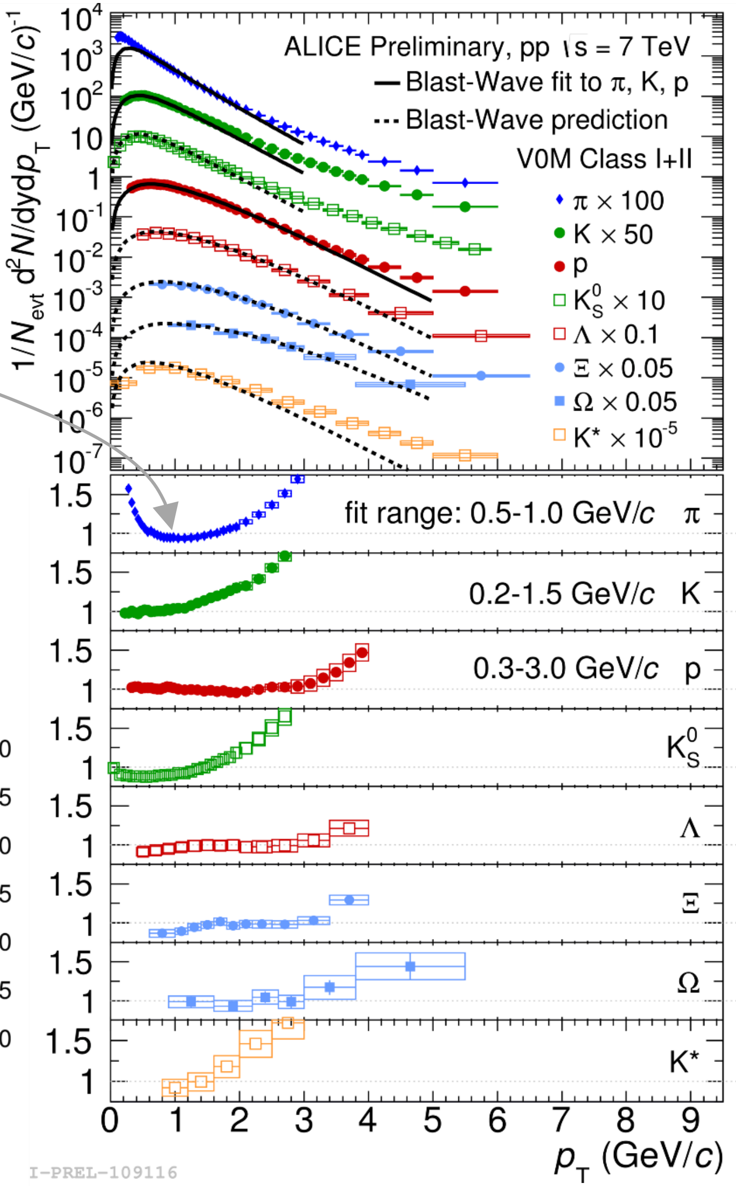

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Collectivity in small systems: anisotropic flow (I)

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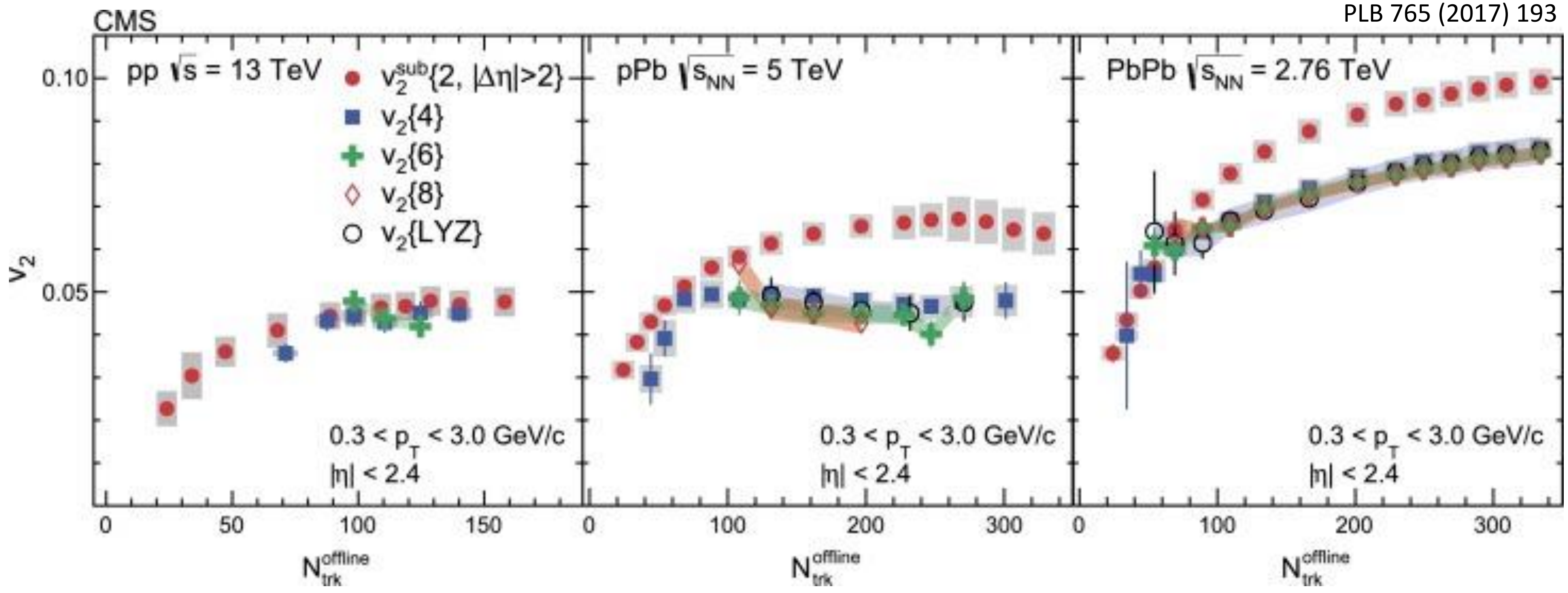
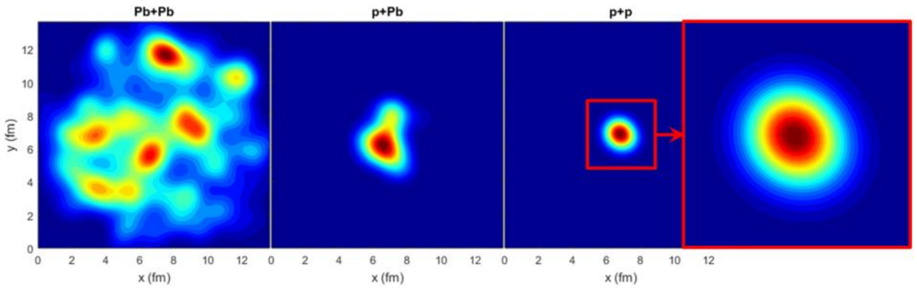


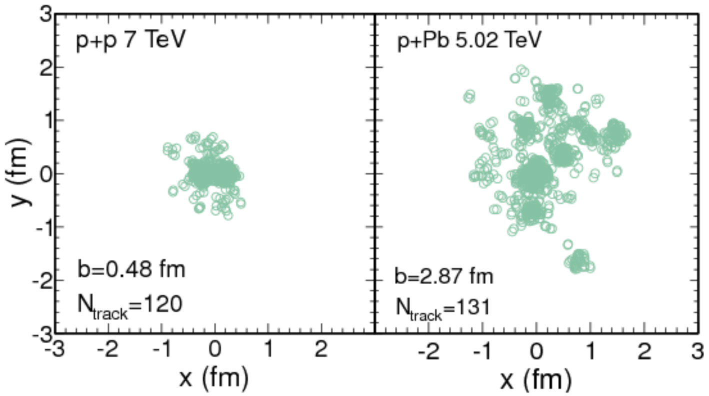
v_2 different from zero observed in all collision systems

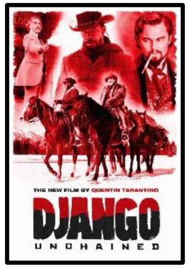
NOTE: contribution of non-flow not easy to estimate in pp (and p-Pb)

…but does this make sense at all? Can hydro develop in so small systems? Moreover.. starting from which spatial asymmetry?

Collectivity in small systems: anisotropic flow (II)







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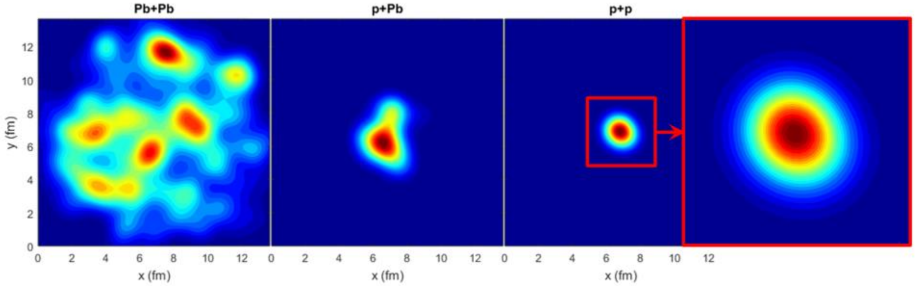
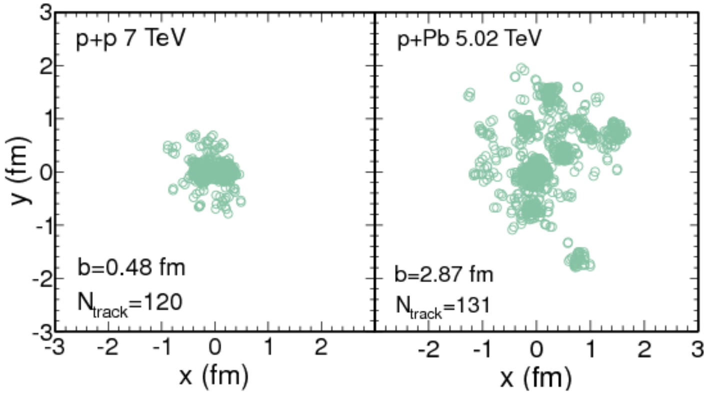
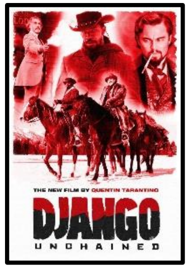
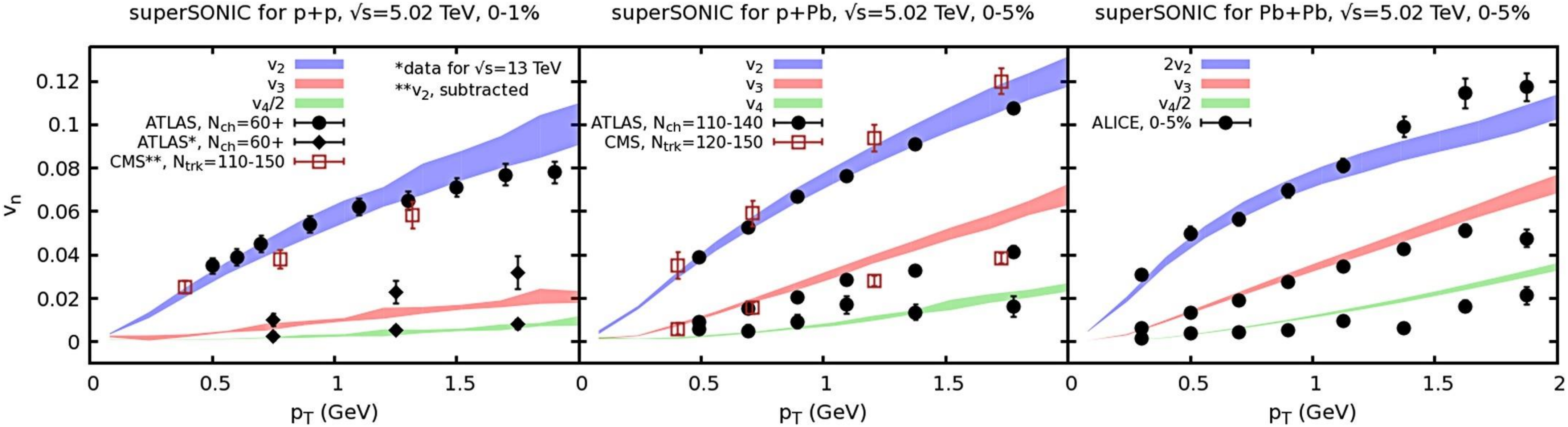






One fluid to rule them all: viscous hydrodynamic description of event-by-event central p+p, p+Pb and Pb+Pb collisions at $\sqrt{s} = 5.02$ TeV

Ryan D. Weller[1] and Paul Romatschke[1,2]



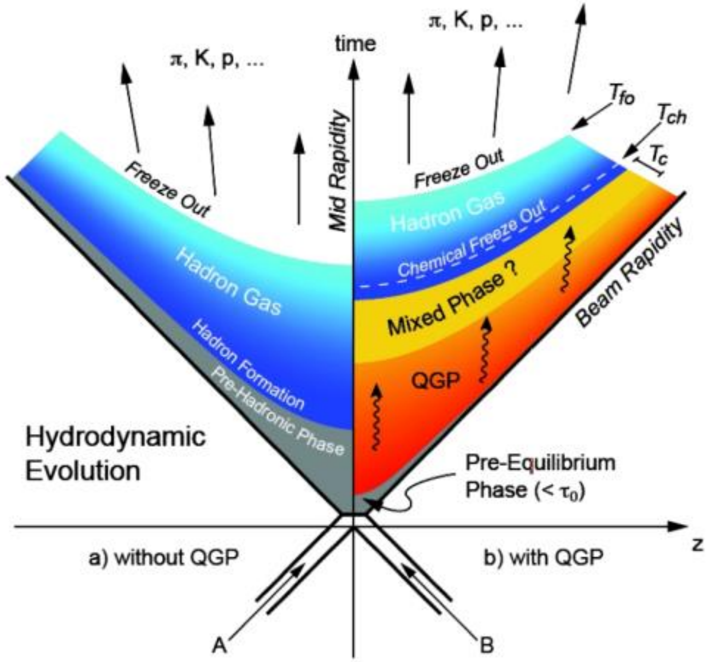
Hadrochemistry

Hadrochemistry as a probe of QGP?

Hadrochemistry: measurement of **relative abundancies of** produced particle **species**

Light hadrons (composed by *u* and *d*) abundantly produced in **elementary collisions**, but **strange hadrons** are **suppressed**!

What happens at high energy densities?



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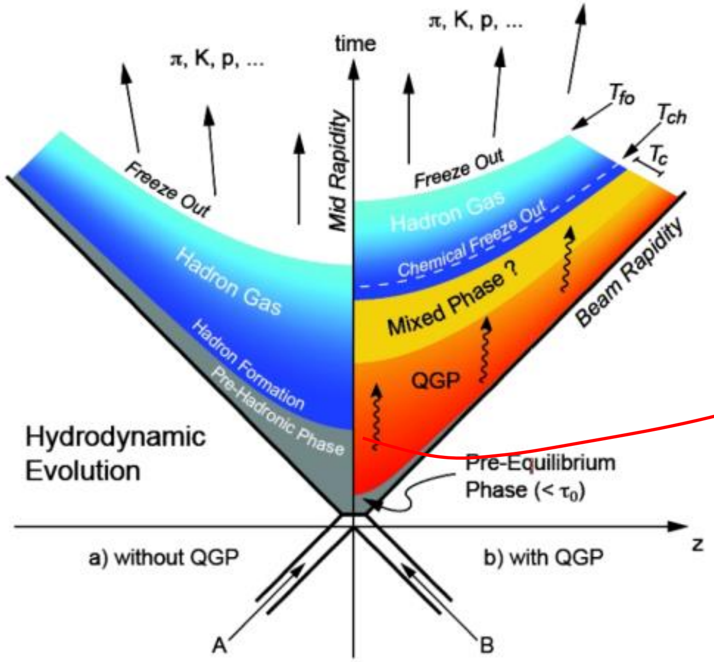

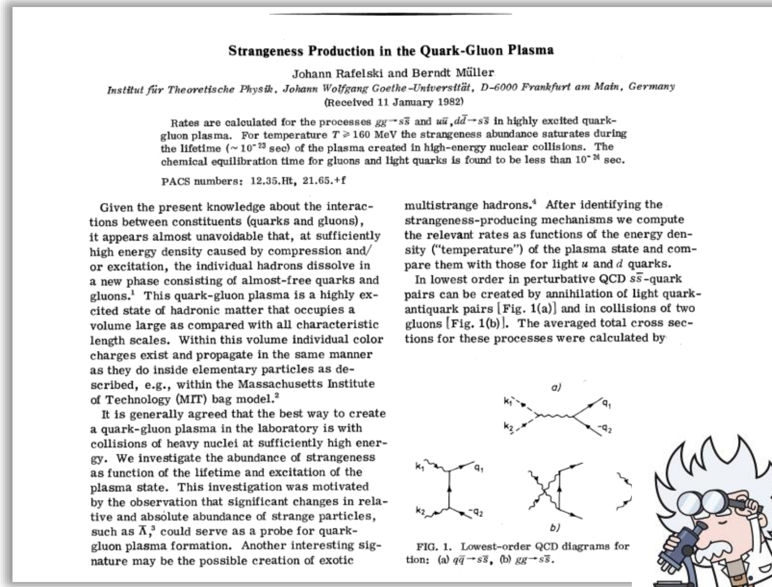

Strangeness Production in the Quark-Gluon Plasma

Johann Rafelski and Berndt Müller
Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, D-6000 Frankfurt am Main, Germany
(Received 11 January 1982)

Rates are calculated for the processes $gg \to s\bar{s}$ and $u\bar{u}, d\bar{d} \to s\bar{s}$ in highly excited quark-gluon plasma. For temperature $T \geqslant 160$ MeV the strangeness abundance saturates during the lifetime ($\sim 10^{-23}$ sec) of the plasma created in high-energy nuclear collisions. The chemical equilibration time for gluons and light quarks is found to be less than 10^{-24} sec.

PACS numbers: 12.35.Ht, 21.65.+f

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It is generally agreed that the best way to create a quark-gluon plasma in the laboratory is with collisions of heavy nuclei at sufficiently high energy. We investigate the abundance of strangeness as function of the lifetime and excitation of the plasma state. This investigation was motivated by the observation that significant changes in relative and absolute abundance of strange particles, such as $\bar{\Lambda}$,[3] could serve as a probe for quark-gluon plasma formation. Another interesting signature may be the possible creation of exotic multistrange hadrons.[4] After identifying the strangeness-producing mechanisms we compute the relevant rates as functions of the energy density ("temperature") of the plasma state and compare them with those for light *u* and *d* quarks.

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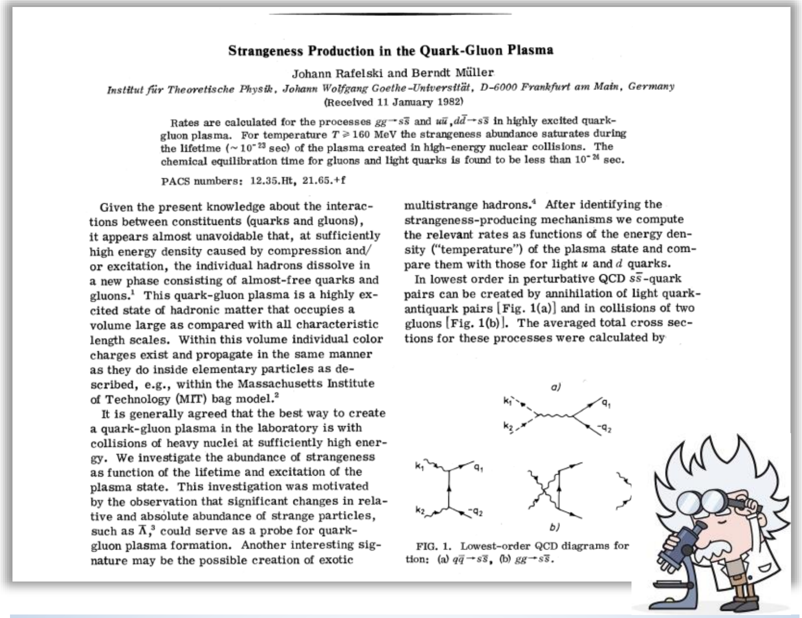

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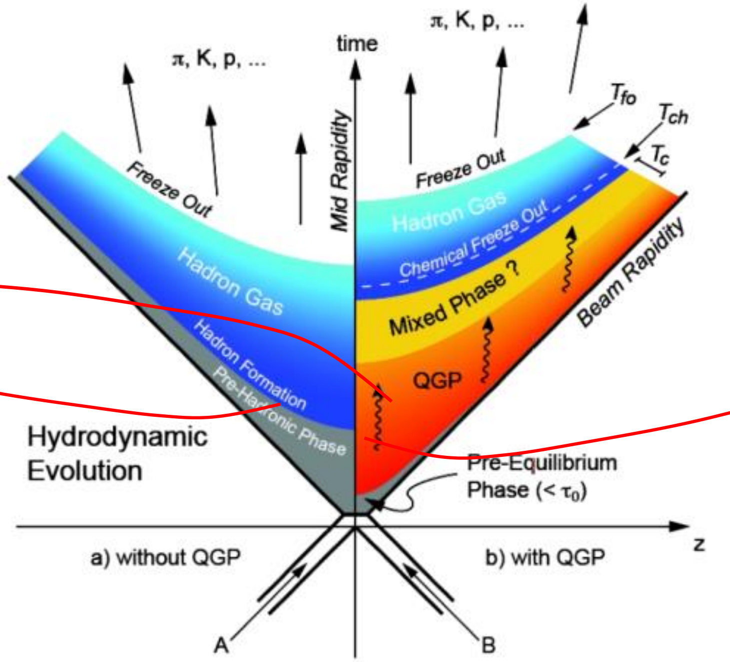

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TAKE HOME

QGP ⇒ (foreseen) altered chemical composition

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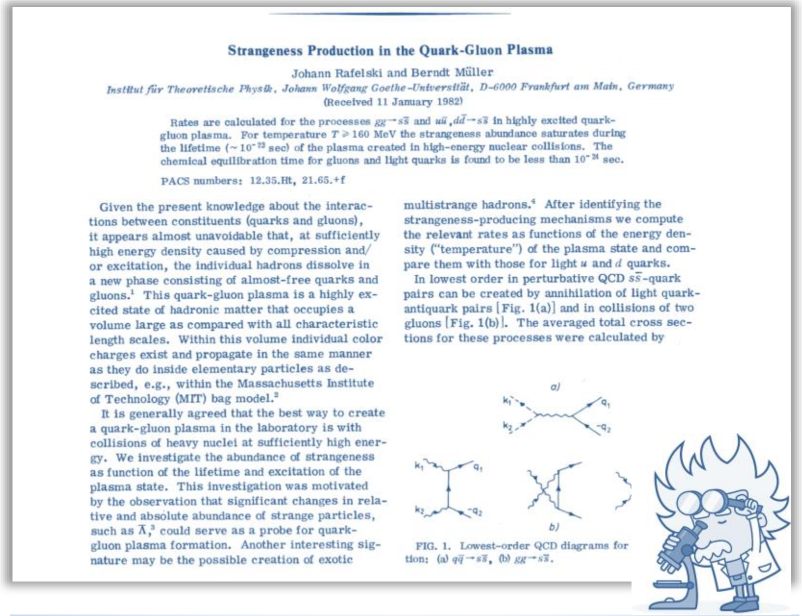

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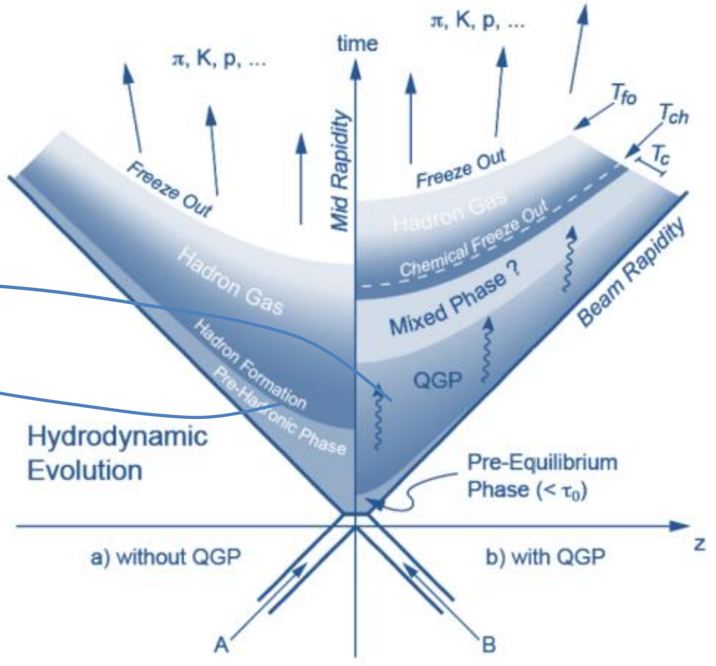

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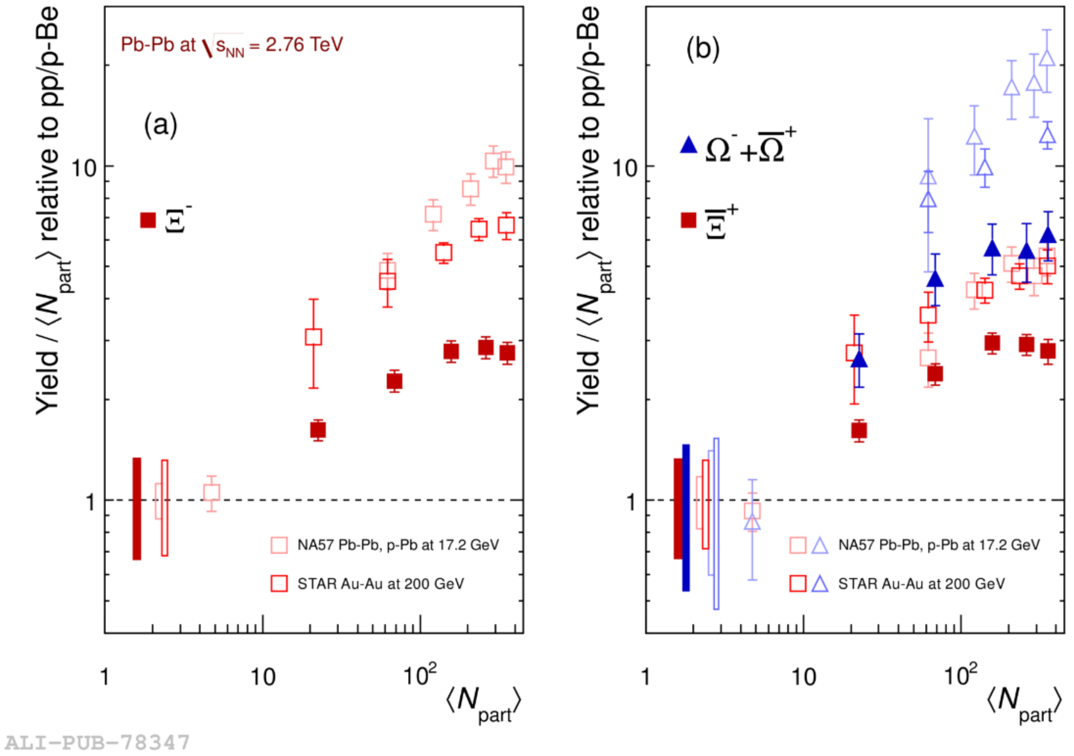
Hadrochemistry in large systems: strangeness

Phys. Lett. B 728 (2014) 216–227



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…but **less important at higher energy…!?!?**

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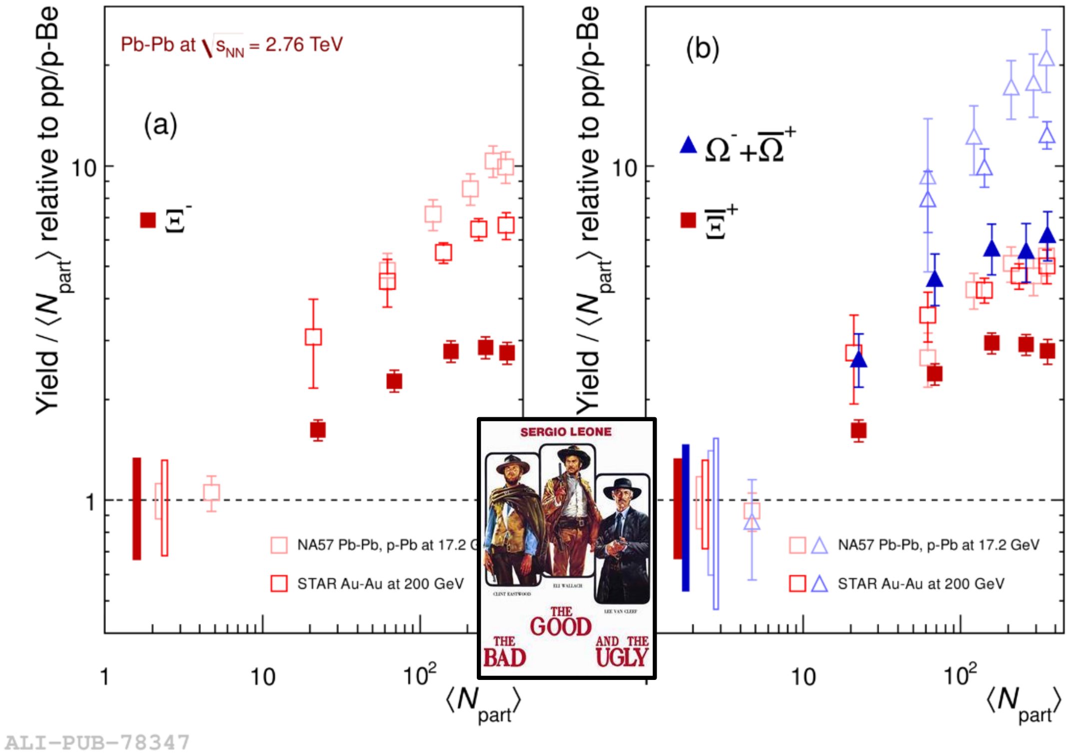

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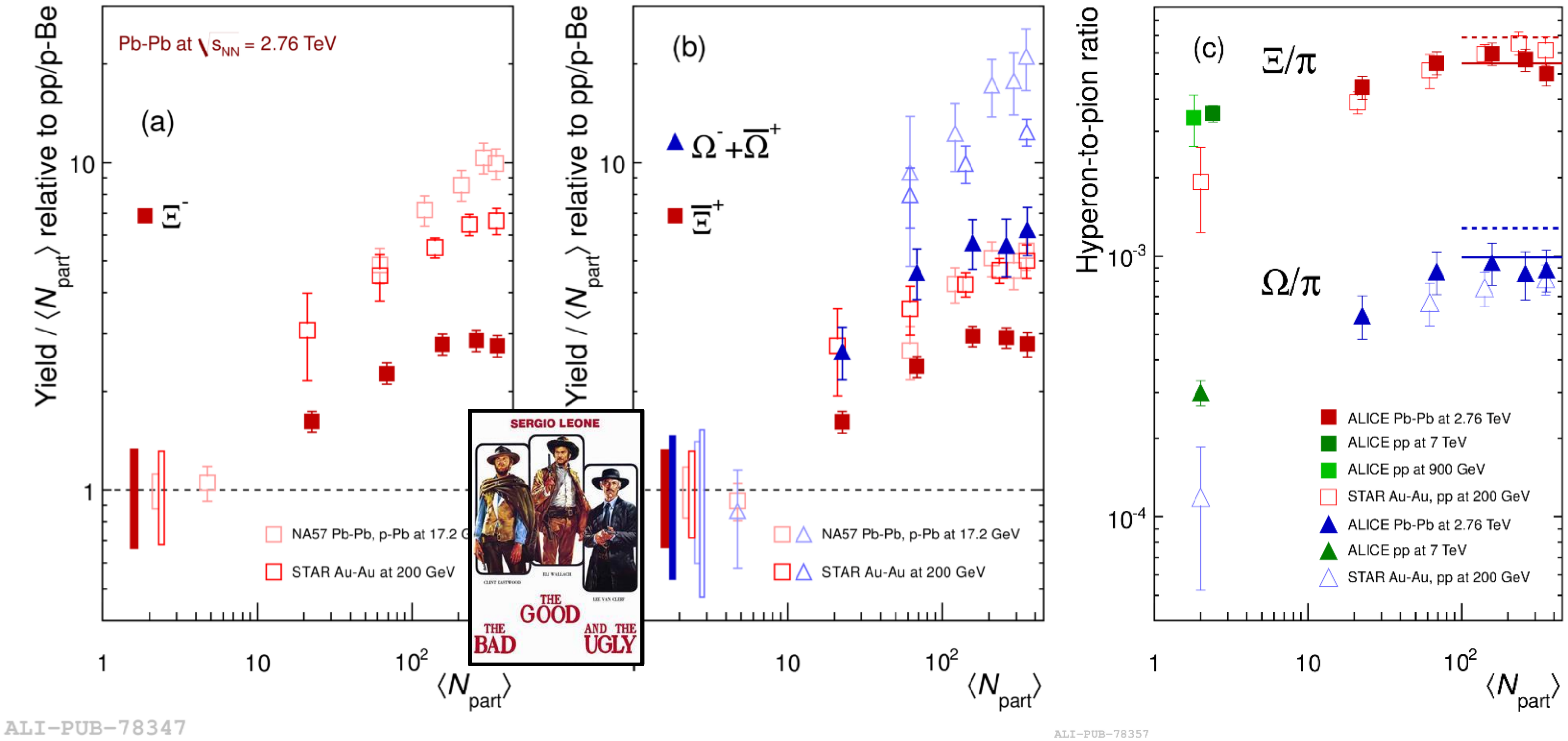

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…and higher than in small collision systems

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…of course!

Because strangeness production in small systems depends on the **energy!**

←

We will see that – at least in high-energy experiments – this is just a byproduct of a completely different dependency!!

…and there Django rulez!

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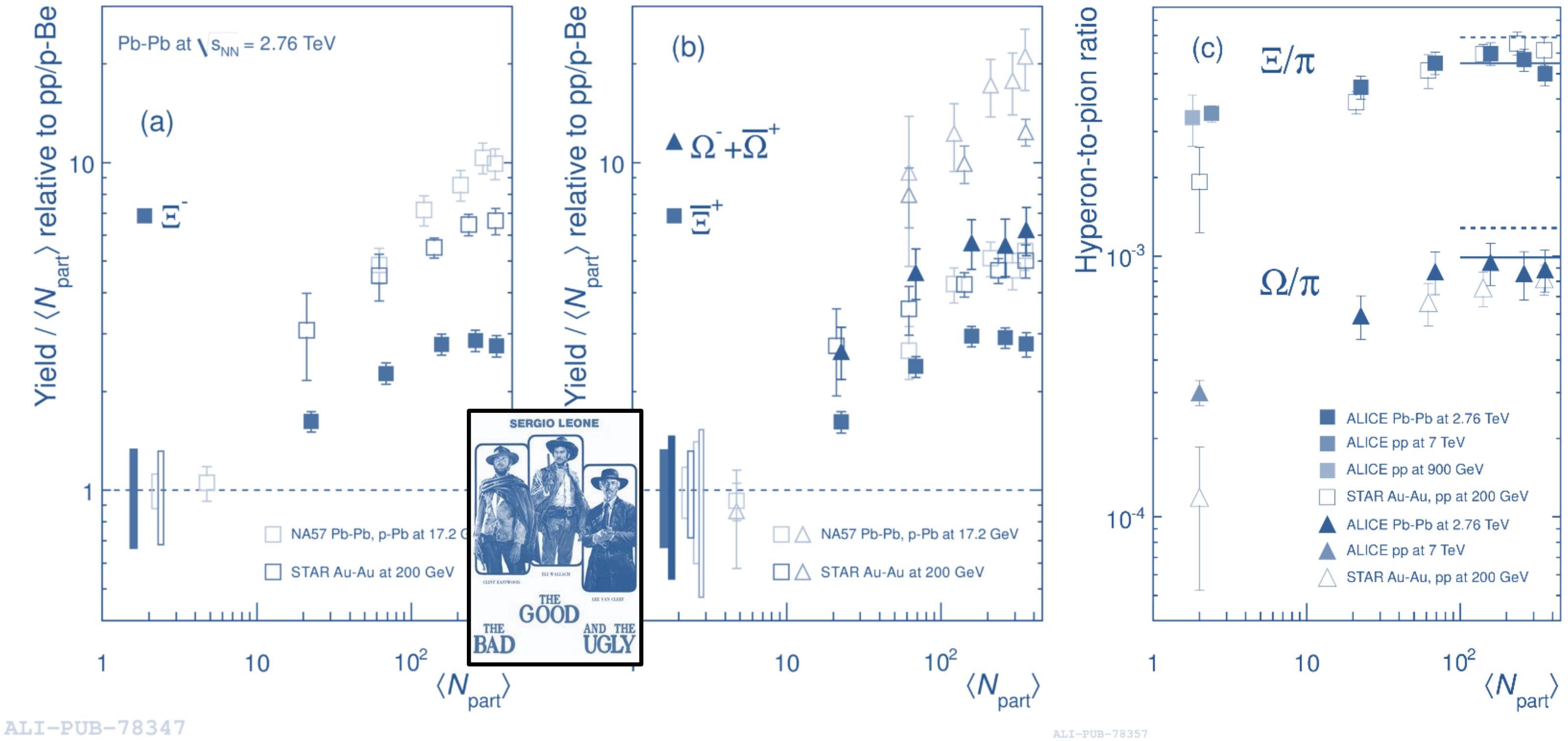

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TAKE HOME

Observed strangeness enhancement in A-A collisions

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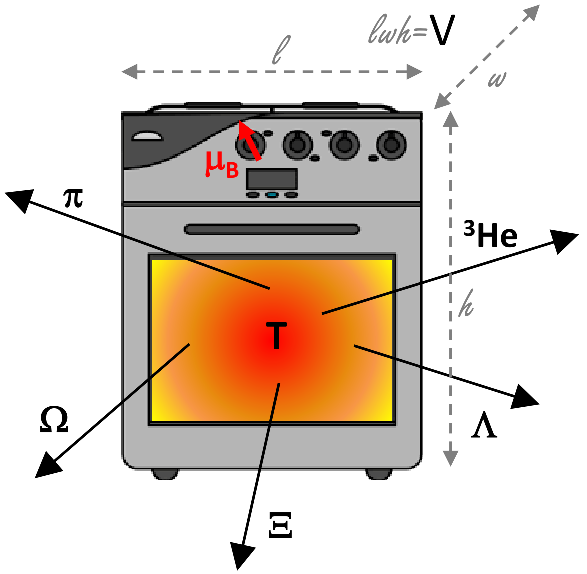
SHM – class of models which:

- see hadronization as particles spilling from an excited state (e.g. hadron resonance gas, …) following pure statistical laws.
- has few parameters at play:
  - **T** : the temperature of the source at chemical freeze-out
  - **V** : the volume of the source
  - μ_B : baryochemical potential (0 at LHC)
  - μ_S : under-equilibration scale for strangeness
  - …

in some flavours of the model



Statistical Hadronization (thermal) model in large systems

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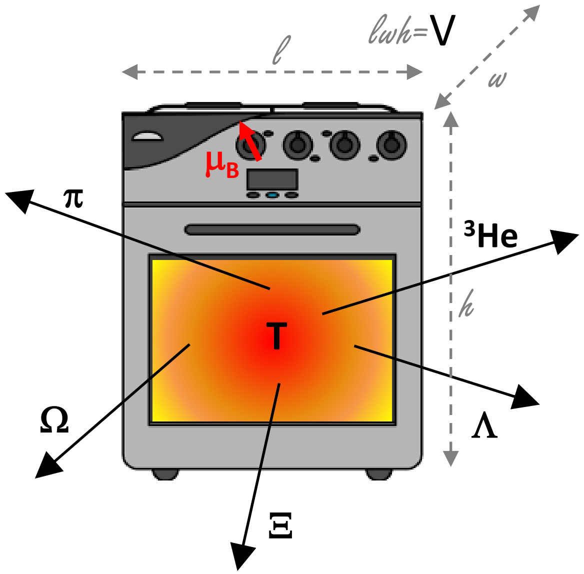

A **fit to particle yields**: estimate parameters for a given experiment.

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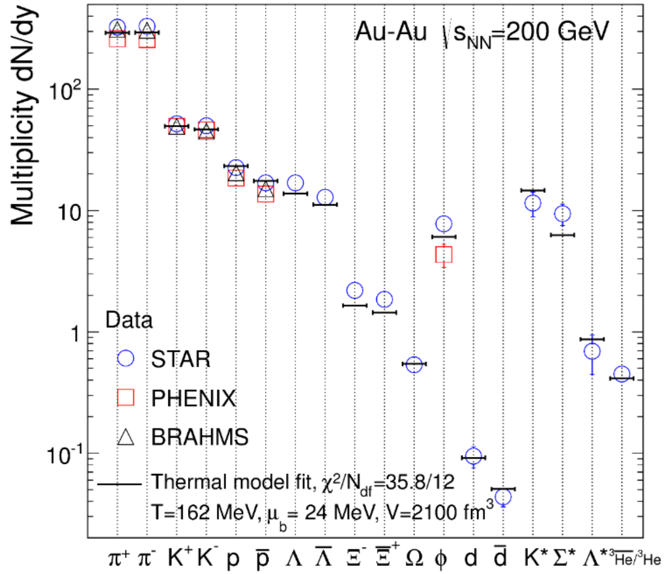
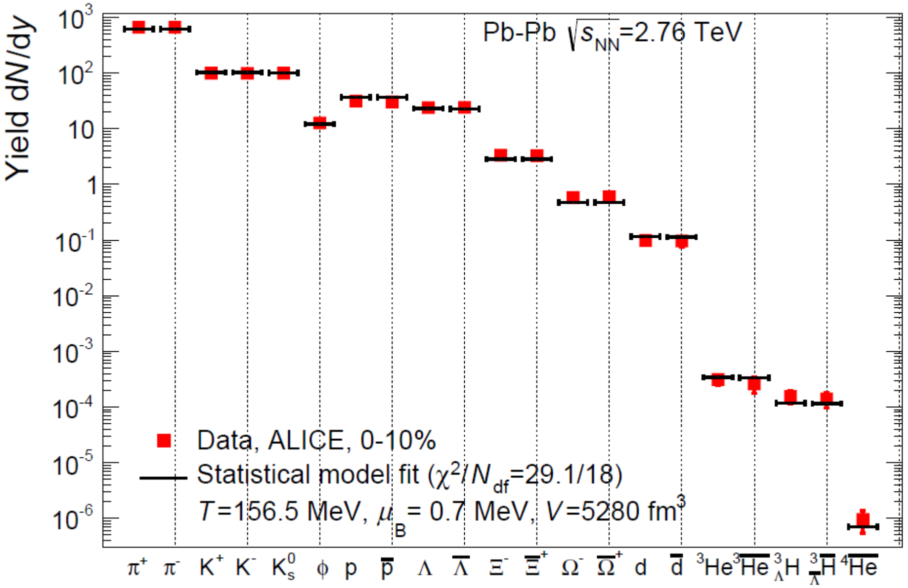


Nucl. Phys. A 904 (2013) 535-538



A.Andronic SQM2016, J.Phys.Conf.Ser. 668 (2016)

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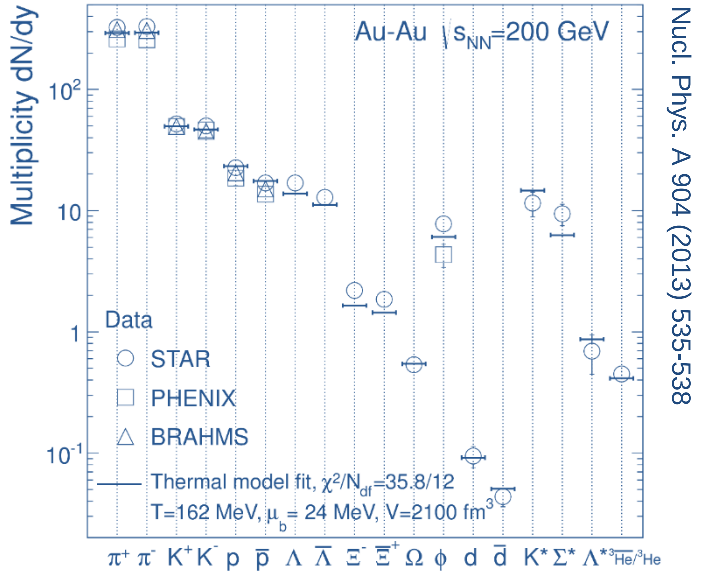
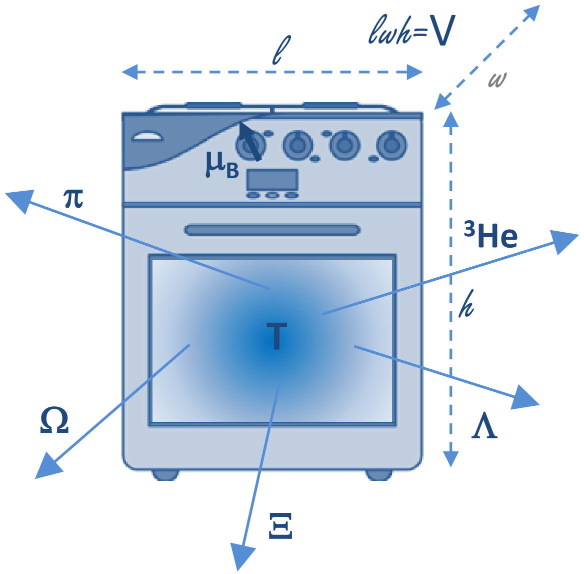
TAKE HOME

Thermal model(s) ~ foresee particle abundancies at different energies in A-A





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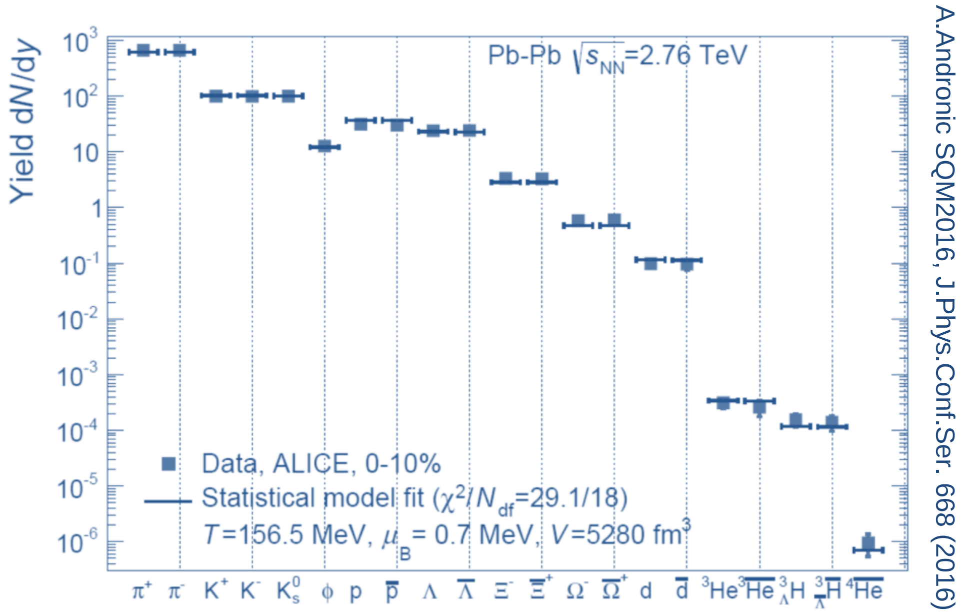
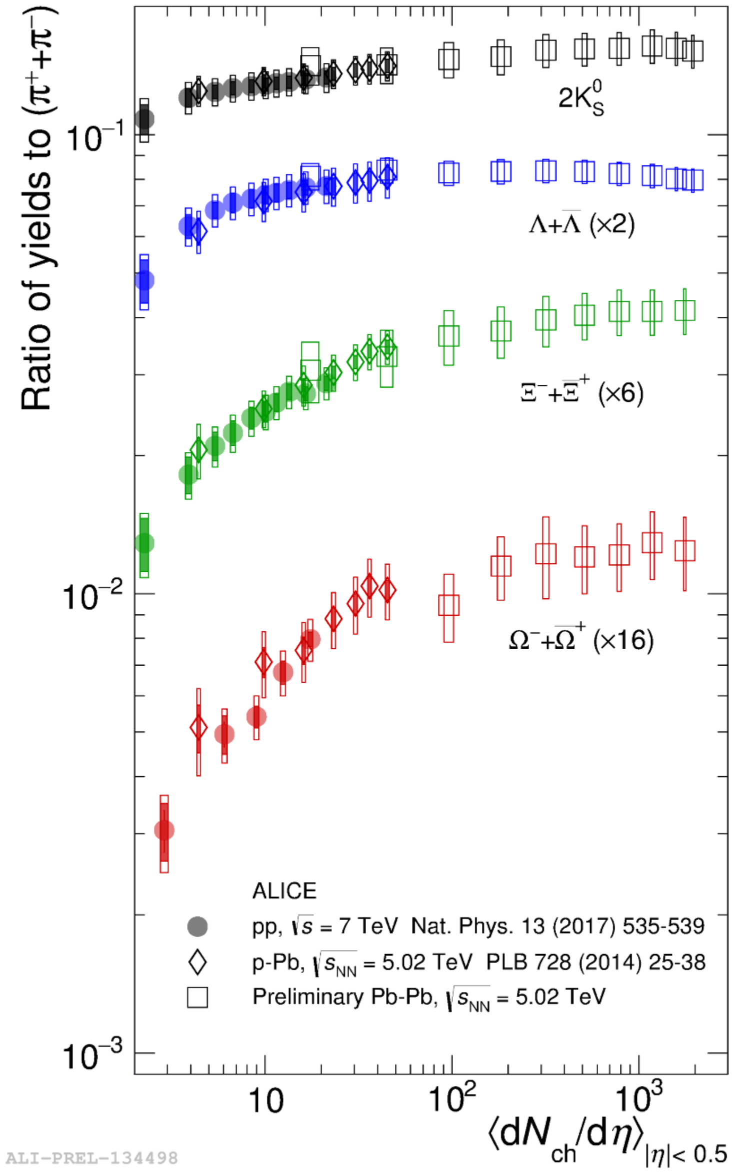


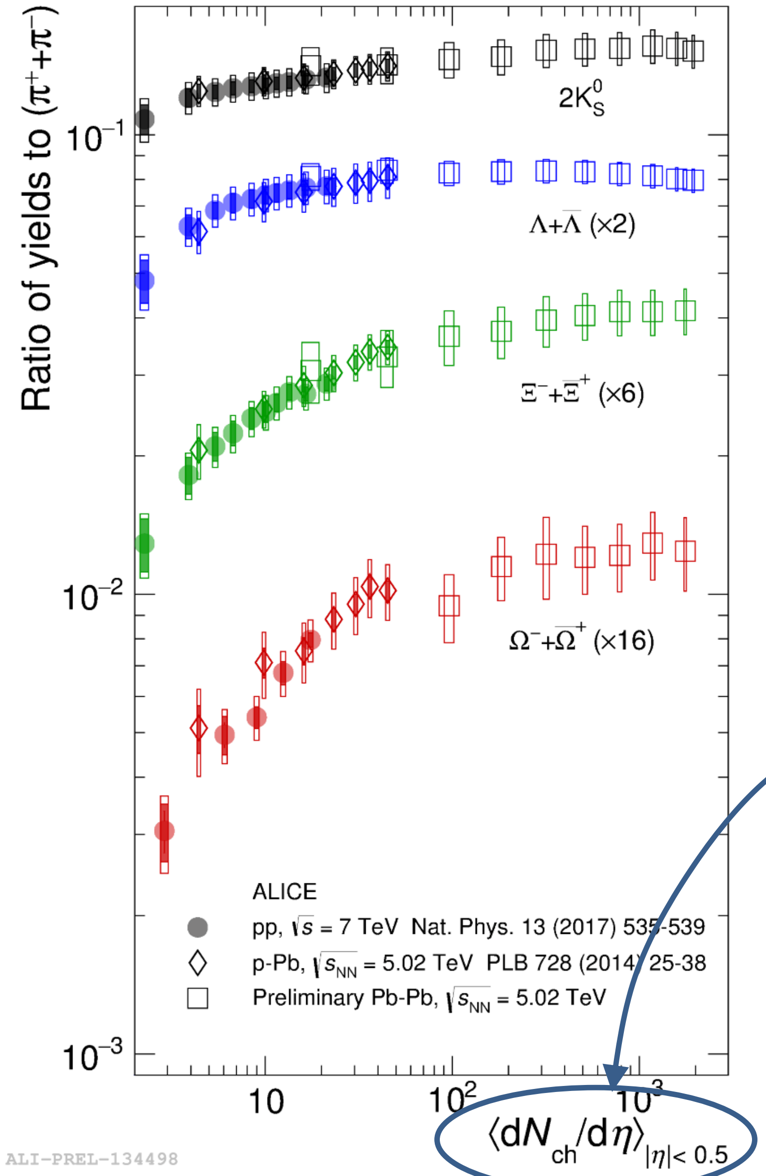


Ratio of yields to (π⁺+π⁻)
10⁻¹
10⁻²
10⁻³
10
10²
10³
⟨dN_ch/dη⟩ |η|< 0.5
2K⁰_S
Λ+Λ̄ (×2)
Ξ⁻+Ξ̄⁺ (×6)
Ω⁻+Ω̄⁺ (×16)
ALICE
pp, √s = 7 TeV Nat. Phys. 13 (2017) 535-539
p-Pb, √s_NN = 5.02 TeV PLB 728 (2014) 25-38
Preliminary Pb-Pb, √s_NN = 5.02 TeV
ALI-PREL-134498

Stranger and stranger…

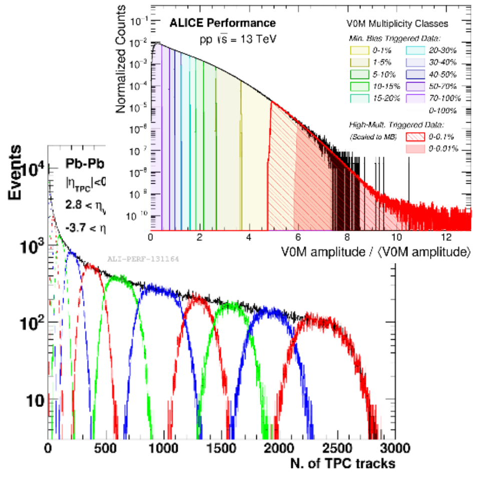
DJANGO
UNCHAINED

Strangeness in small systems: how-to

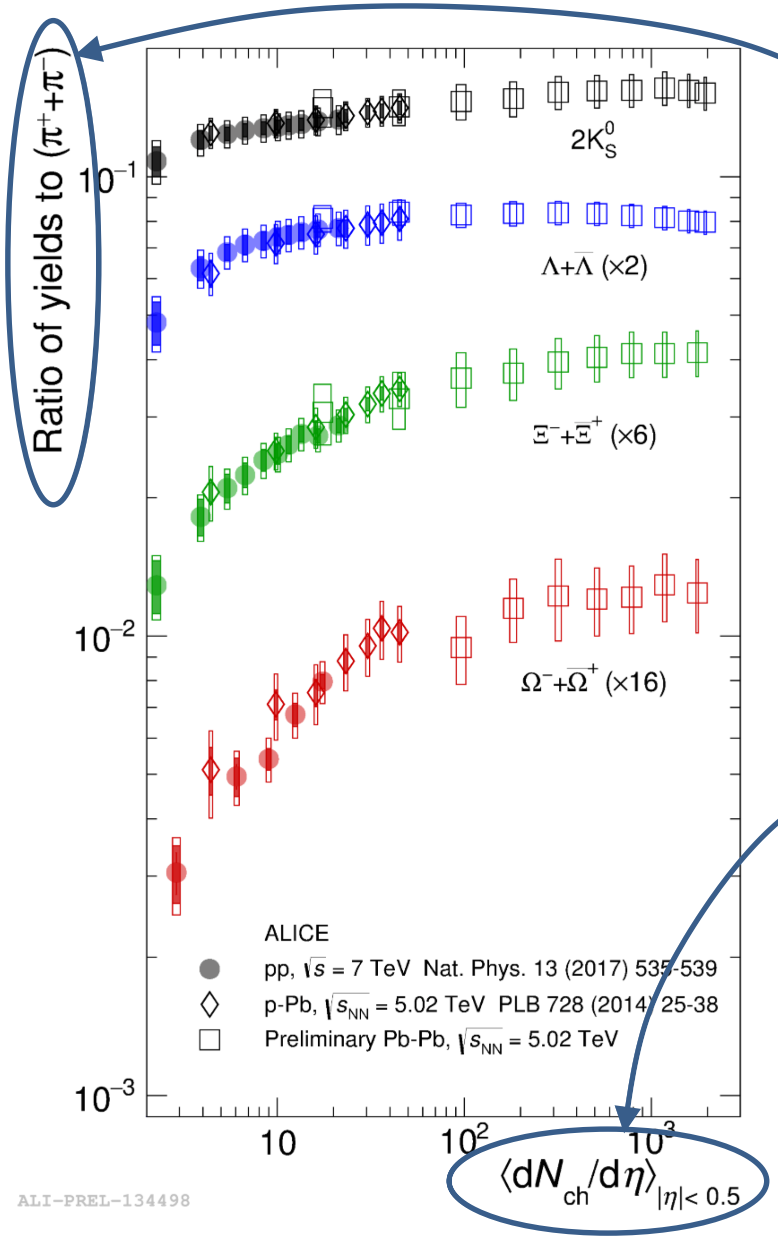


x-values:

- ∀ multiplicity class (fwd-rapidity estimator), count the number of primary charged particles at central rapidity and build-up $dN_{ch}/d\eta$ distribution
- Take statistical average of every distribution

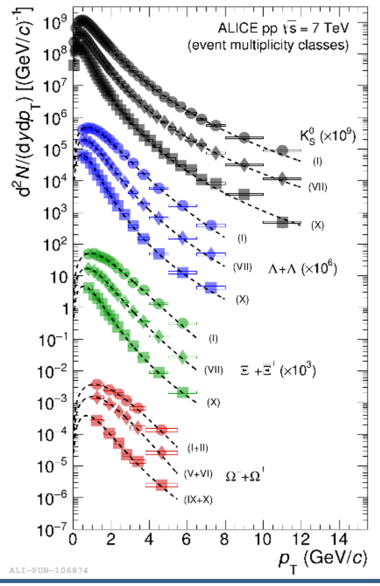


Strangeness in small systems: how-to



y-values:

- Measure p_T spectra of strange particles and pions in pp events characterized by different multiplicities (fwd-rapidity estimator)
- Integrate spectra extrapolating at low and high p_T with suitable functions.
- Calculate Y^S/Y^π



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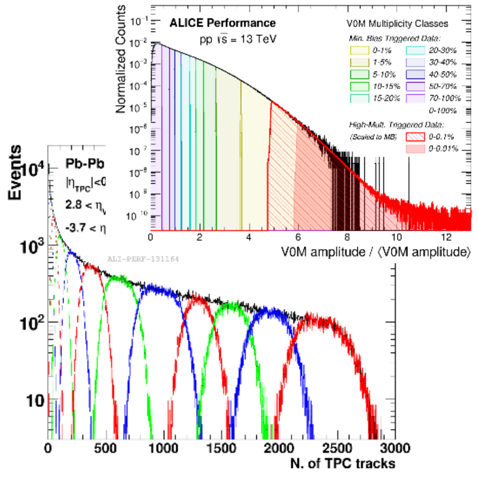
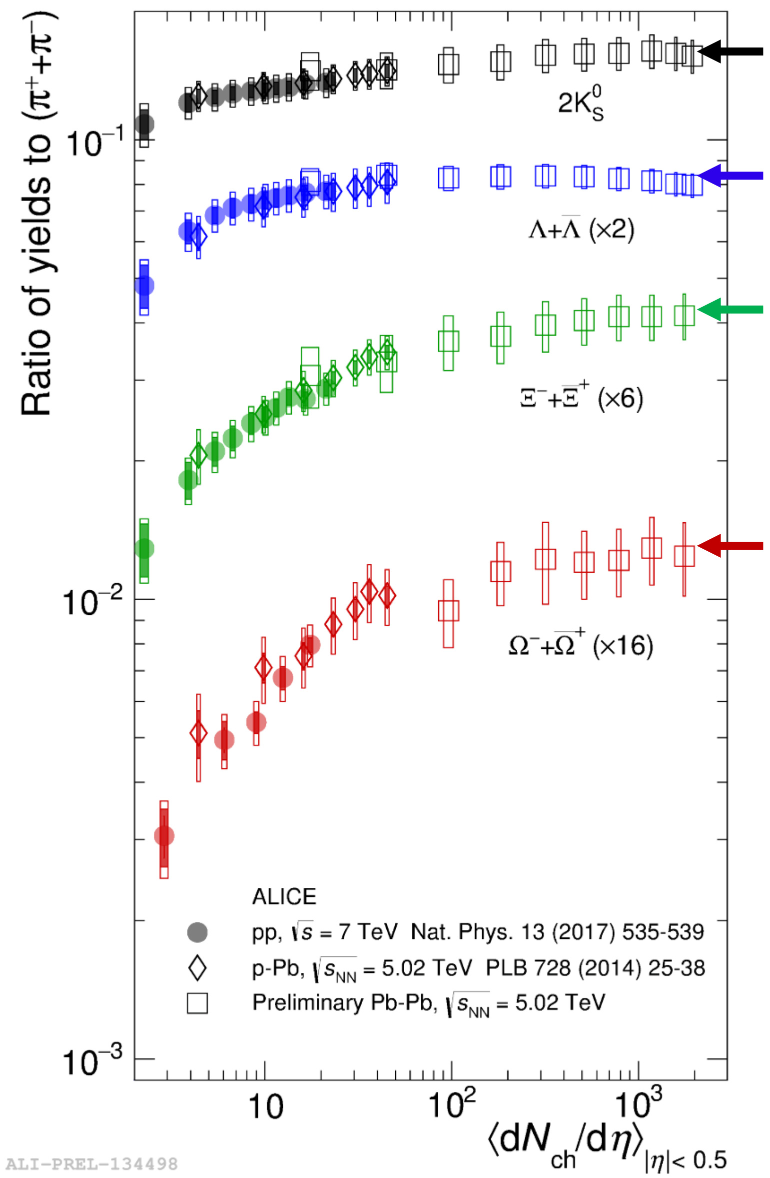
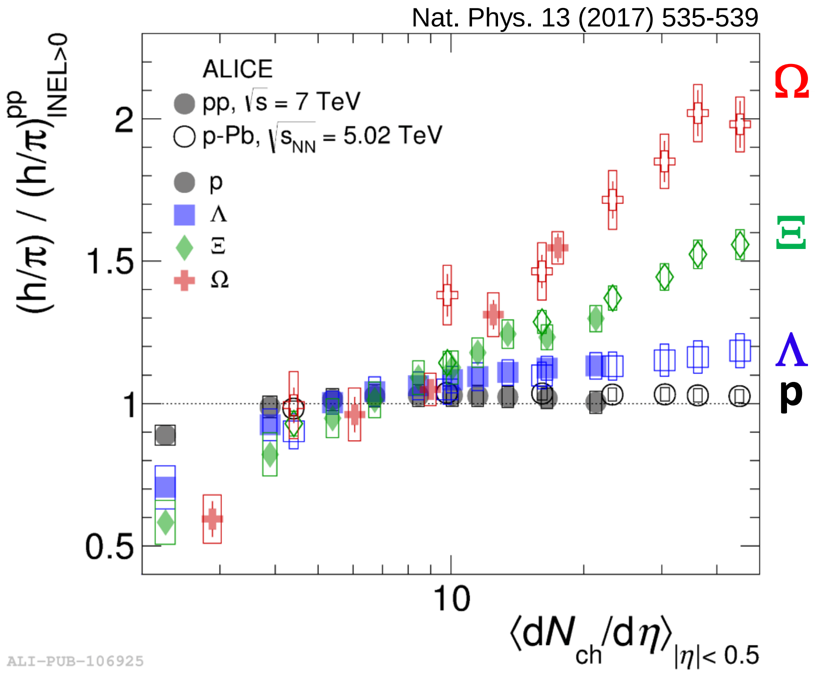


Strangeness in small systems: observation



Strangeness enhancement in small collision systems (pp and p-Pb)

The larger the content in strangeness of the hadron, the steeper the increase is:



Strangeness production saturates at high multiplicity

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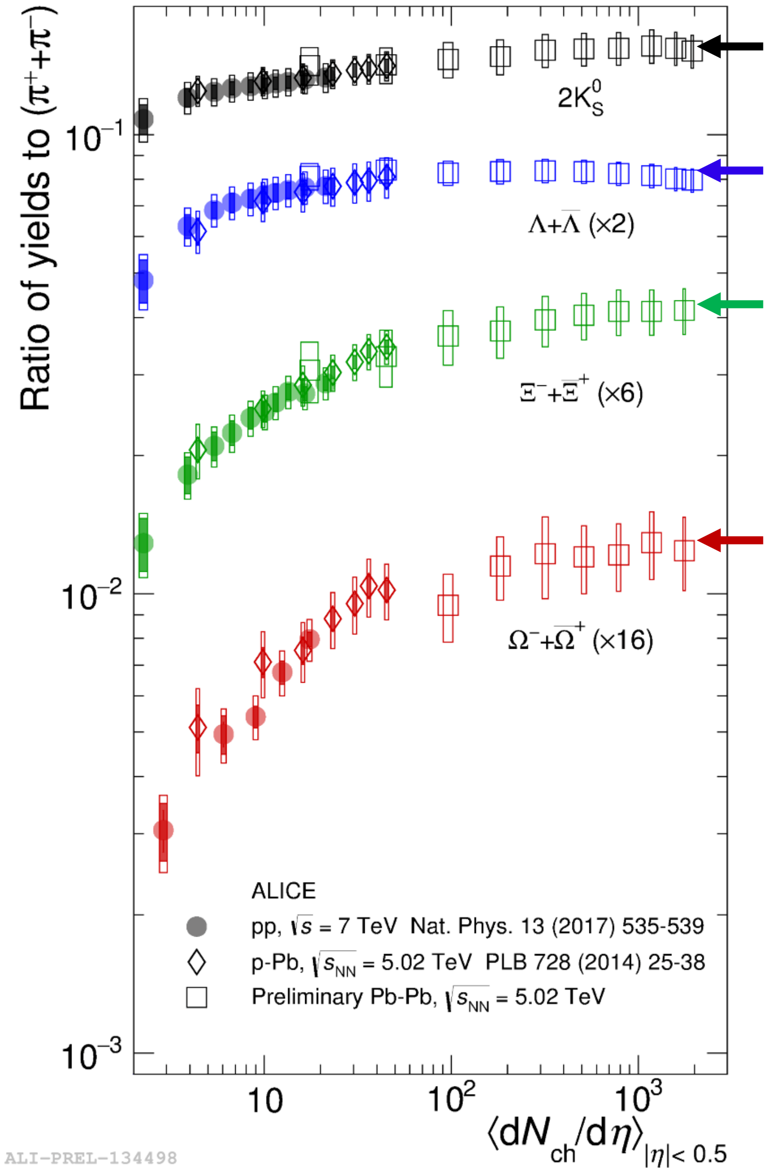

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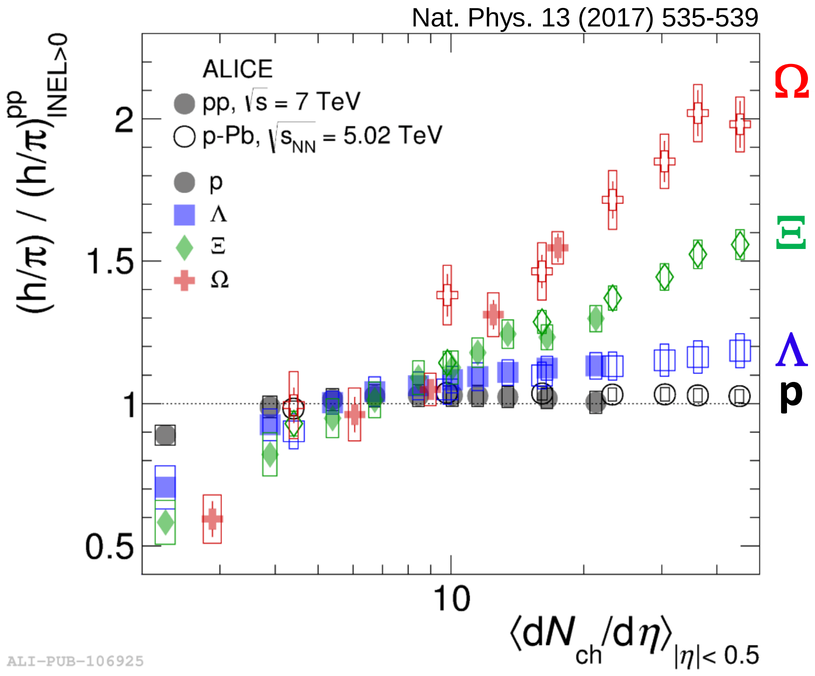
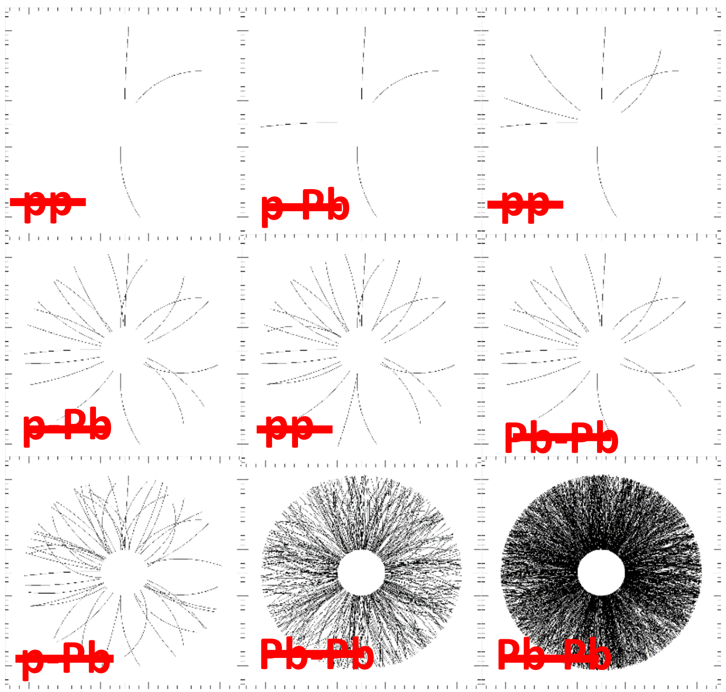
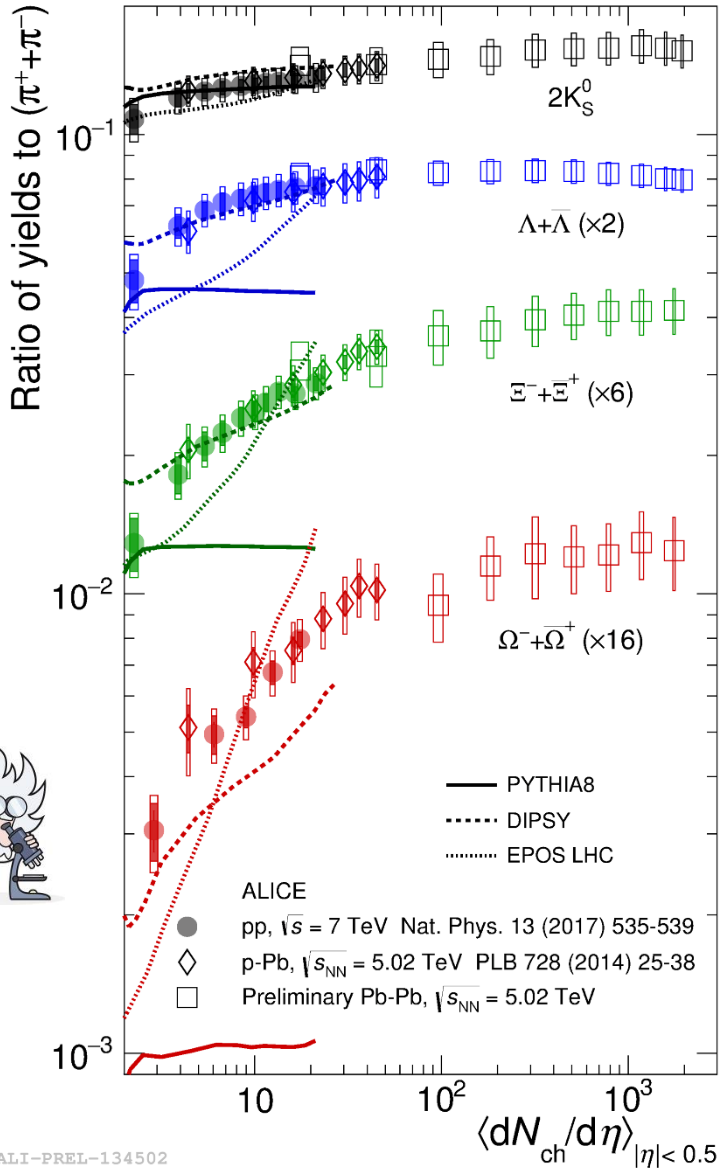


Strangeness production saturates at high multiplicity

No matter what the system/energy is! Tell me the multiplicity of the event and I'll tell you how many strange hadrons will be produced

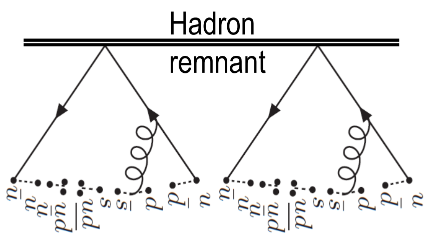


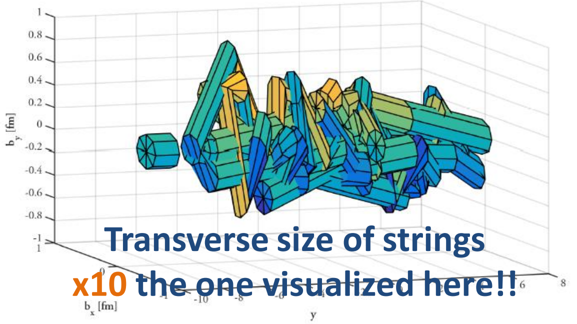


Microscopic models:

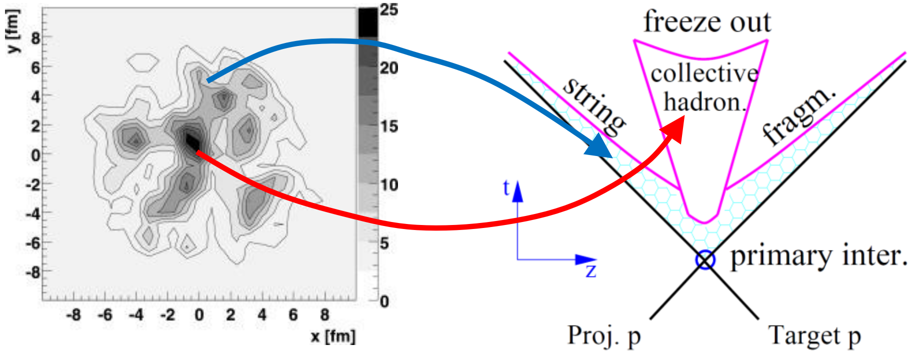
None (by now) is able to reproduce the increasing trend:

- PYTHIA (Lund string model) dramatically fails. Colour Reconnection does not help.
- DIPSY (including color ropes) qualitatively describes the increase
- EPOS (hard-soft interaction + hydro + core-corona + …) qualitatively ok





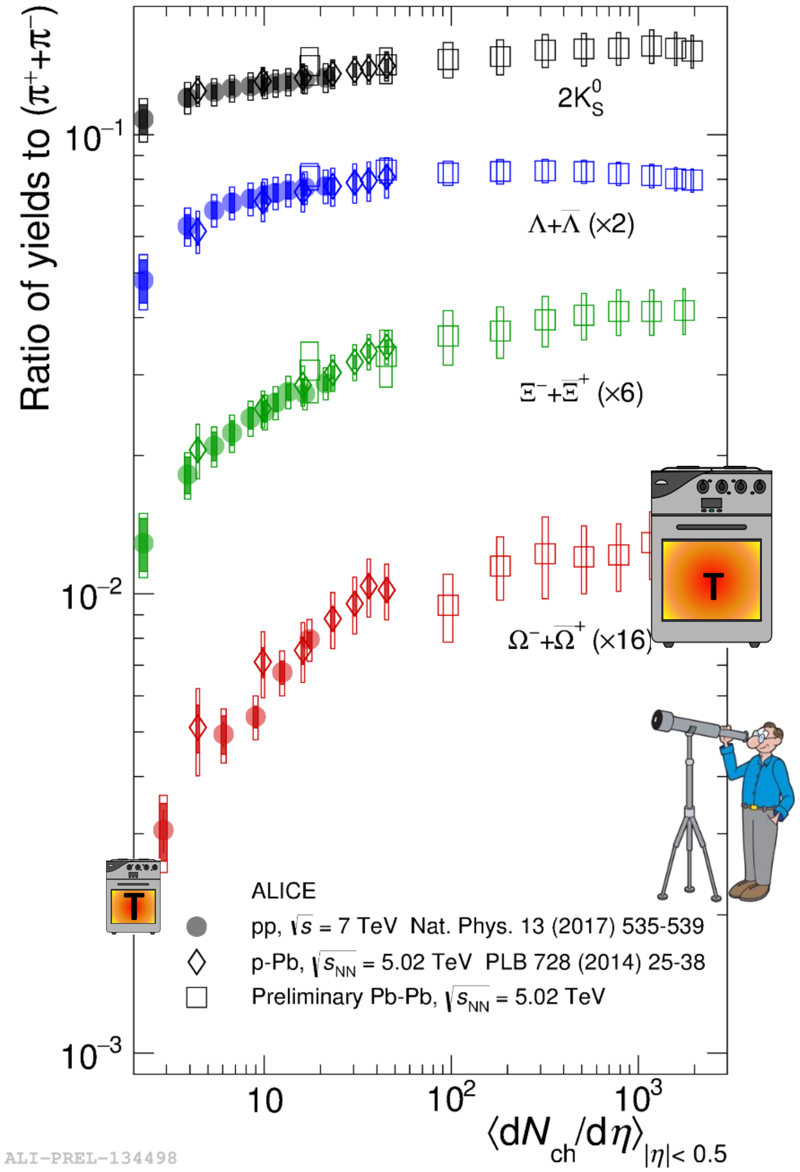
Transverse size of strings x10 the one visualized here!!



TAKE HOME

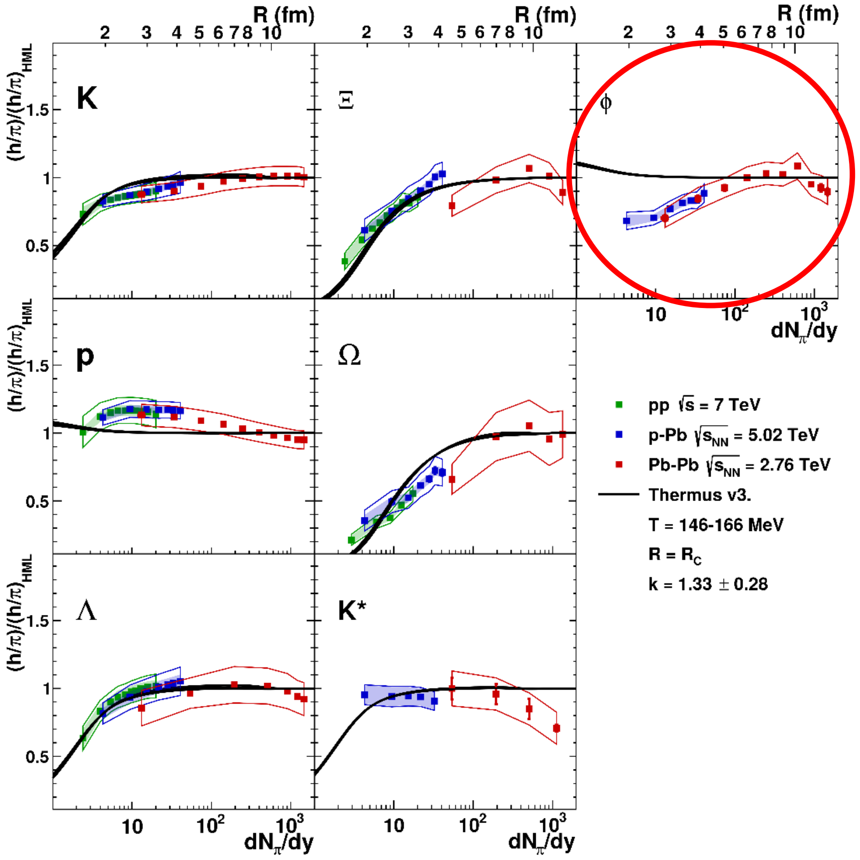
Microscopic models need more tuning and (possibly) new mechanisms to describe data

Strangeness in small systems: comparison to models



Macroscopic models:

- In the thermal model picture strangeness enhancement can come from
  - Canonical suppression (volume evolution of the source)
  - Non-full equilibration in small systems
- Increasing trend qualitatively in agreement with progressive release of canonical suppression
- But the ϕ meson is a weak point!

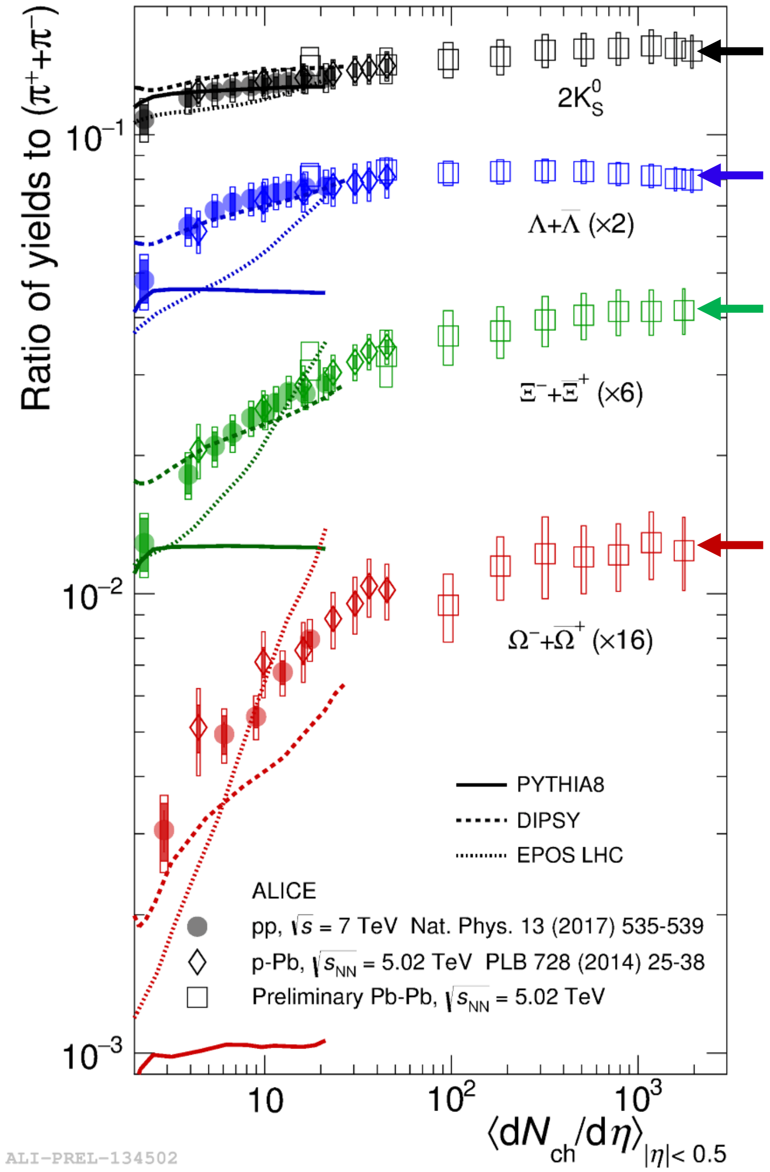


TAKE HOME

Thermal models with variable volume describe the data. Pure canonical suppression scenario problem

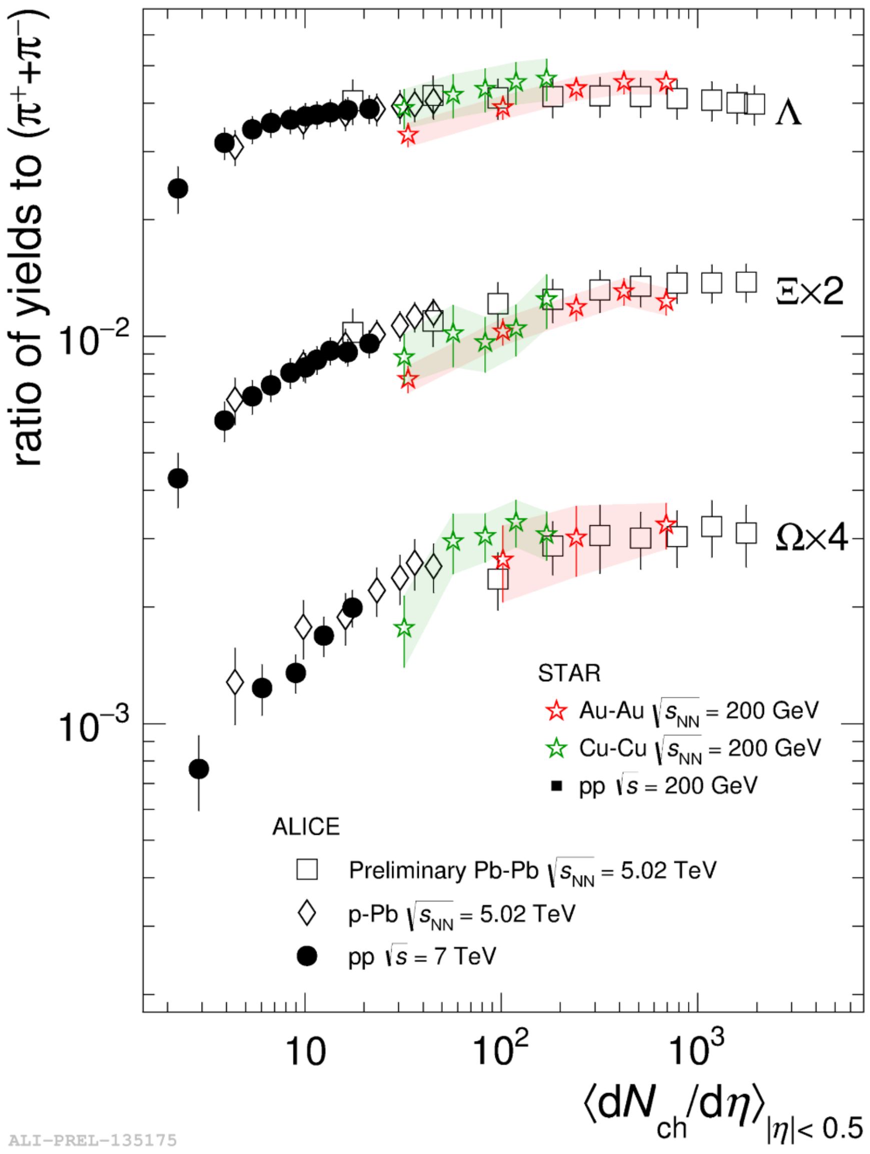
V. Vislavicius, A. Kalweit aXiv:1610.03001 [nucl-ex]

Strangeness in small systems: models wrap-up



These data warrant a synergic attempt for their description from theorists belonging to different communities

Is this true at the LHC only?



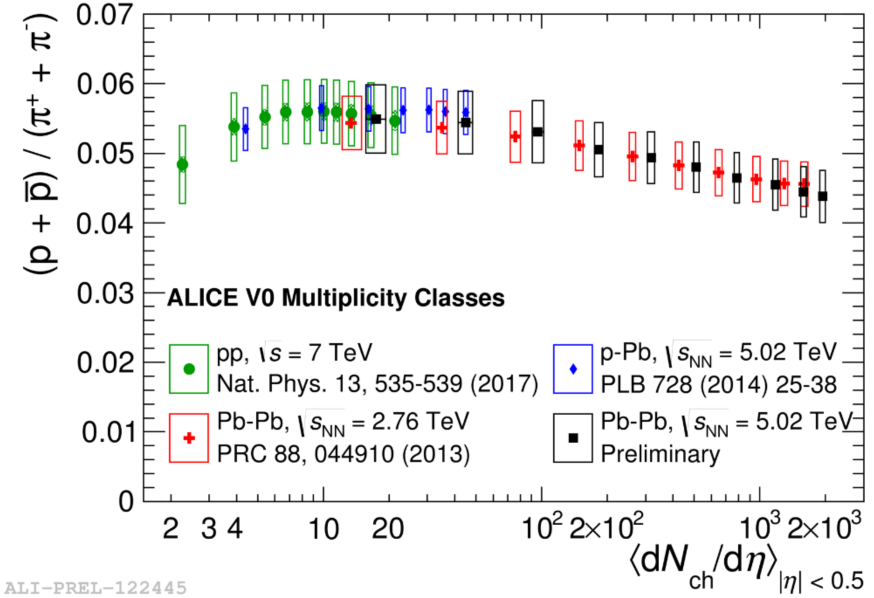
Data from STAR in heavy ions nicely pile-up to the saturation lines measured at the LHC

RHIC data from BES?

Other energies?

d-Au?

Is this true for strangeness only?



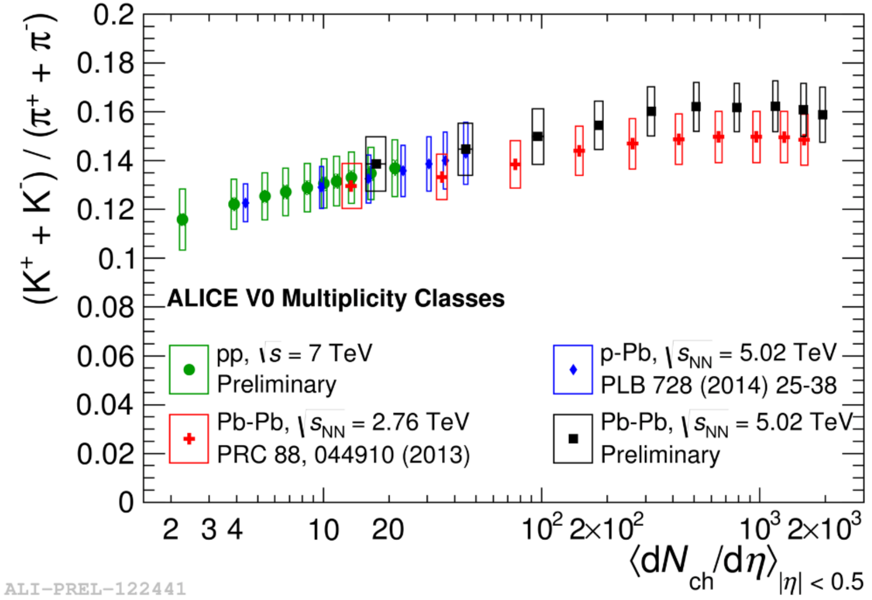
Same study performed for protons, charged kaons, deuteron, resonances (e.g. K*)

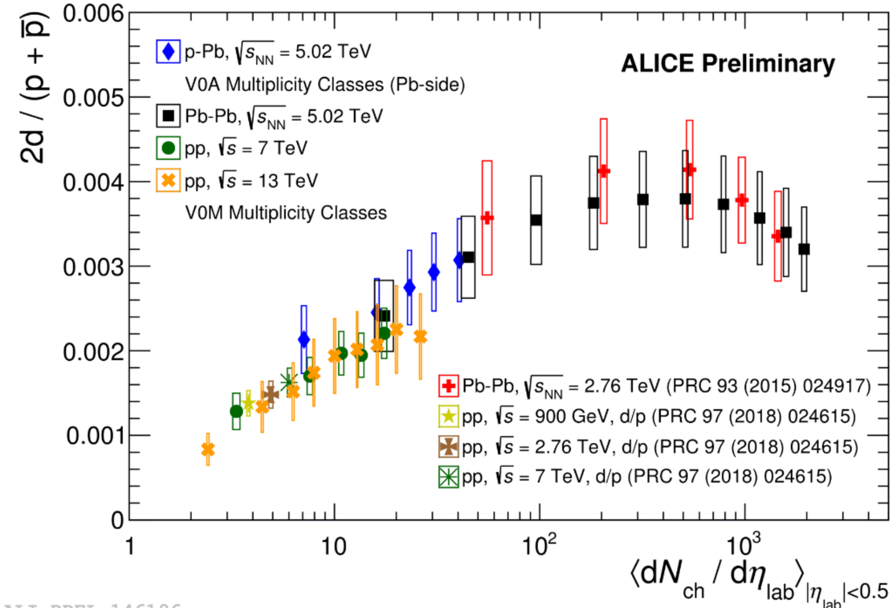
TAKE HOME

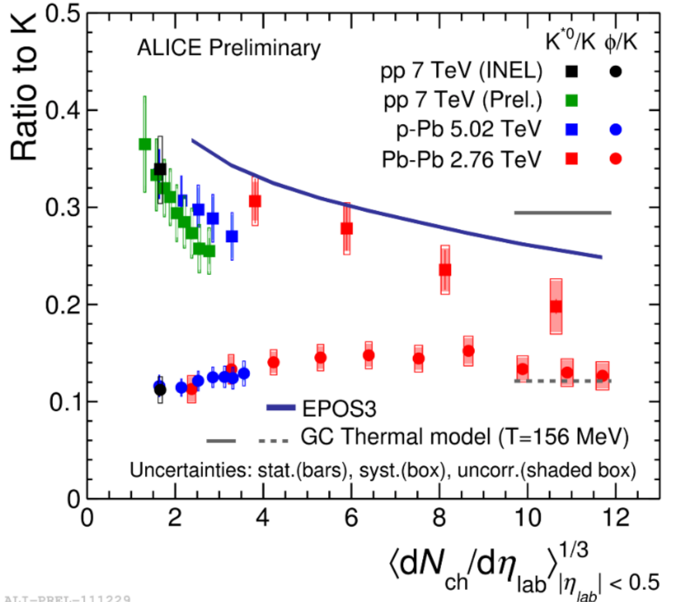
Multiplicity connects different collision systems for all "light" particles

If curious to know what's going on with K*, ask and check the backup ;)

↓





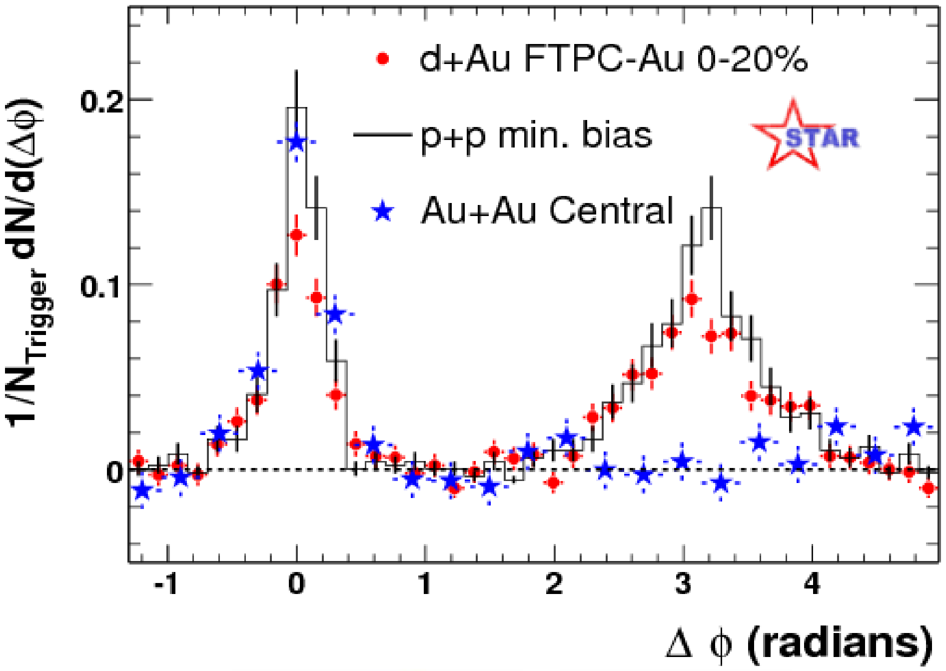


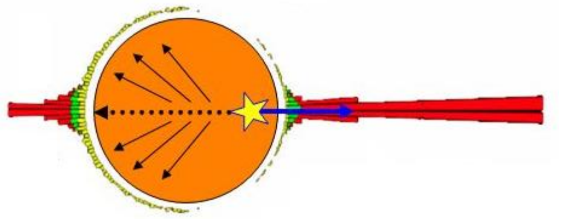
Hard Probes

Jets in A-A collisions

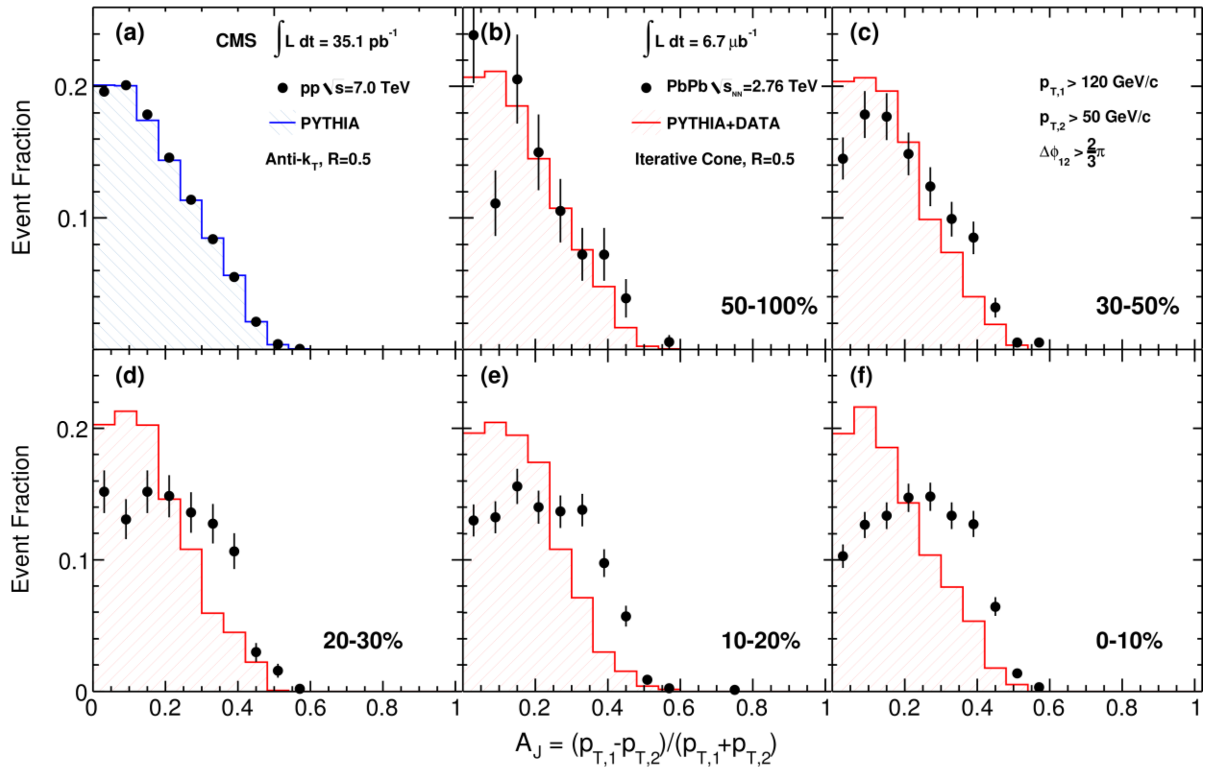
Recoiling jet suppressed by energy loss inside the medium

Clearly observed by STAR at RHIC…





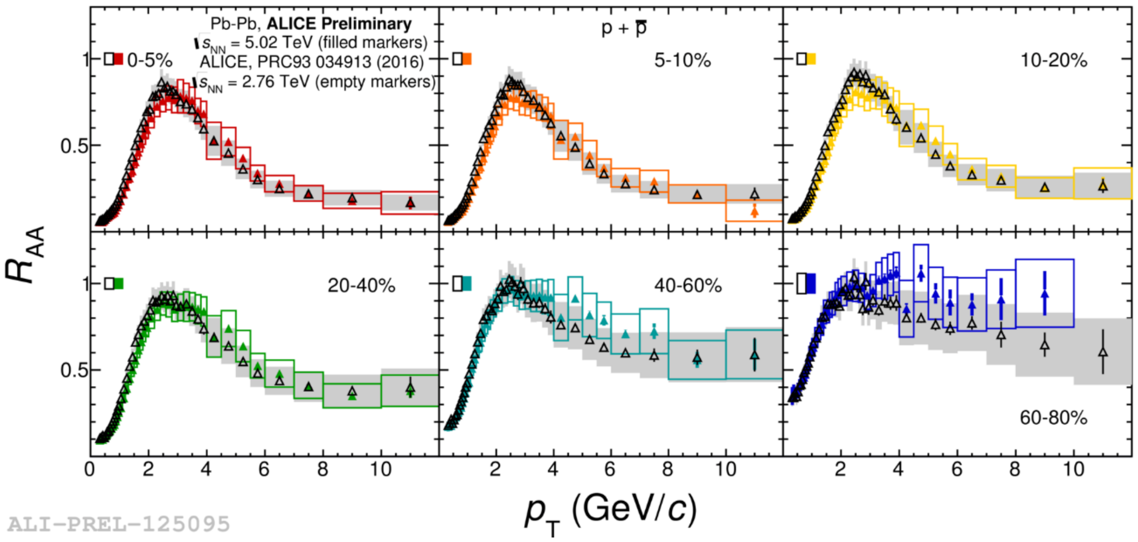
… and extensively studied at the LHC

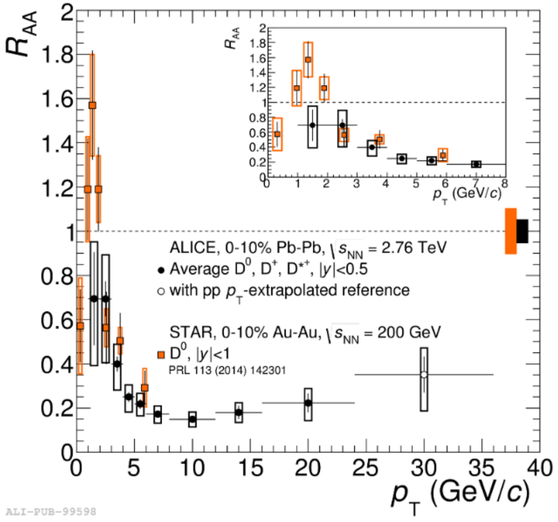


Nuclear modification factor (R_{AA}): heavy ions

Nuclear modification factor, indicates how far A-A observations are from the "normal" pp (binary scaled)

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dydp_T}{<N_{coll}> d^2N^{pp}/dydp_T}$$





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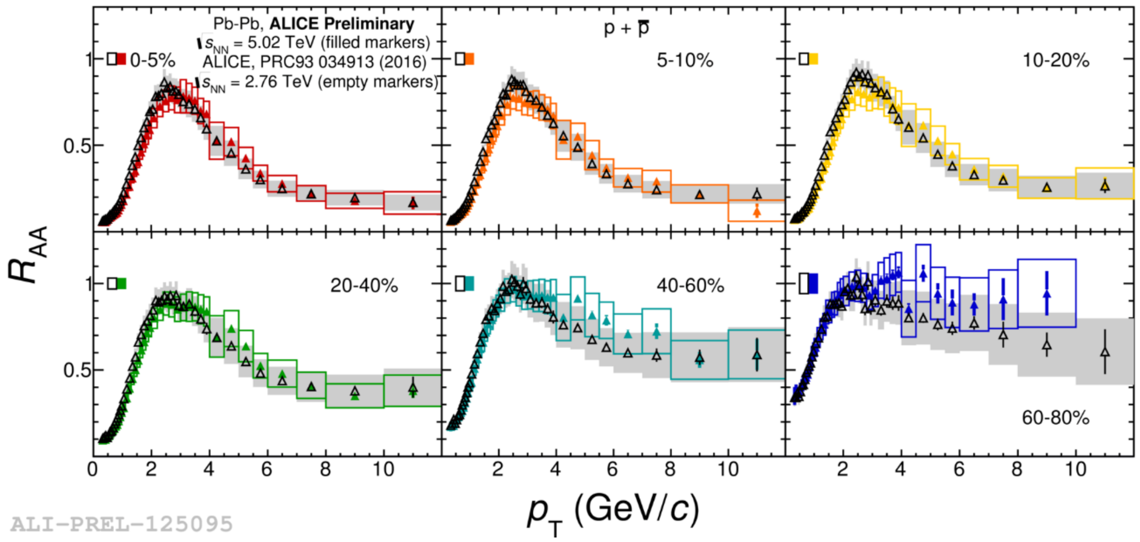
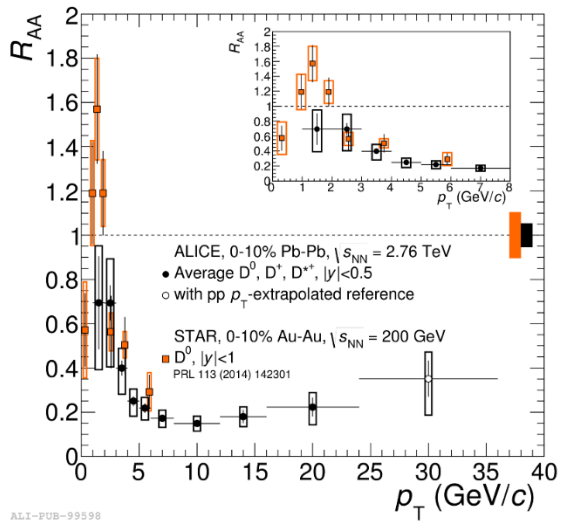
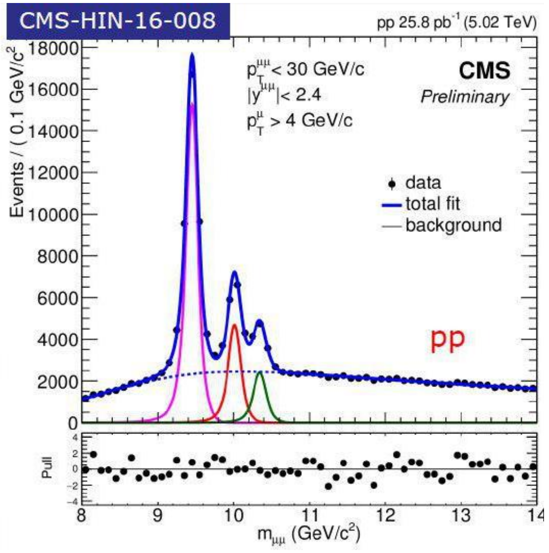
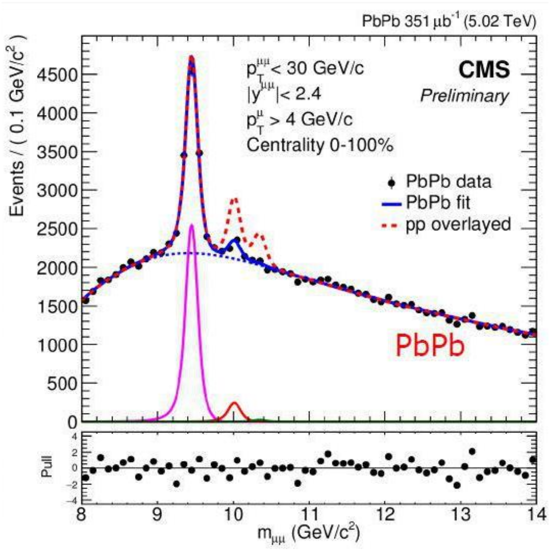
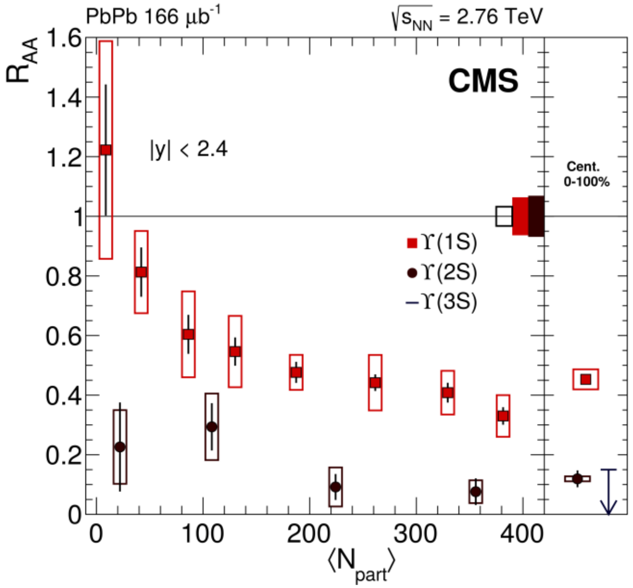


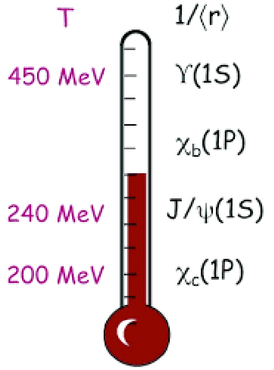




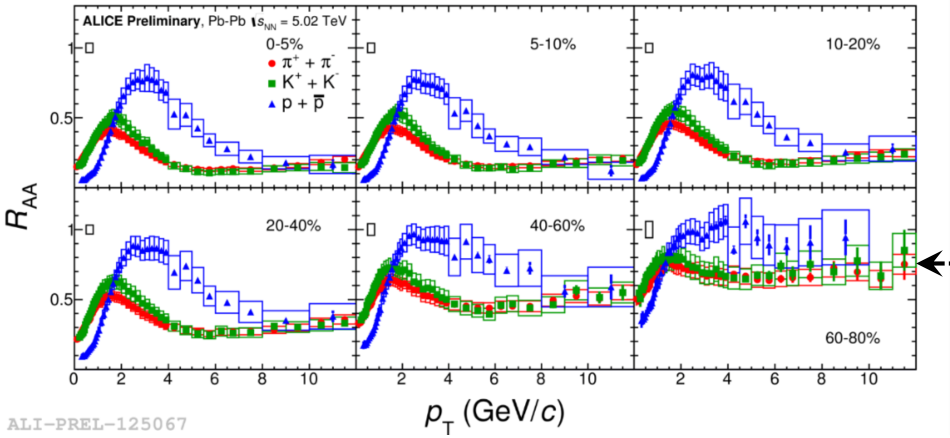


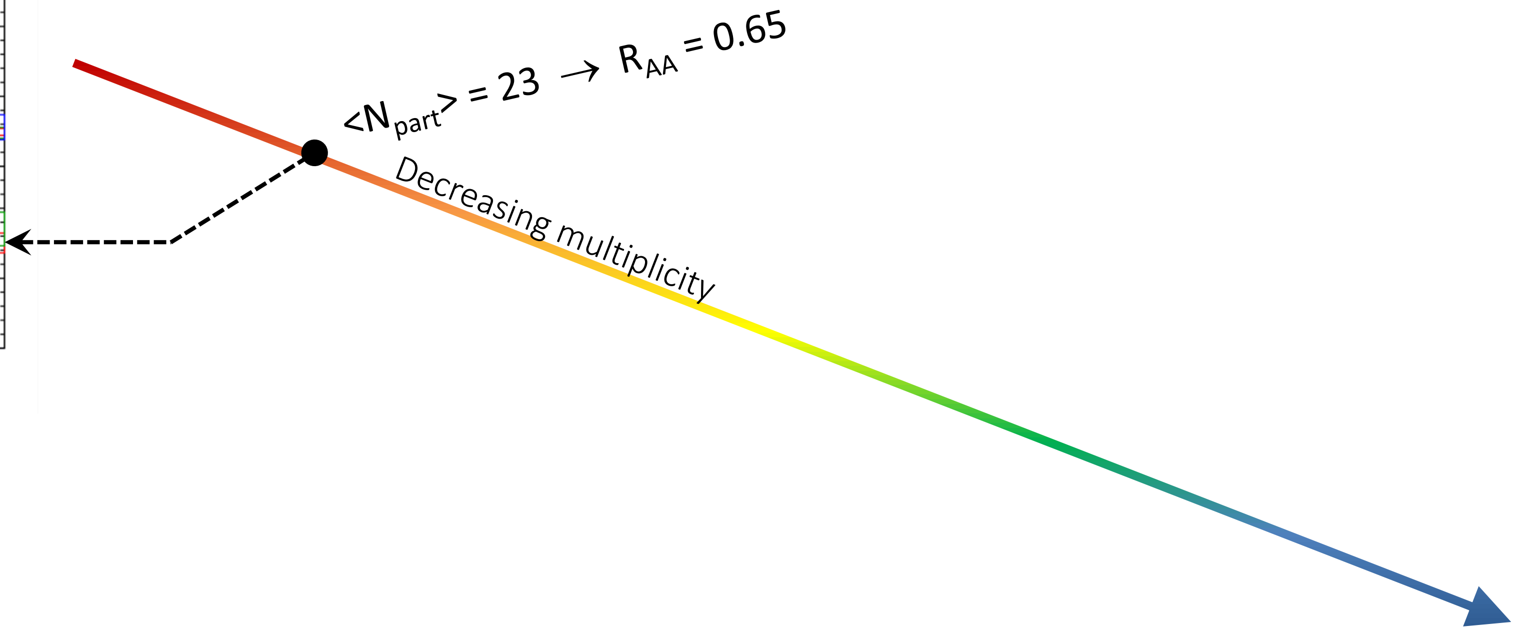


Quarkonia sequential suppression: less-bound states will survive less in a colored medium (Debye screening)

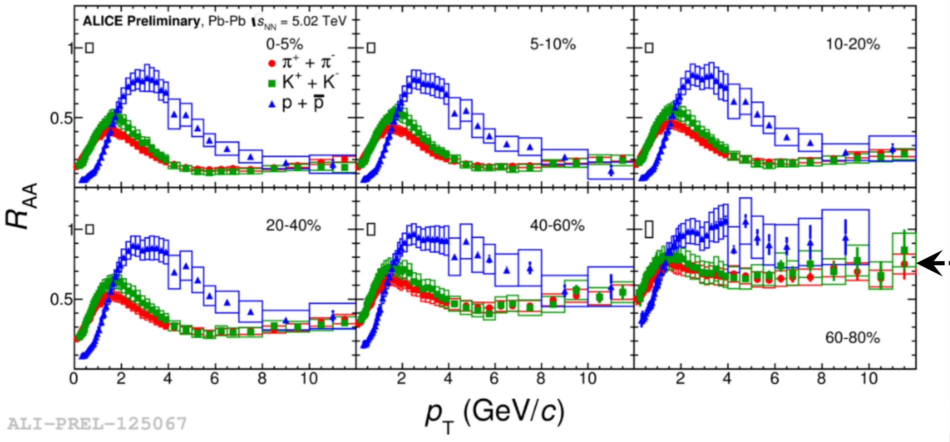


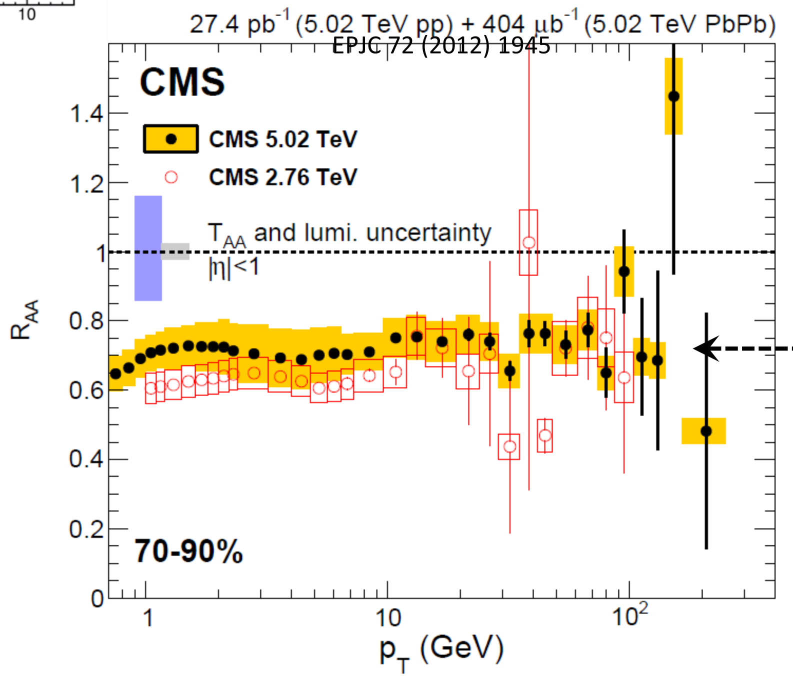
Livio Bianchi
QM 2018
Students day





Hard probes: moving towards smaller systems



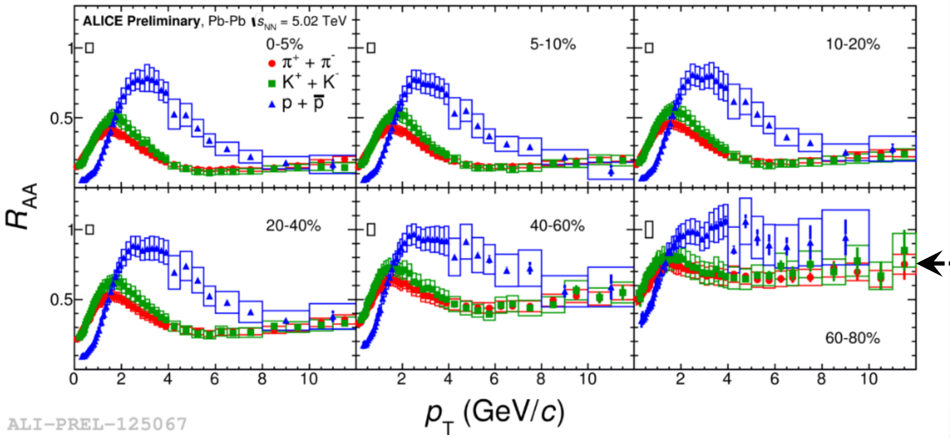


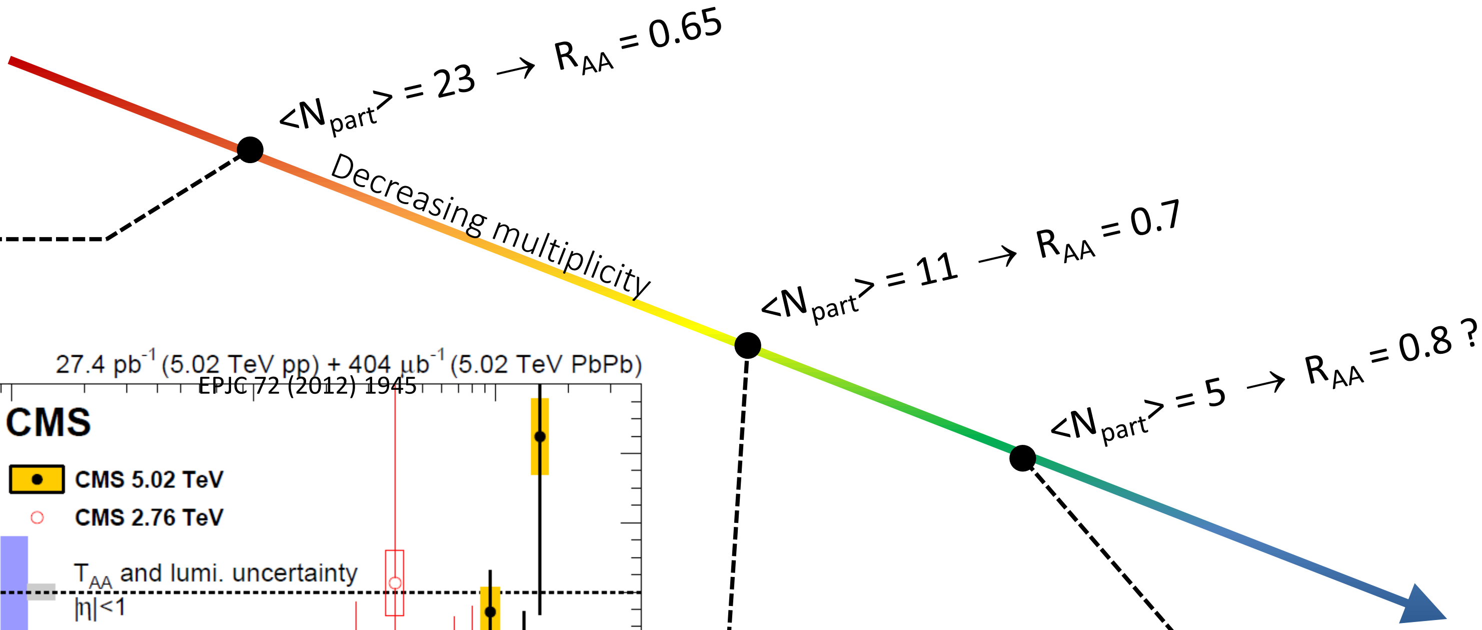
$\langle N_{part} \rangle = 23 \rightarrow R_{AA} = 0.65$

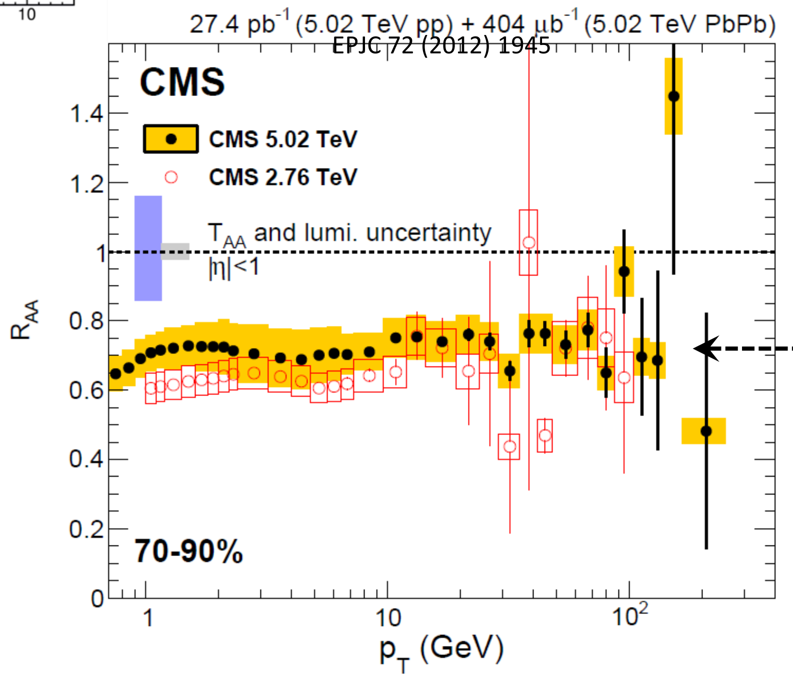
Decreasing multiplicity

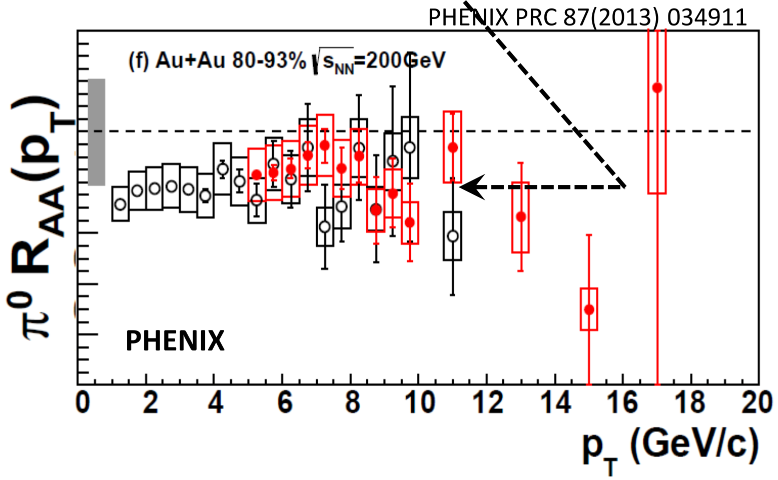
$\langle N_{part} \rangle = 11 \rightarrow R_{AA} = 0.7$

Hard probes: moving towards smaller systems









$R_{AA} \neq 1$ in A-A down to very low <N$_{part}$> (hence multiplicities)

But what happens in small collision systems?

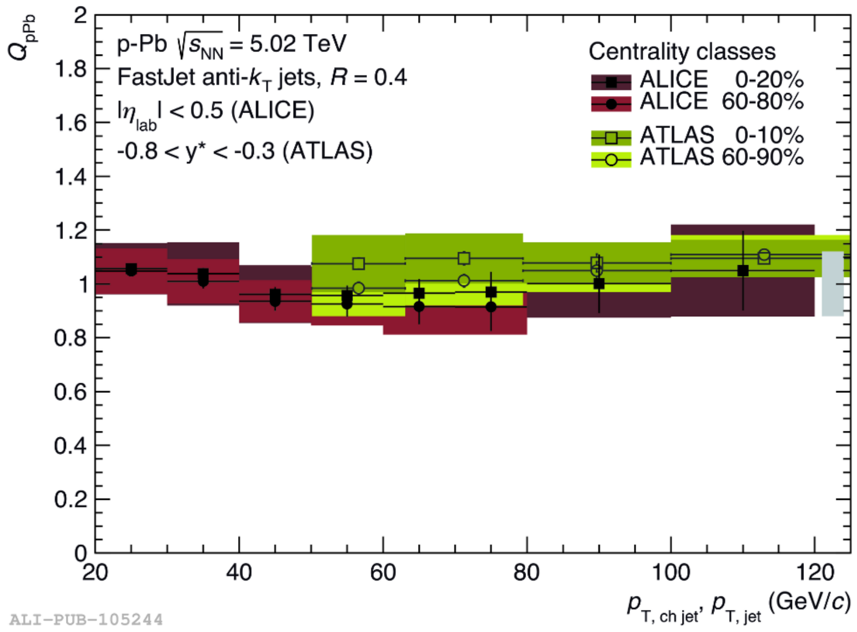
Difficult to define an R_{AA} in pp…!!!

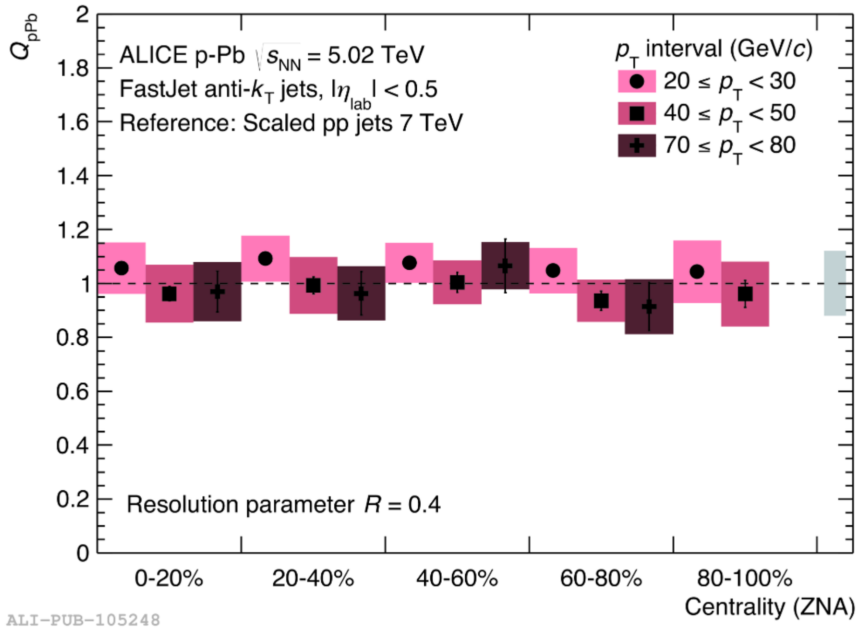
Let's concentrate on p-Pb

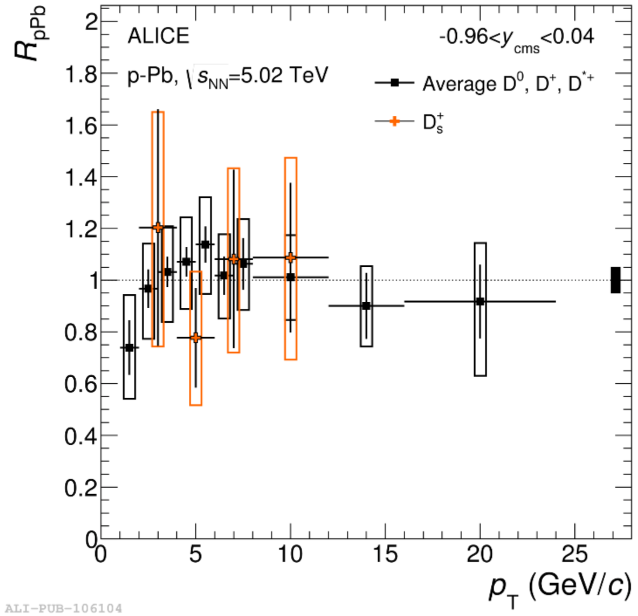
↓

Hard probes in small collision systems: energy loss

Livio Bianchi
QM 2018
Students day

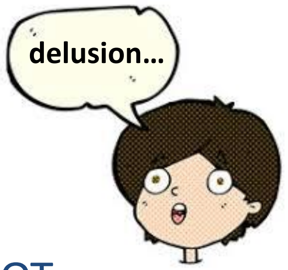






No evidence of **jet quenching in p-Pb** collisions at the LHC

High-pT hadrons do also not show any suppression

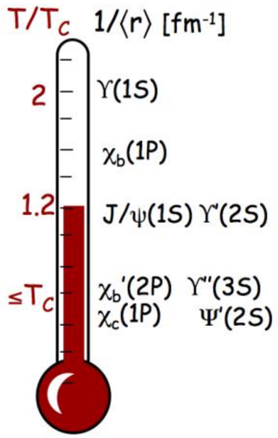


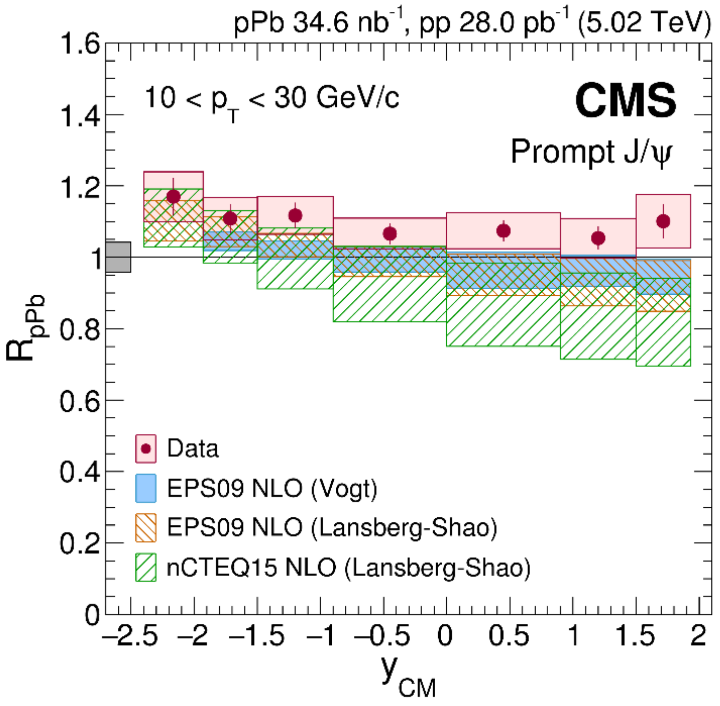
…but multiplicity in 0-20% p-Pb is higher than in all cases discussed in the previous slide…! ⇨ …should we conclude that multiplicity is NOT the driving quantity for "hard" observables?

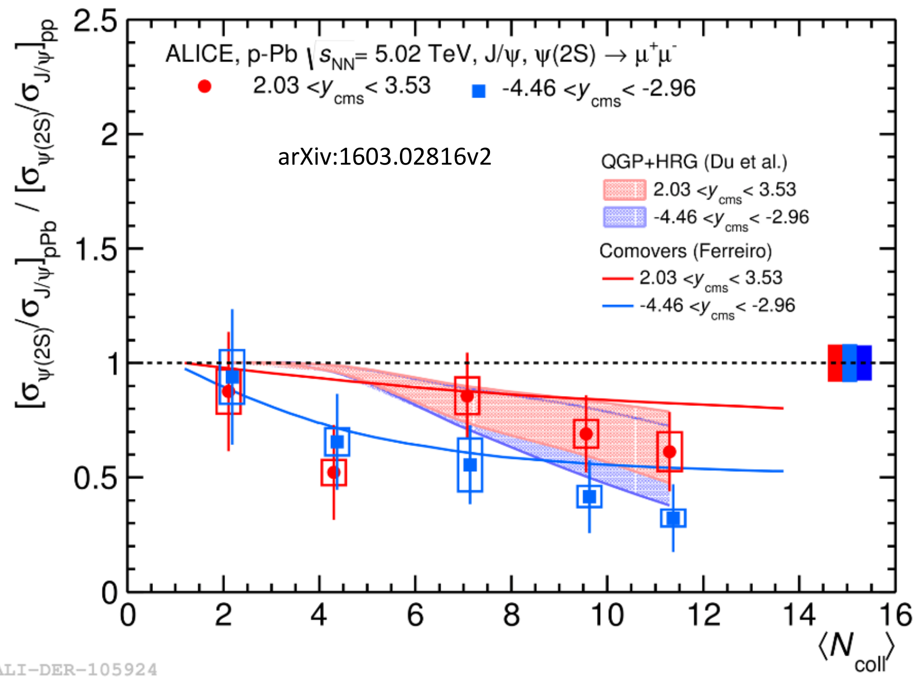
J/ψ not suppressed in p-Pb collisions

…but ratio ψ(2S)/J/ψ significantly lower than 1 at large N_{coll}!!

Makes sense in the "sequential suppression scenario": ψ(2S) should dissociate at lower T







Hard probes in small collision systems: quarkonia

J/ψ not suppressed in p-Pb collisions

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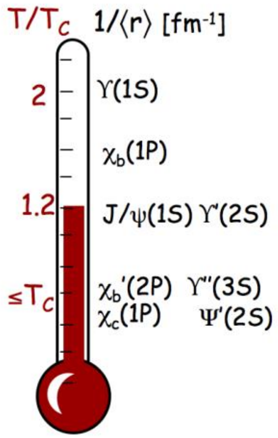
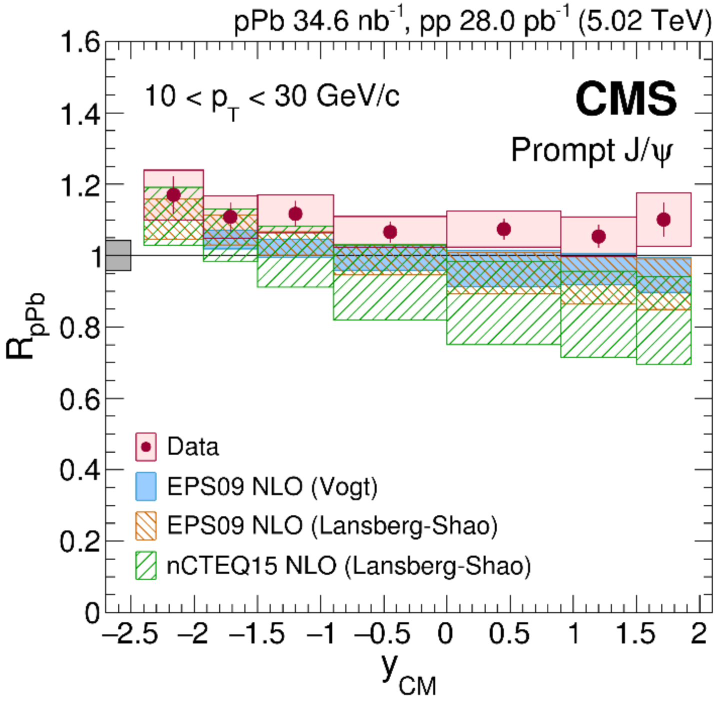
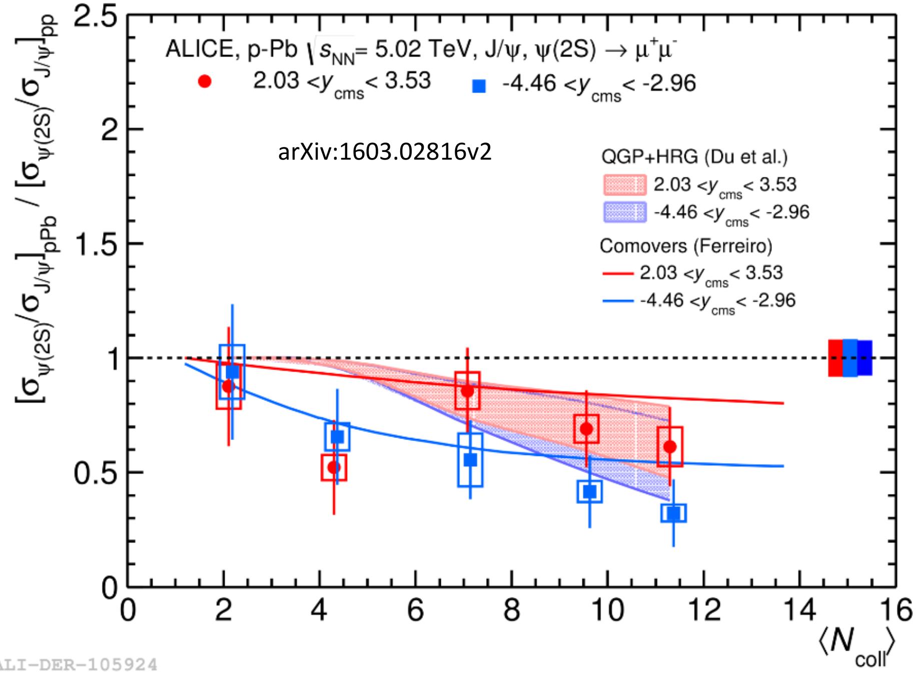
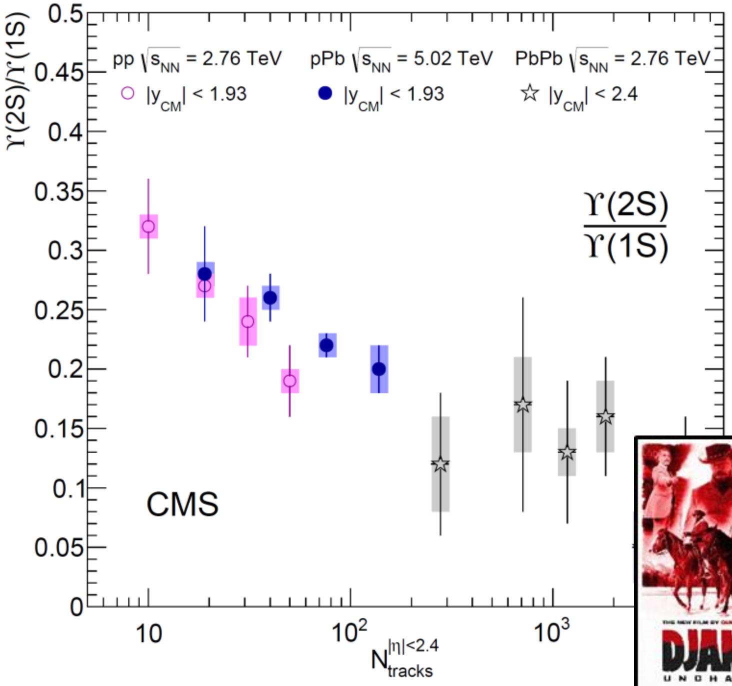


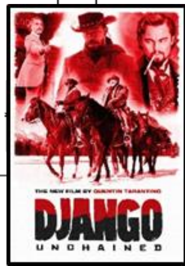
…but then, why ϒ(2S) is suppressed in p-Pb and even pp high-multiplicity events?

(NOTE: comparison among systems may be biased by absence of η-gap estimator-measurement)





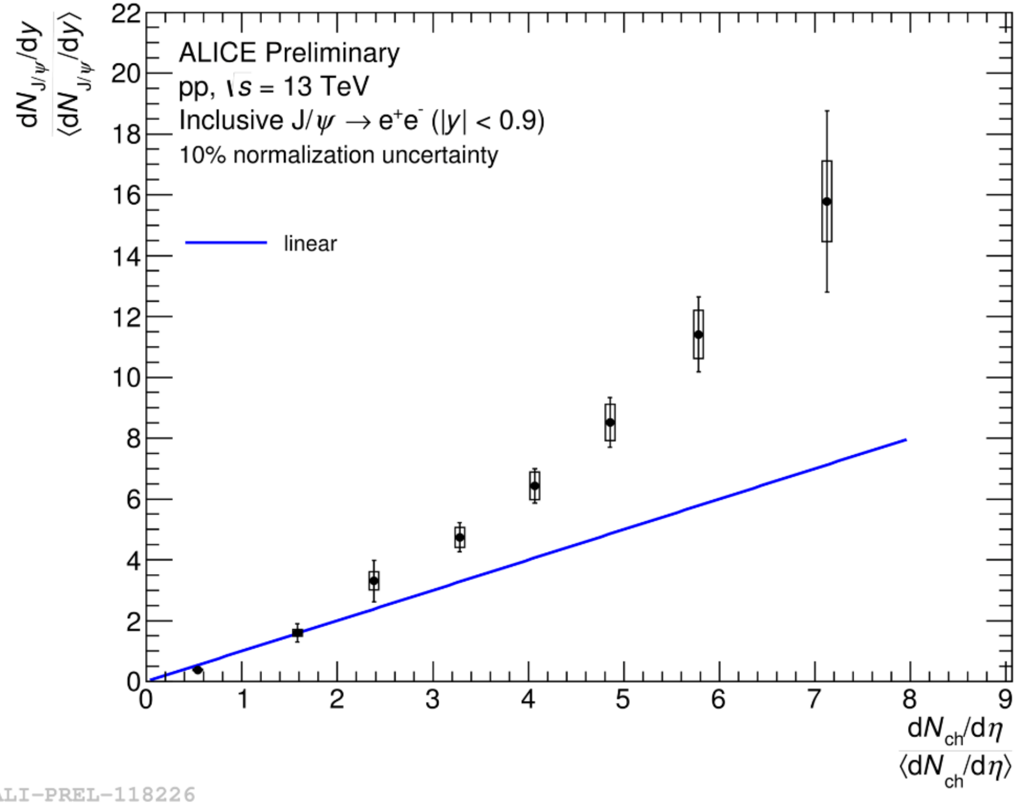




Hard probes: multiplicity progression

Heavy flavour and quarkonium production as a function of multiplicity in pp collisions.

More than linear increase



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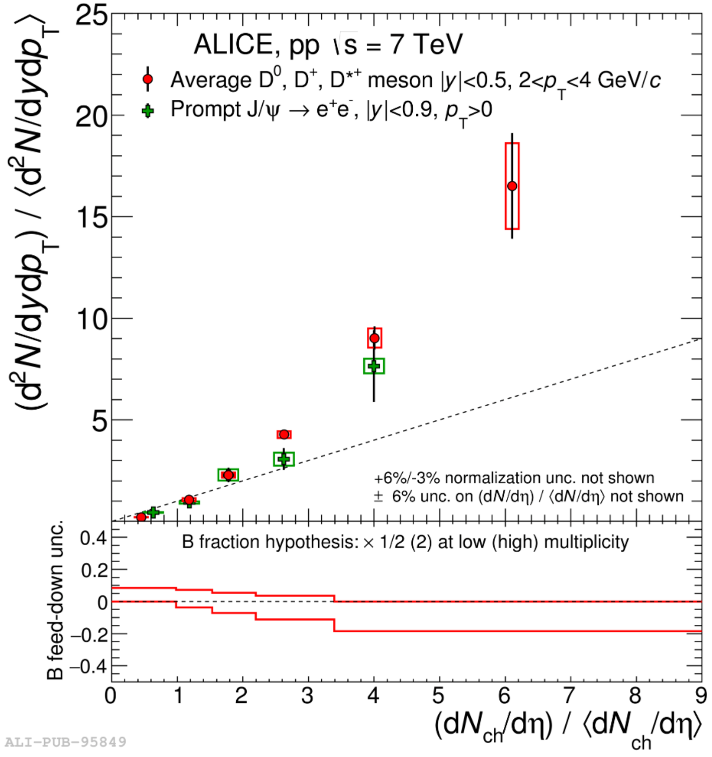
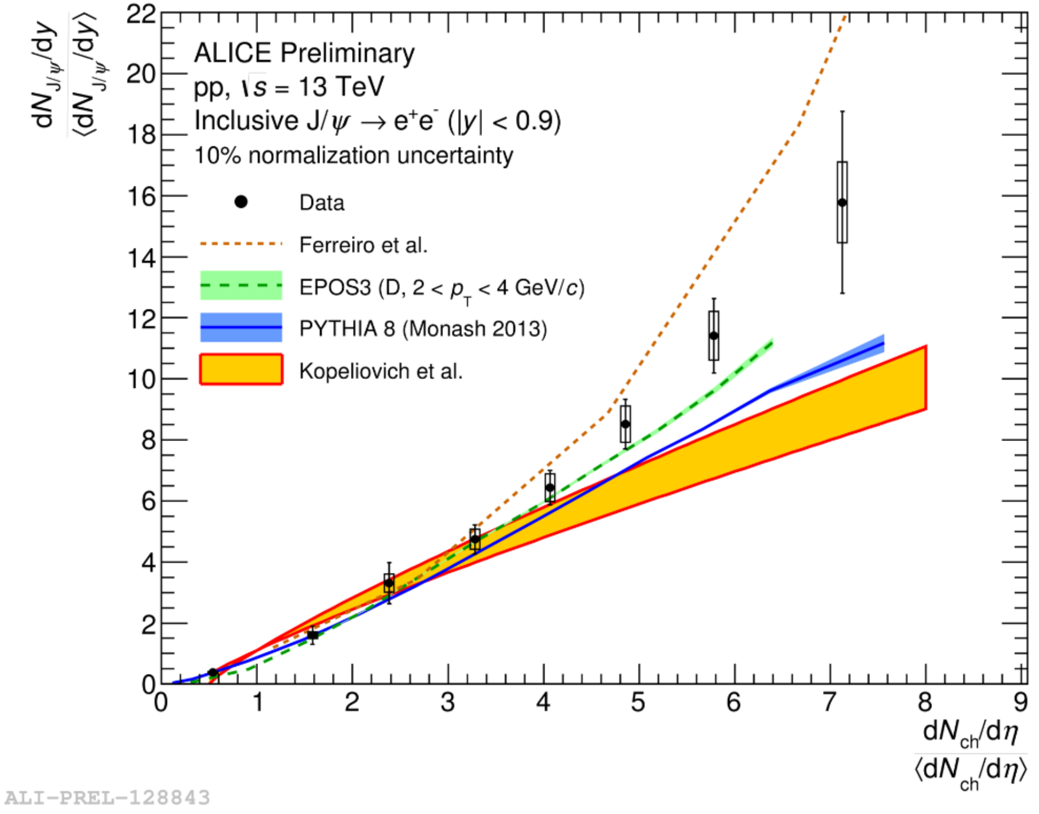


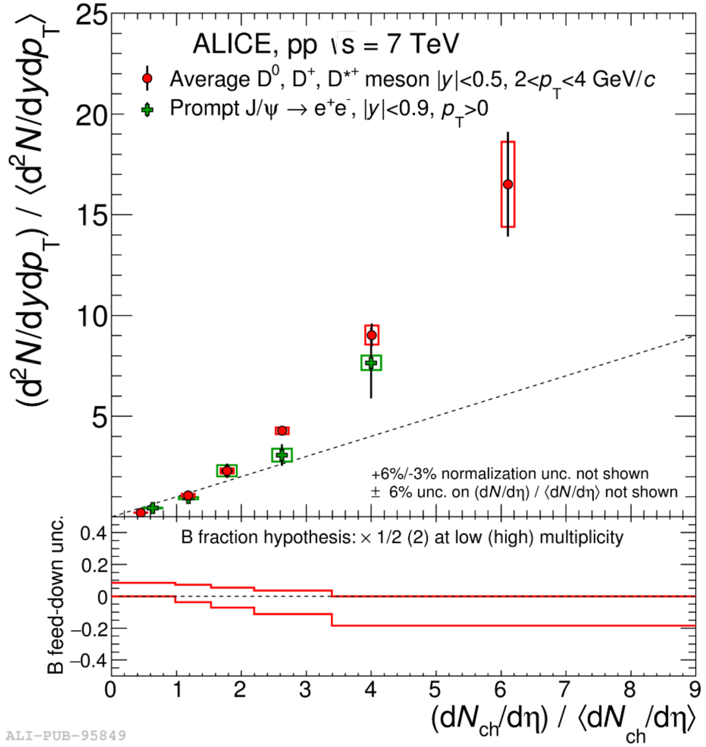
ALI-PUB-95849

Hard probes: multiplicity progression

Models implementing core-corona (EPOS) or some sort of gluon saturation (Ferreiro) qualitatively describe the data



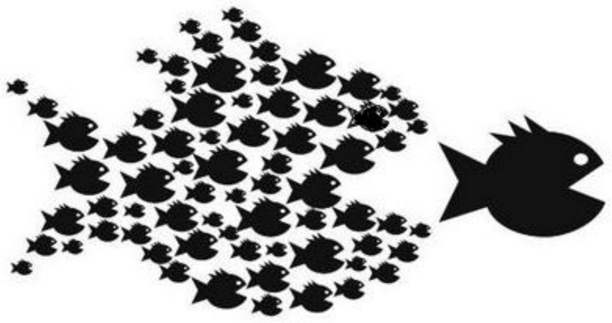
Self-normalized yields (+ potential multiplicity estimator bias) make comparison among systems difficult



Final considerations

Final considerations

- **"Small systems" are lot of fun:**
  - Heavy ion physicists: possibility of testing their understanding of excited QCD in "simpler" environments than A-A
  - HEP physicists: acknowledge the failure of broadly-used MC generators and have hard times identifying micro-mechanisms justifying new observations



Final considerations

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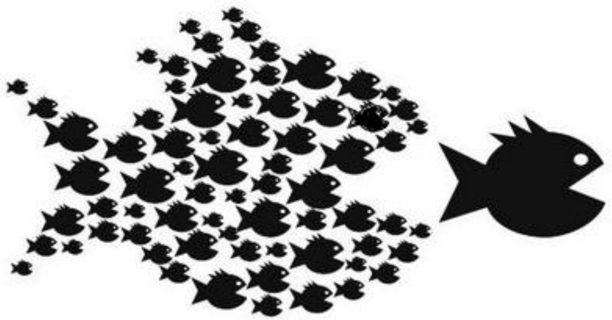
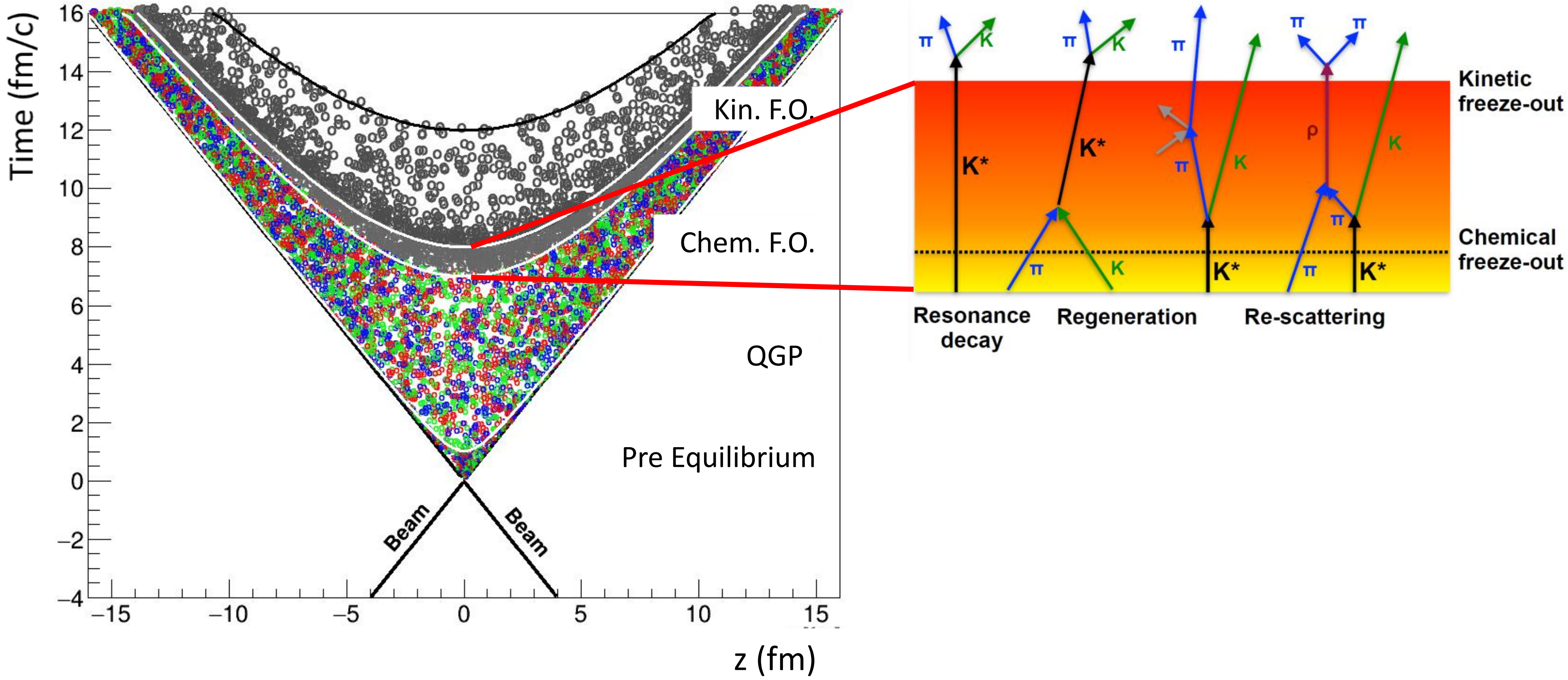


- **The quest is just at the beginning:**
  - Need to complement our understanding using all observables
  - Need to understand "hard probes" peculiarity
  - …always being aware of multiplicity biases which can affect the comparison among systems!

Backup

The resonances’ story (I)

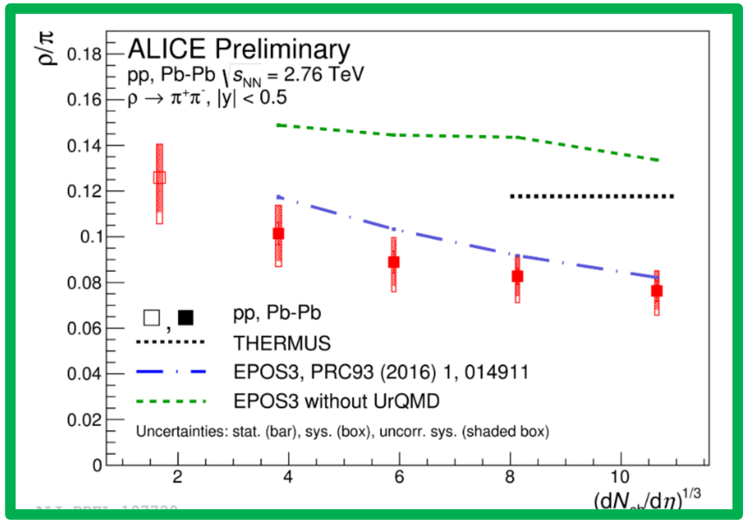
Resonances are powerful tools to probe the hadronic phase after chemical freeze-out

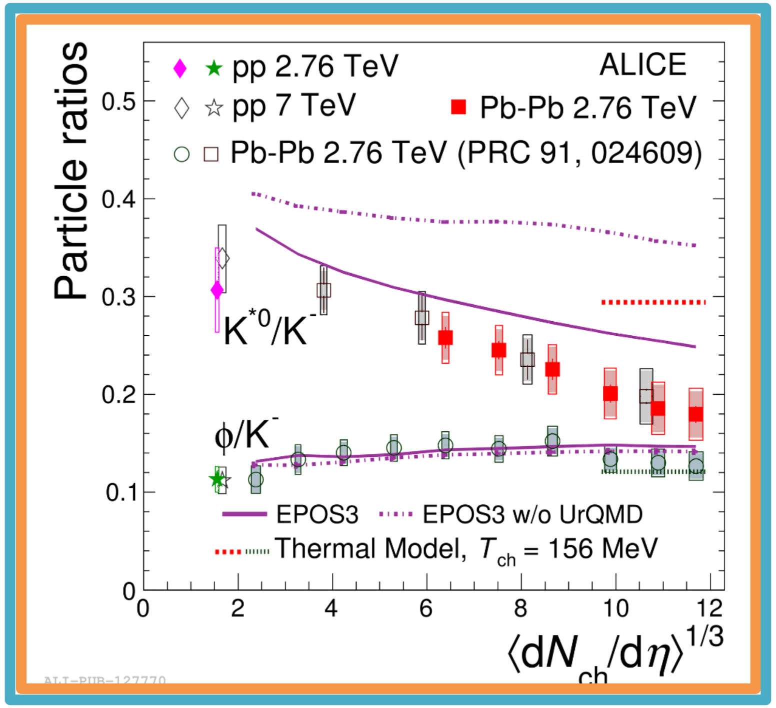


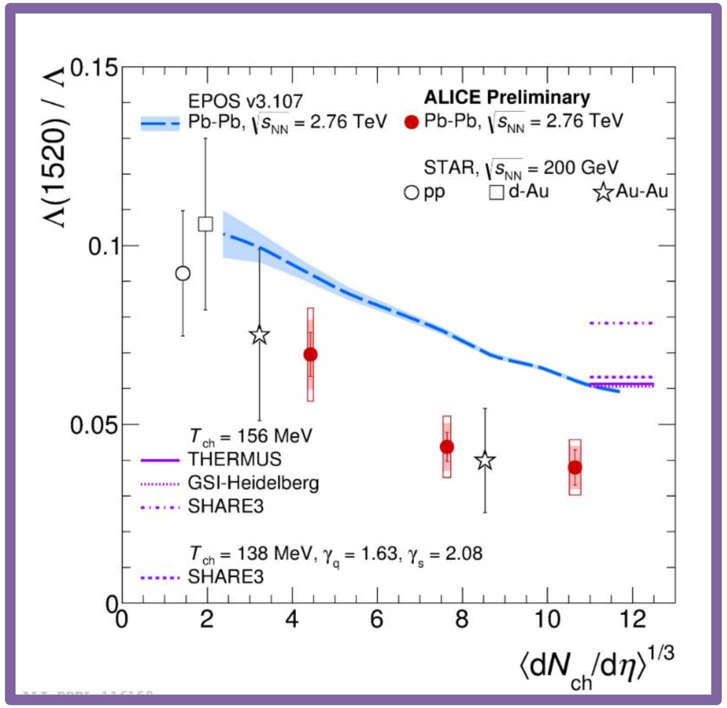
The resonances' story (II)

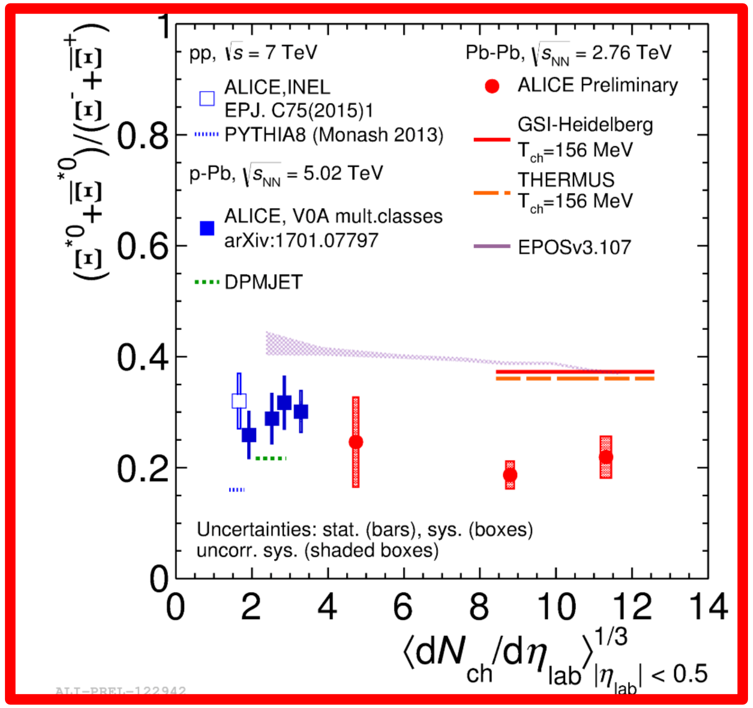
Resonances are powerful tools to probe the hadronic phase after chemical freeze-out

Lifetime [fm/c] : ρ [1.3] < K* [4.2] < Λ* [12.6] < Ξ^{0}* [21.7] < ϕ [46.2]



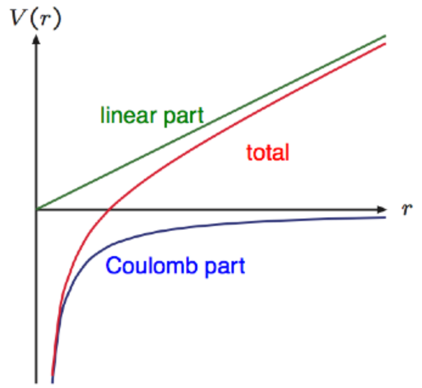






The Lund string model: basics

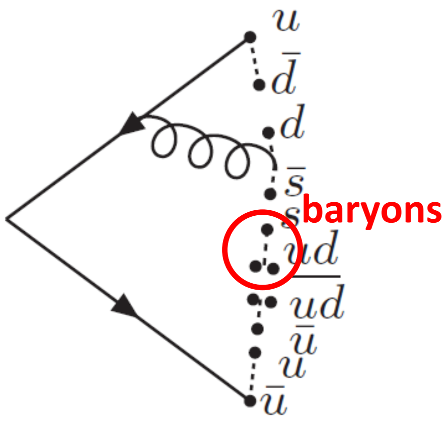
- Linear confinement potential for large distances (confirmed by lattice QCD). For short distances perturbation theory holds



- Confined colour fields described as strings with tension κ = 1 GeV/fm

- Breaking of strings (tunneling) give hadrons

$$P \propto e^{-\frac{\pi m_T^2}{\kappa}} = e^{-\frac{\pi m_q^2}{\kappa}} \cdot e^{-\frac{\pi p_{Tq}^2}{\kappa}}$$

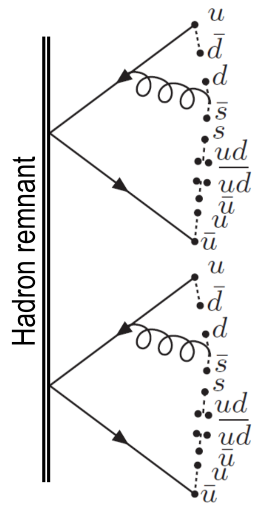


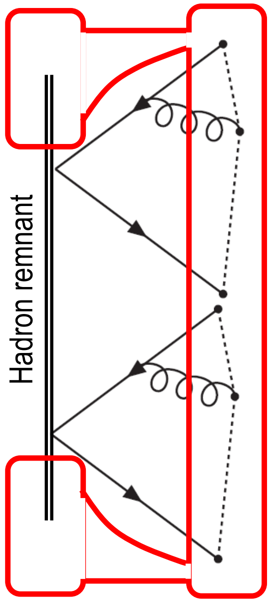
- Flavour of hadrons determined by the Gaussian mass suppression term (which mass to put? If current → less s-suppression than observed. If constituent → too much s-suppression. s/u empirical number to be tuned on data)

Fischer & Sjostrand, arXiv:1610.09818 (2017)

The Lund string model: MPI & CR

- In **hadronic collisions** multiple strings are needed to describe multiplicity distribution (**MPI**)
- In the LC Lund model each string is hadronizing separately with respect to the others
- The multiplicity increases, but not the $\langle p_T \rangle$ nor the relative flavor abundancies!

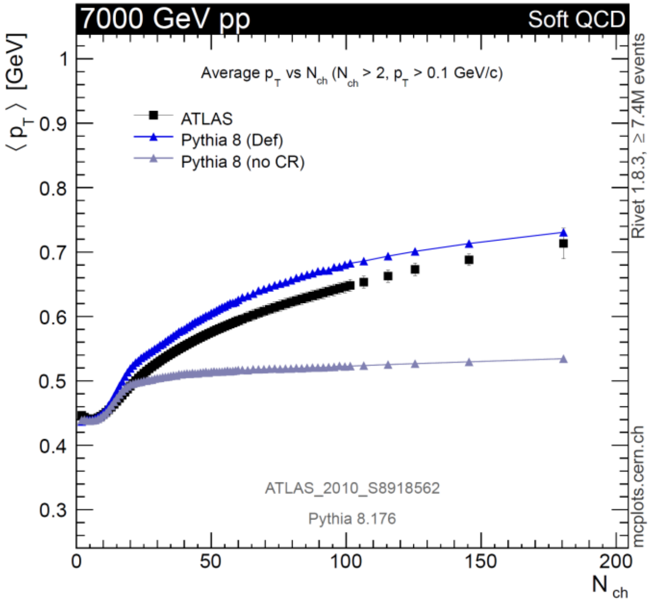




- Multiple strings are close in space-time. Dynamical interaction is not implemented in this model, but **colour re-arrangement** can happen: **Colour Reconnection** (CR)
- Takes place after parton shower and takes into account all SU(3) permitted configurations. **Selection parameter: minimum total string length**
- After re-arrangement of the strings, hadronization takes place
- Correctly takes into account the colour re-arrangement in the remnant

Christiansen & Skands, arXiv:1505.01681 (2015)

PYTHIA: effect of CR

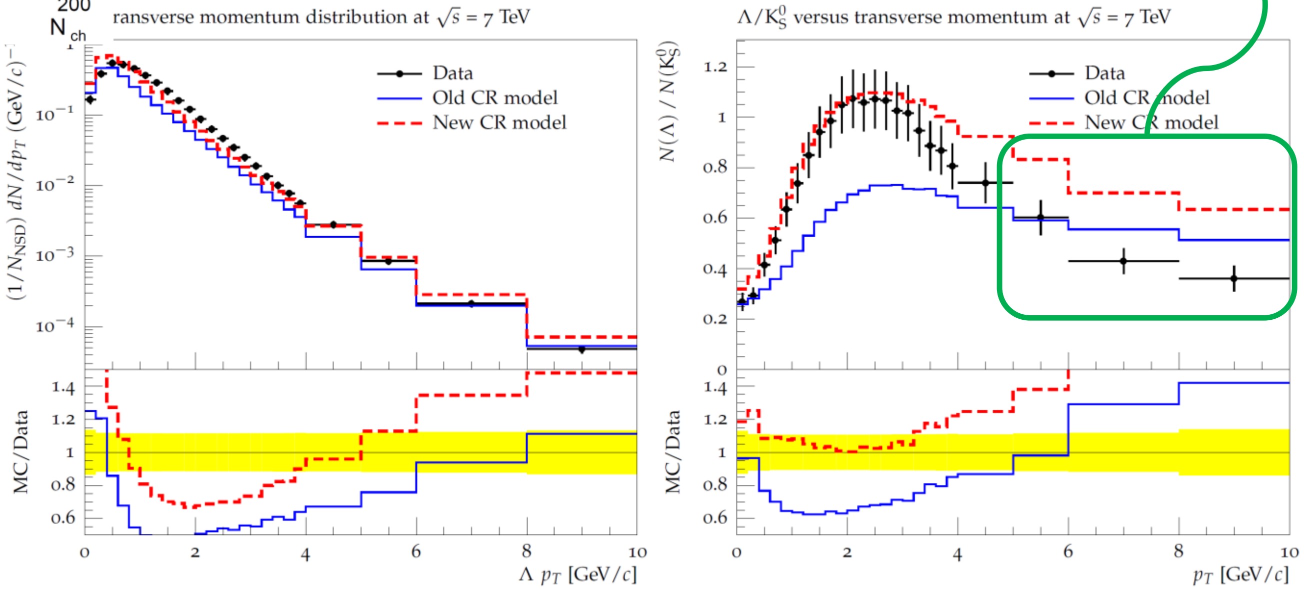


- 3 main parameters tuned on data: c_{time} ($\langle p_T \rangle$), c_j (Λ/K^0_S) and p_T^{ref} ($dN_{ch}/d\eta$).
- The presence of **junctions increases baryon production** at intermediate p_T, but not sufficient to reproduce data
- Λ/K^0_S shape (magnitude is tuned!) reproduces data up to 3 GeV/c → problem in spectra common to baryons and mesons?

Leading Colour strings dominate: can't be attributed to CR

TAKE HOME

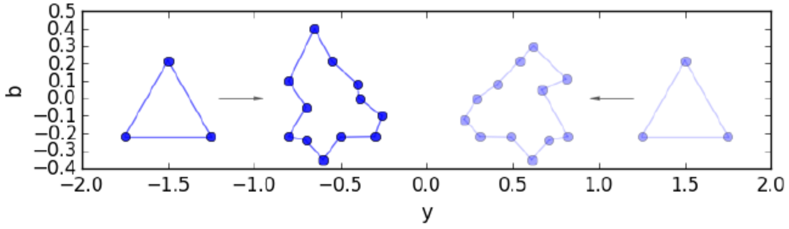
CR mimics features that we traditionally attribute to collective flow, but something more is needed. Tuning?

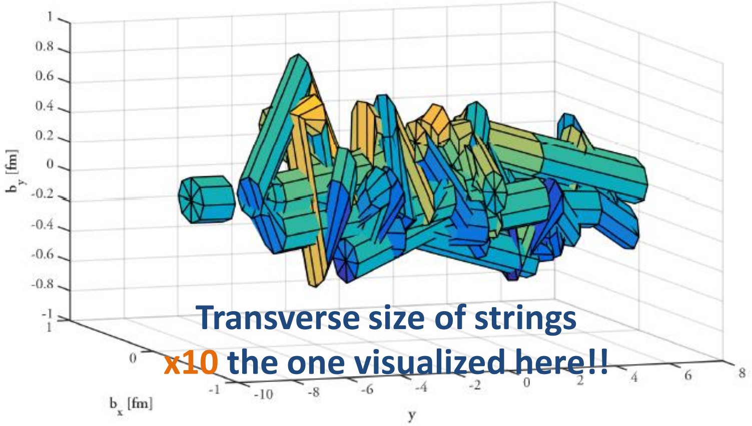


Christiansen & Skands, arXiv:1505.01681 (2015)

The DIPSY model: basics & ropes

- Partonic model in impact parameter space and rapidity (**D**ipole evolution in **I**mpact **P**arameter **S**pace and rapidit**Y**)
- Mueller dipole model (LL-BFKL)
- Proton/Nucleus structure built up dynamically from dipole splittings
- Builds-up initial state + collision in impact parameter space. Naturally treats saturation and MPI





Transverse size of strings
x10 the one visualized here!!

To the question "Which are the strings that can interact?" the DIPSY model answers following the evolution of colour strings during the whole parton shower

How do strings interact?

Stack of colour strings close in the IP-y space: can form colour singlets or multiplets according to the summing rules of SU(3)
Singlets correspond to simple re-arrangement of single strings,
Multiplets correspond to **ROPES**.

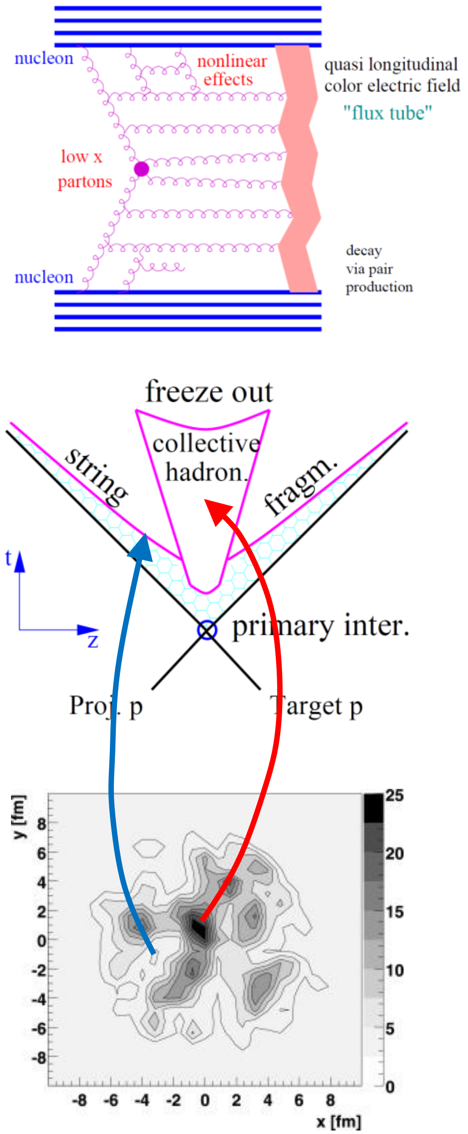
Hadronizing a rope means fragmenting string-by-string
with an **effective string tension $\kappa > \kappa_0$**

As we know from previous works,
higher string tension $\Rightarrow$ more baryons and more flavours$\neq$(*u,d*)

Before hadronizing a string
a "swing" mechanism further allow colour re-arrangements
(in analogy with colour re-connection)

Flensburg et al. arXiv:1103.4321
Bierlich & Christiansen, arXiv:1507.02091

EPOS: the melting pot

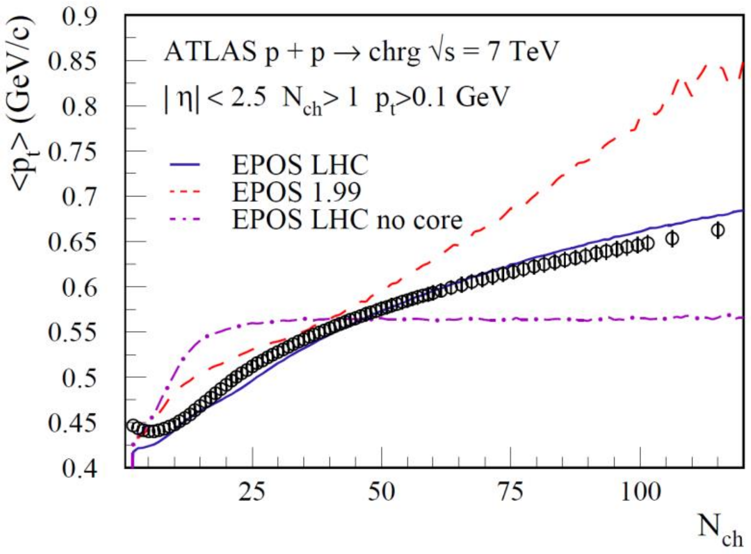


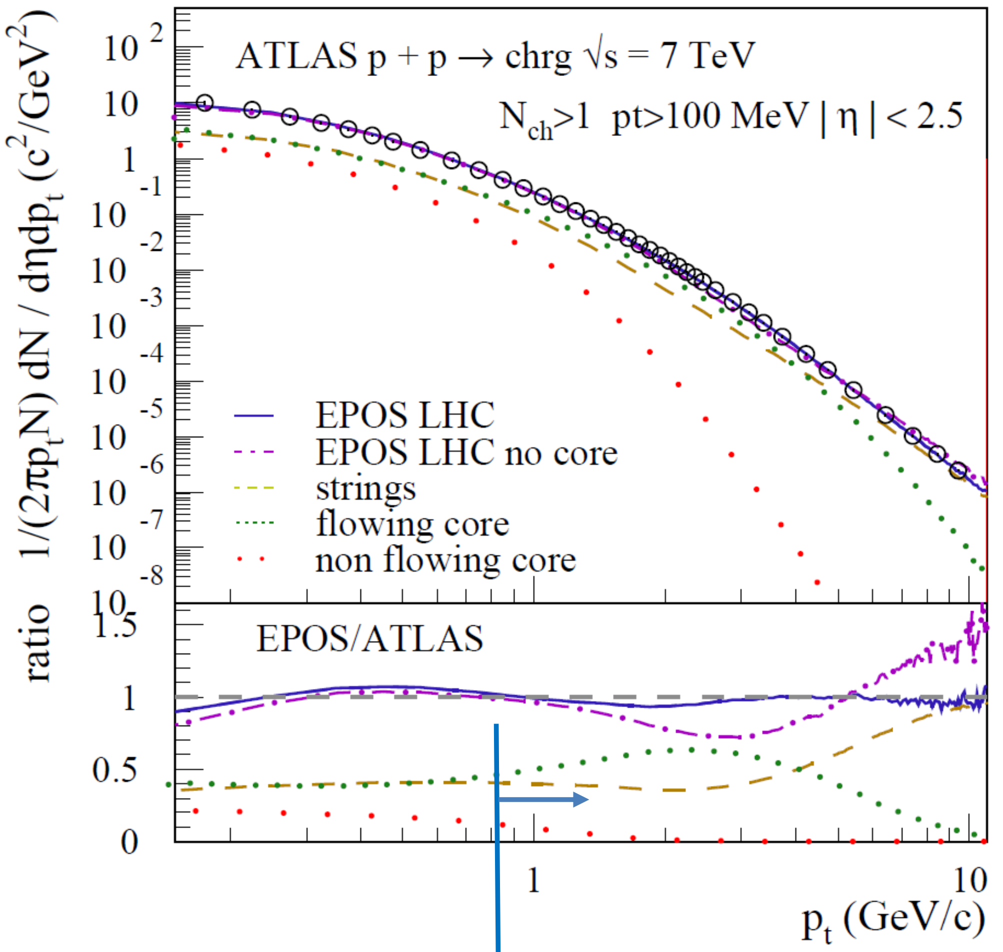
- Hard scattering treated with the addition of several DGLAP parton "ladders" (pomerons) + a CGC-inspired saturation scale
- Parton ladders are then considered as relativistic strings, conveniently treated in a string fragmentation approach (a-la Lund)
- At time τ_0 (well before hadronization) strings are divided into: fluid (CORE) and escaping (CORONA) according to their momenta and density of the string segments
  - **CORONA**: strings can hadronize as in the Lund approach
  - **CORE**: from the time τ_0 evolves as a viscous hydrodynamic system. Hadronization happens statistically at a common T_H
- After hadronization hadron-hadron rescattering can ba considered, baking use of an afterburner (e.g. UrQMD)

NOTE: parameters governing the core-only part are 6 (τ_0, ρ_0, ε_{FO}, y_{rad}, f_{ecc}, γ_s), to be tuned on data!!

Werner, PRL 98, 152301 (2007)

EPOS: effects of Core-Corona (I)



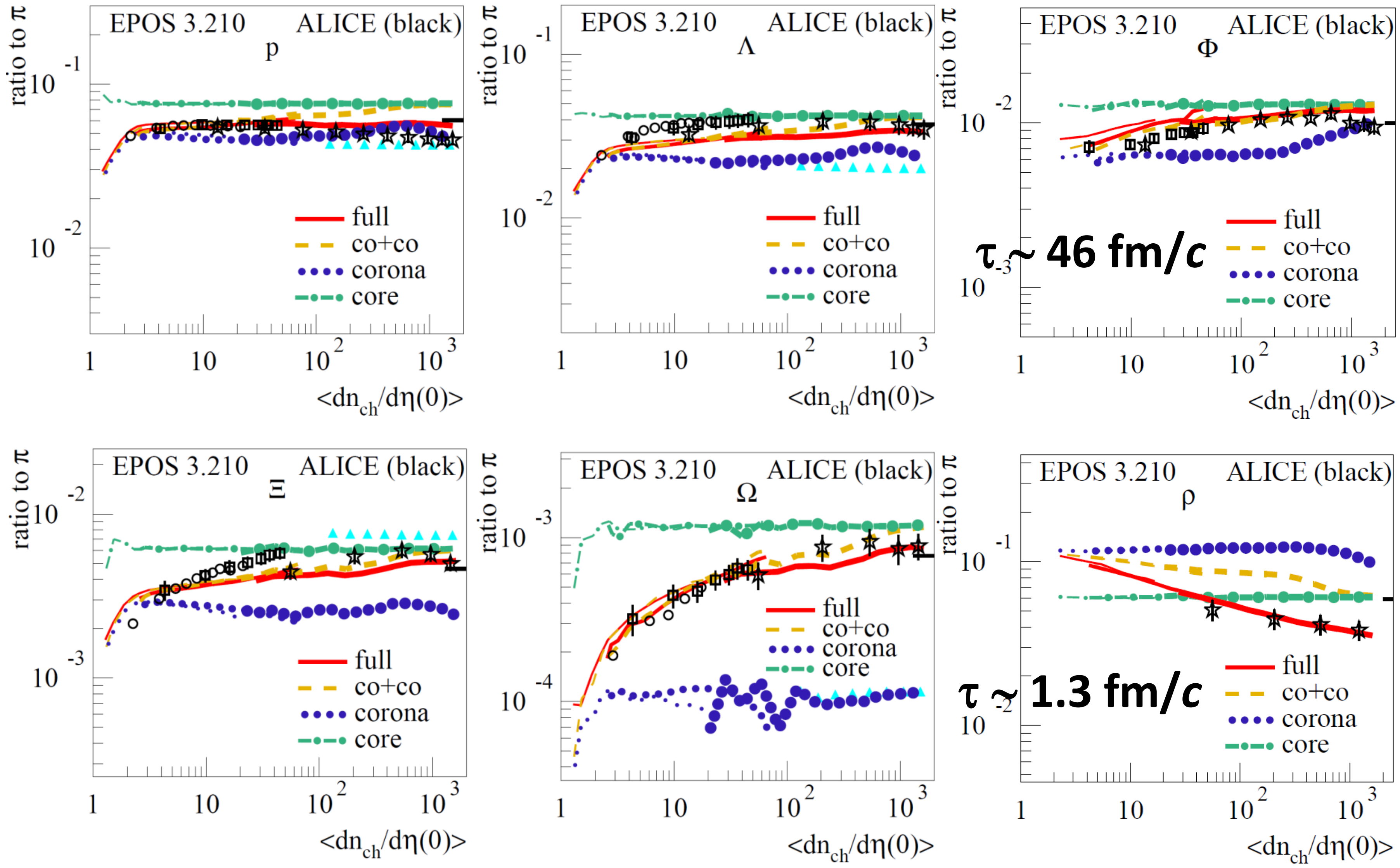


- $\langle p_T \rangle$ increases only when introducing a flowing core
- **Radial flow** of the core also **dominates** the **intermediate** region of the $\boldsymbol{p_T}$ spectrum
- High p_T is dominated by escaping fragmenting strings

NOTE: the exact onset of the effect depends on tuning (p_T cut-off for escaping strings)

Pierog & Karpenko & Katzy & Yatsenko & Werner, arXiv:1306.0121

EPOS: effects of Core-Corona (II)



Observed trends of relative particle yields **reproduced** thanks to **interplay** between **core** and **corona** (+ UrQMD)

TAKE HOME

Spectra + yields described in EPOS through evolution with multiplicity of relative importance of CORE and CORONA

NOTE: Does this imply QGP in small systems? NO! May or may not be.

- Relative importance of CORE/CORONA in the yields for long and short living resonances is strikingly different
- Mild Φ enhancement with multiplicity observed in EPOS