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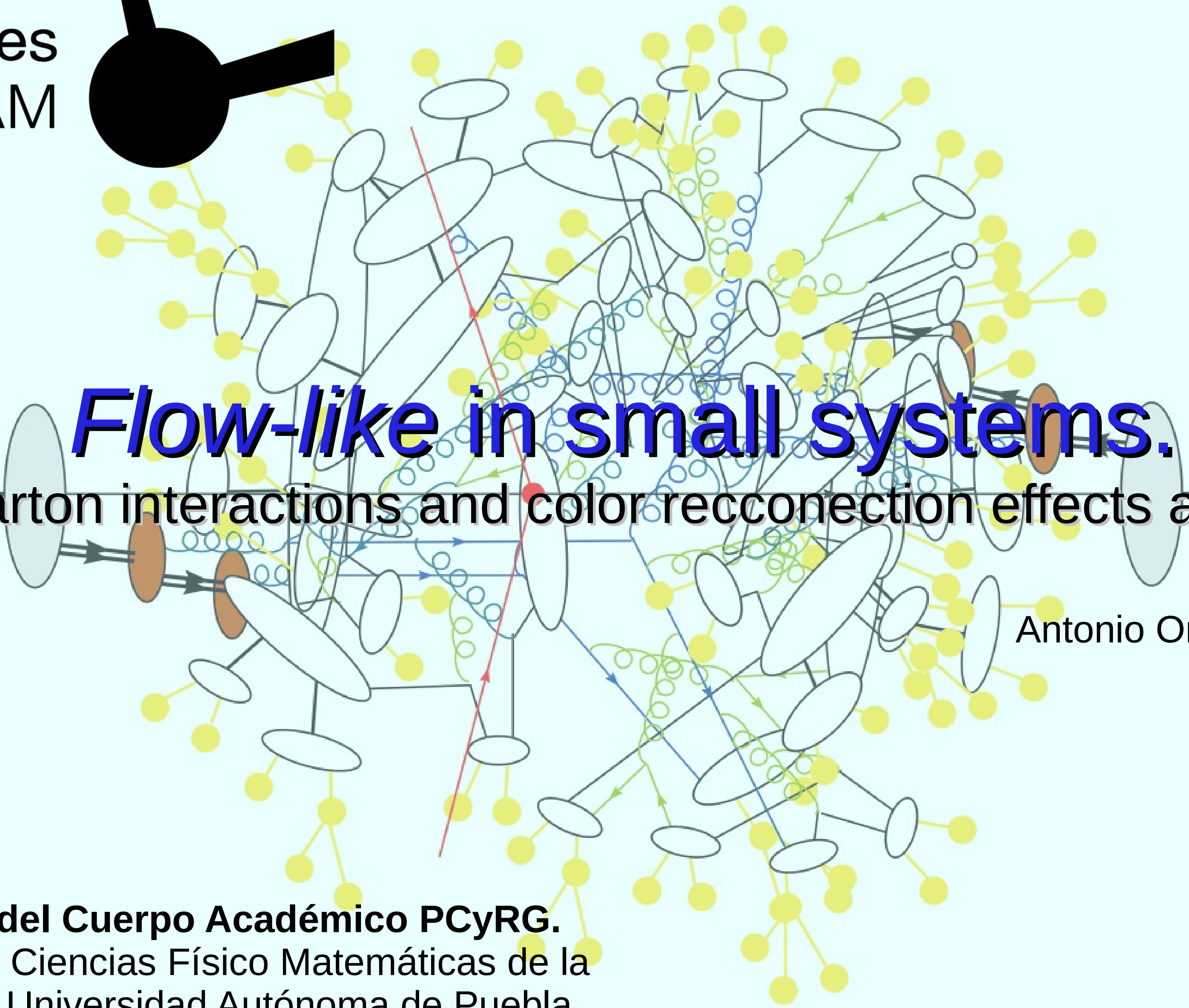
Flow-like in small systems.

(multi-parton interactions and color recconection effects at the LHC)

Antonio Ortiz Velasquez



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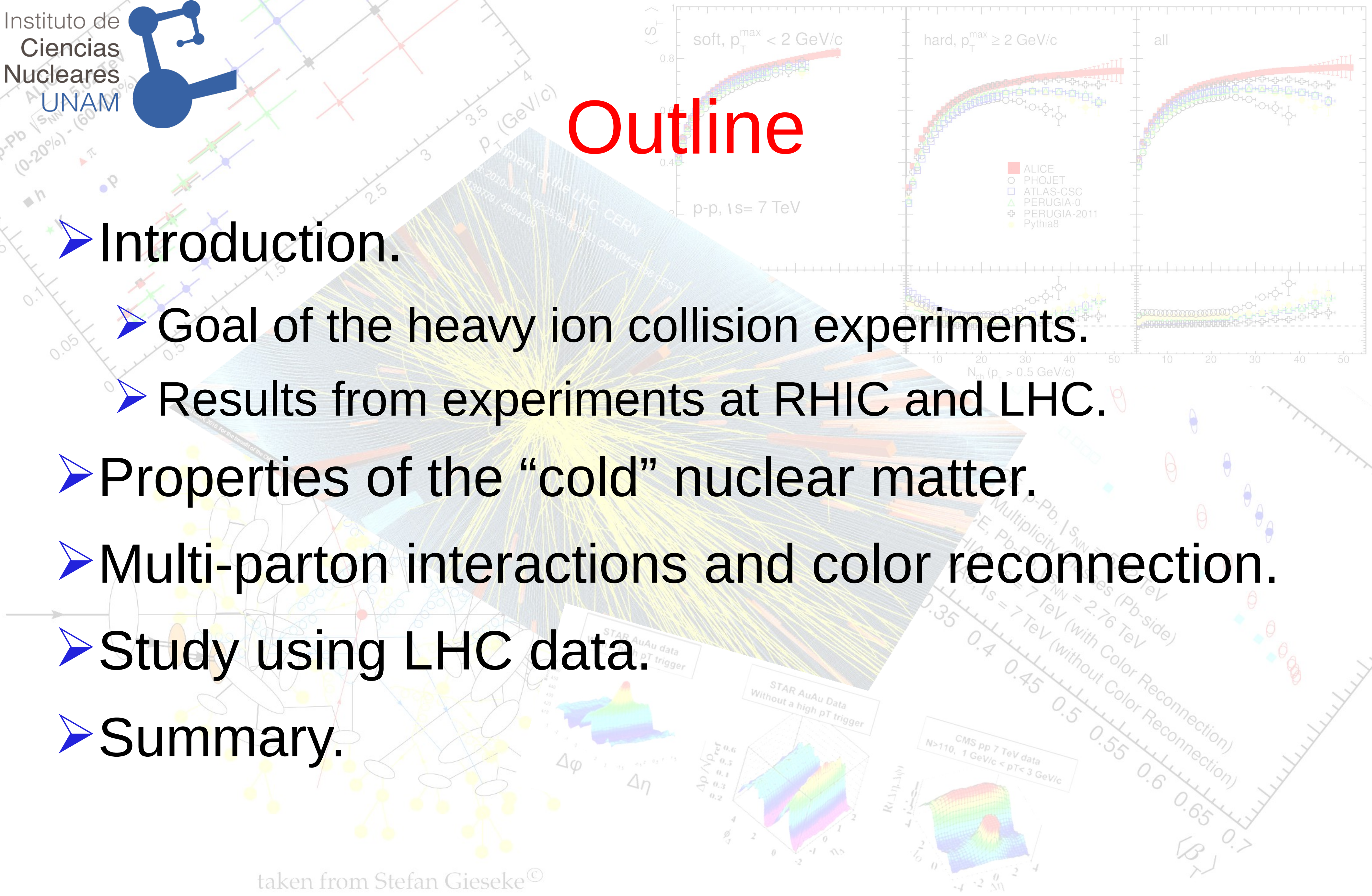
Seminario del Cuerpo Académico PCyRG.
Facultad de Ciencias Físico Matemáticas de la
Benemérita Universidad Autónoma de Puebla.
March 4, 2015.

Outline

- Introduction.
  - Goal of the heavy ion collision experiments.
  - Results from experiments at RHIC and LHC.
- Properties of the “cold” nuclear matter.
- Multi-parton interactions and color reconnection.
- Study using LHC data.
- Summary.



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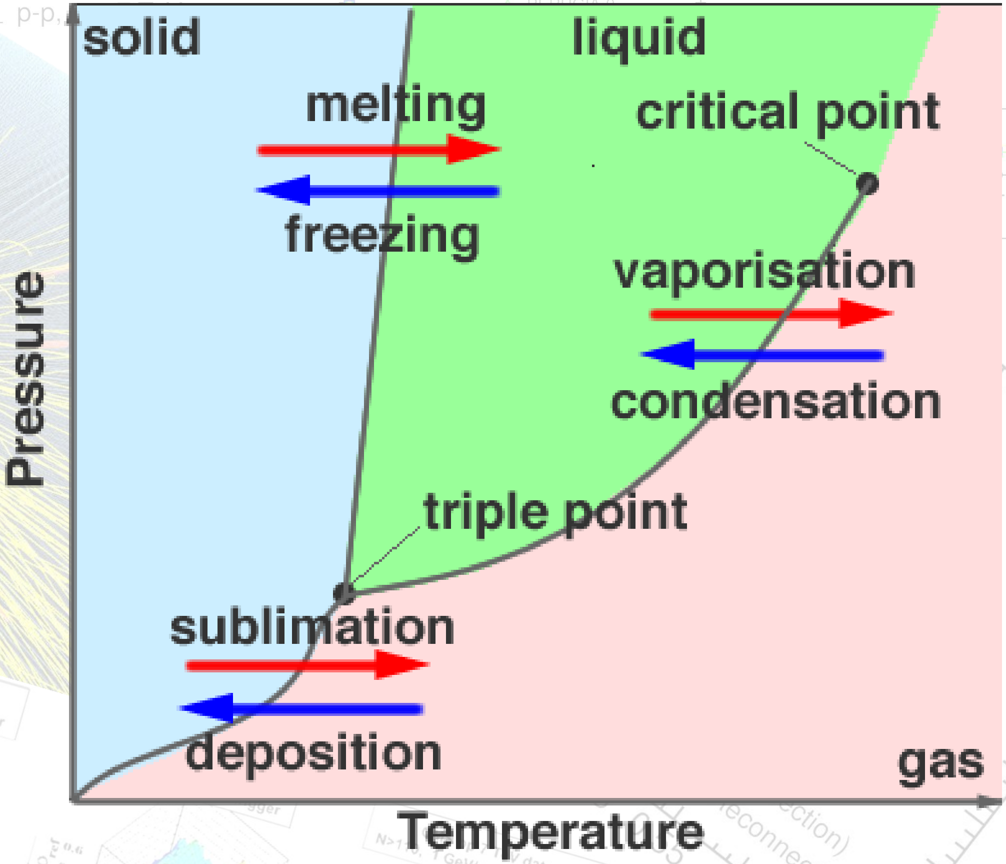
Introduction

Matter that surrounds us comes in a variety of phases which can be transformed into each other by a change of external conditions such as temperature, pressure, composition etc.



Example: the phase diagram of H_2O (Besides the liquid and gaseous phases a variety of crystalline and amorphous phases occurs.).

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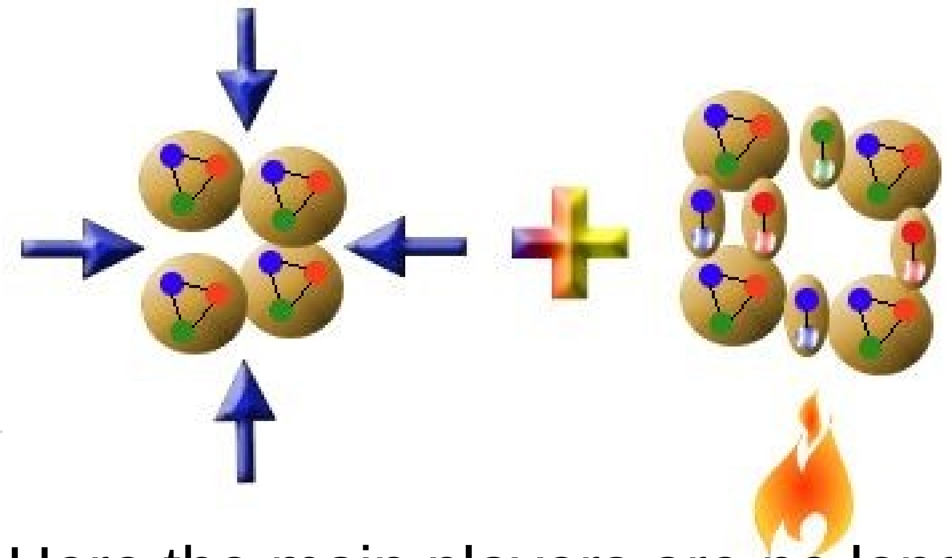
Matter at extreme conditions!



One may ask what ultimately happens when matter is heated and compressed (extreme conditions).

Here the main players are no longer forces of electromagnetic origin but the strong interaction, which is responsible for the binding of quarks and gluons into hadrons. In the standard model of particle physics, the strong interaction is described by quantum chromodynamics (QCD).

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Strenght of QCD interactions

- In QCD, quarks and gluons are the elementary degrees of freedom.
- Quarks and gluons carry “color charge” as an additional quantum number.
- A pronounced variation (“running”) of the strong fine structure constant with (space-time) distance or momentum transfer *Q*.

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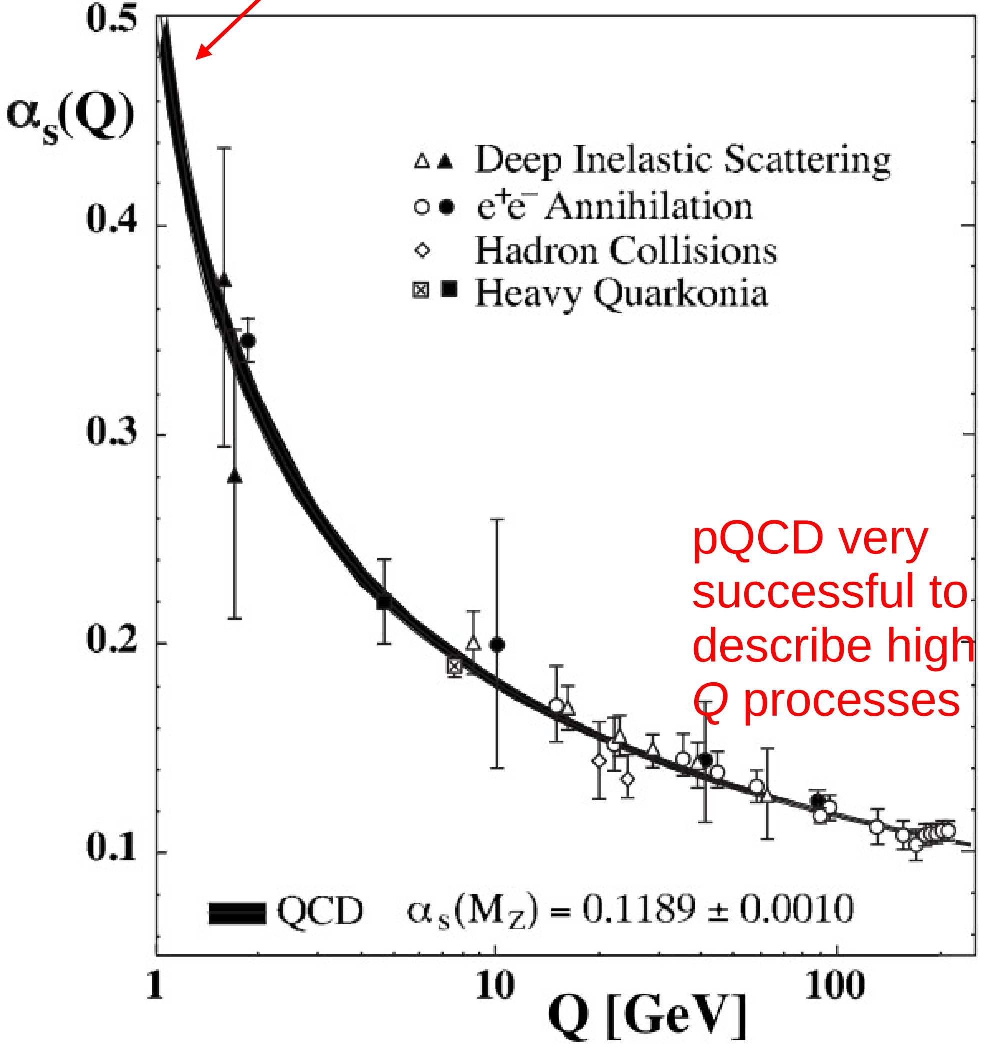
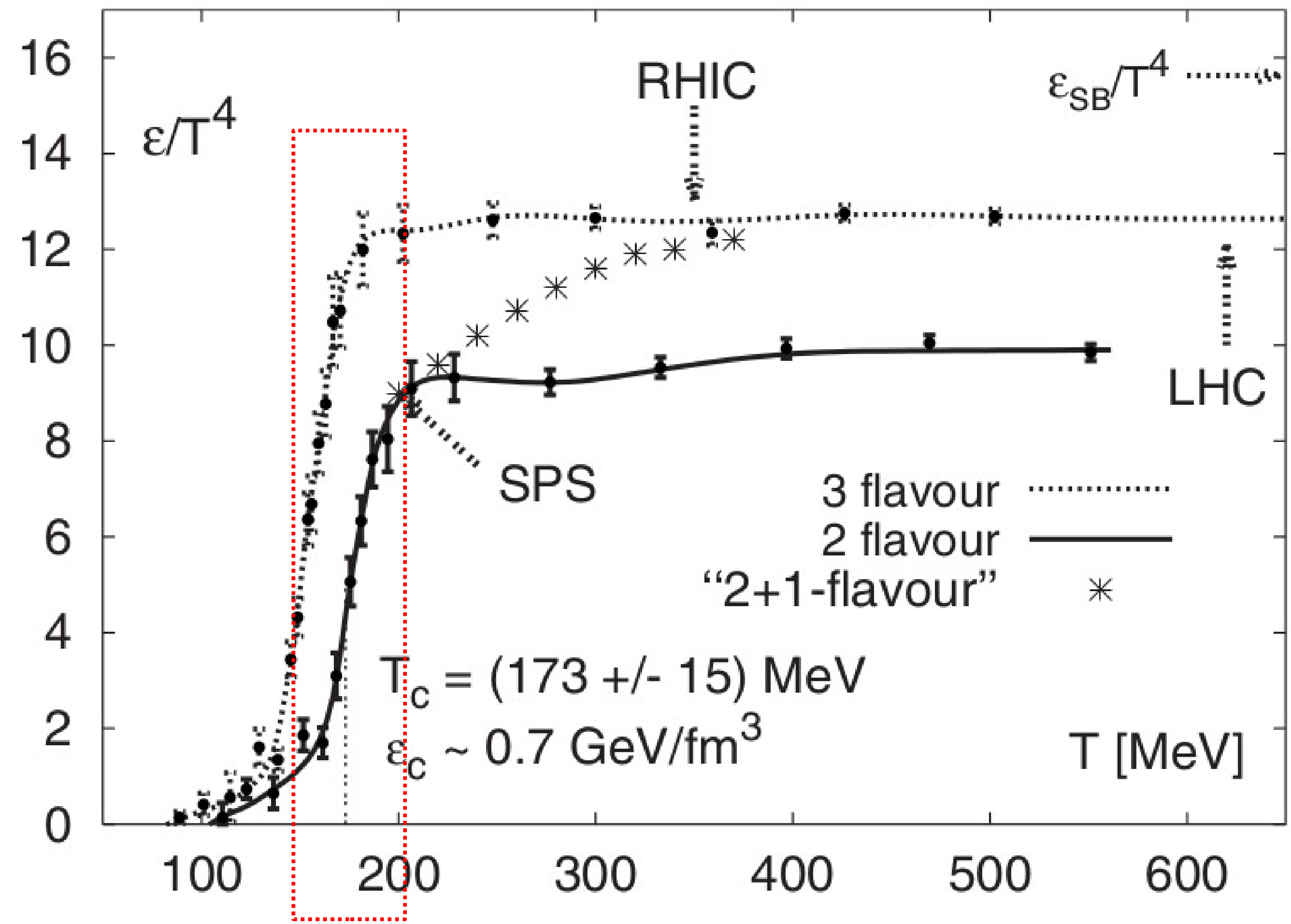


Confinement

pQCD very successful to describe high *Q* processes

Theoretical expectation

The description of the strongly interacting matter under heating and compression can not be done using perturbative methods, which are very successful for QCD processes at high *Q*. Instead lattice QCD calculations are used.



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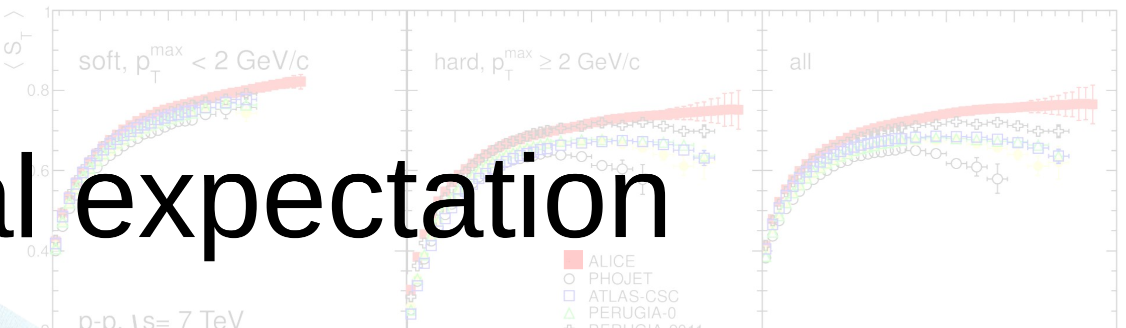
Rapid variation which signals the transition from hadronic matter to the Quark Gluon "Plasma" (QGP).

Theoretical expectation



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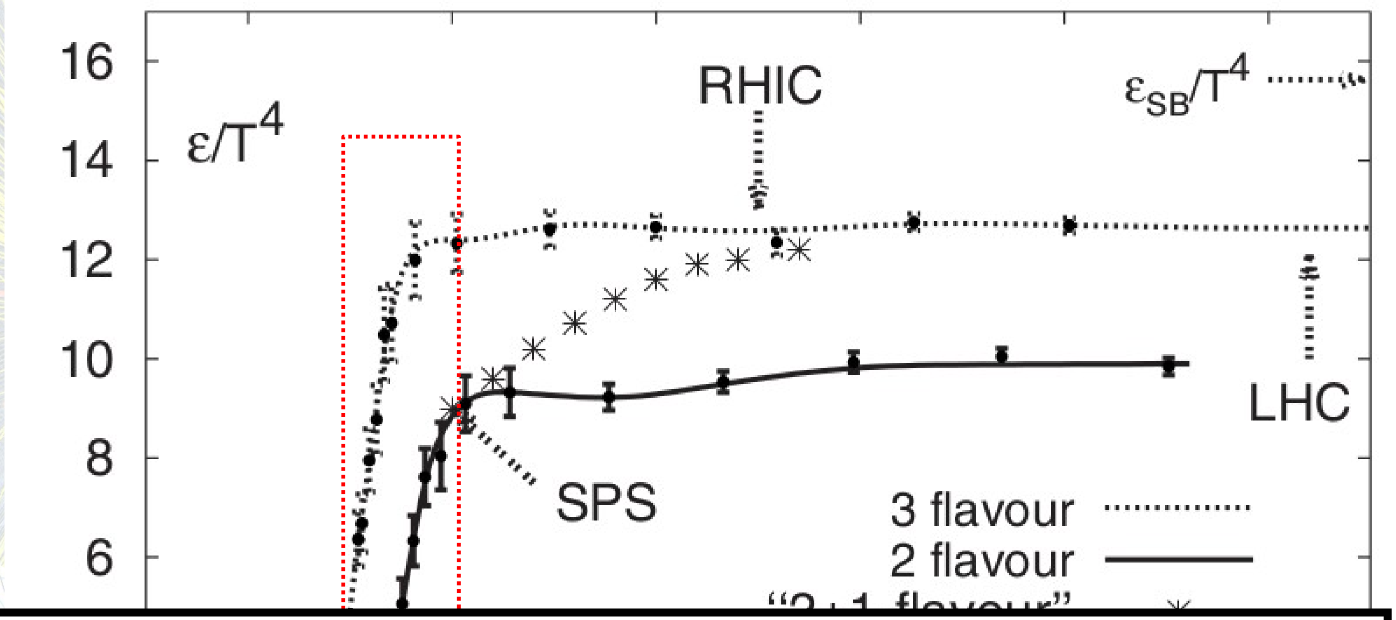
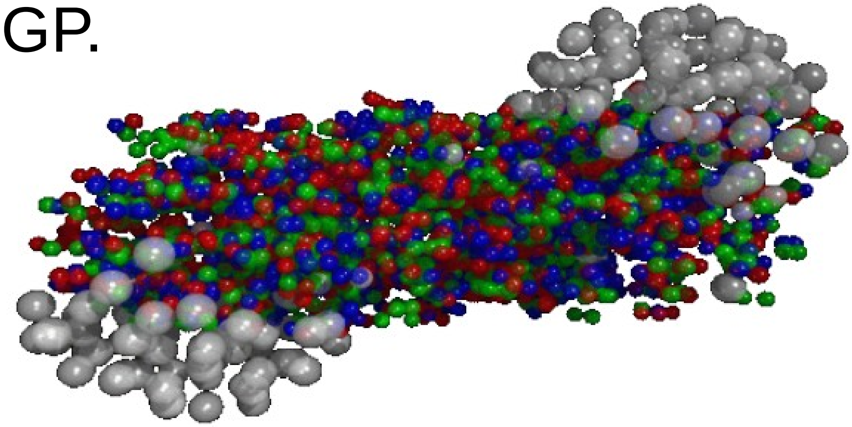


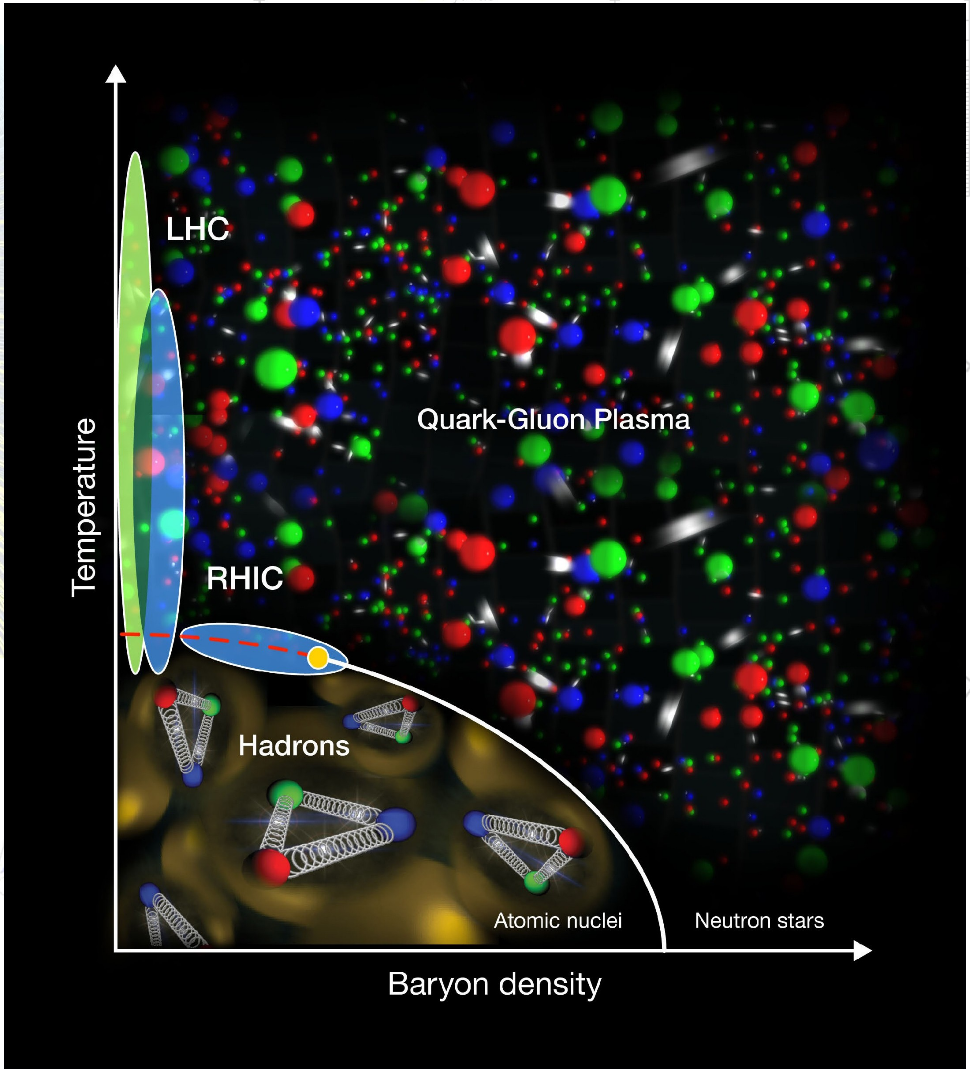
‘State of matter’ at high temperature and energy density: **‘The QGP’**

- ⇨ **theoretical** expectations & predictions :
  - ✪**weakly interacting plasma** / ideal gas of (quasi-free) quarks & gluons
  - ✪partons are **deconfined** (not bound into composite color neutral hadrons)
  - ✪**chiral symmetry** is restored (partons ≈ massless)
- ⇨ **experimental** definition

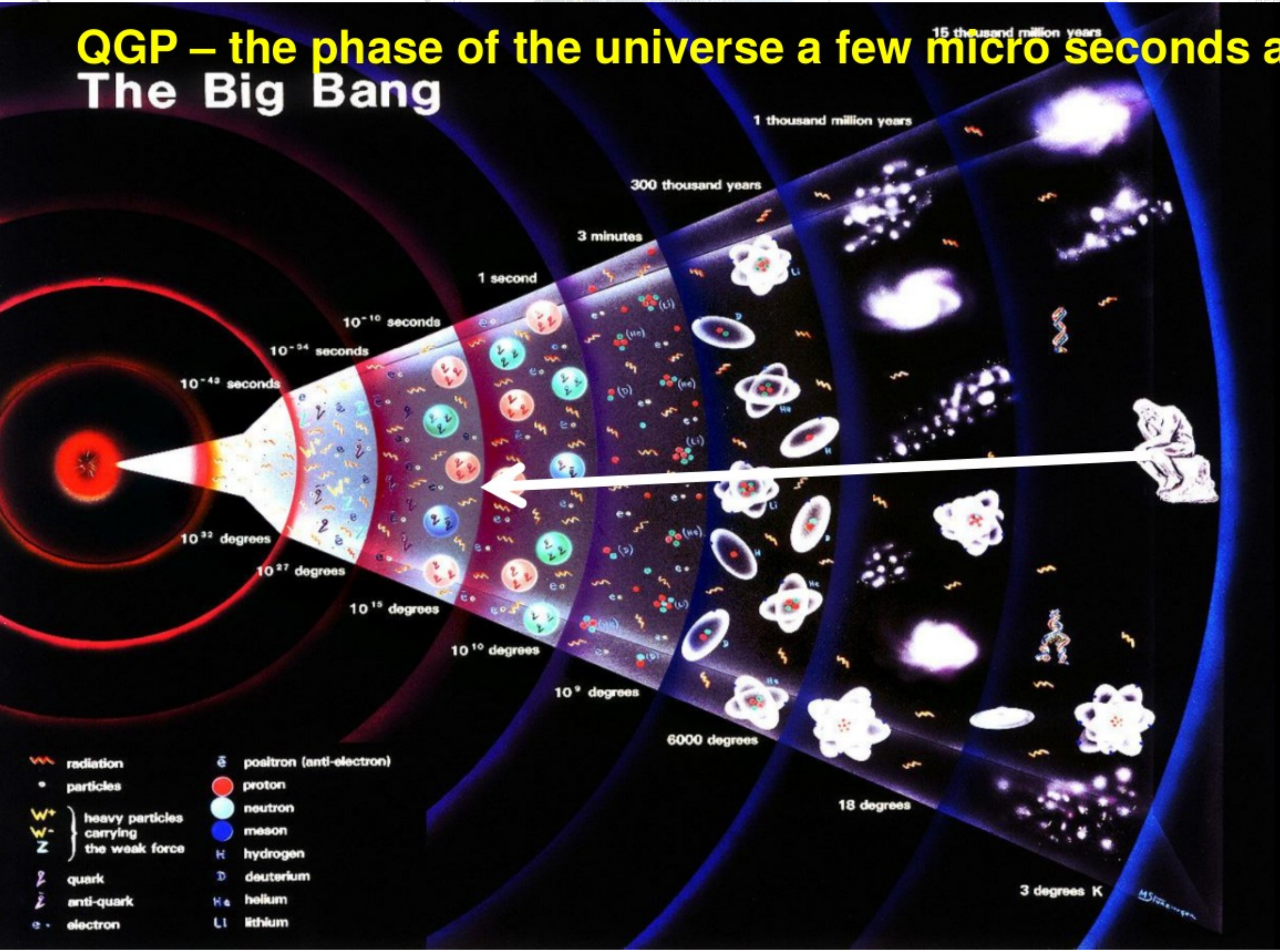
Heavy ion collisions (HIC)

The main goal of Heavy Ion Collisions is to study the behavior of matter under extreme condition, to explore and test QCD phase diagram and to address the fundamental question of hadron confinement and chiral symmetry breaking, which are related to the existence and properties of the QGP.





The Big-Bang



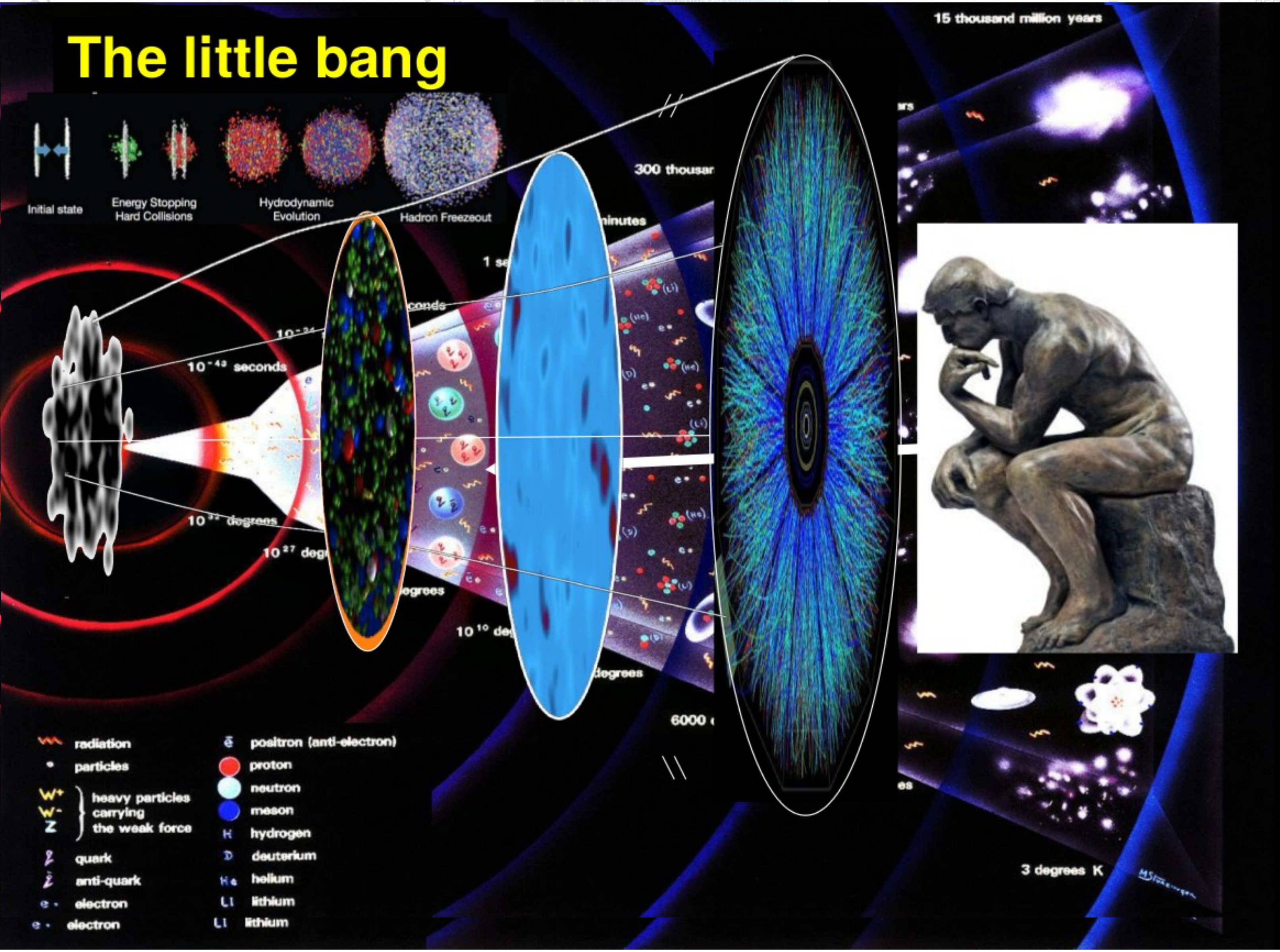
T~170MeV (phase transition)

~$2X10^{12}$K

(T core sun: $16X10^6$ K)

These studies are also relevant to learn about the early stages of the Universe as we go backwards in time in the cosmic evolution.

The little bang



T~170MeV (phase transition)

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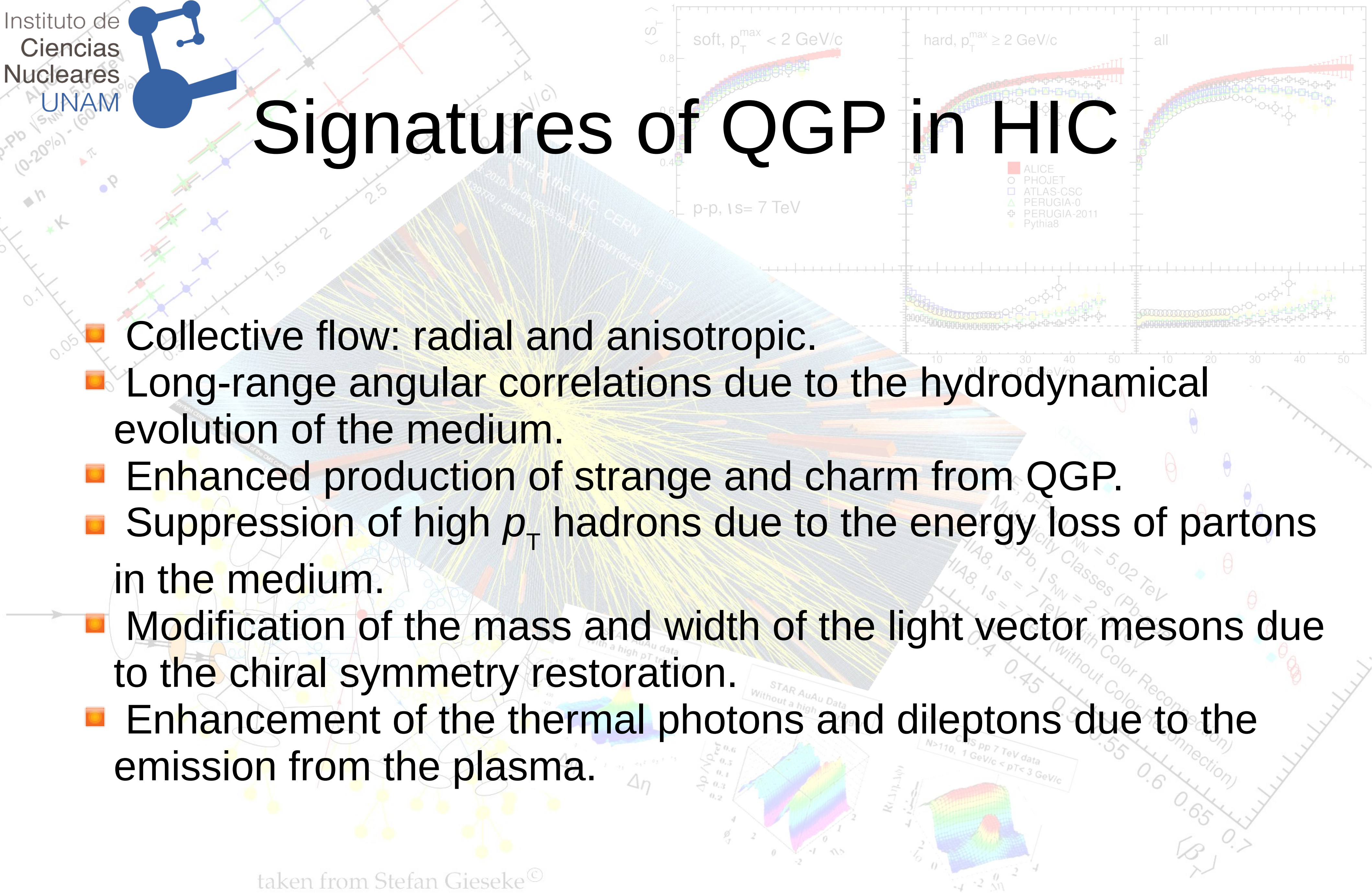
How?

- ☐ Heavy ion collisions (hot and dense QCD matter), at the LHC: Pb-Pb $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV.

- ☐ Control experiment: p-Pb (accsess to cold nuclear matter effects, initial state effects and much more...).

- ☐ pp collisions are the benchmark for larger systems.

Signatures of QGP in HIC



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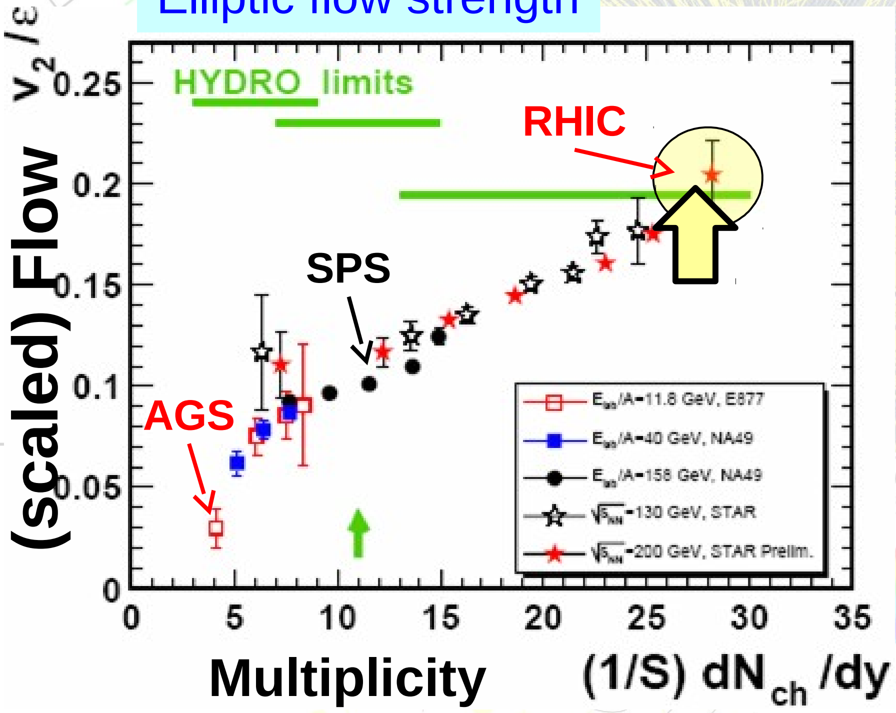
- Collective flow: radial and anisotropic.
- Long-range angular correlations due to the hydrodynamical evolution of the medium.
- Enhanced production of strange and charm from QGP.
- Suppression of high p_T hadrons due to the energy loss of partons in the medium.
- Modification of the mass and width of the light vector mesons due to the chiral symmetry restoration.
- Enhancement of the thermal photons and dileptons due to the emission from the plasma.

Main results from RHIC

- strong elliptic flow
  - ⇨ ~ maximum possible i.e. 'ideal liquid' (η/s ≈ 0)
  - ⇨ mostly produced in the early phase (partonic?)

Elliptic flow strength



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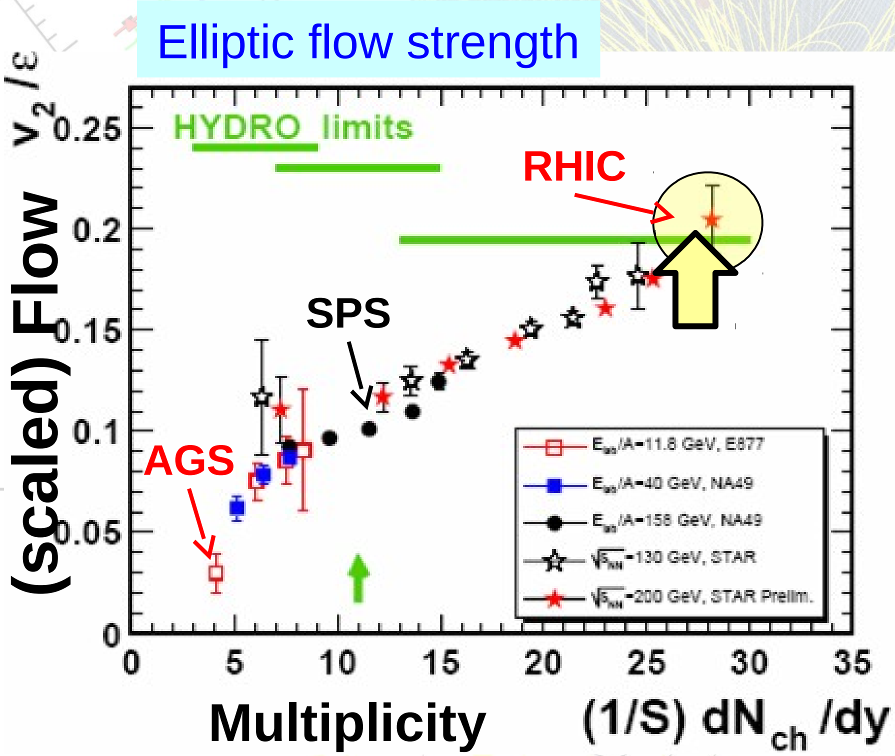
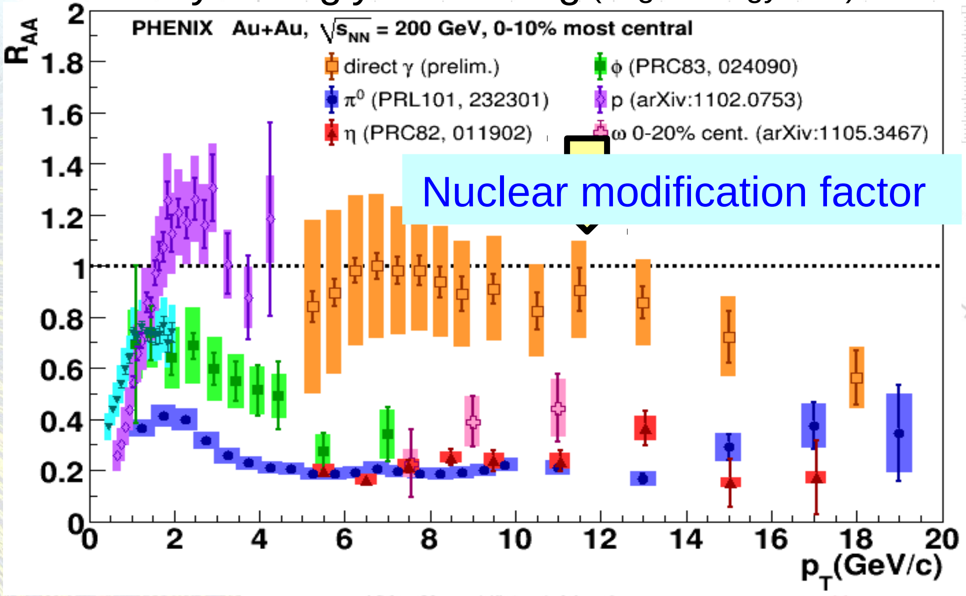
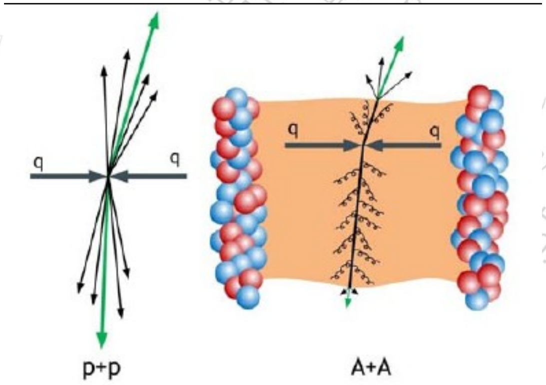

Elliptic flow strength

- high p_T suppression 'jet-quenching'
  - ⇨ very strongly interacting (large energy loss)


Nuclear modification factor



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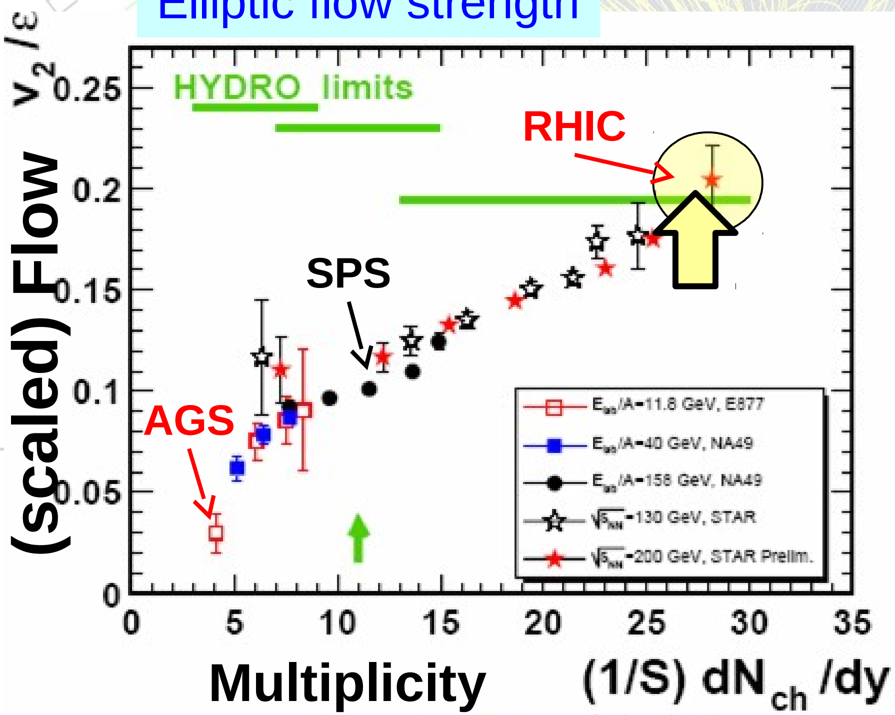

- **direct 'thermal' photons** => 'hot matter'
  - ⇨ data: inverse slope T ~ 220 ± 20 MeV
    model dependent T_0: 300 - 600 MeV

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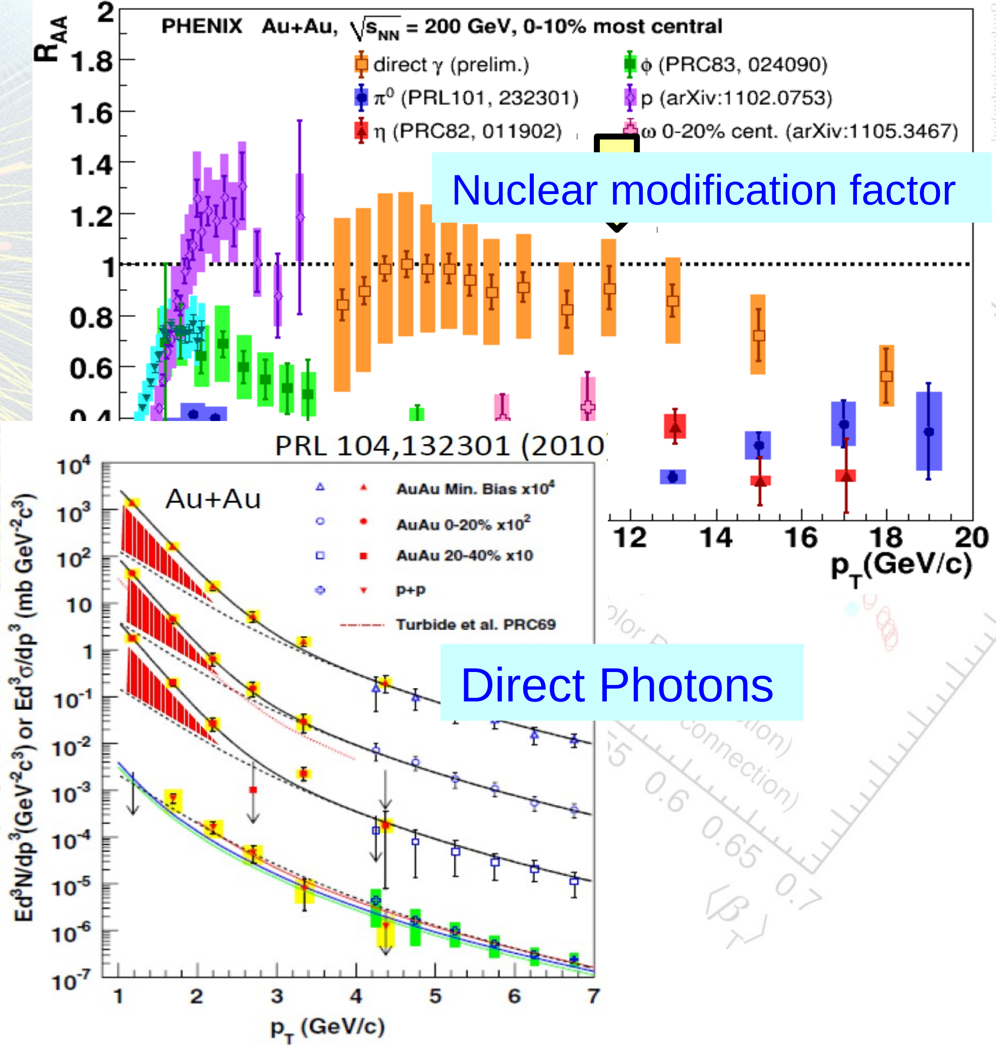

Nuclear modification factor

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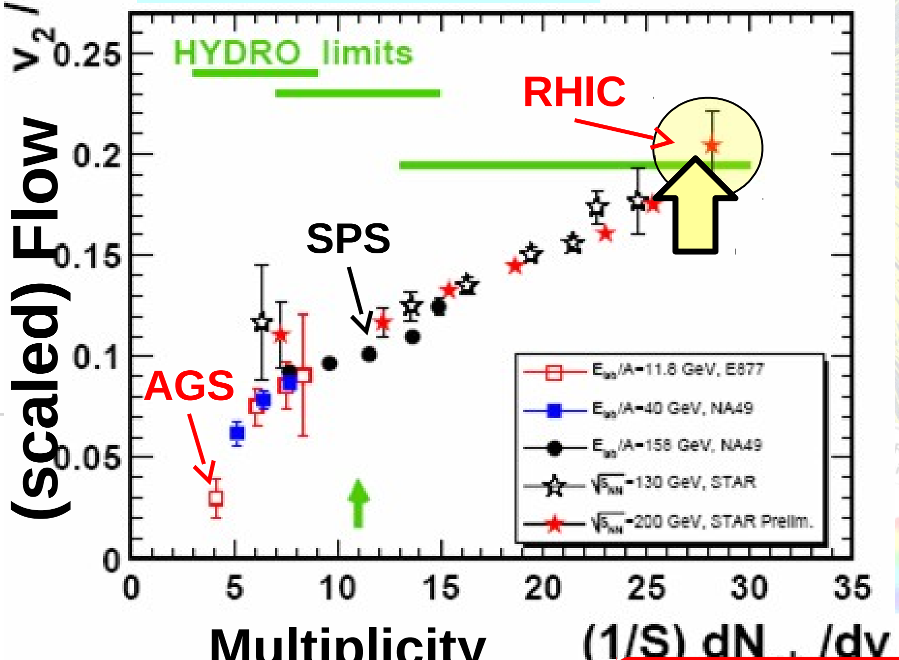

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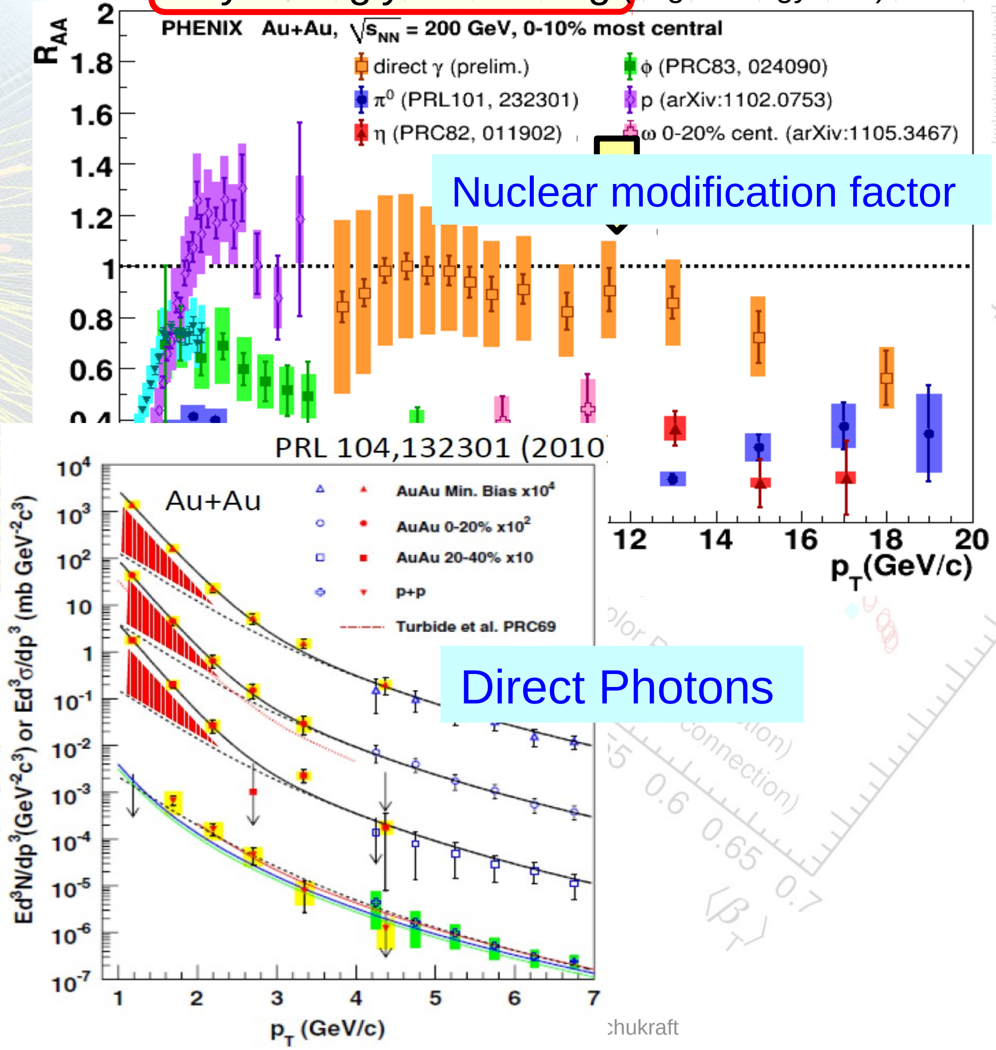
Direct Photons



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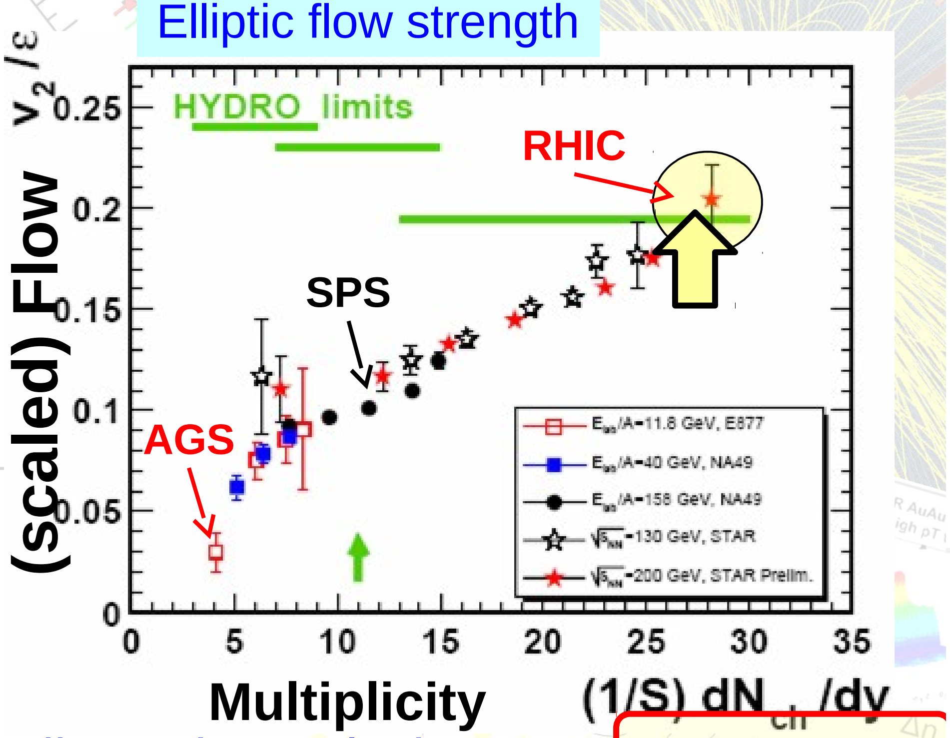

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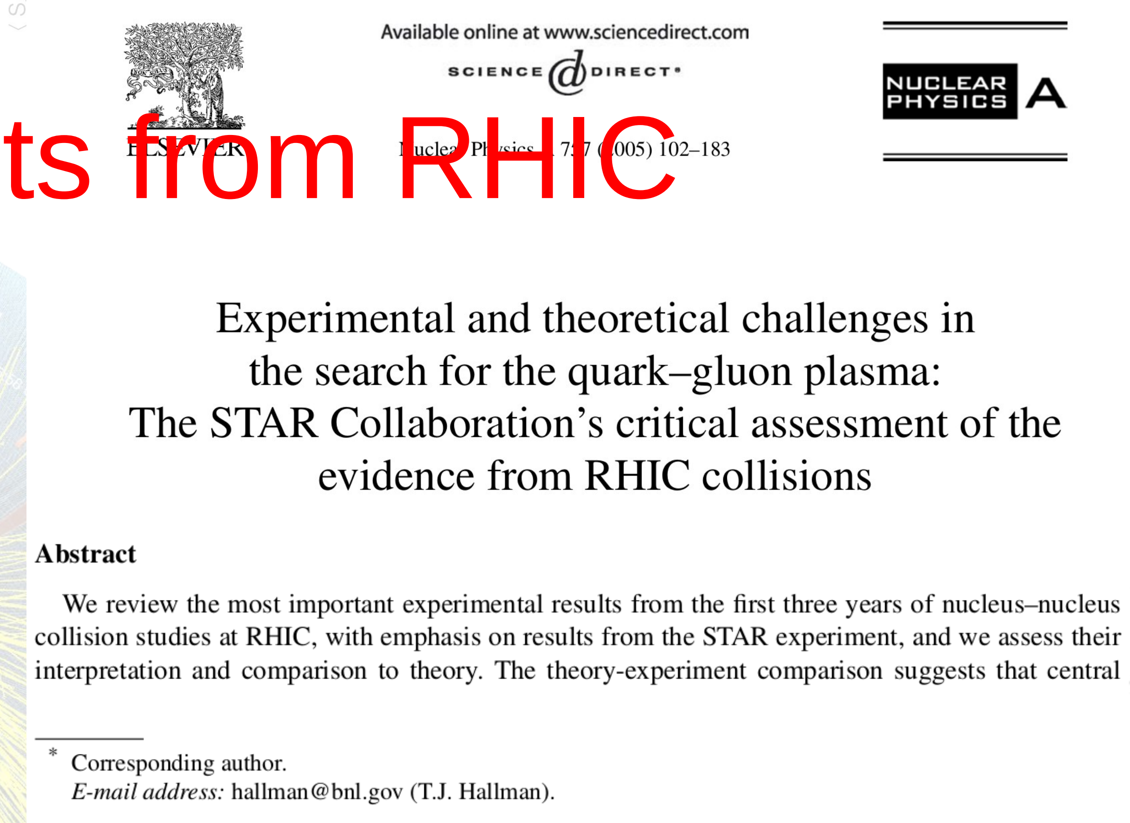
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NUCLEAR PHYSICS A

Experimental and theoretical challenges in the search for the quark–gluon plasma: The STAR Collaboration's critical assessment of the evidence from RHIC collisions

Abstract

We review the most important experimental results from the first three years of nucleus–nucleus collision studies at RHIC, with emphasis on results from the STAR experiment, and we assess their interpretation and comparison to theory. The theory-experiment comparison suggests that central

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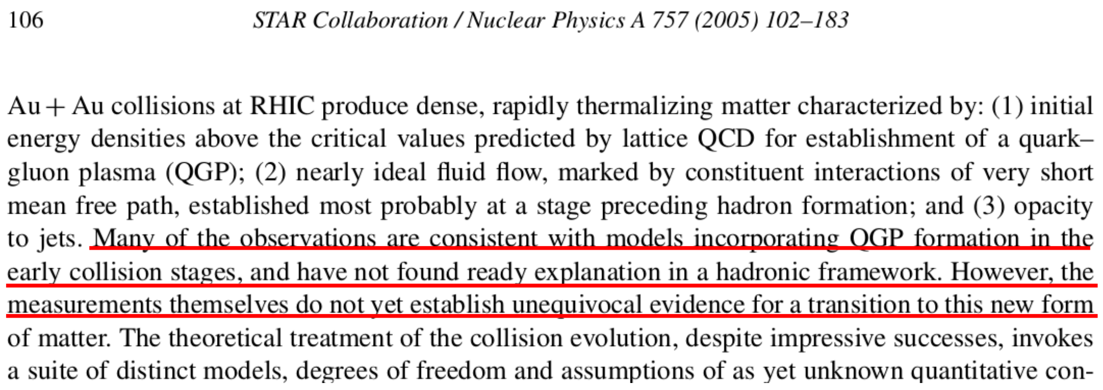
[*] Corresponding author.
E-mail address: hallman@bnl.gov (T.J. Hallman).

This is not the expected QGP, but a QGP: sQGP.



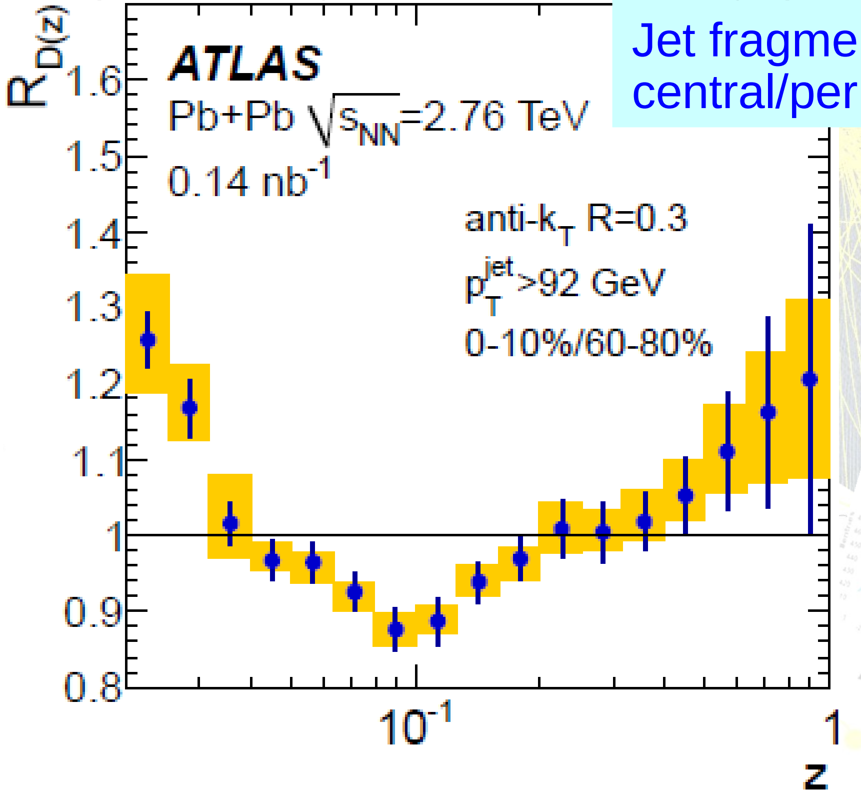
Au + Au collisions at RHIC produce dense, rapidly thermalizing matter characterized by: (1) initial energy densities above the critical values predicted by lattice QCD for establishment of a quark–gluon plasma (QGP); (2) nearly ideal fluid flow, marked by constituent interactions of very short mean free path, established most probably at a stage preceding hadron formation; and (3) opacity to jets. Many of the observations are consistent with models incorporating QGP formation in the early collision stages, and have not found ready explanation in a hadronic framework. However, the measurements themselves do not yet establish unequivocal evidence for a transition to this new form of matter. The theoretical treatment of the collision evolution, despite impressive successes, invokes a suite of distinct models, degrees of freedom and assumptions of as yet unknown quantitative con-

Main results from LHC

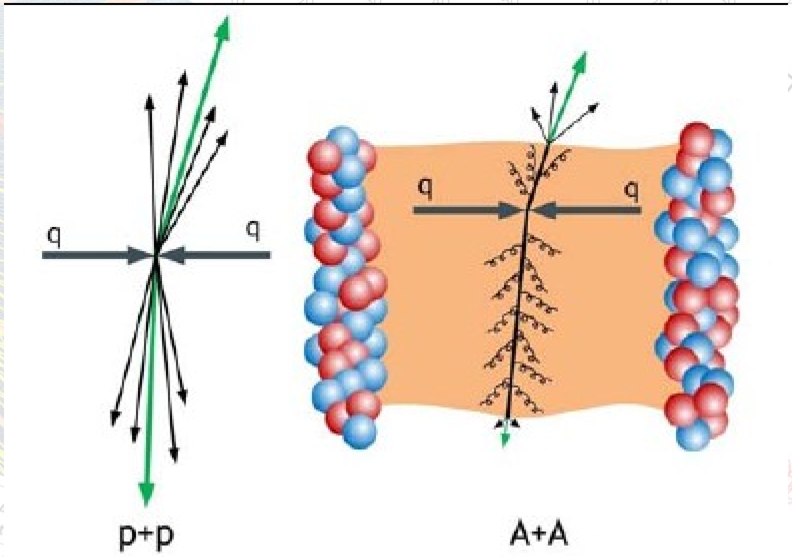
- in-medium jet fragmentation

→ insight into dynamics of jet quenching

  ✪ multiple soft gluon radiation at large angles (inverted angular and time ordering !!)



Jet fragmentation D(z) central/peripheral



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Main results from LHC

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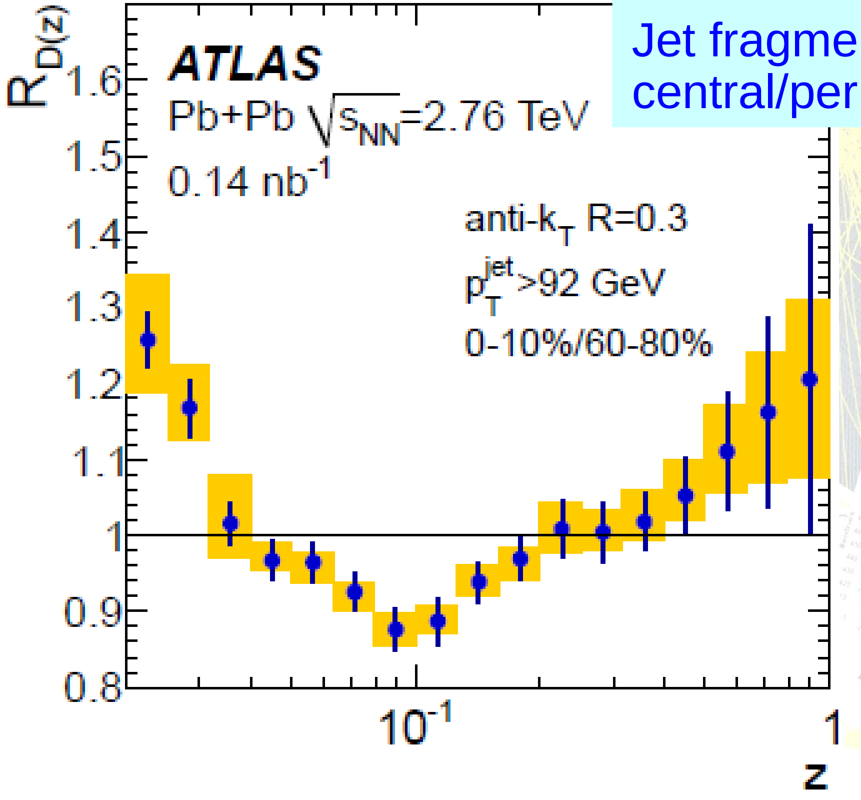
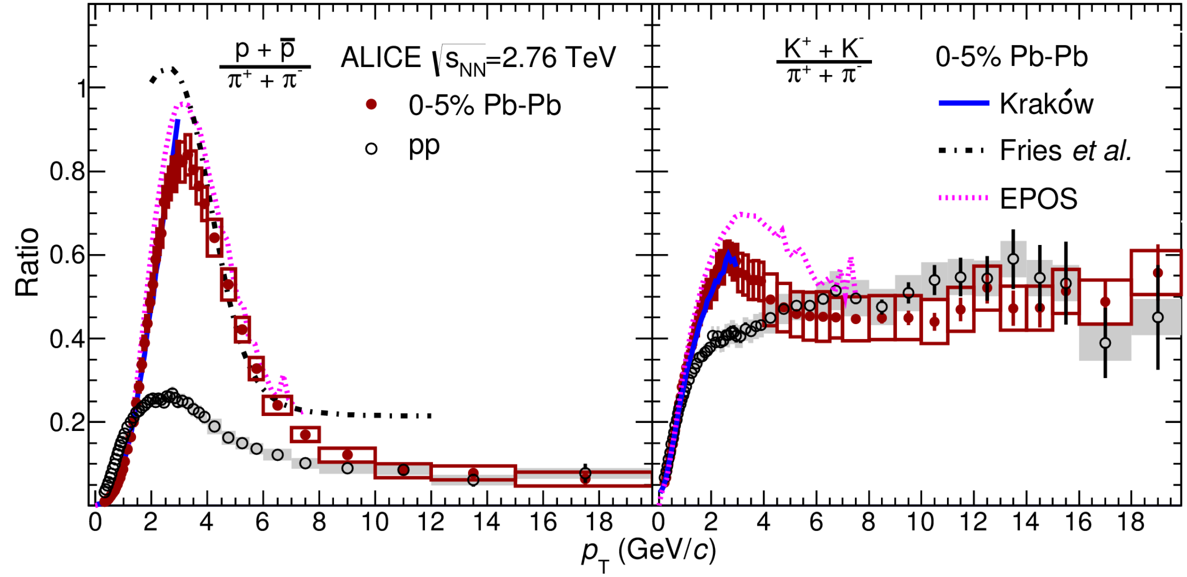


Jet fragmen
central/peri

- **the so-called baryon anomaly was killed!**
  - ➔ Data do not favor models which predicts signatures of new hadronization mechanims like recombination.



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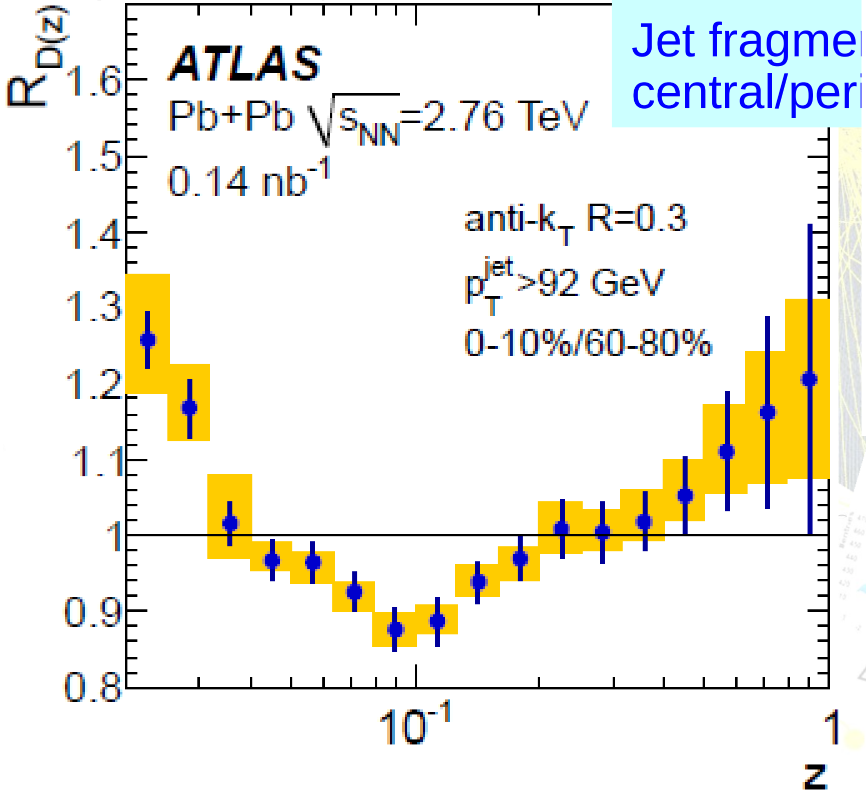
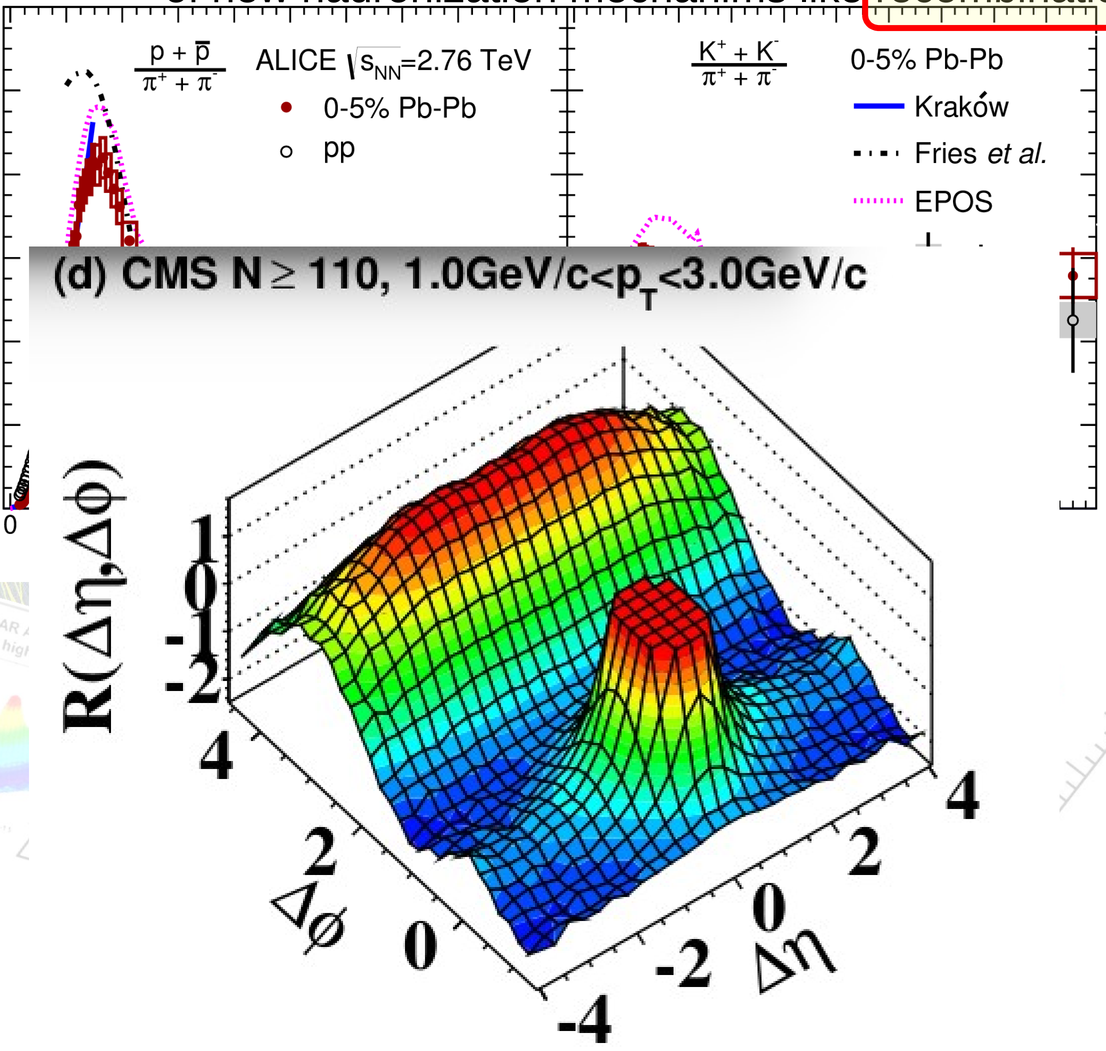


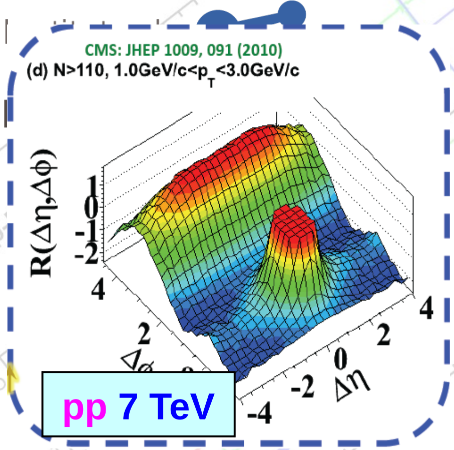
Jet fragme
central/peri

- The **first LHC discovery** (2010)!

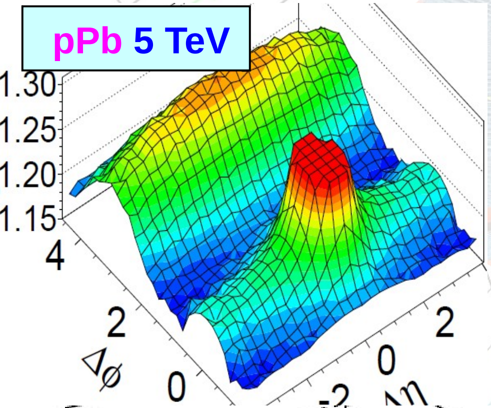
- the so-called baryon anomaly was killed!
  - Data do not favor models which predicts signatures of new hadronization mechanims like recombination



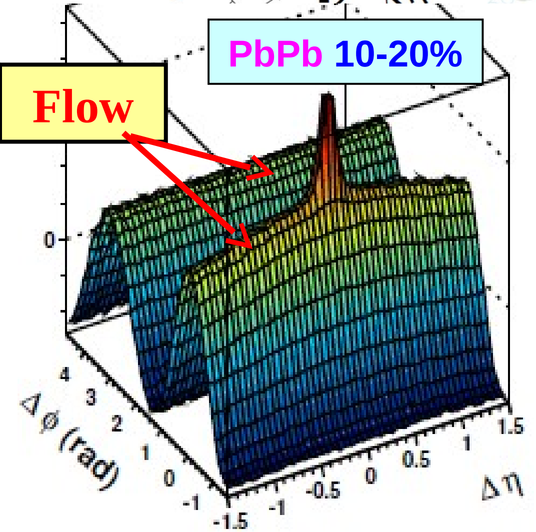
Cold matter also shows signatures of flow.
Is this matter already hot?



pp 7 TeV

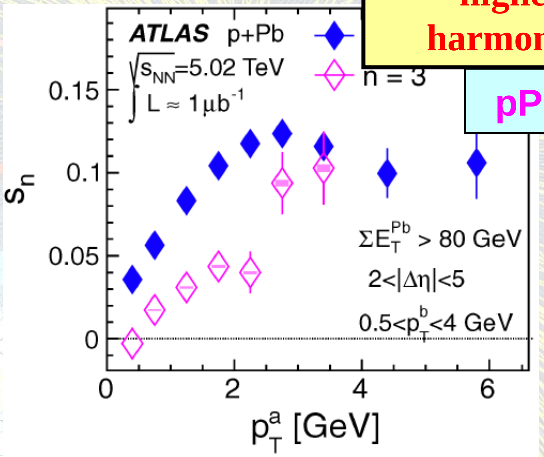


pPb 5 TeV



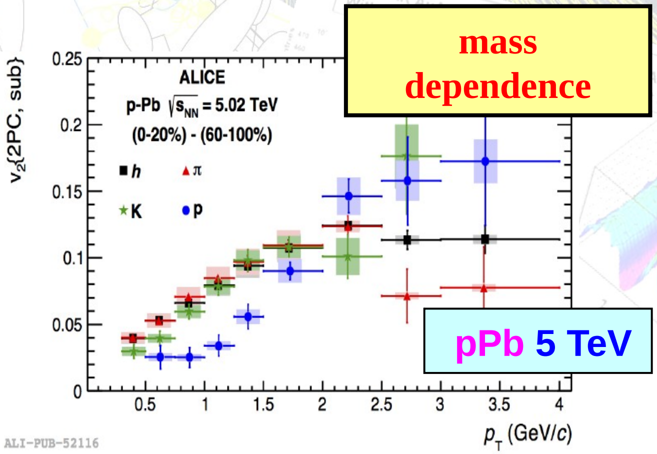
PbPb 10-20%

Flow



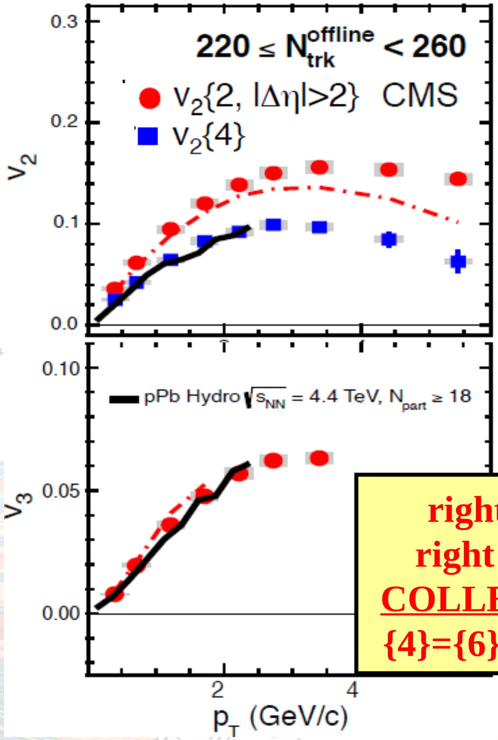
higher harmonics

pPb 5 TeV



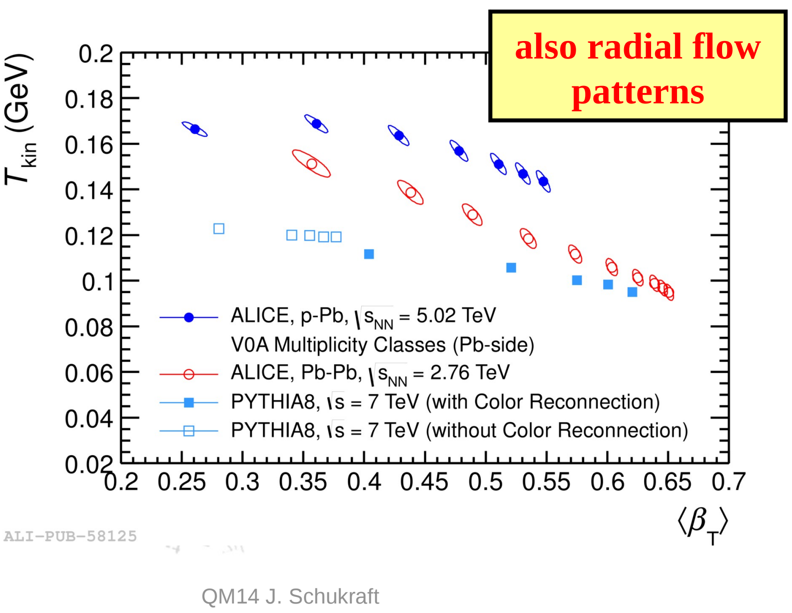
mass dependence

pPb 5 TeV



pPb 5 TeV

right size
right shape
COLLECTIVE
{4}={6}={8}= ∞

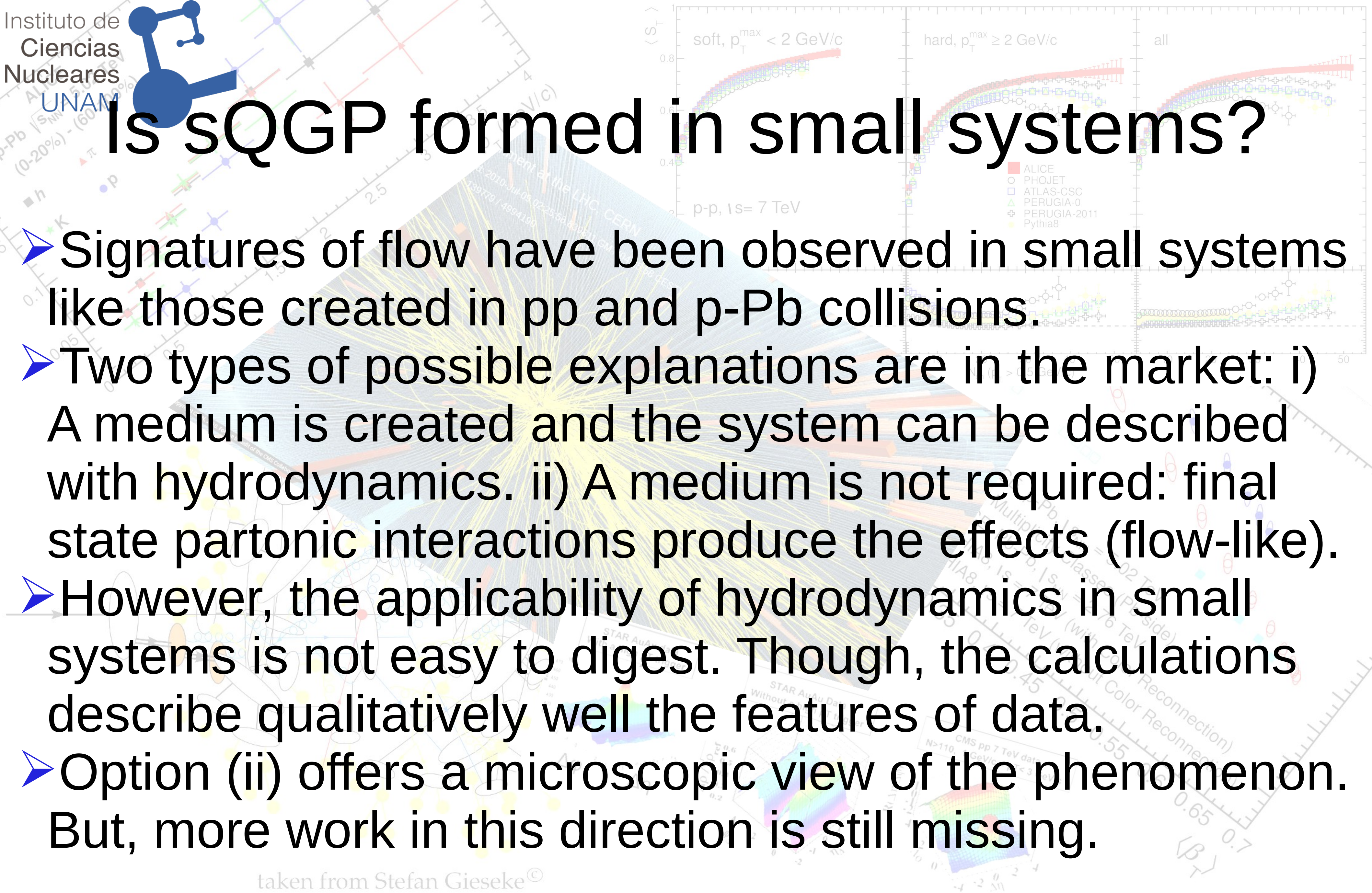


also radial flow patterns

QM14 J. Schukraft

Is sQGP formed in small systems?

- Signatures of flow have been observed in small systems like those created in pp and p-Pb collisions.
- Two types of possible explanations are in the market: i) A medium is created and the system can be described with hydrodynamics. ii) A medium is not required: final state partonic interactions produce the effects (flow-like).
- However, the applicability of hydrodynamics in small systems is not easy to digest. Though, the calculations describe qualitatively well the features of data.
- Option (ii) offers a microscopic view of the phenomenon. But, more work in this direction is still missing.



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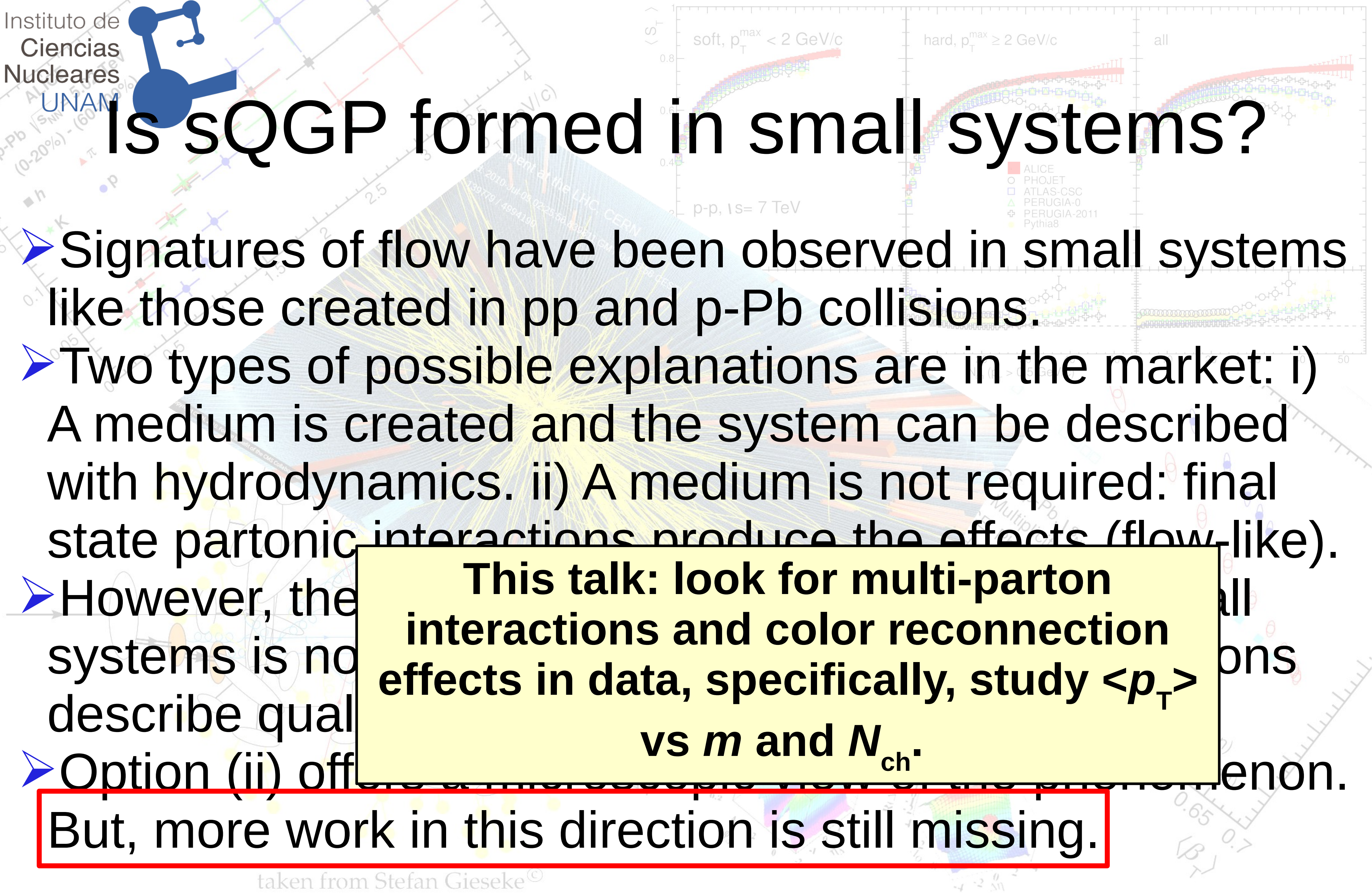

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This talk: look for multi-parton interactions and color reconnection effects in data, specifically, study <p_T> vs m and N_{ch}.

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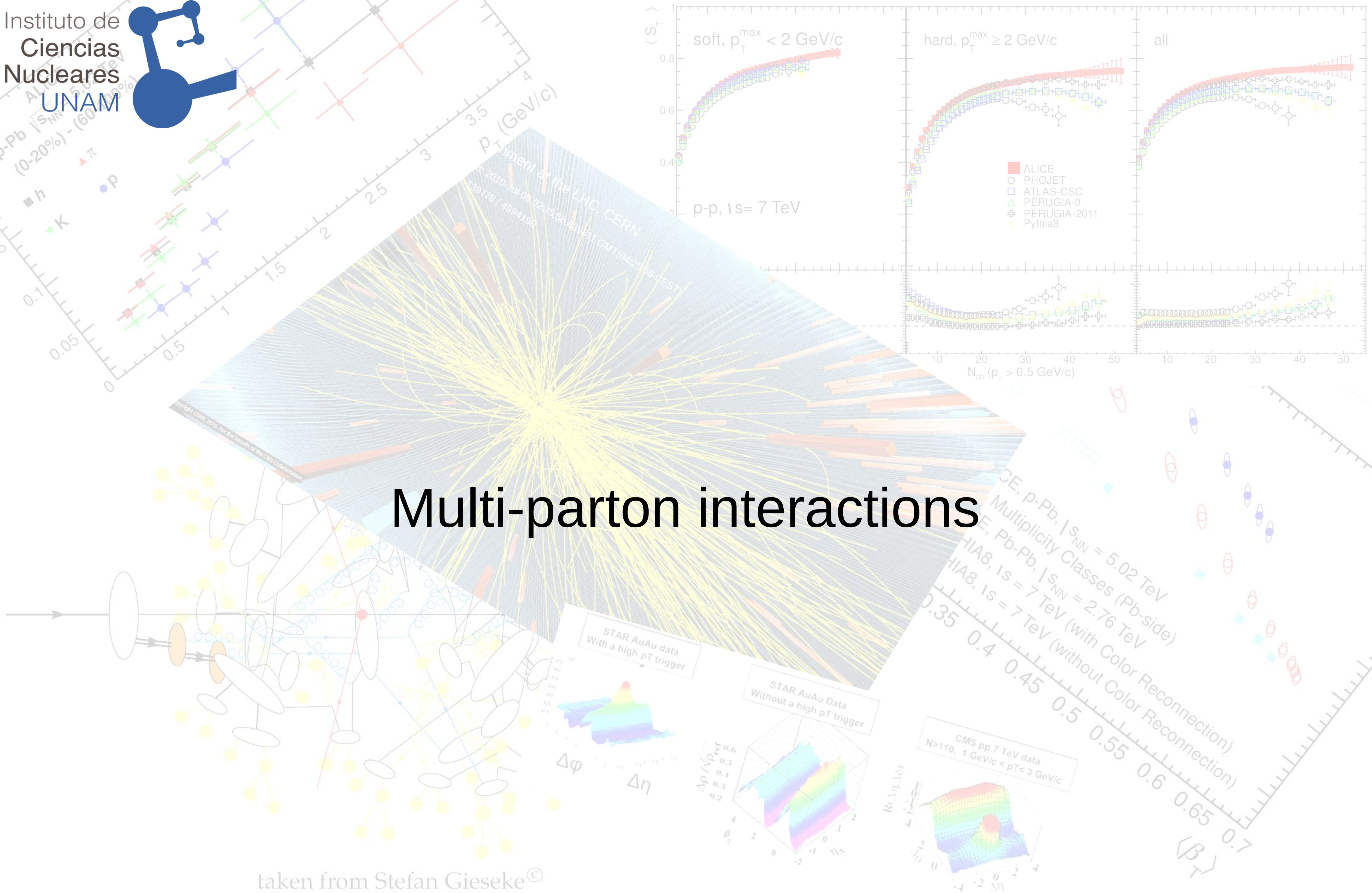
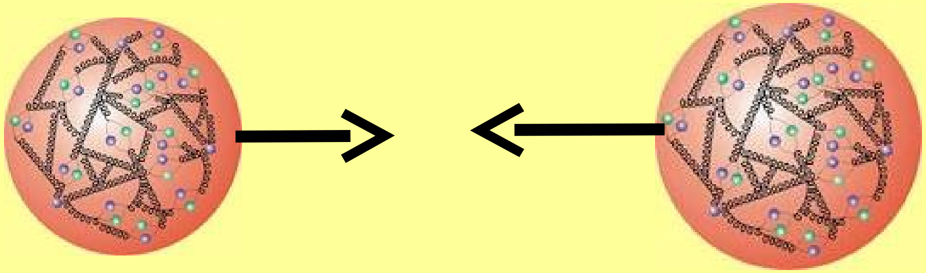


Multi-parton interactions

Basis

Due to the simple fact that hadrons are composite, multi-parton interactions (several distinct parton-parton interactions in one and the same hadron-hadron collision) will always be there.



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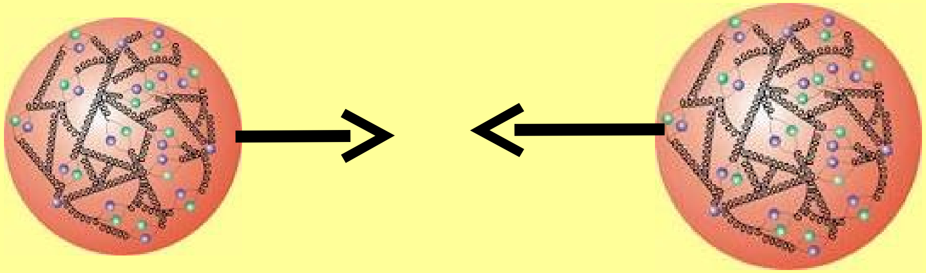

The first crucial observation is that the *t*-channel propagators appearing in perturbative QCD 2 → 2 scattering almost go on shell at low p_T, causing the differential cross sections to become very large, behaving roughly as:

$$d\sigma_{2\to2} \propto \frac{dt}{t^2} \sim \frac{dp_T^2}{p_T^4}$$

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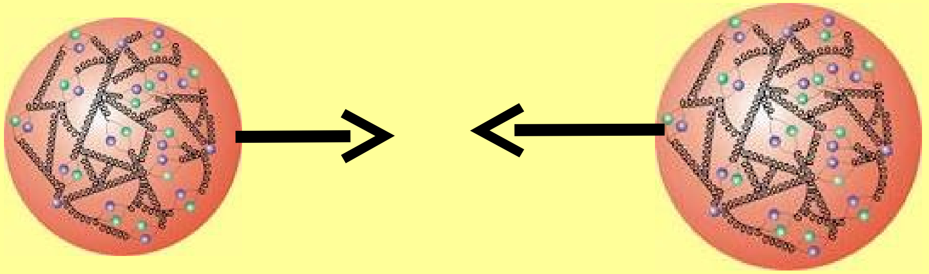


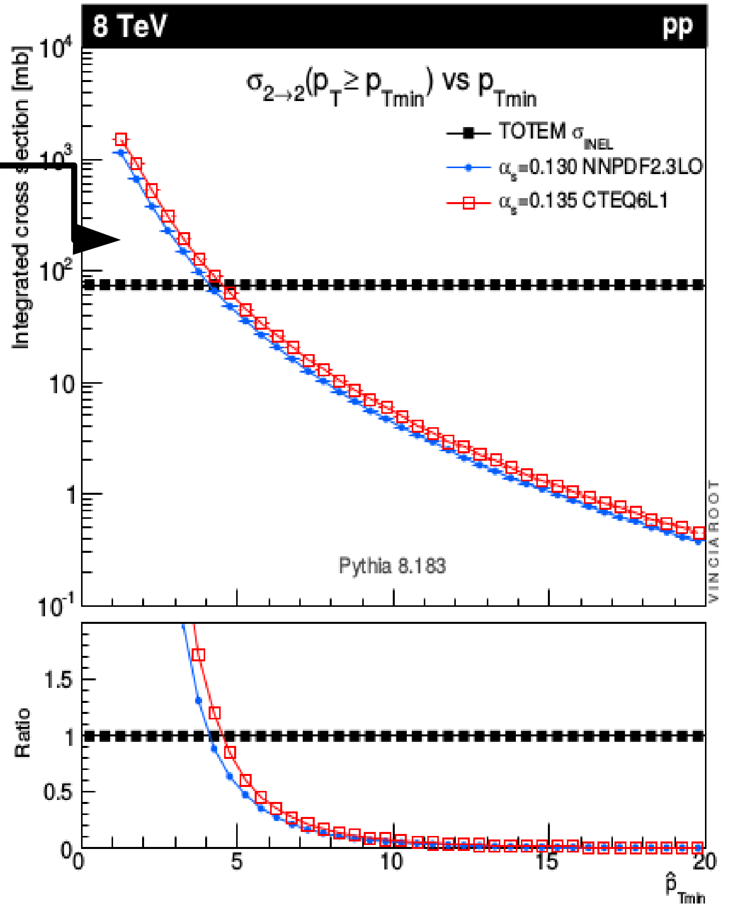
The first crucial observation is that the *t*-channel propagators appearing in pert QCD 2 → 2 scattering almost p_T, causing the differential cro become very large, behaving roughly as:

Each hadron-hadron collision contains several few-GeV parton-parton collisions (MPI)!

$$d\sigma_{2\to2} \propto \frac{dt}{t^2} \sim \frac{dp_T^2}{p_T^4}$$

At LHC energies, the parton-parton cross section becomes larger than the total hadron-hadron cross section at p_T scales of order 4-5 GeV.

P. Skands, “Introduction to QCD,” arXiv:1207.2389v4



Basis

In the limit that all the partonic interactions are independent and equivalent, one would simply have a Poisson distribution in the number of MPI, with average:

$$\langle n \rangle (p_{Tmin}) = \frac{\sigma_{2\to 2}(p_{Tmin})}{\sigma_{tot}}$$

σ_{tot} is the inelastic hadron-hadron cross section and p_{Tmin} is a lower cutoff scale.

Some considerations:

- The interactions can not use up more momentum than is available in the parent hadron.
- In Pythia-based models, the MPI are ordered in p_T, and the parton densities for each successive interaction are explicitly constructed so that the sum of *x* fractions can never be greater than one.

taken from Stefan Gieseke©

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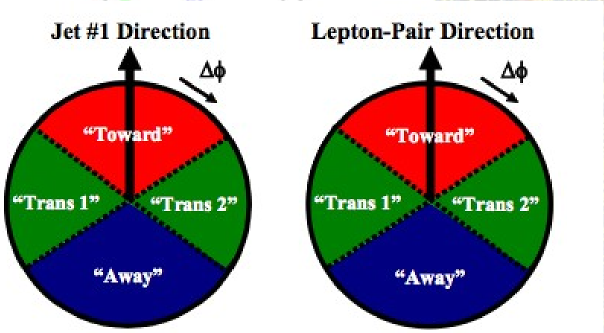
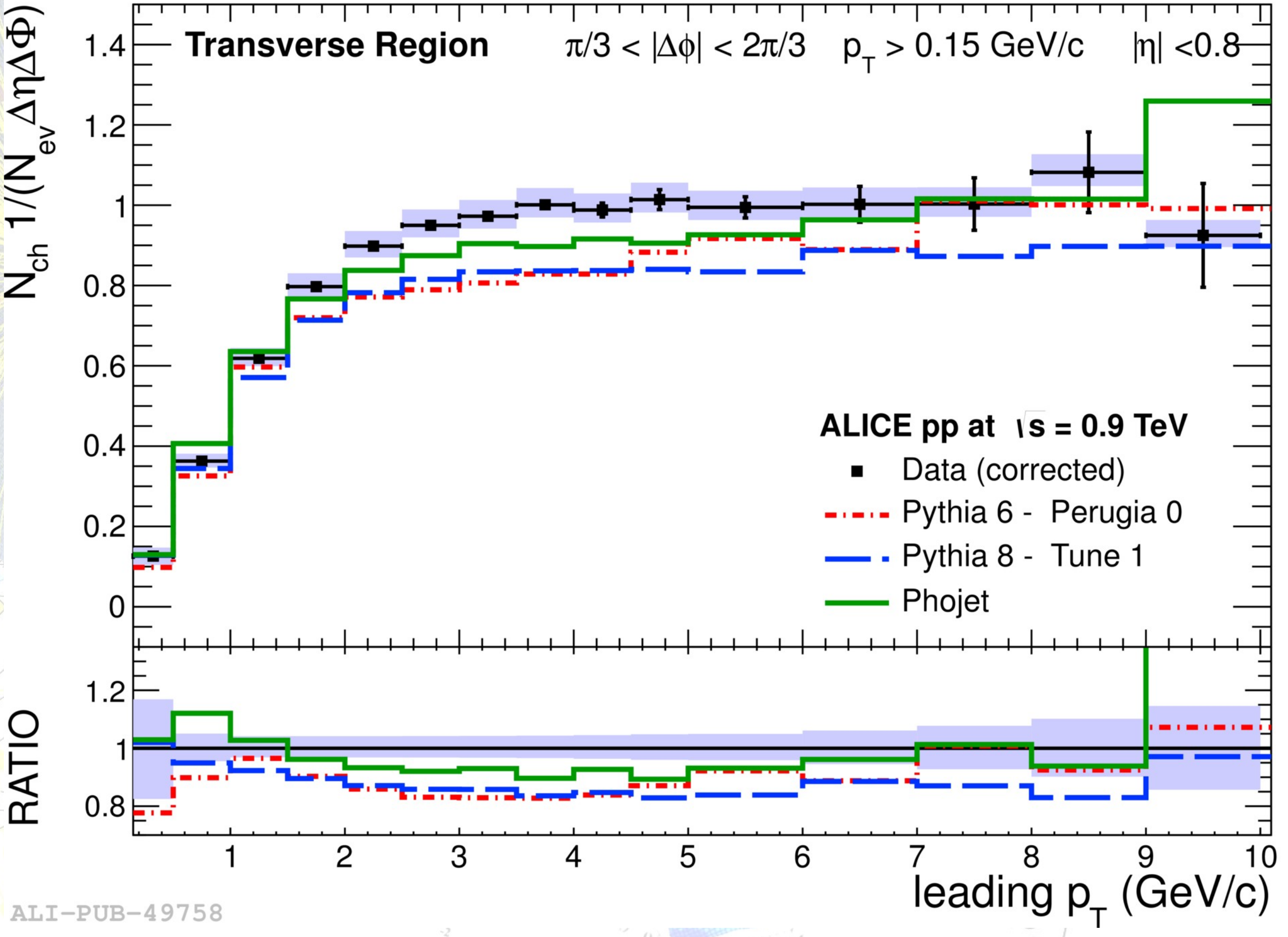
Impact-parameter dependence



- Hard jets appear to sit on top of a higher "pedestal" of underlying activity than events with no hard jets.

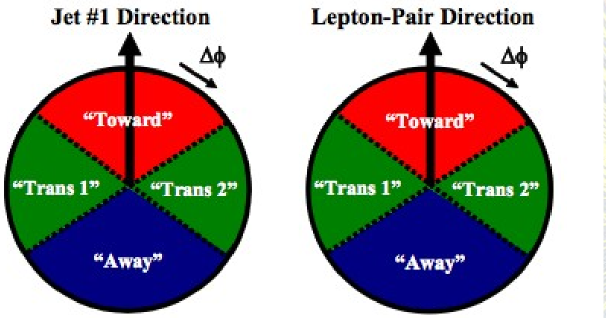
taken from Stefan Gieseke©

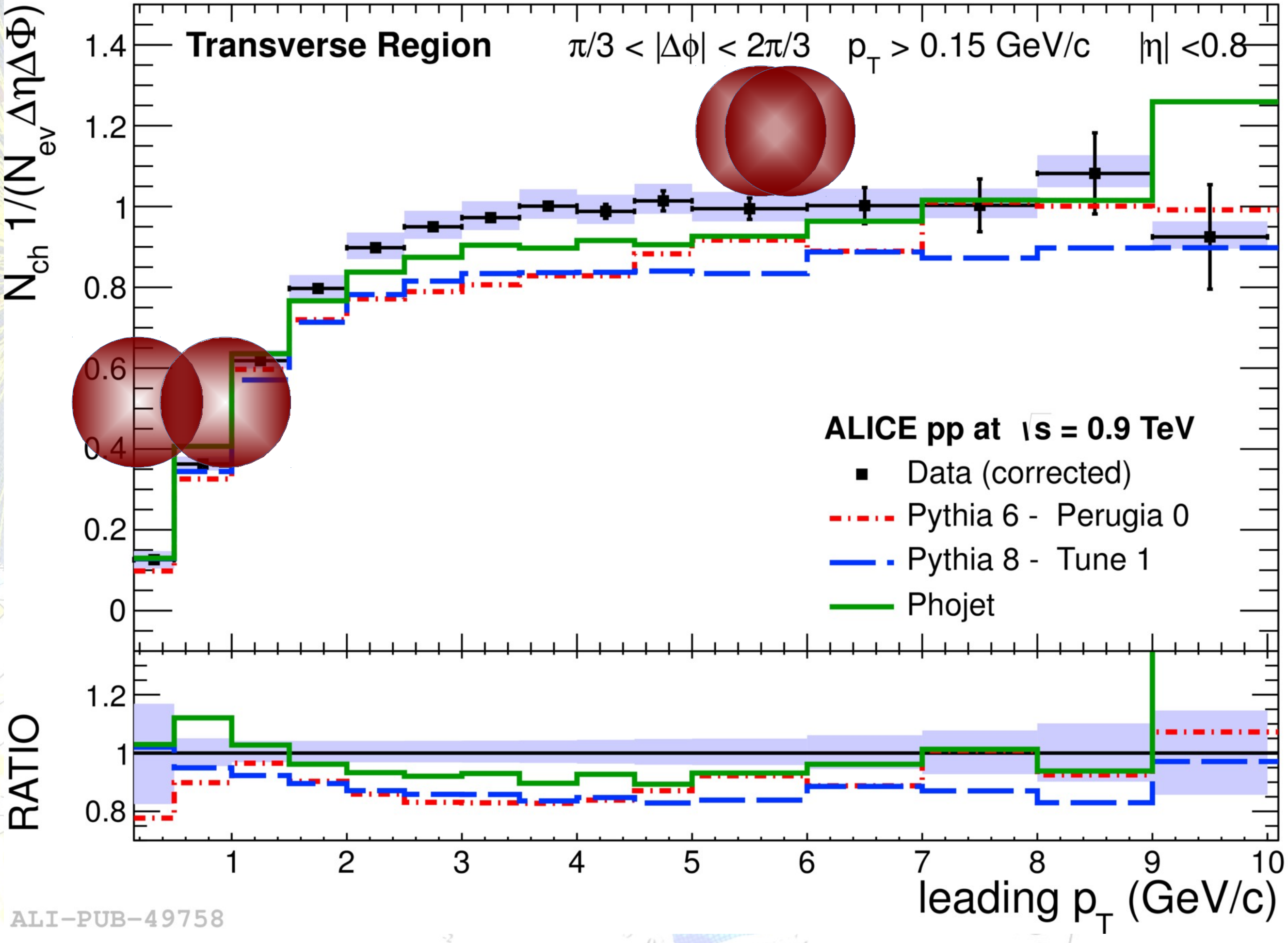


ALI-PUB-49758

The ALICE Collaboration, JHEP 116, 2012.

Impact-parameter dependence





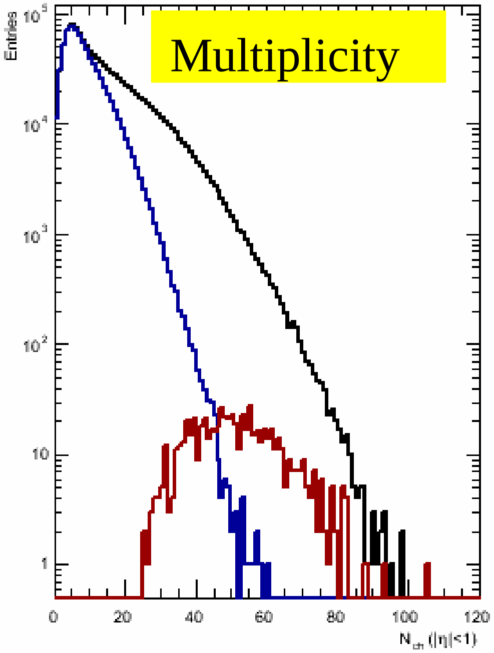
taken from Stefan Gieseke©

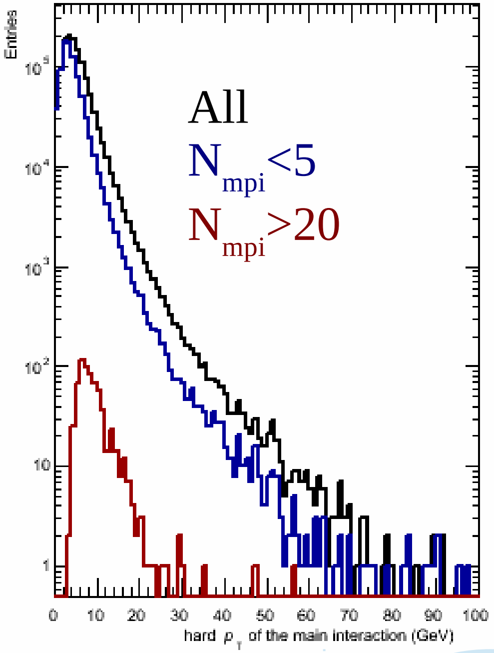
- ➢ Hard jets appear to sit on top of a higher "pedestal" of underlying activity than events with no hard jets.
  ➔Centrality bias in pp collisions!

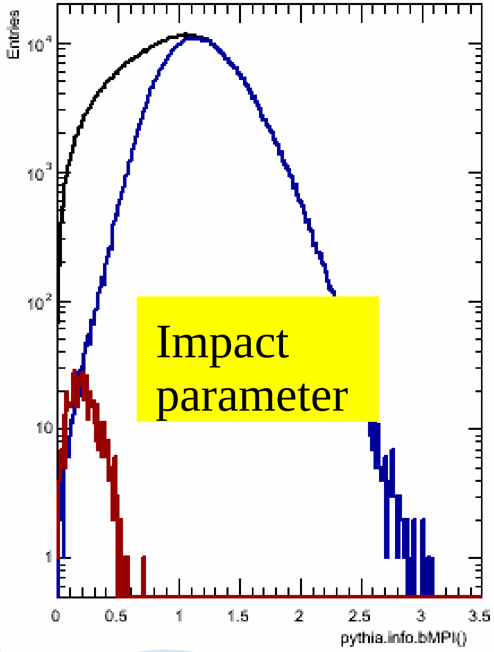
The ALICE Collaboration, JHEP 116, 2012.

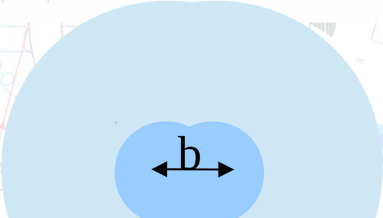
Simulations with Pythia 8

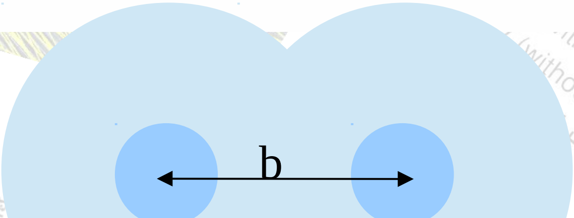
$pp\ \sqrt{s}=7$ TeV









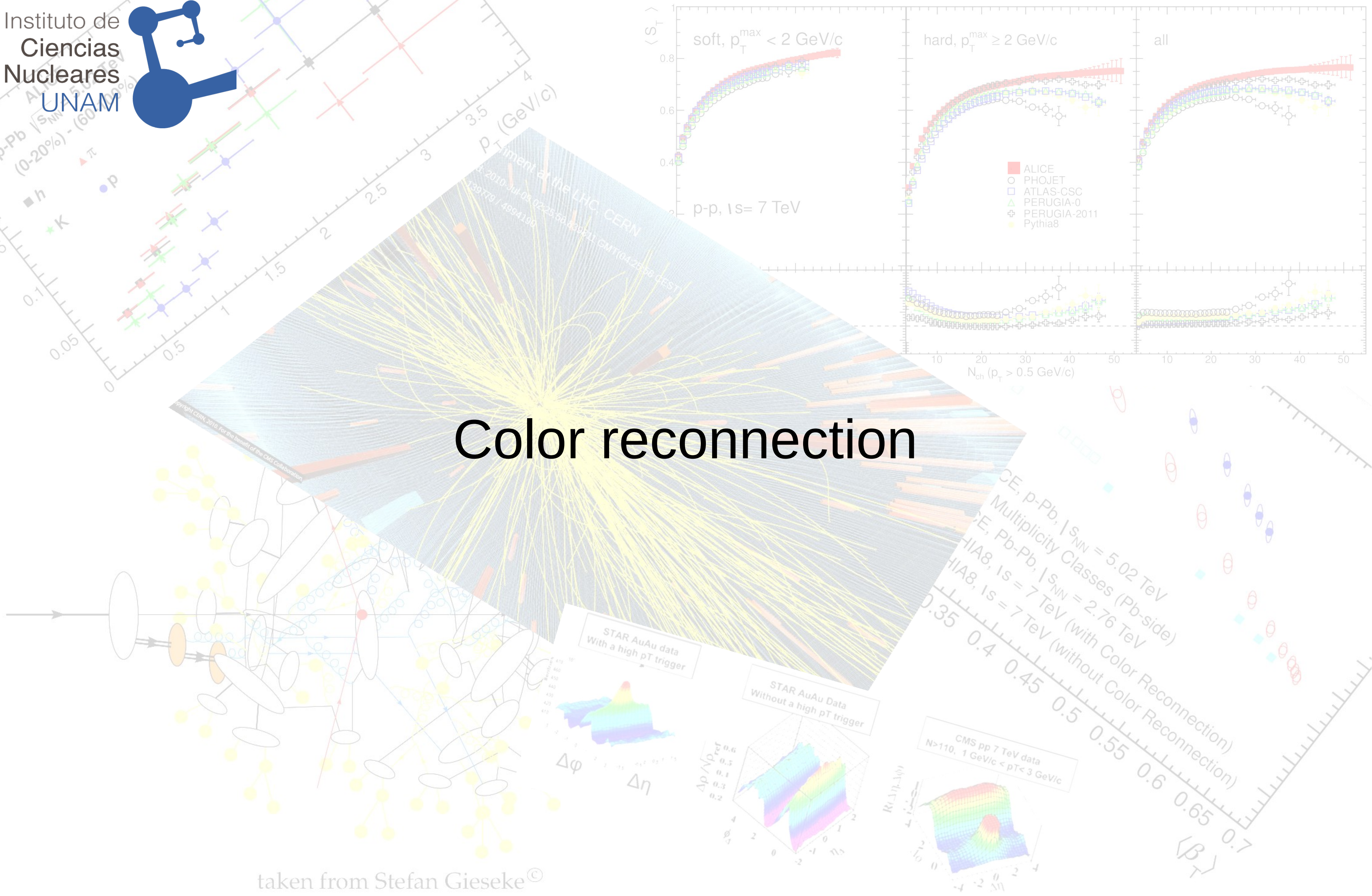


Central collisions:

- Hard p_T scale.
- Many MPI - > High Multiplicity Events

Peripheral collisions:

- Smaller hard p_T scale.
- Few MPI - > Smaller Multiplicity

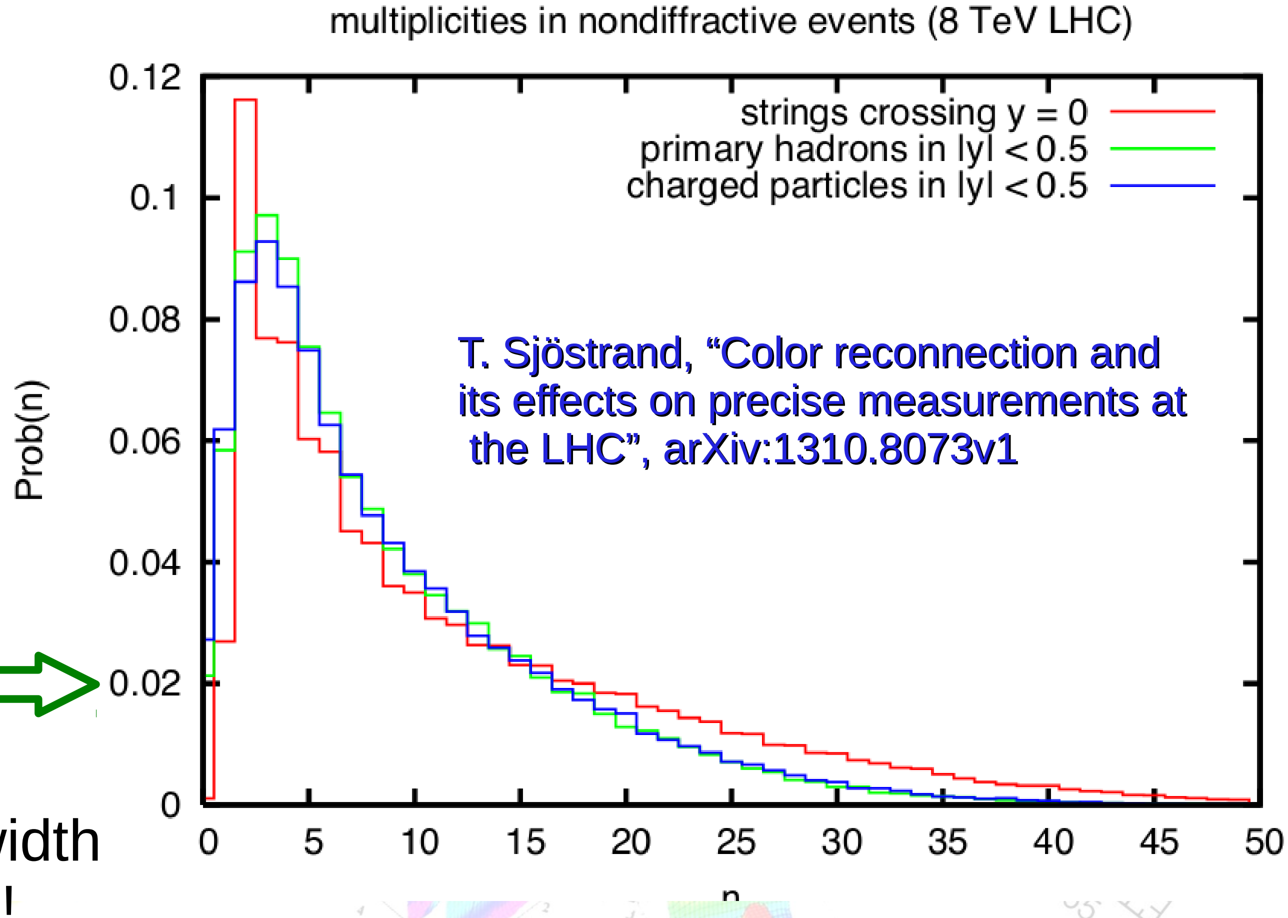


Color reconnection

Strings overlap in space and time

LHC events have complicated structure, the different physics components (MPI, ISR, FSR, BR) may produce high density of color charges, that may interact (color reconnection) in a nontrivial nonlinear manner.

To quantify the effect, let us consider MB events.



T. Sjöstrand, "Color reconnection and its effects on precise measurements at the LHC", arXiv:1310.8073v1

String width ~ hadronic width
⇒ Overlap factor ~ 10!
Larger for hard collisions
(small impact parameter)

taken from Stefan Gieseke©

Color reconnection

In Pythia, the final step at parton level before the hadronization is the color **reconnection** CR, its aim is to describe the hadronization of a many parton system in a single event with multiple hard sub collisions.

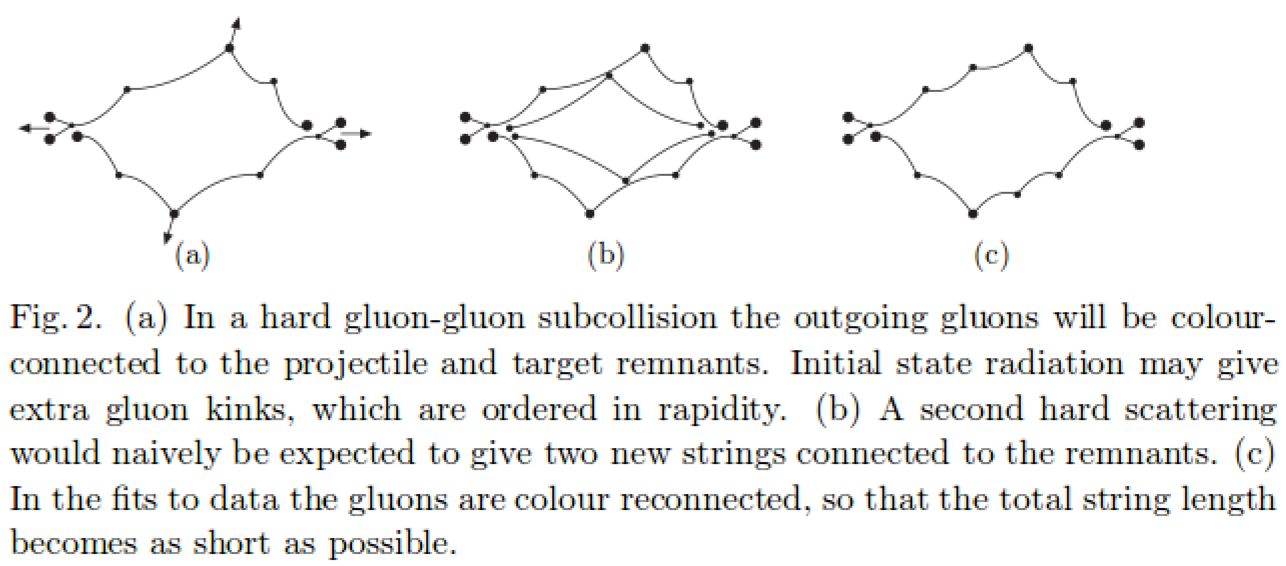


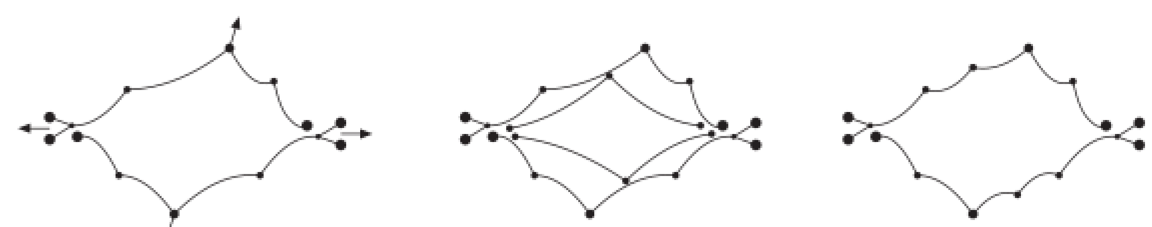
Fig. 2. (a) In a hard gluon-gluon subcollision the outgoing gluons will be colour-connected to the projectile and target remnants. Initial state radiation may give extra gluon kinks, which are ordered in rapidity. (b) A second hard scattering would naively be expected to give two new strings connected to the remnants. (c) In the fits to data the gluons are colour reconnected, so that the total string length becomes as short as possible.

G. Gustafson, Acta Phys.Polon.B40:1981-1996,2009

taken from Stefan Gieseke©

Color reconnection

In Pythia, the final step at parton level before the hadronization is the color **reconnection** CR, its aim is to describe the hadronization of a many parton system in a single event with multiple hard sub collisions.



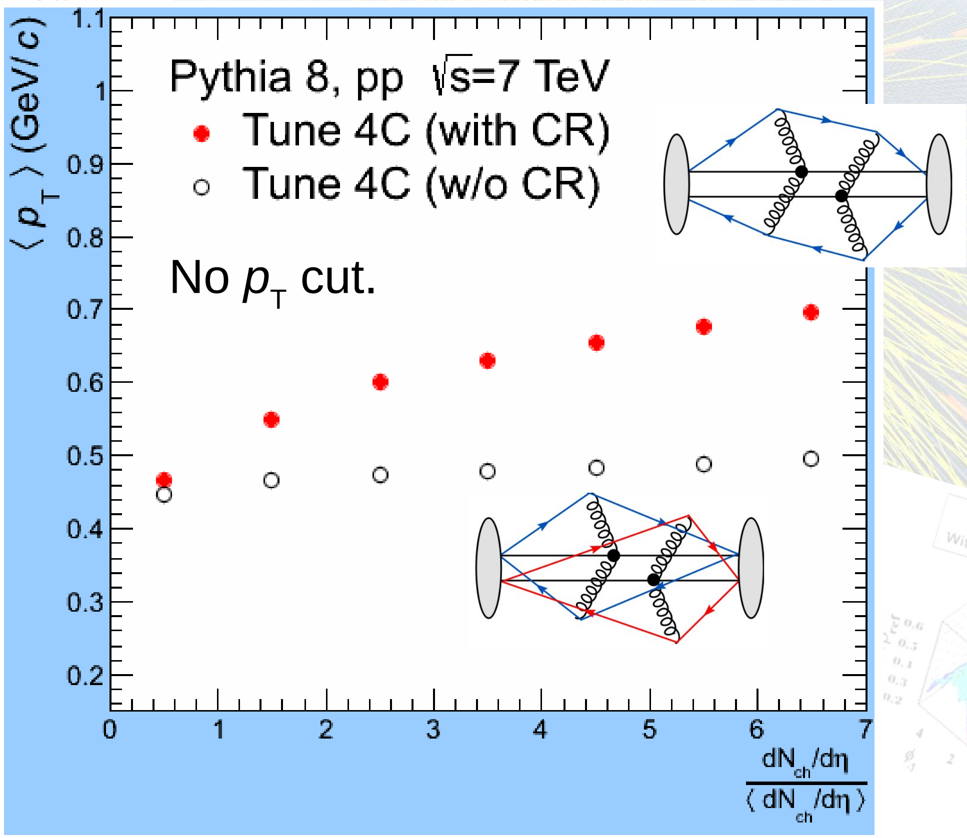
The tune 4C (Pythia 8.1.2), uses a model where either all or none of the final-state partons of a MPI system are attached to the string pieces of a higher-p_T system, in a way so as to keep the total string length minimal.

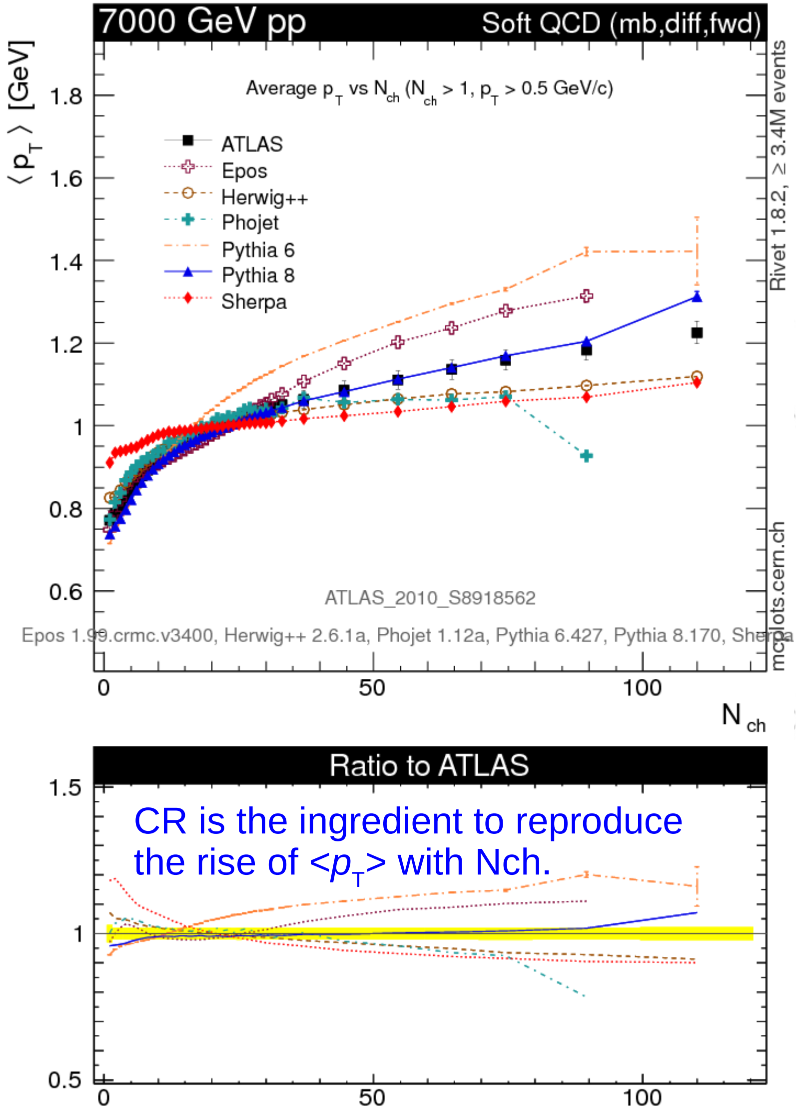
G. Gustafson, Acta Phys.Polon.B40:1981-1996,2009

taken from Stefan Gieseke©

CR is needed to describe data

CR is the mechanism which produces the rise of $<p_T>$ with multiplicity

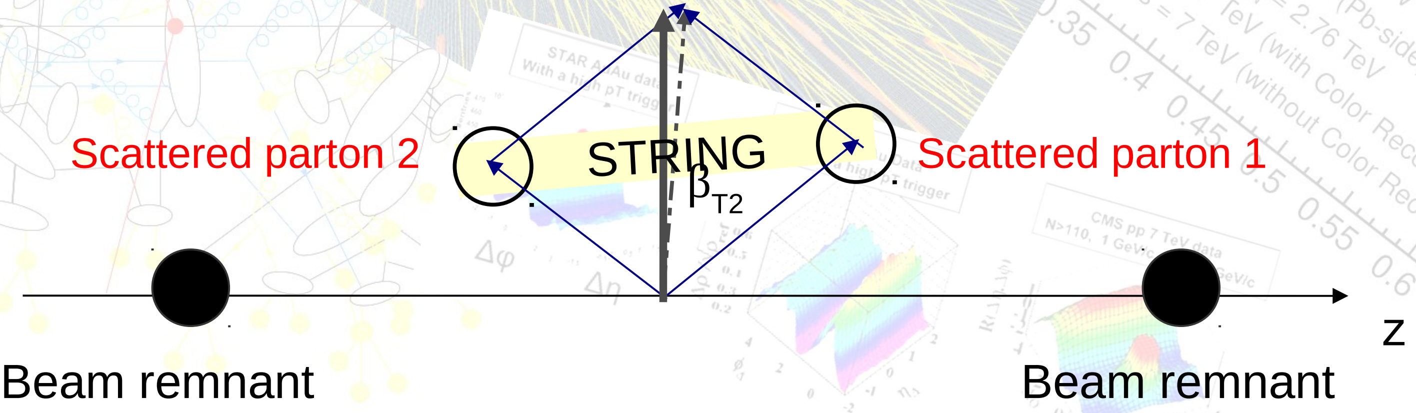




CR is the ingredient to reproduce the rise of $<p_T>$ with Nch.

But also we discovered that CR produces flow-like effects

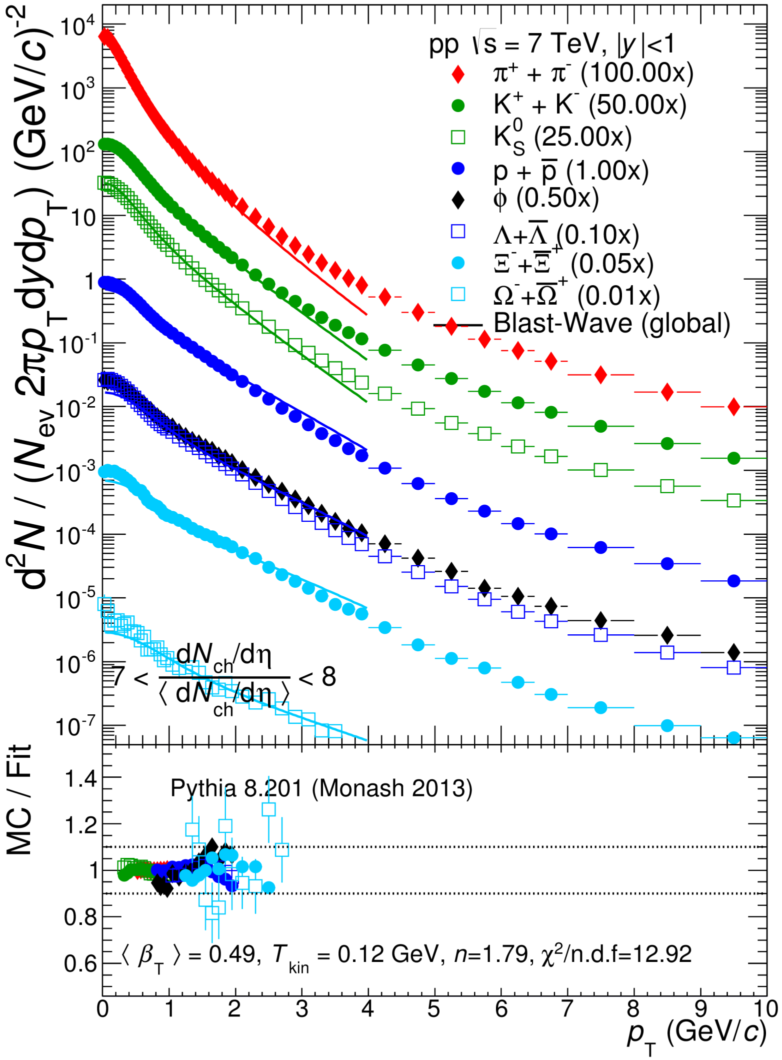
- A string piece moving with some transverse velocity tends to transfer that velocity to the particle produced from it, albeit with large fluctuations, thereby giving larger transverse momenta to heavier hadrons.
- A string piece has a larger transverse velocity the closer to each other the two endpoint partons are moving, which is precisely what is favored by CR scenarios intended to reduce the string length.



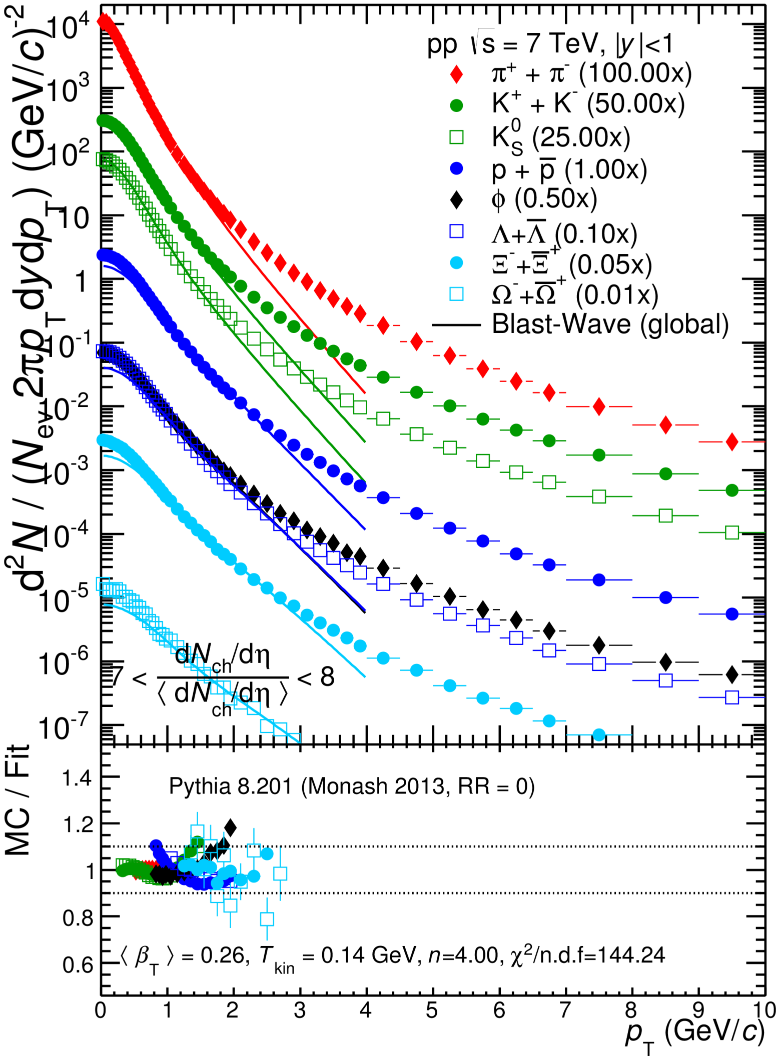
A. Ortiz et al., Phys. Rev. Lett. 111, 042001, 2013.

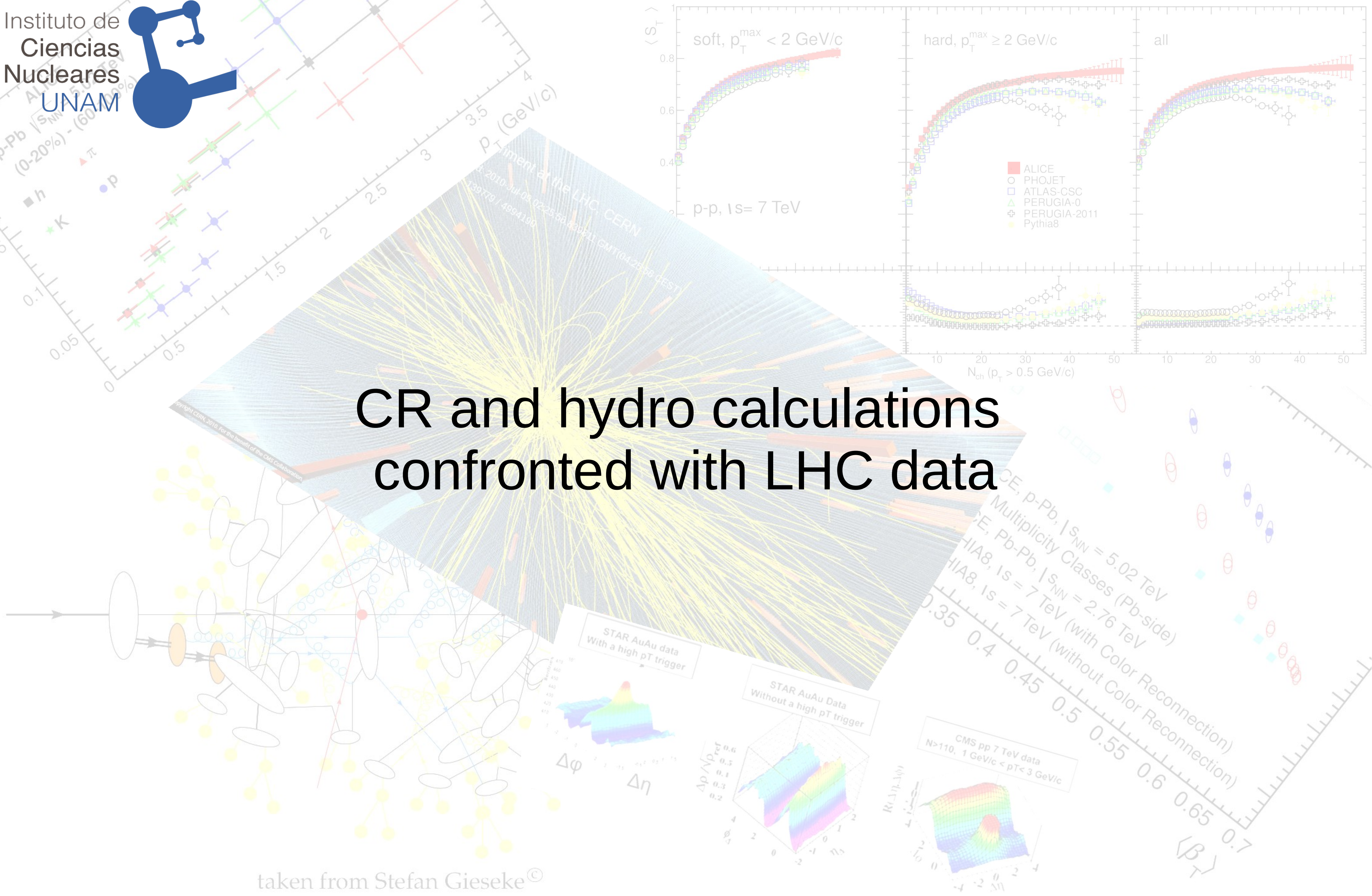
Hydro model fitted to p_T spectra

MC, Pythia CR, pp



MC, Pythia no CR, pp





CR and hydro calculations confronted with LHC data

taken from Stefan Gieseke©

Average p_T vs m

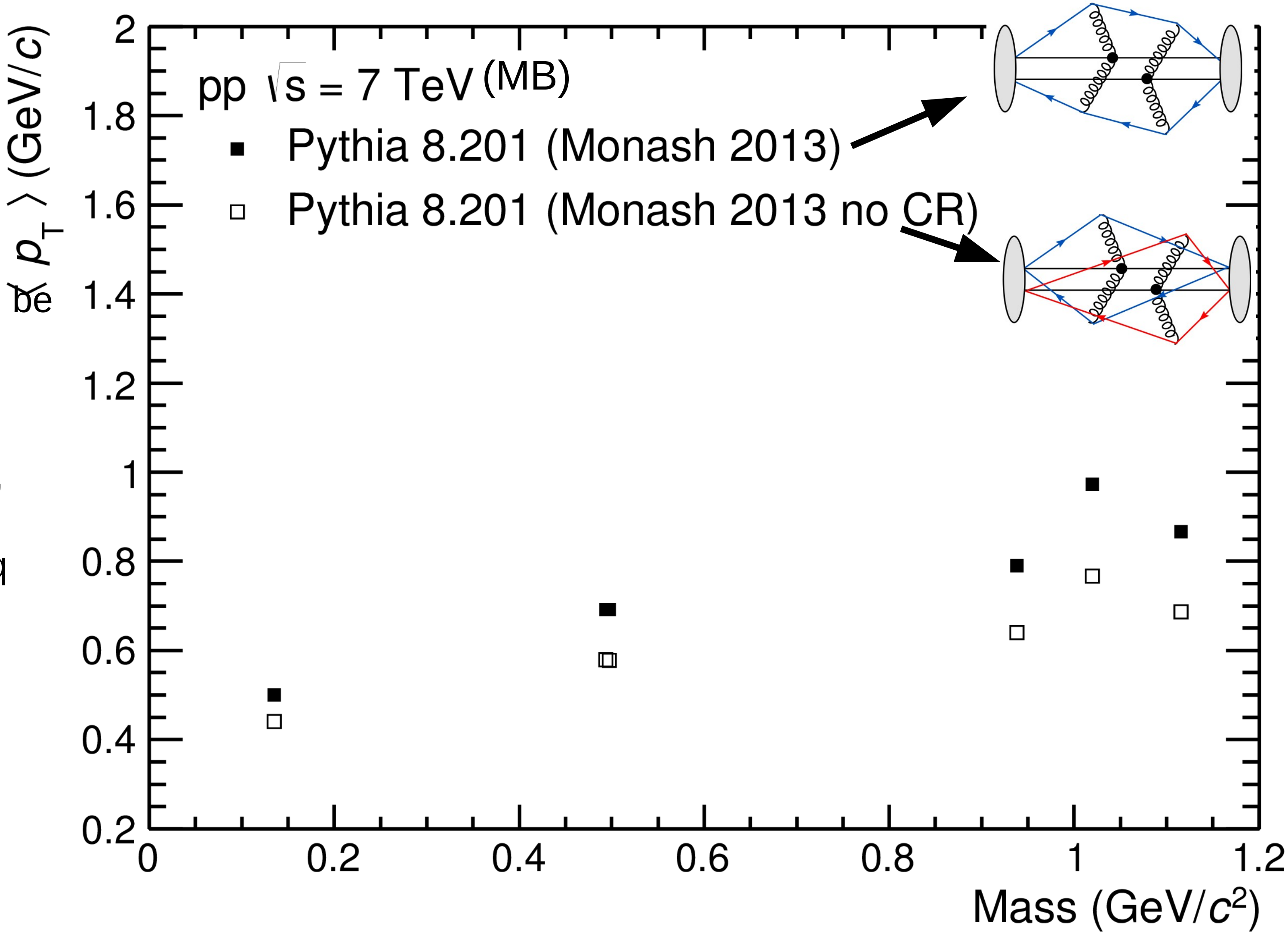
Pythia 8.201:
T. Sjöstrand et al., arXiv:1410.3012

Tune Monash 2013.
P. Skands et al., EPJ C74 (2014) 8, 3024.

In Pythia 8, the average p_T can be affected by:

- Collective flow-like due to transversely boosted string pieces ($<p_T> \sim k*m$, PRL 11, 042001, 2013).
- At each string breaking the q and qbar are supposed to receive opposite and compensating p_T kicks according to a Gaussian distribution in p_x and p_y separately (Gaussian fragmentation p_T).

Different scaling for baryons and mesons?



http://home.thep.lu.se/~torbjorn/pythia82html/Fragmentation.html

Scaling with m/n_q

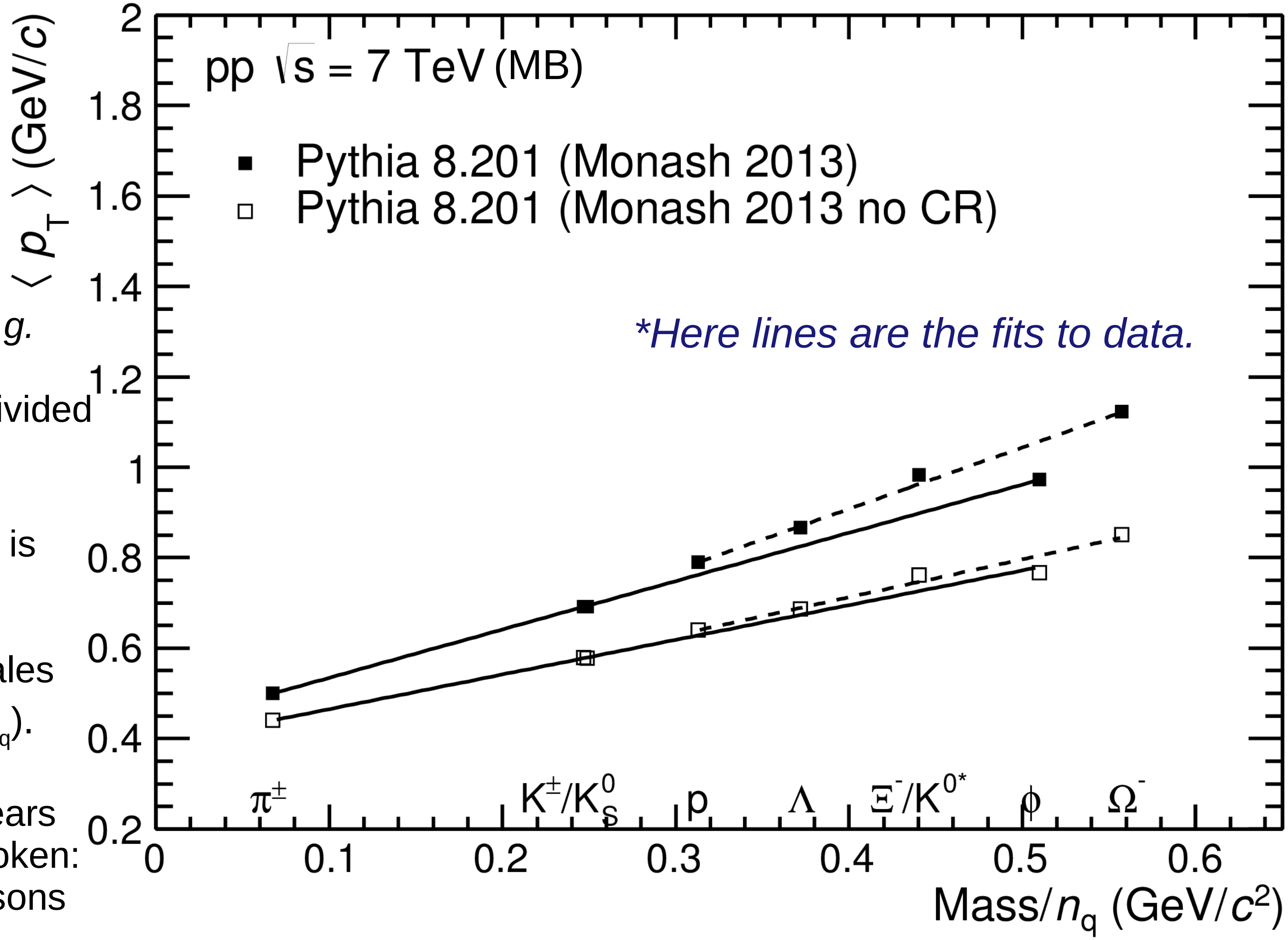
Pythia 8.201:
T. Sjöstrand et al., arXiv:1410.3012

Tune Monash 2013.
P. Skands et al., EPJ C74 (2014) 8, 3024.

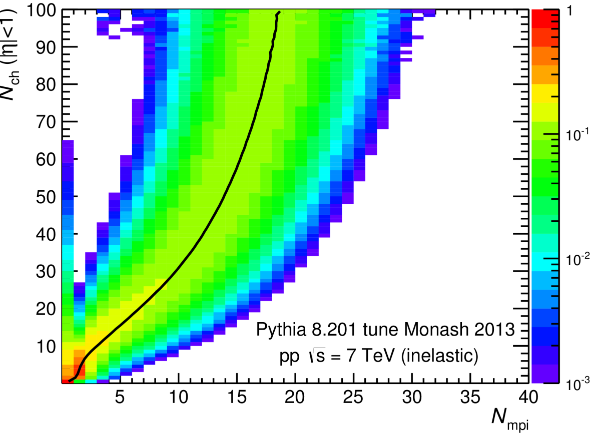
To facilitate the comparison (*e.g.* slopes) between bayons and mesons, the hadron mass is divided by the number of quark (n_q).

When color reconnection (CR) is switched off (independent fragmentation of the partonic systems), mean p_T roughly scales with m/n_q, $\langle p_T \rangle$~constant*(m/n_q).

With CR, flow-like effects appears and the universal scaling is broken: the $\langle p_T \rangle$s for baryons and mesons scale with m/n_q, independently.



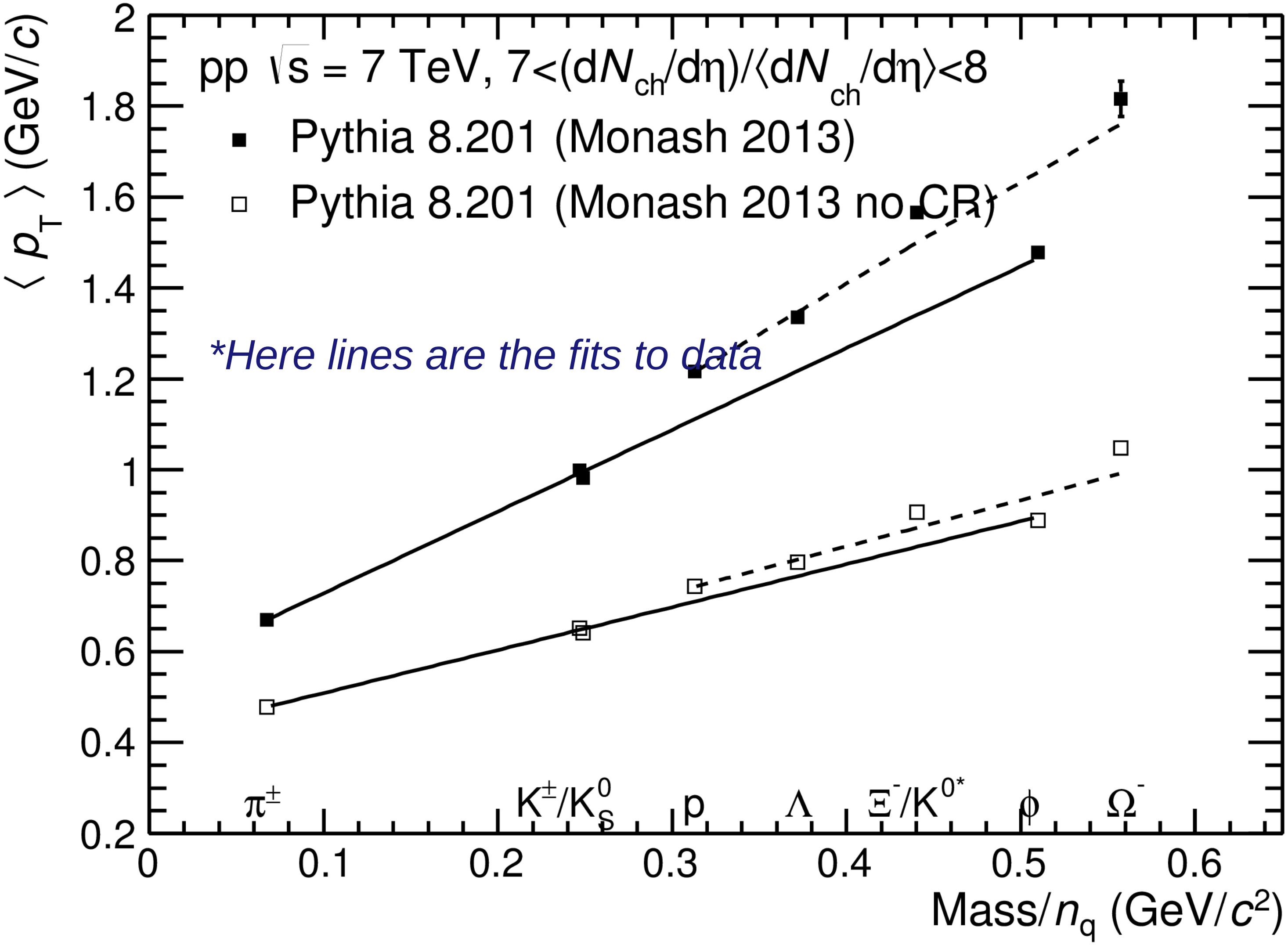
Pythia: high multiplicity



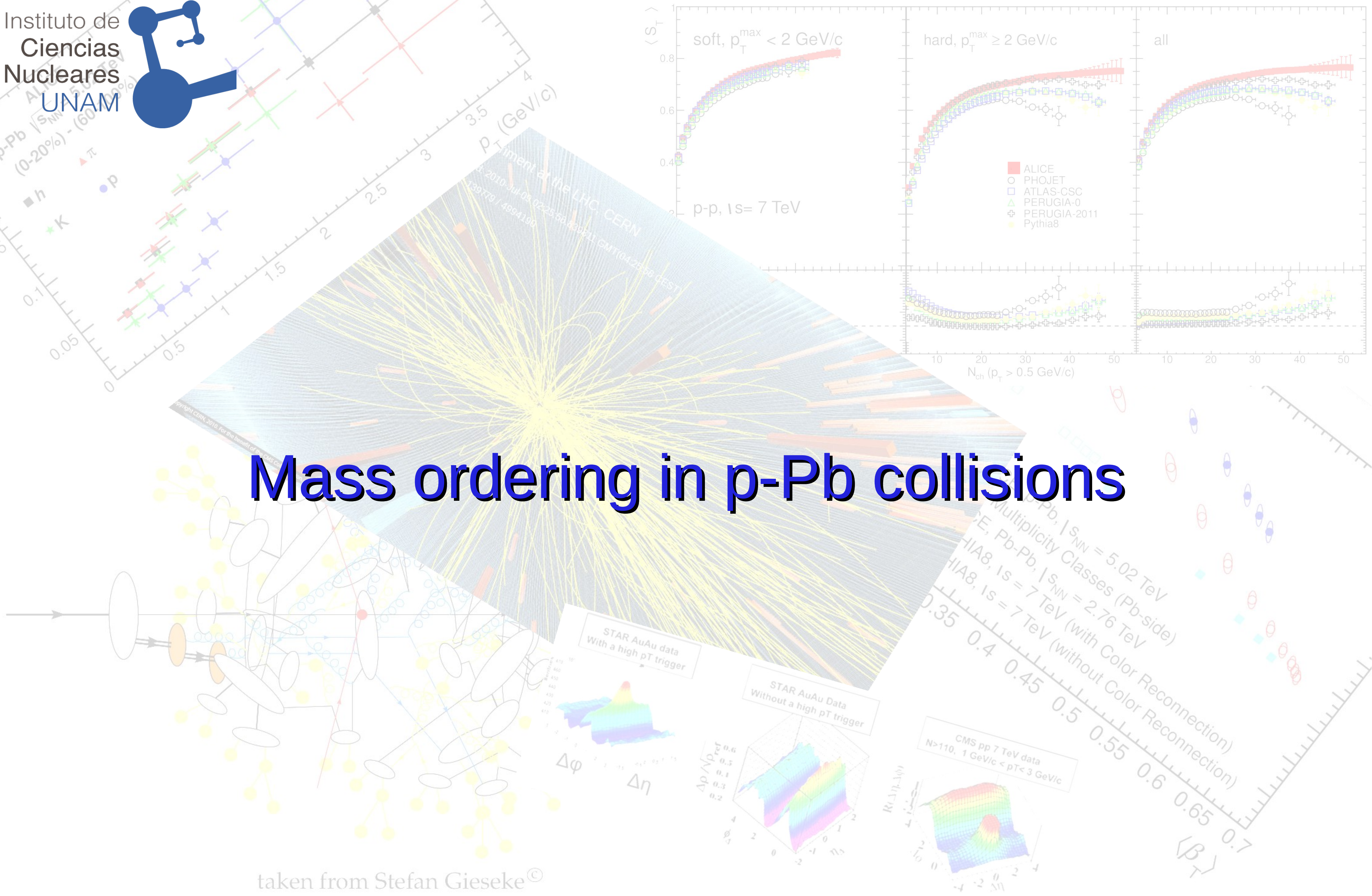
When the number of multi-parton interactions is increased (large multiplicity) we observe an overall increase of the average p_T.

The mean p_T is larger when CR is activated. Baryons have an overall larger mean p_T than mesons.

Without CR, $\langle p_T \rangle$ is still closer to the universal scaling with m/n_q.



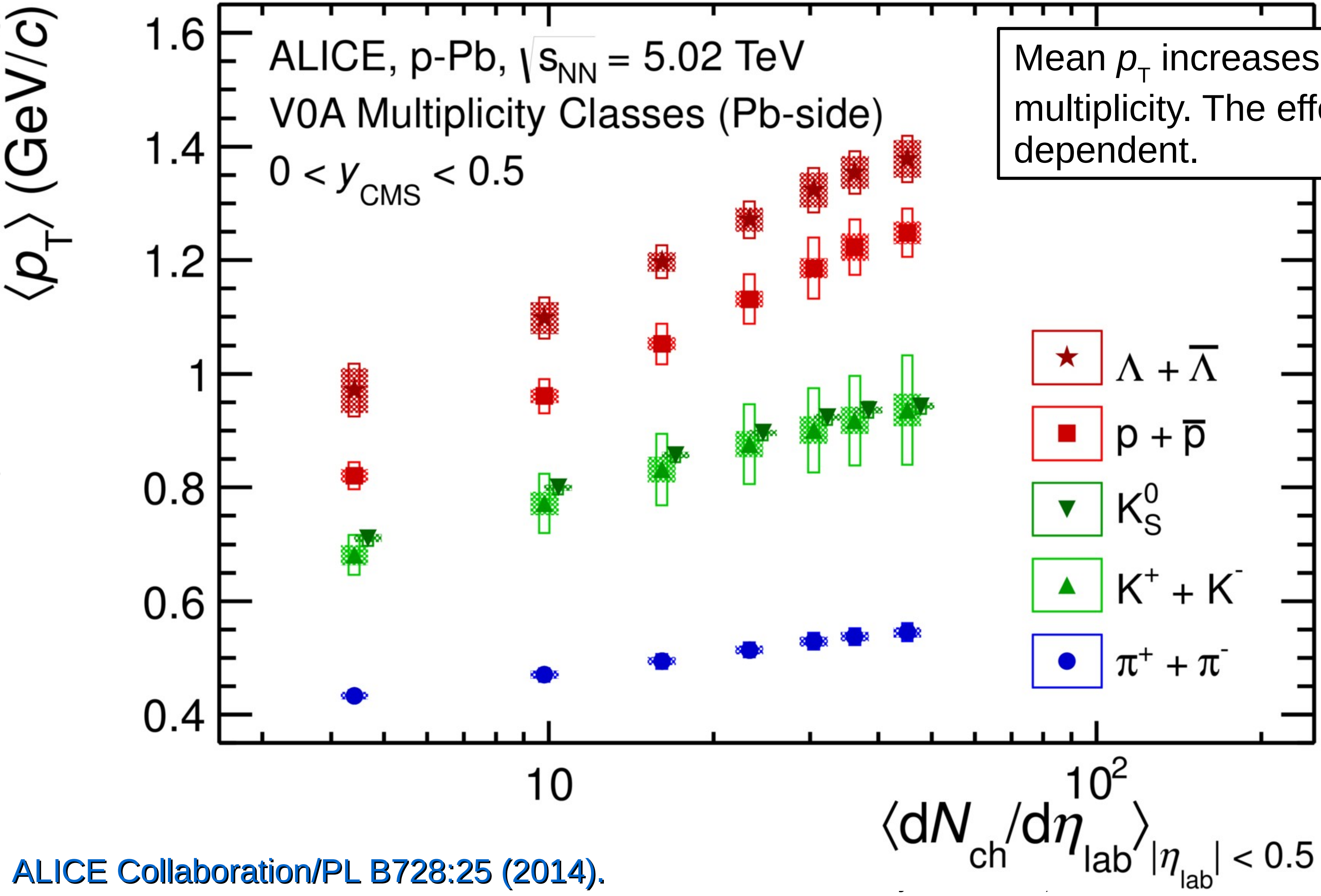
*Here lines are the fits to data



taken from Stefan Gieseke©

Mass ordering in p-Pb collisions

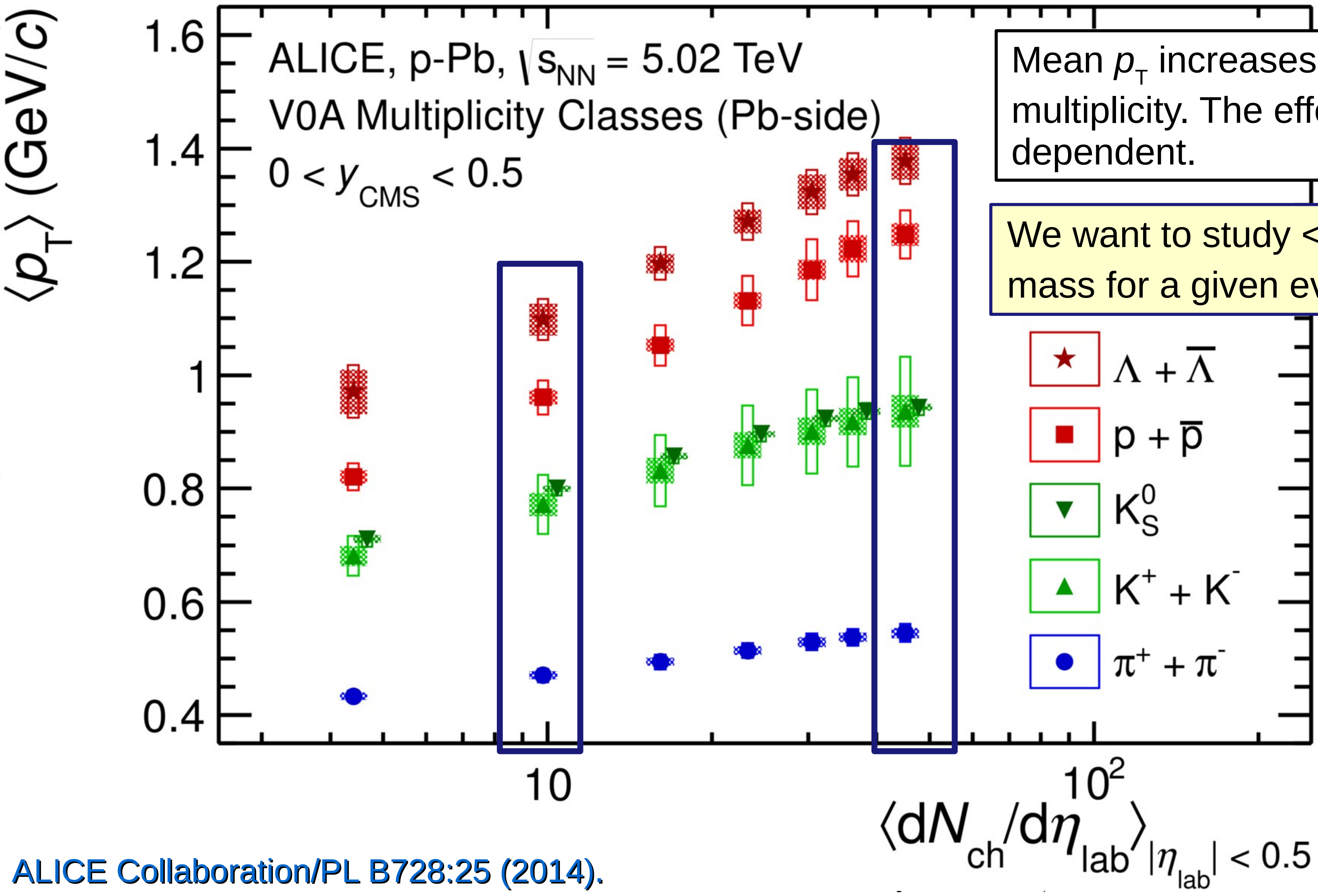
$\langle p_T \rangle$ vs N_{ch} in p-Pb collisions



Mean p_T increases with the event multiplicity. The effect is mass dependent.

ALICE Collaboration/PL B728:25 (2014).

$\langle p_T \rangle$ vs N_{ch} in p-Pb collisions



Mean p_T increases with the event multiplicity. The effect is mass dependent.

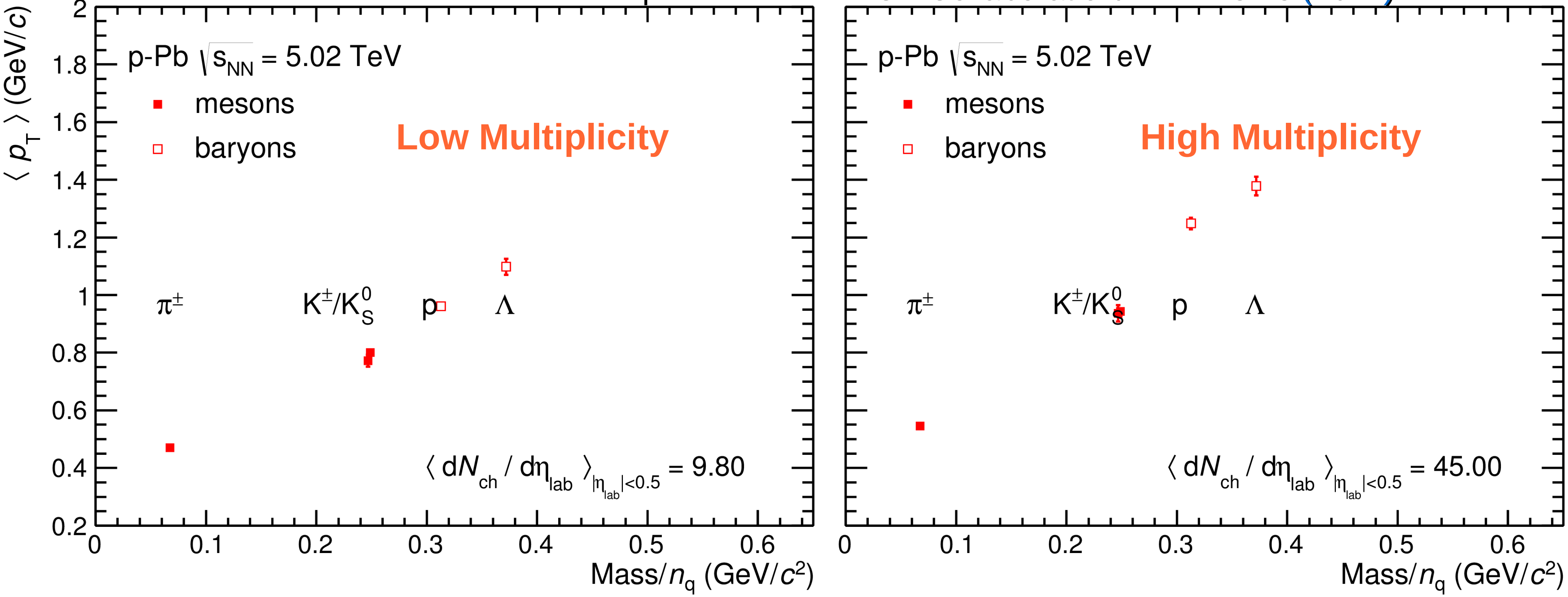
We want to study $\langle p_T \rangle$ vs hadron mass for a given event class

ALICE Collaboration/PL B728:25 (2014).

$\langle p_T \rangle$ vs hadron mass

Mass (m) is divided by the number of quarks constituents (n_q).

Points obtained from fits to the data reported here: ALICE Collaboration/PL B728:25 (2014).

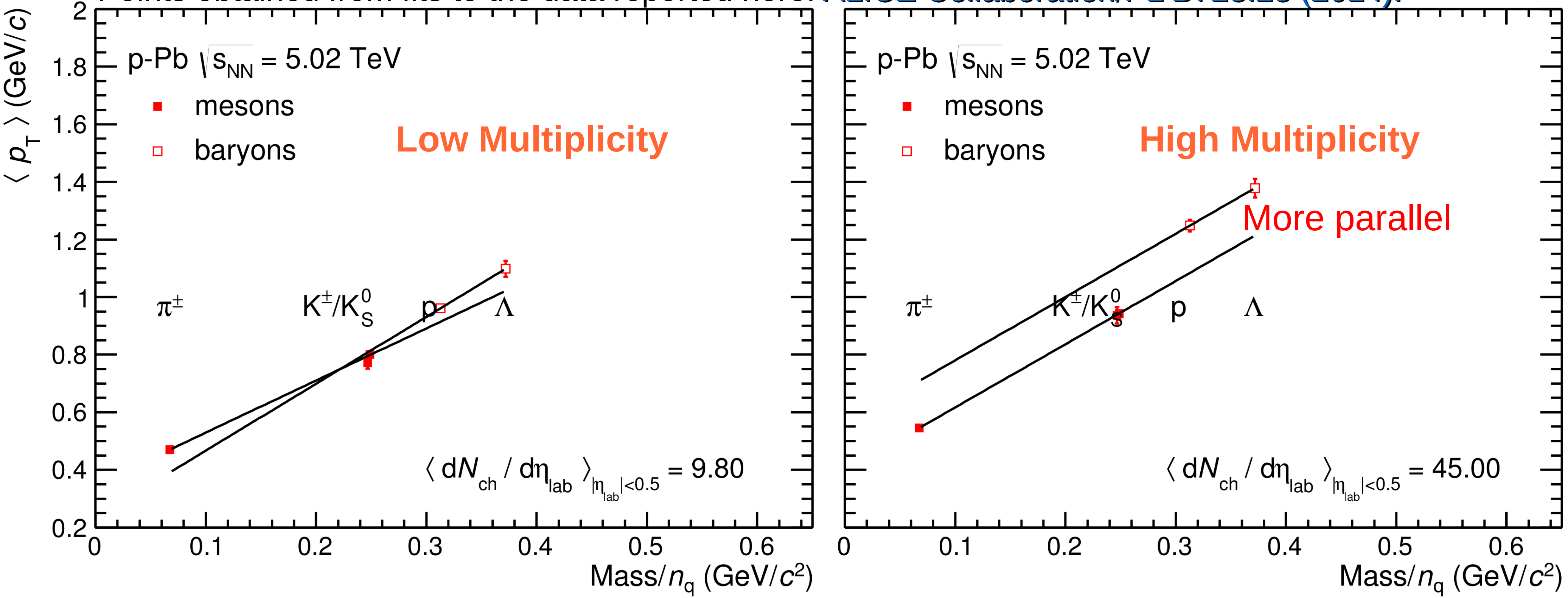


Mean p_T seem to scale with m/n_q, $\langle p_T \rangle \sim c(m/n_q)$.

$\langle p_T \rangle$ vs hadron mass

Mass (m) is divided by the number of quarks constituents (n_q).

Points obtained from fits to the data reported here: ALICE Collaboration/PL B728:25 (2014).

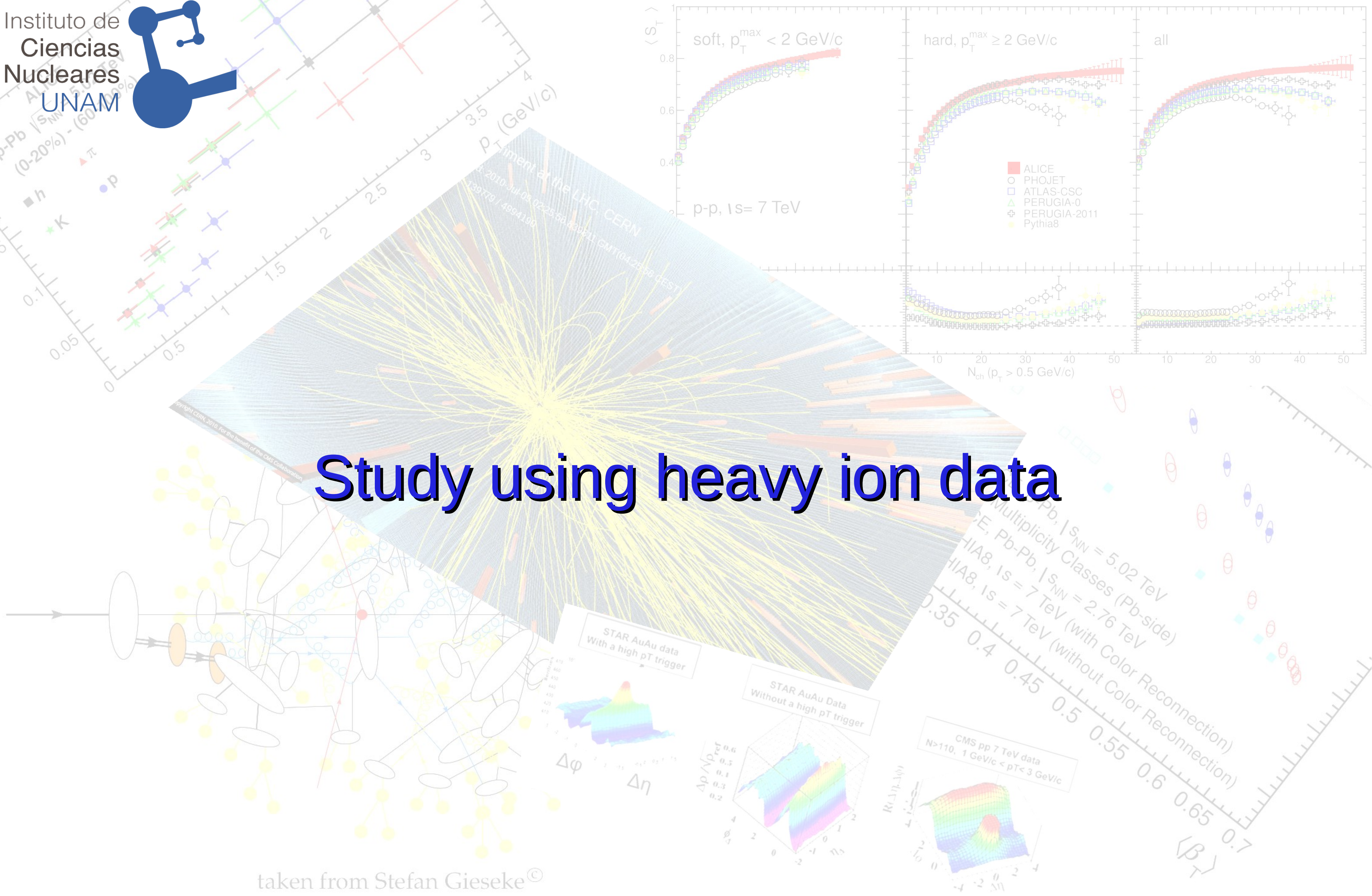


Low Multiplicity

High Multiplicity

More parallel

Larger *c* is obtained for baryons than for mesons. The data are fitted to linear functions, the parameters as a function of multiplicity are studied in the next slides ...



taken from Stefan Gieseke©

Study using heavy ion data

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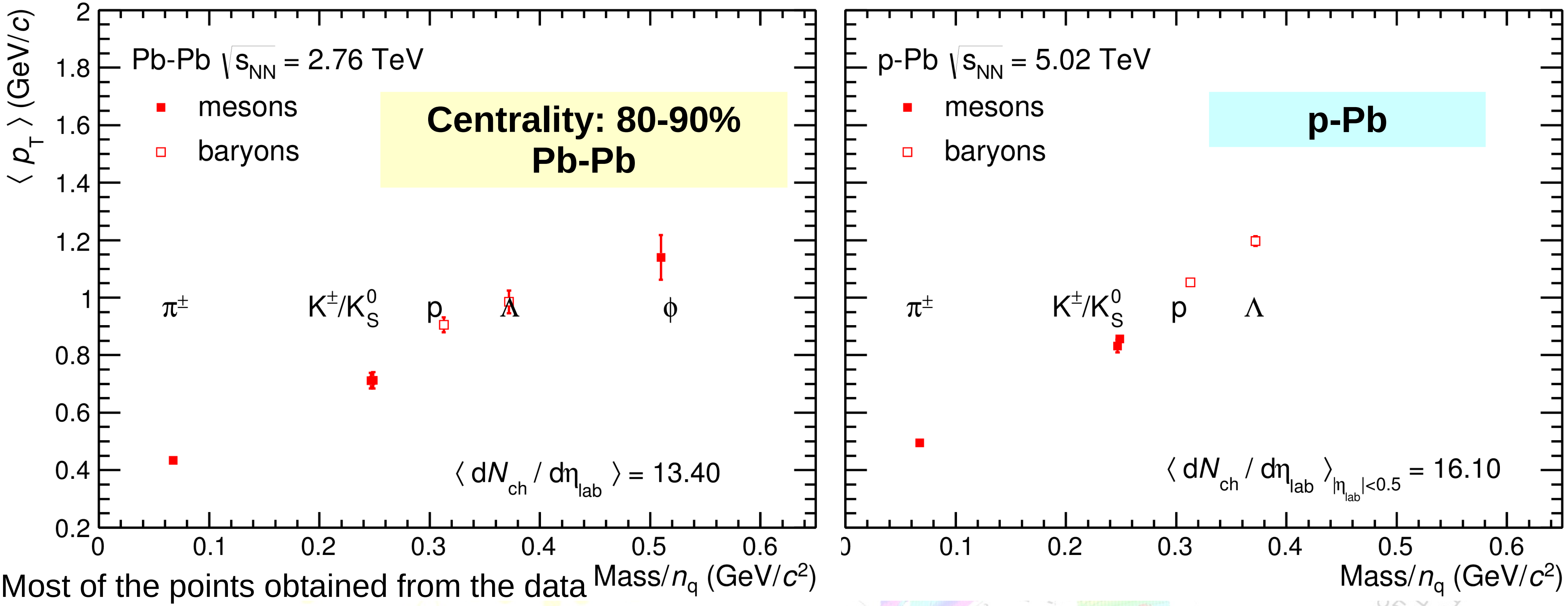
$<p_T>$ vs m/n_q, comparison with Pb-Pb

Low multiplicity events



Most of the points obtained from the data reported here:

ALICE Collaboration/PR C88, 044910 (2013).

ALICE Collaboration/PL B728:25 (2014).

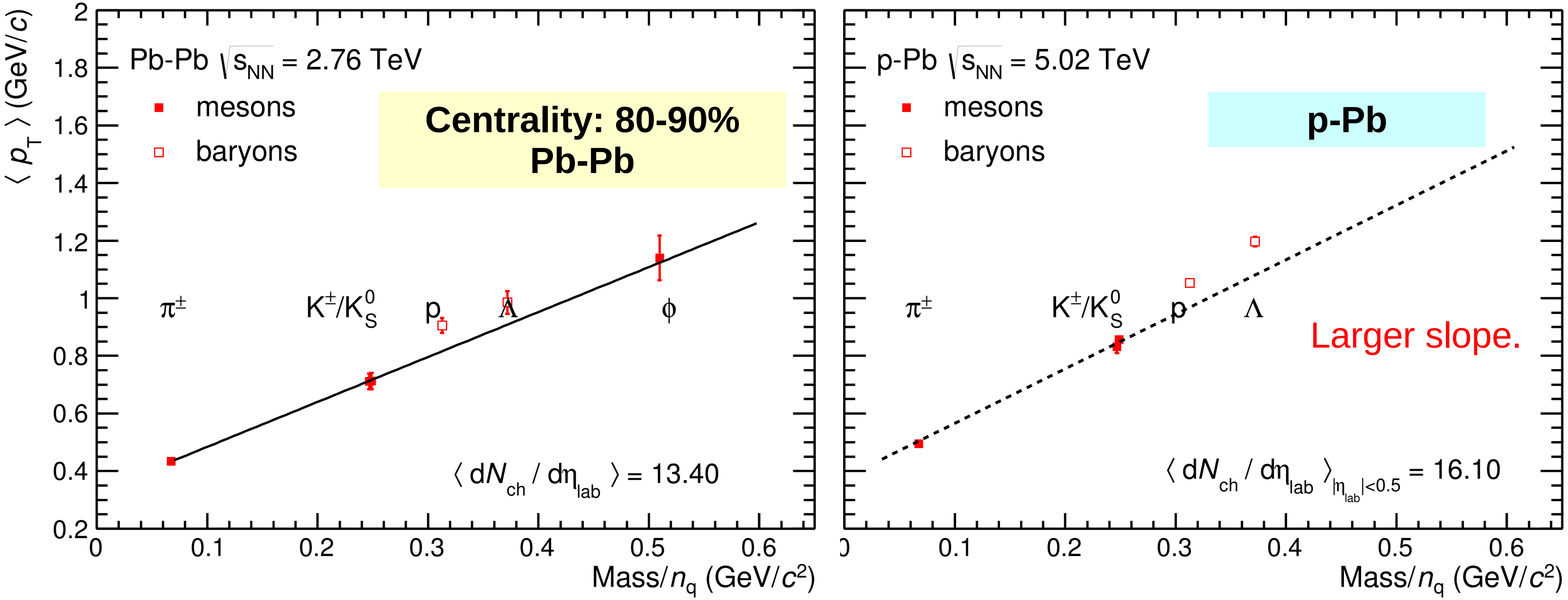
ALICE Collaboration/arXiv:1404.0495

Mean p_T for Λ and K^0_S in Pb-Pb collisions are derived from spectra reported here:

ALICE Collaboration/PRL. 111 (2013) 222301.

$<p_T>$ vs m/n_q, comparison with Pb-Pb

Low multiplicity events



Centrality: 80-90%
Pb-Pb

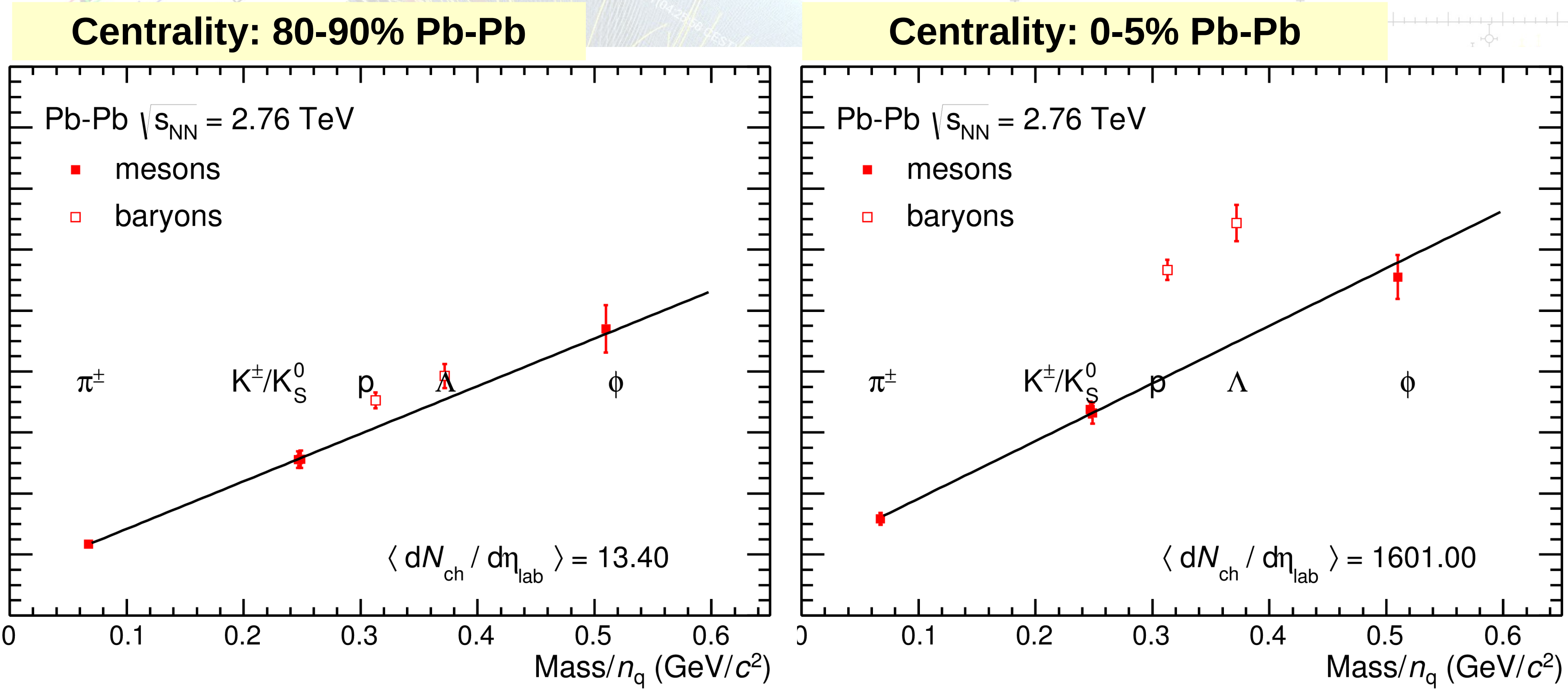
p-Pb

Larger slope.

Close to the universal scaling: **$<p_T>$ ~ constant*(m/n_q)**

$\langle p_T \rangle$ vs m/n_q, comparison with Pb-Pb

Central vs Peripheral Pb-Pb collisions



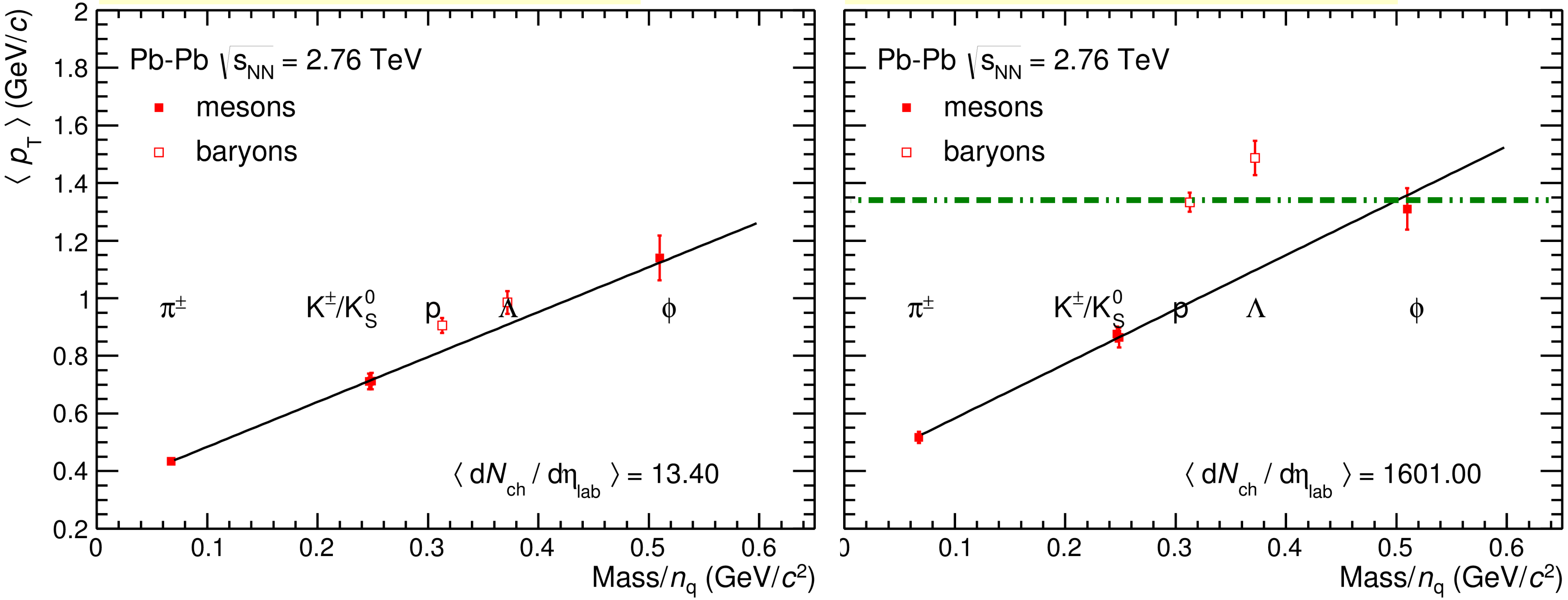
In the most central Pb-Pb collisions a deviation from the universal scaling, **$\langle p_T \rangle$ ~ constant*(m/n_q)**, is observed.

$\langle p_T \rangle$ vs m/n_q, comparison with Pb-Pb

Central vs Peripheral Pb-Pb collisions

Centrality: 80-90% Pb-Pb

Centrality: 0-5% Pb-Pb



In central Pb-Pb collisions, the φ meson $\langle p_T \rangle$ is the same to that for protons.

Is this an universal scaling with hadron mass and not with *m*/n_q?

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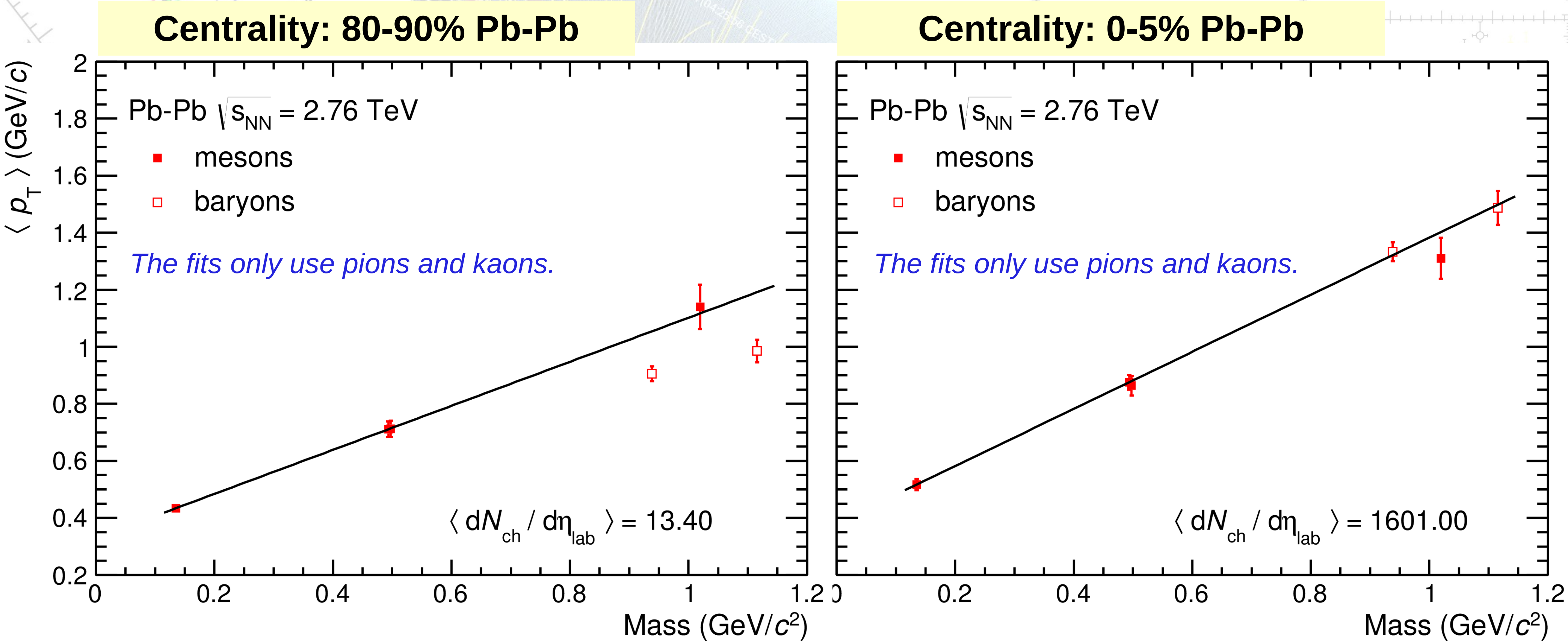
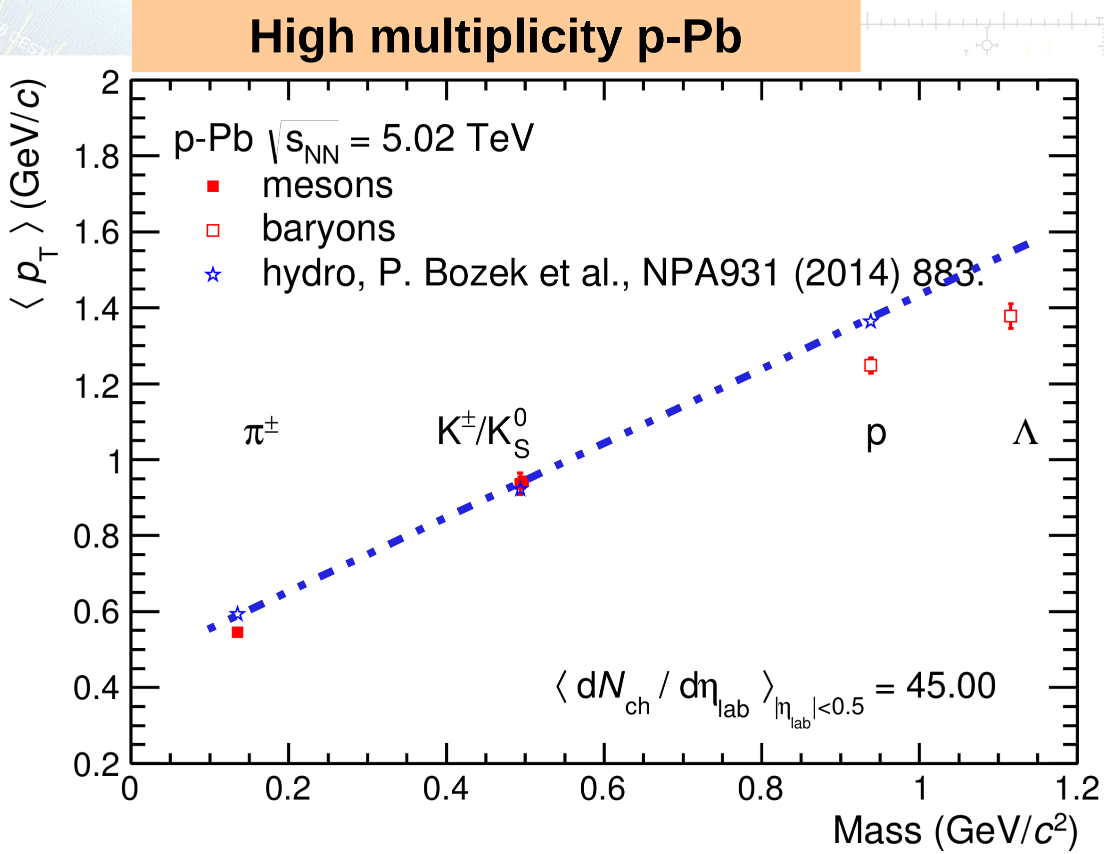
$<p_T>$ vs m/n_q, comparison with Pb-Pb

Central vs Peripheral Pb-Pb collisions



Actually, **the answer is YES**, but this scaling is only observed in central (0-40%) Pb-Pb collisions (the effect is not present in p-Pb events).

For p-Pb, the scaling with mass is seen in hydro calculations but not in data



Actually, the calculations for p-Pb collisions gives a scaling of $<p_T>$ with the hadron mass. Here we do not observe the dependence with the number of quark constituents.

→ p-Pb data behave like Pythia with MPI and color reconnection.

taken from Stefan Gieseke©

Summary

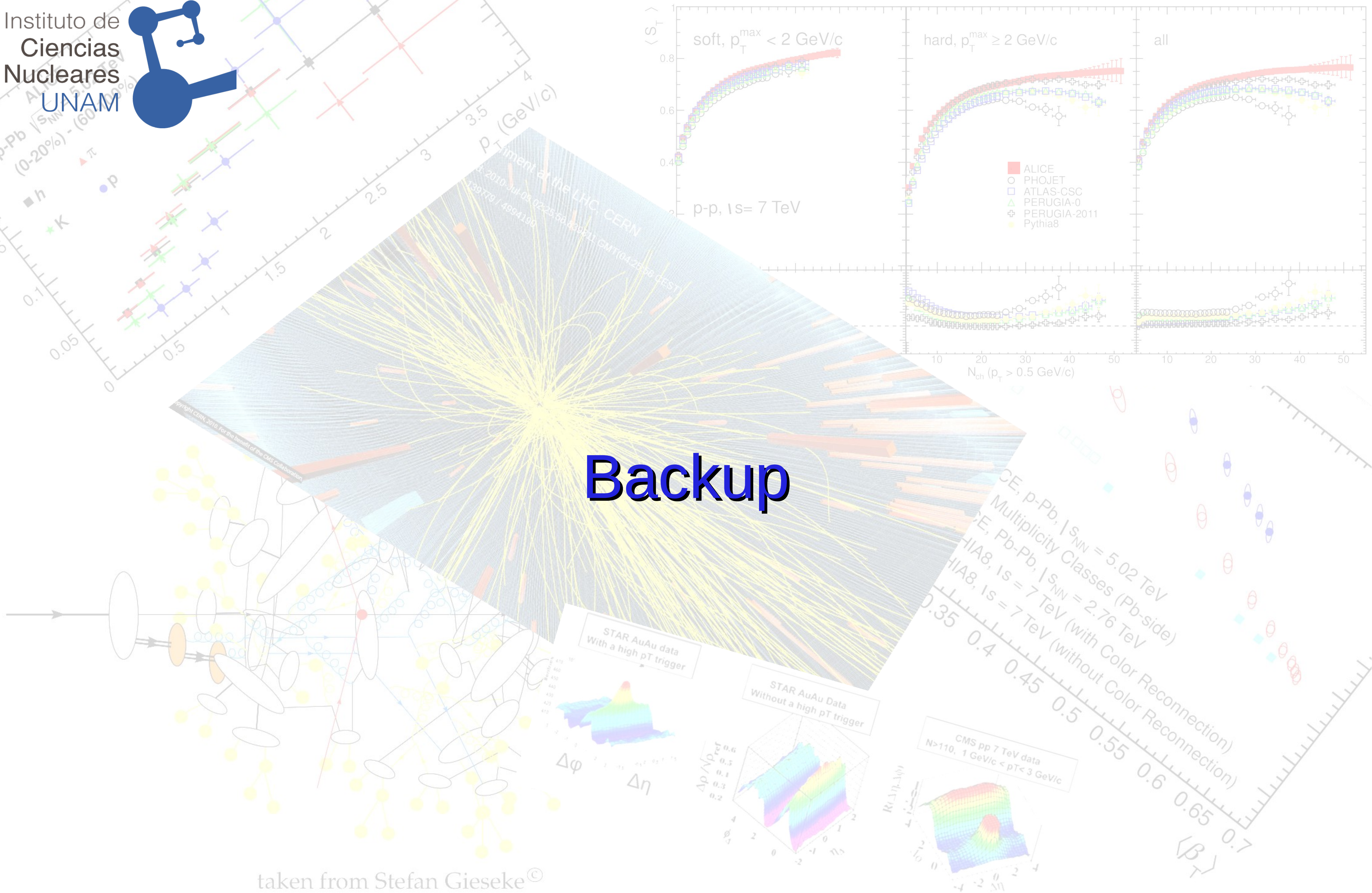
From Pythia studies:

- Without color reconnection (independent fragmentation) we observe an universal scaling of $<p_T>$ with m/n_q.
- When color reconnection is activated (flow-like), baryons and mesons follow different linear trends, $c_B > c_M$, for low to semi-high multiplicity. At high multiplicity, $c_B = c_M$.

From studies with data:

- pp, p-Pb and peripheral Pb-Pb data behave like Pythia with color reconnection. Is this an indication of flow-like in small systems?
- The central Pb-Pb collisions indicate an universal scaling of $<p_T>$ with m, and not with m/n_q.

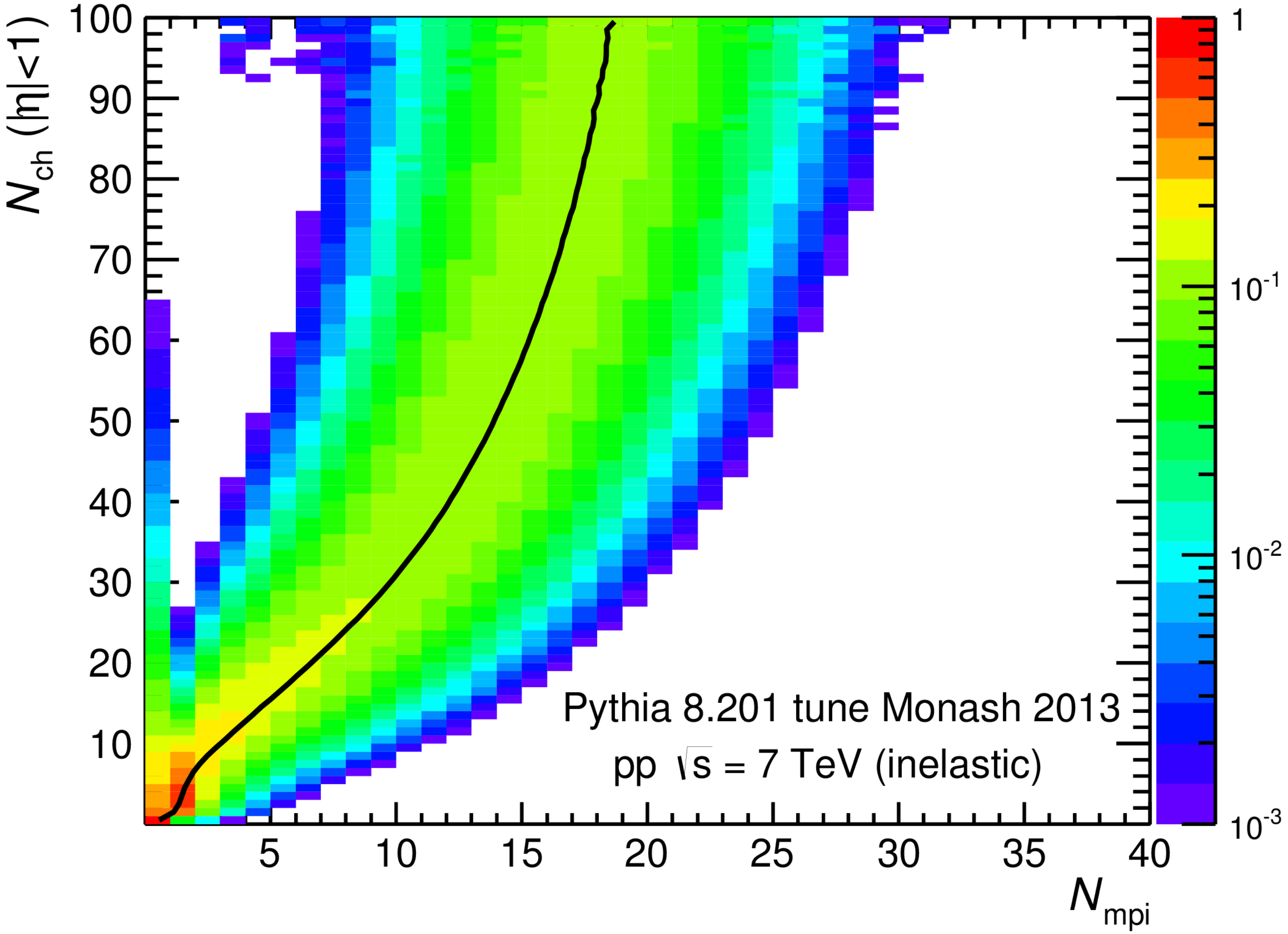
taken from Stefan Gieseke©



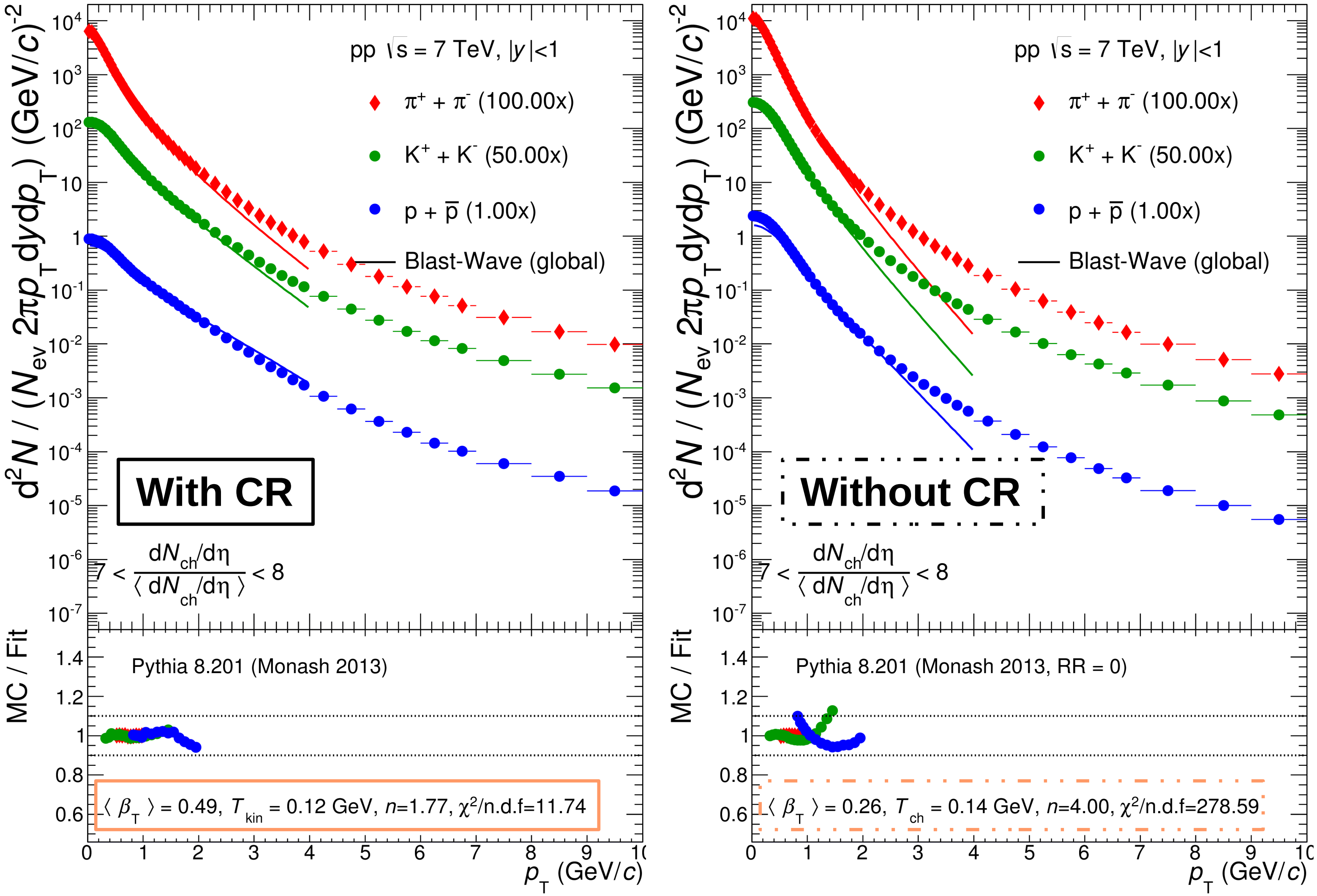
taken from Stefan Gieseke©

Backup

Pythia: high multiplicity



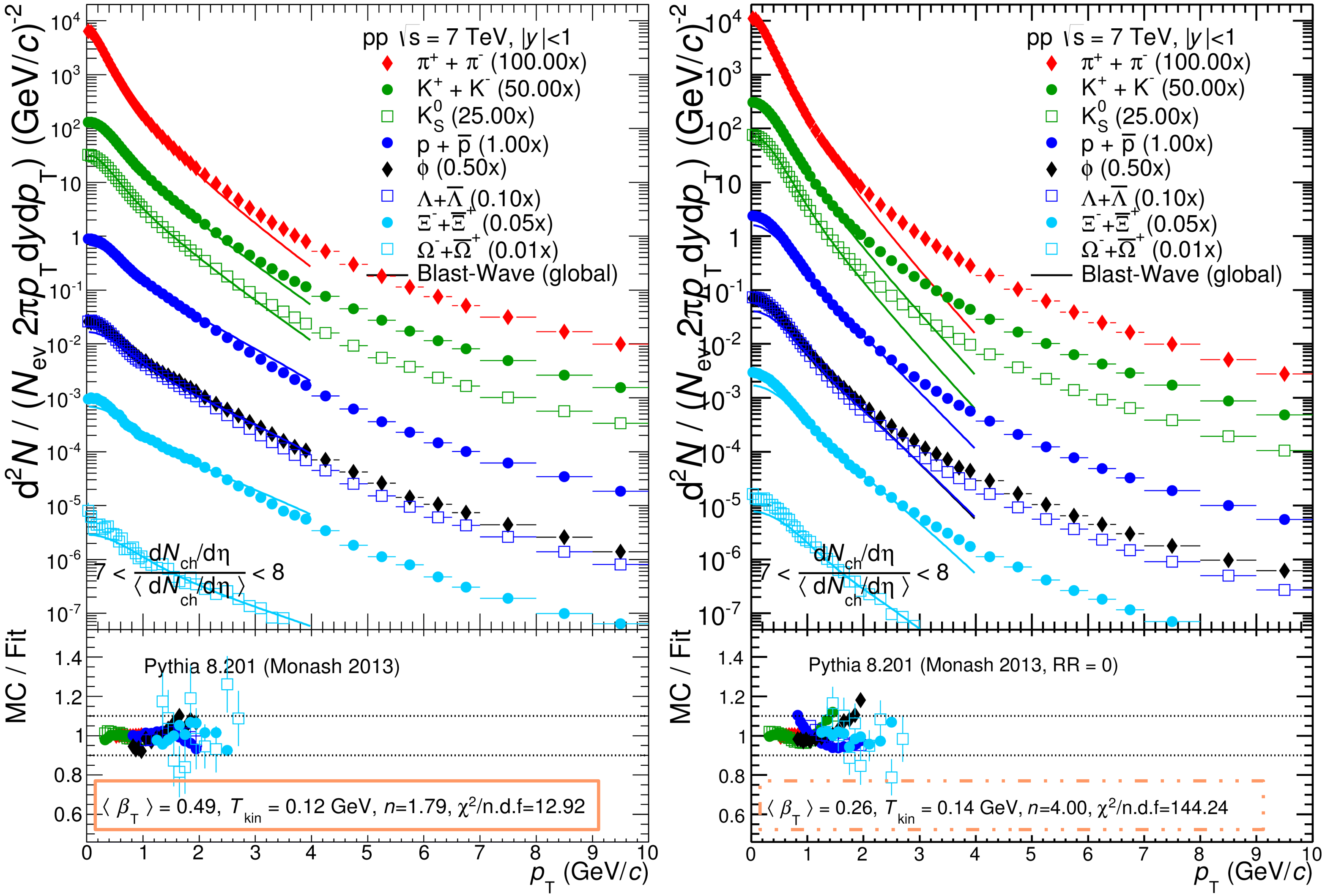
Spectra at high multiplicity



taken from Stefan Gieseke©

Simultaneous blast-wave fit to the pion, kaon and proton spectra. Within 10% the spectra are well desribed by the model when color reconnection is on.

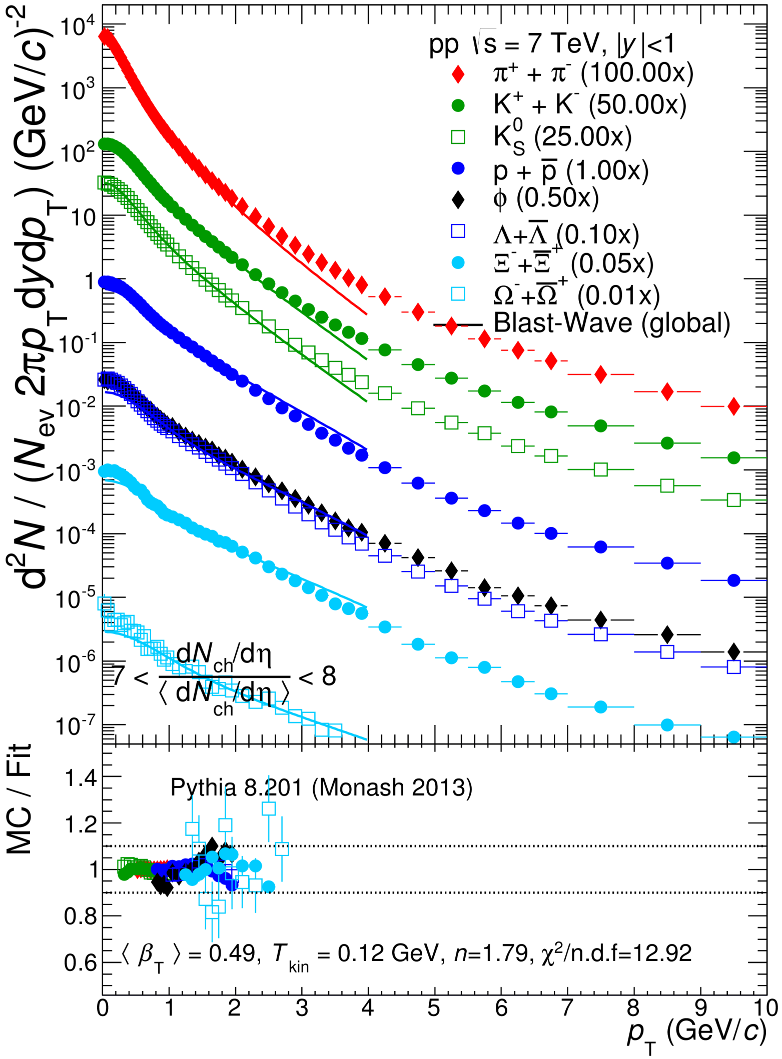
Spectra at high multiplicity



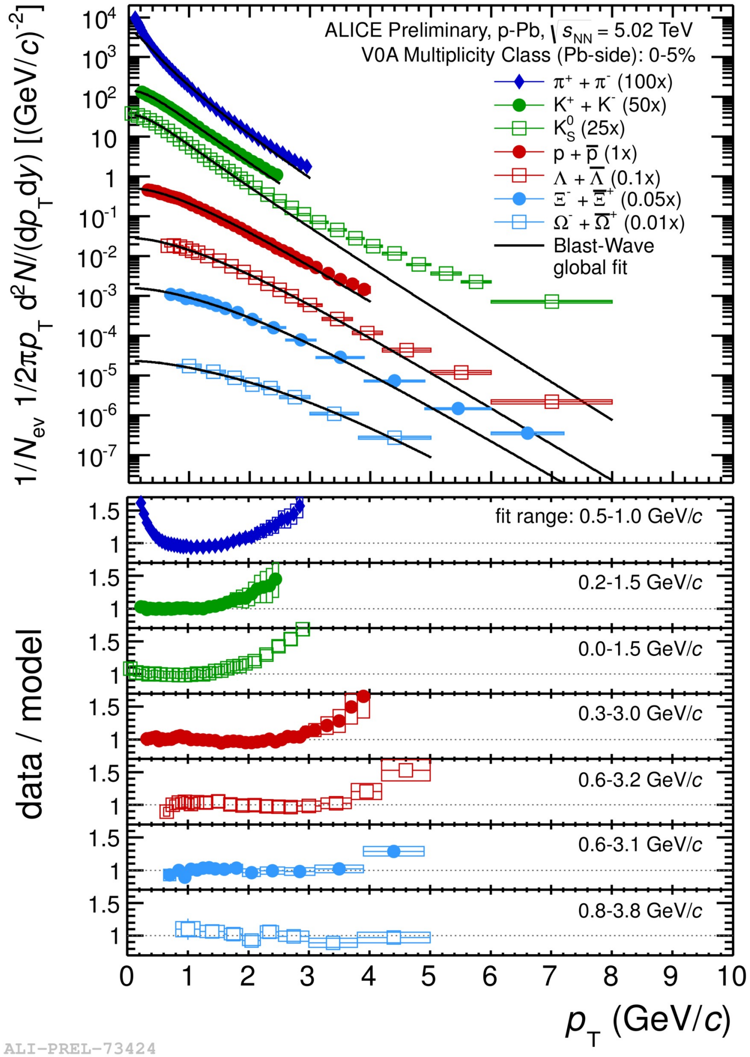
Same result when heavier hadrons are included.

Hydro model fitted to p_T spectra

MC, Pythia CR, pp



ALICE p-Pb data!



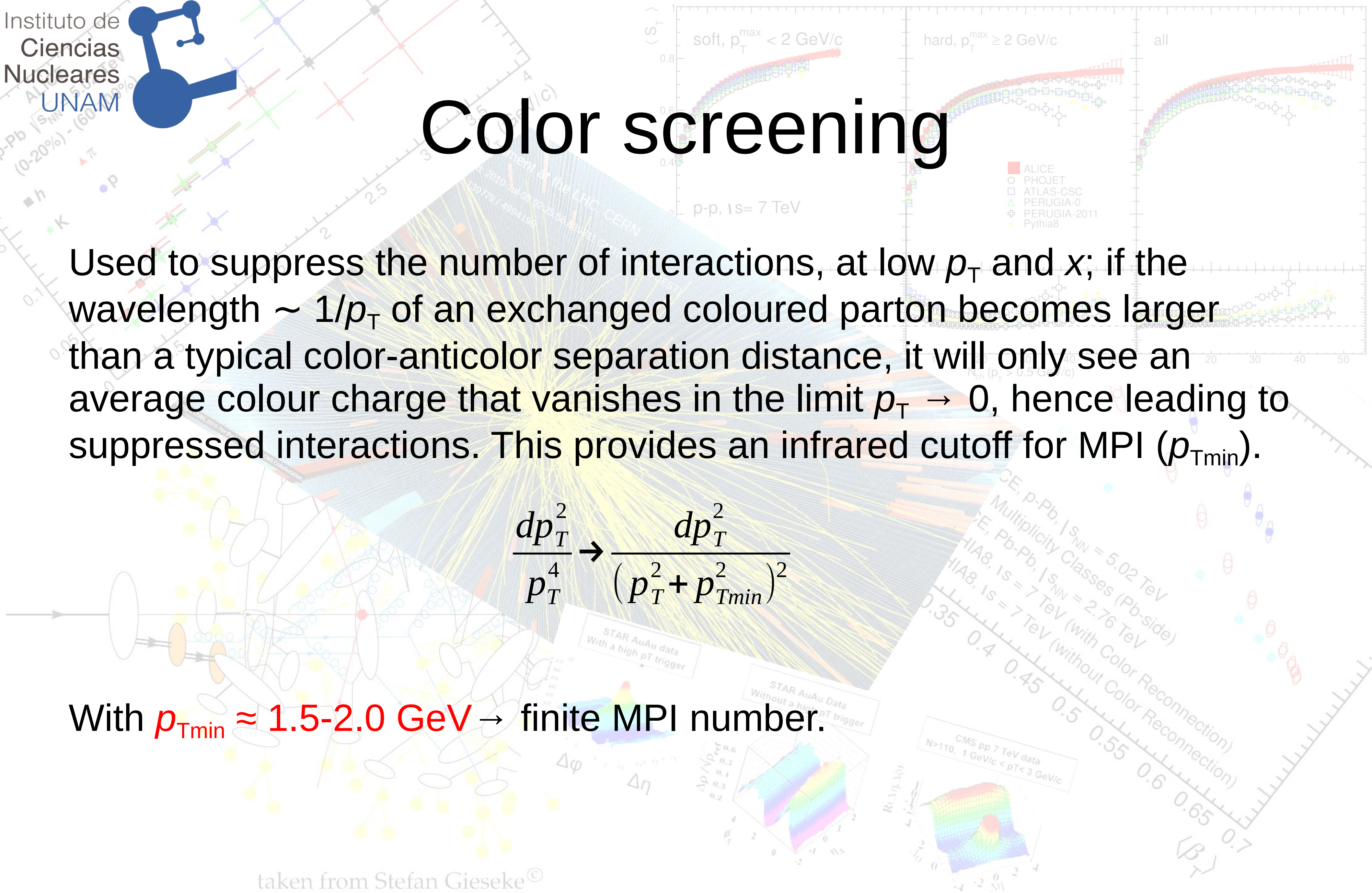
ALI-PREL-73424

Color screening

Used to suppress the number of interactions, at low p_T and x; if the wavelength ~ $1/p_T$ of an exchanged coloured parton becomes larger than a typical color-anticolor separation distance, it will only see an average colour charge that vanishes in the limit $p_T \rightarrow 0$, hence leading to suppressed interactions. This provides an infrared cutoff for MPI ($p_{T\min}$).

$$\frac{dp_T^2}{p_T^4} \rightarrow \frac{dp_T^2}{\left(p_T^2+p_{T\min}^2\right)^2}$$

With $p_{T\min} \approx 1.5\text{-}2.0$ GeV → finite MPI number.



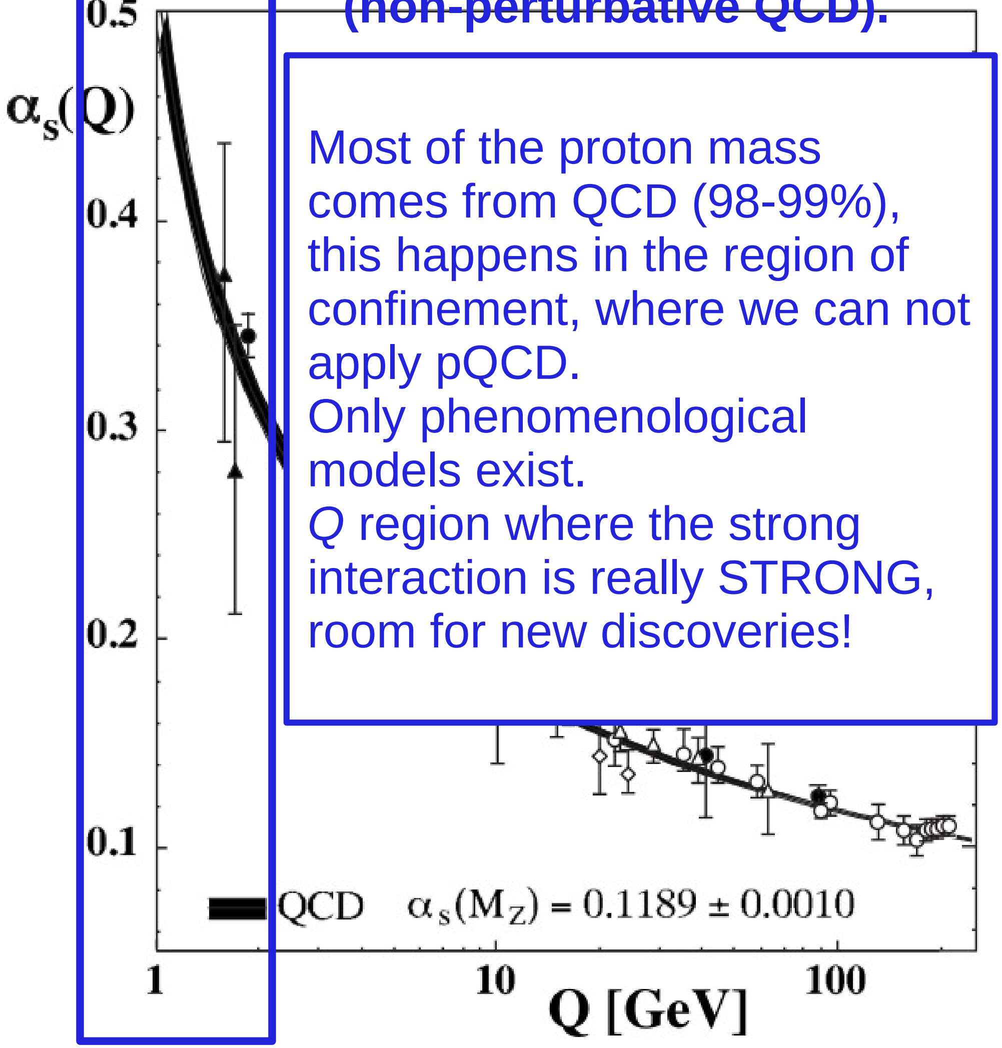
taken from Stefan Gieseke©

P. Skands, "Introduction to QCD," arXiv:1207.2389v4

Strenght of QCD interactions

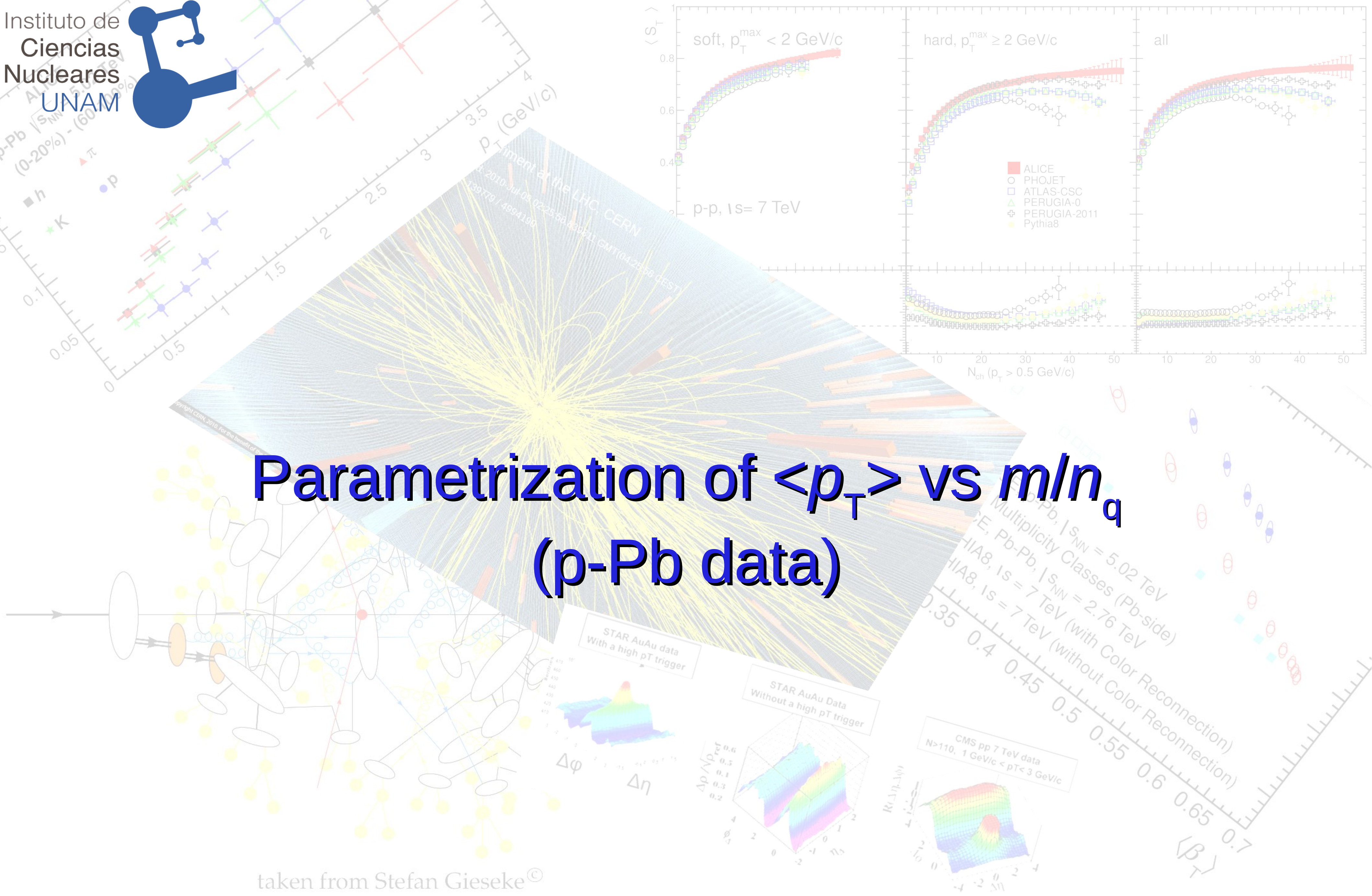
- In QCD, quarks and gluons are the elementary degrees of freedom.
- Quarks and gluons carry “color charge” as an additional quantum number.
- A pronounced variation (“running”) of the strong fine structure constant with (space-time) distance or momentum transfer *Q*.

taken from Stefan Gieseke©



Confinement (non-perturbative QCD).

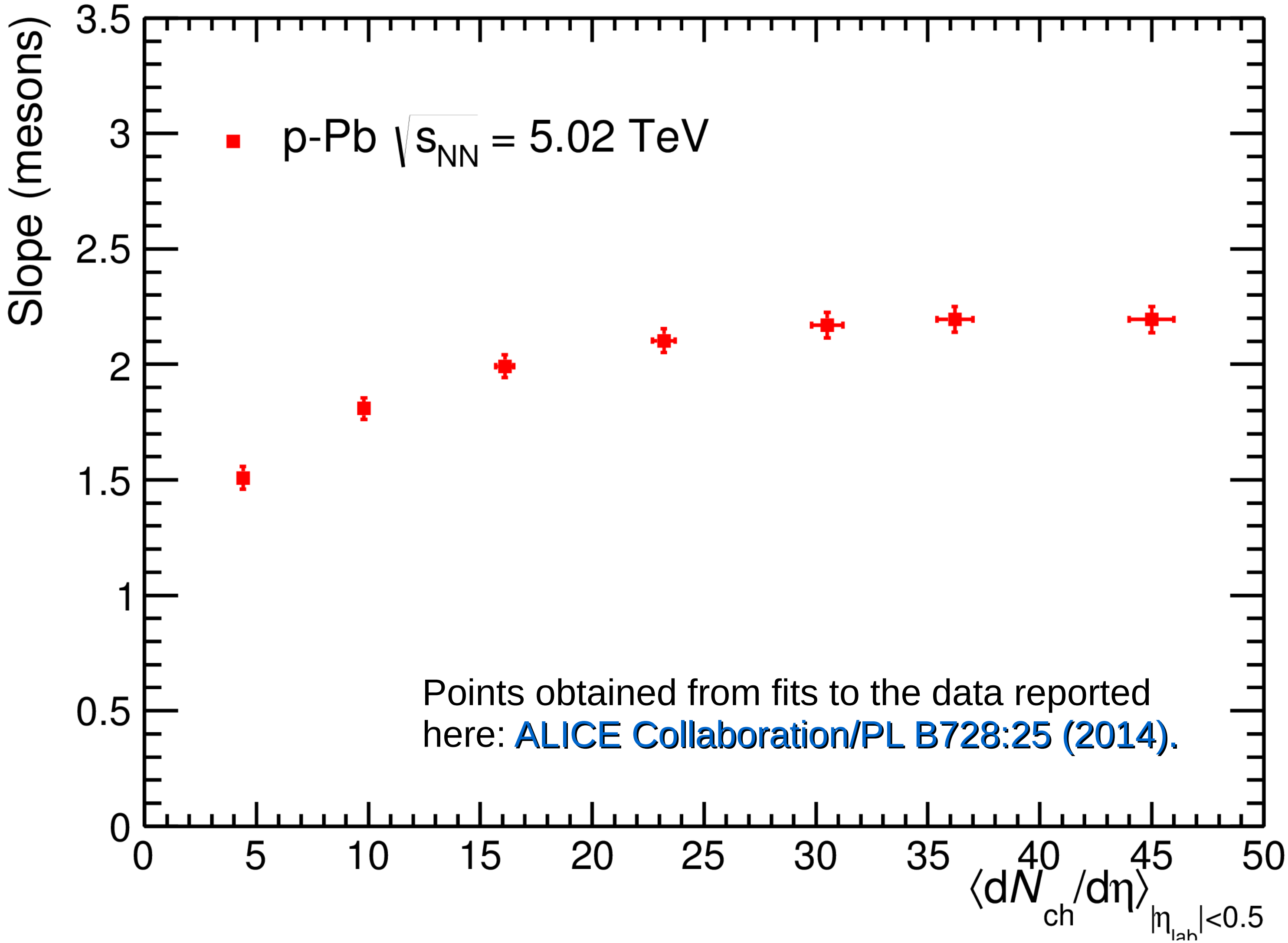
Most of the proton mass comes from QCD (98-99%), this happens in the region of confinement, where we can not apply pQCD.
Only phenomenological models exist.
Q region where the strong interaction is really STRONG, room for new discoveries!



Parametrization of $<p_T>$ vs m/n_q (p-Pb data)

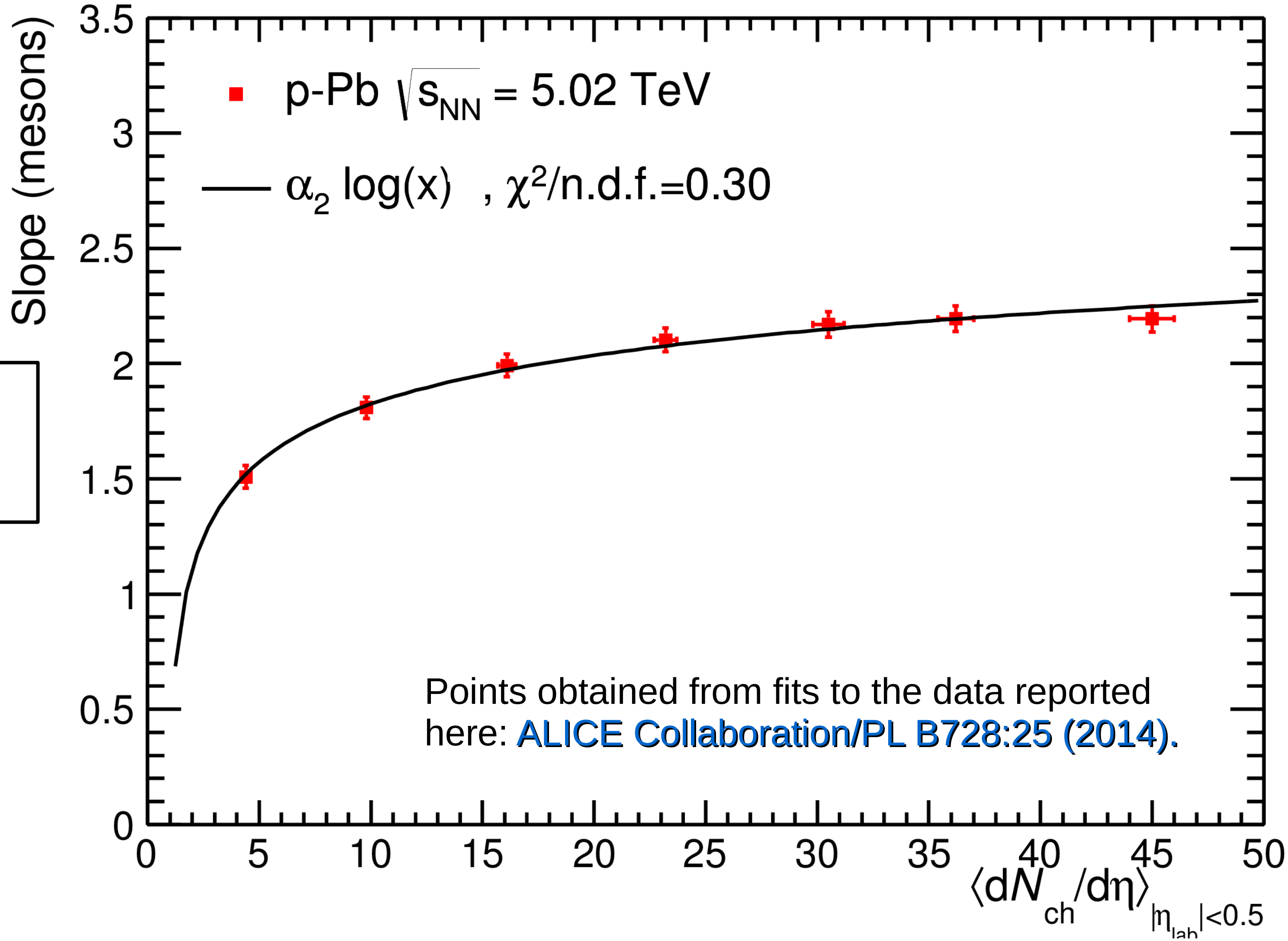
Slope vs N_{ch} (mesons)

The slope increases with the event multiplicity, then it shows a weaker rise.



Points obtained from fits to the data reported here: ALICE Collaboration/PL B728:25 (2014).

Slope vs N_{ch} (mesons)



Data are well described by a logarithmic function.

Points obtained from fits to the data reported here: ALICE Collaboration/PL B728:25 (2014).

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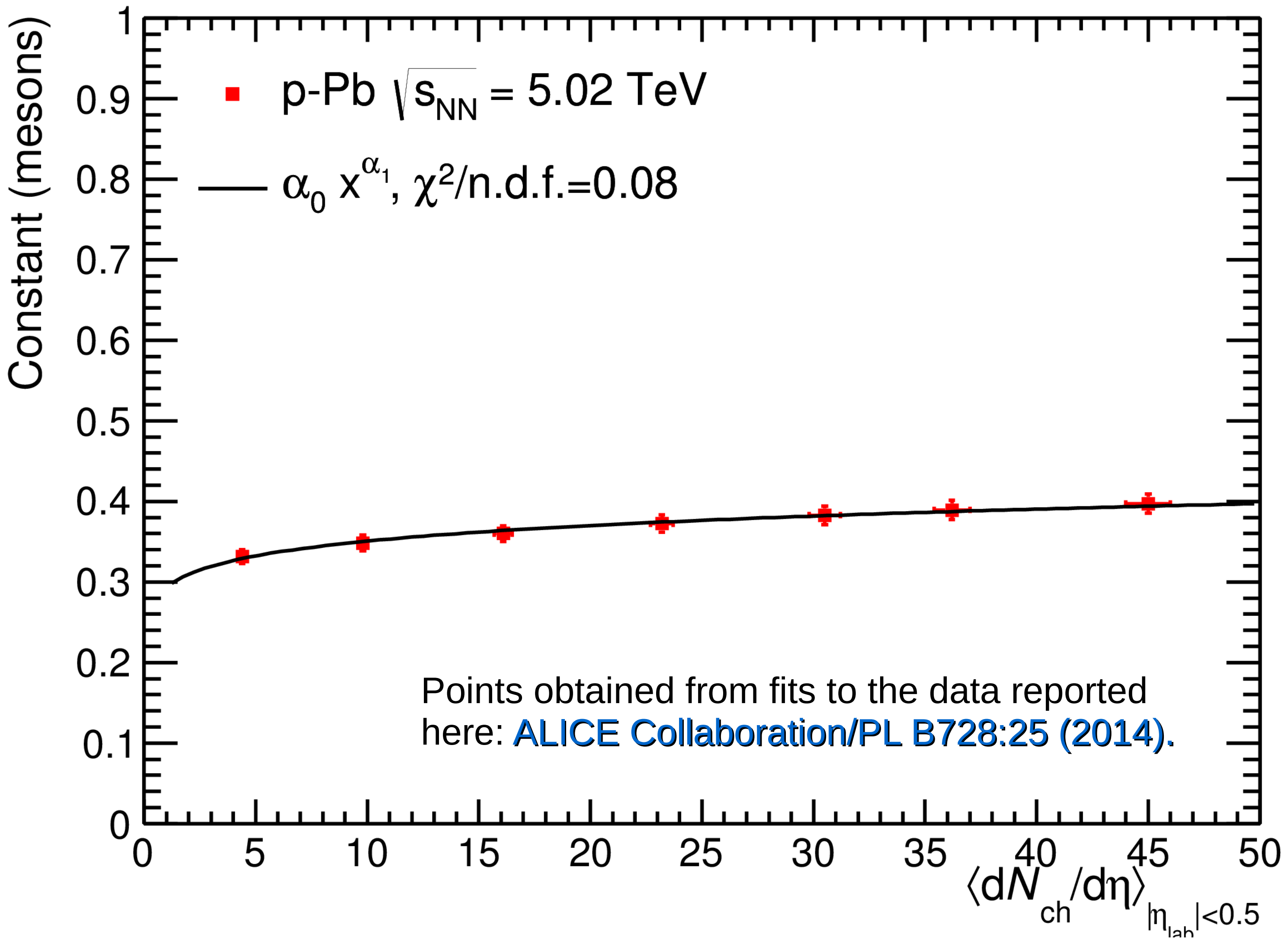
Constant vs N_{ch} (mesons)

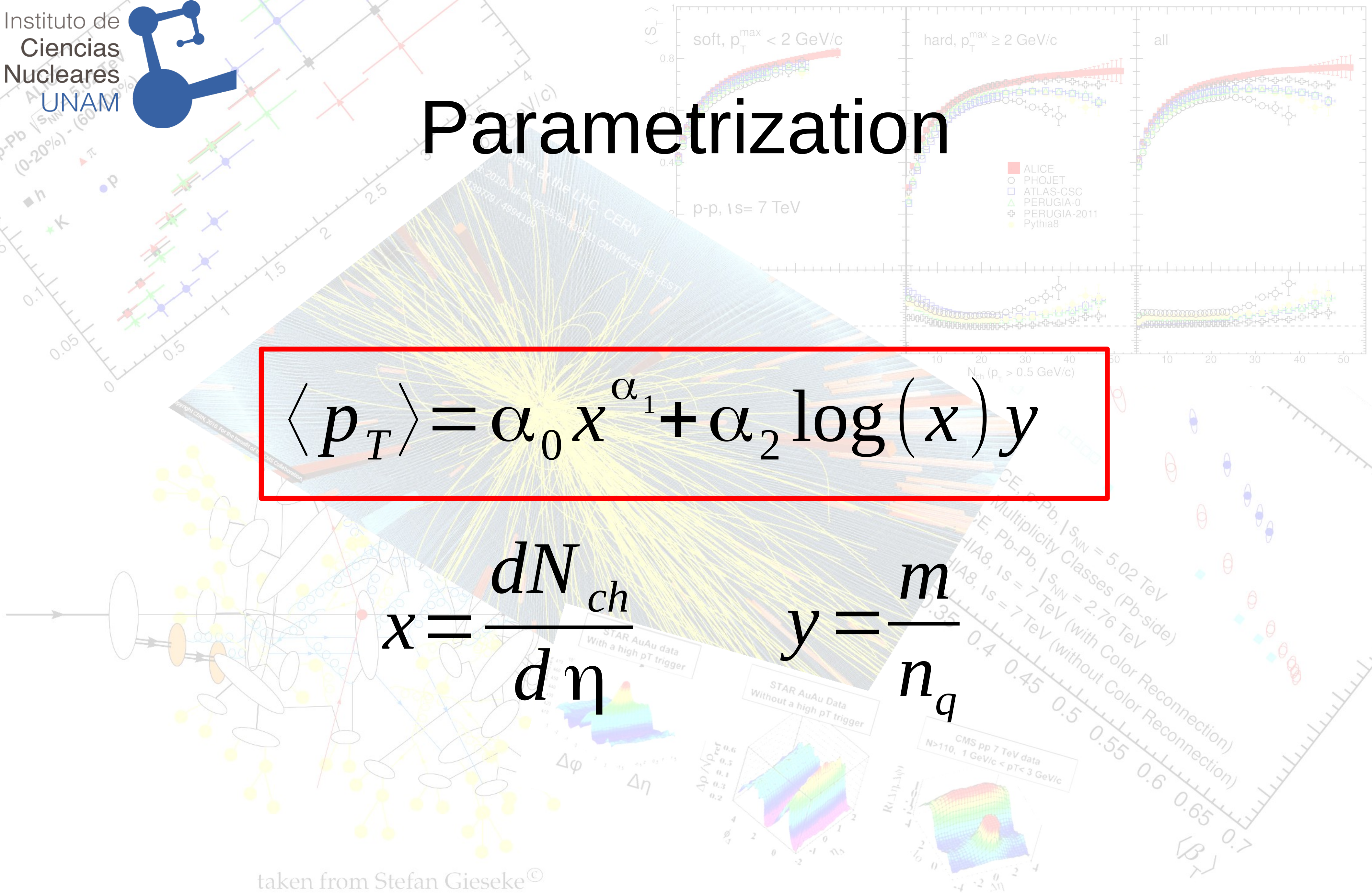


Points obtained from fits to the data reported here: ALICE Collaboration/PL B728:25 (2014).

The constant vs multiplicity can be described by a power law function.

taken from

Parametrization

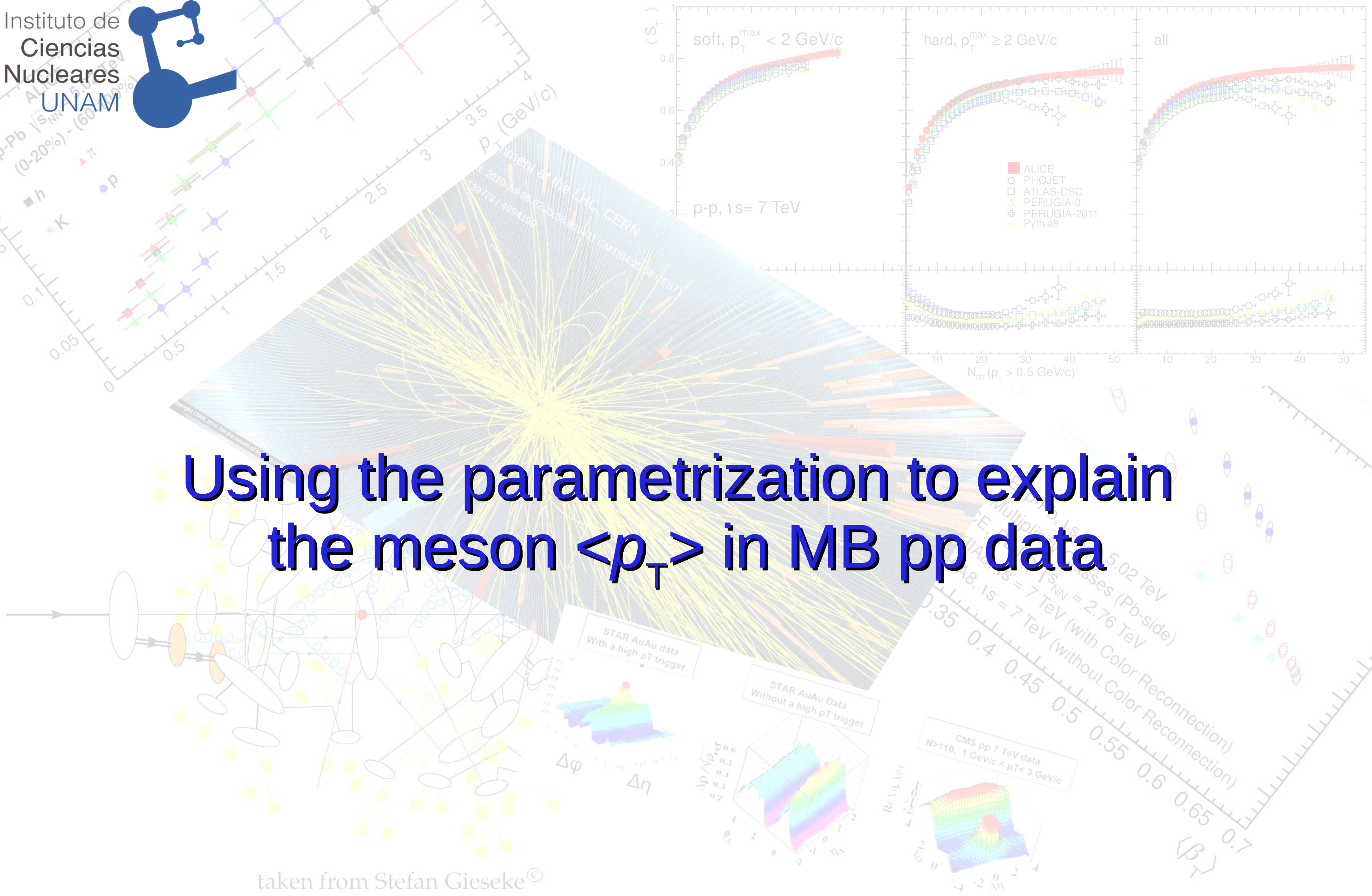


$$\boxed{\langle p_T\rangle = \alpha_0 x^{\alpha_1} + \alpha_2 \log(x)\, y}$$

$$x = \frac{dN_{ch}}{d\eta} \qquad y = \frac{m}{n_q}$$

taken from Stefan Gieseke©

Using the parametrization to explain the meson $<p_T>$ in MB pp data



taken from Stefan Gieseke©

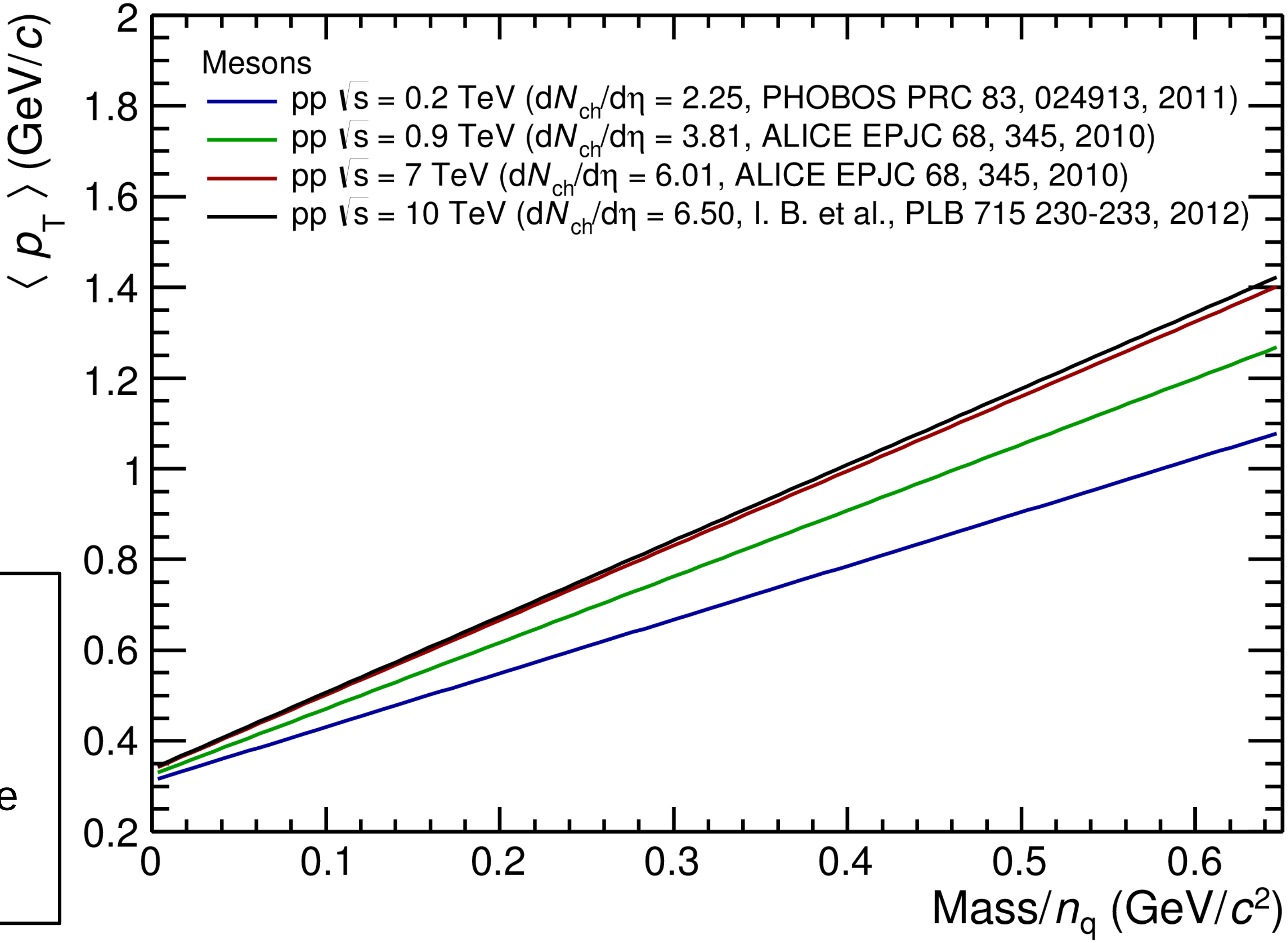
Instituto de Ciencias Nucleares UNAM

Evaluating $<p_T>$ at N_{ch} for MB pp

$$\langle p_T \rangle = \alpha_0 x^{\alpha_1} + \alpha_2 \log(x) y$$

$$x = \frac{dN_{ch}}{d\eta} \qquad y = \frac{m}{n_q}$$

A prediction for higher center-of-mass energy is included. Modest increase for pp at √s = 10 TeV, with respect to 7 TeV, due to the expected small multiplicity increase.

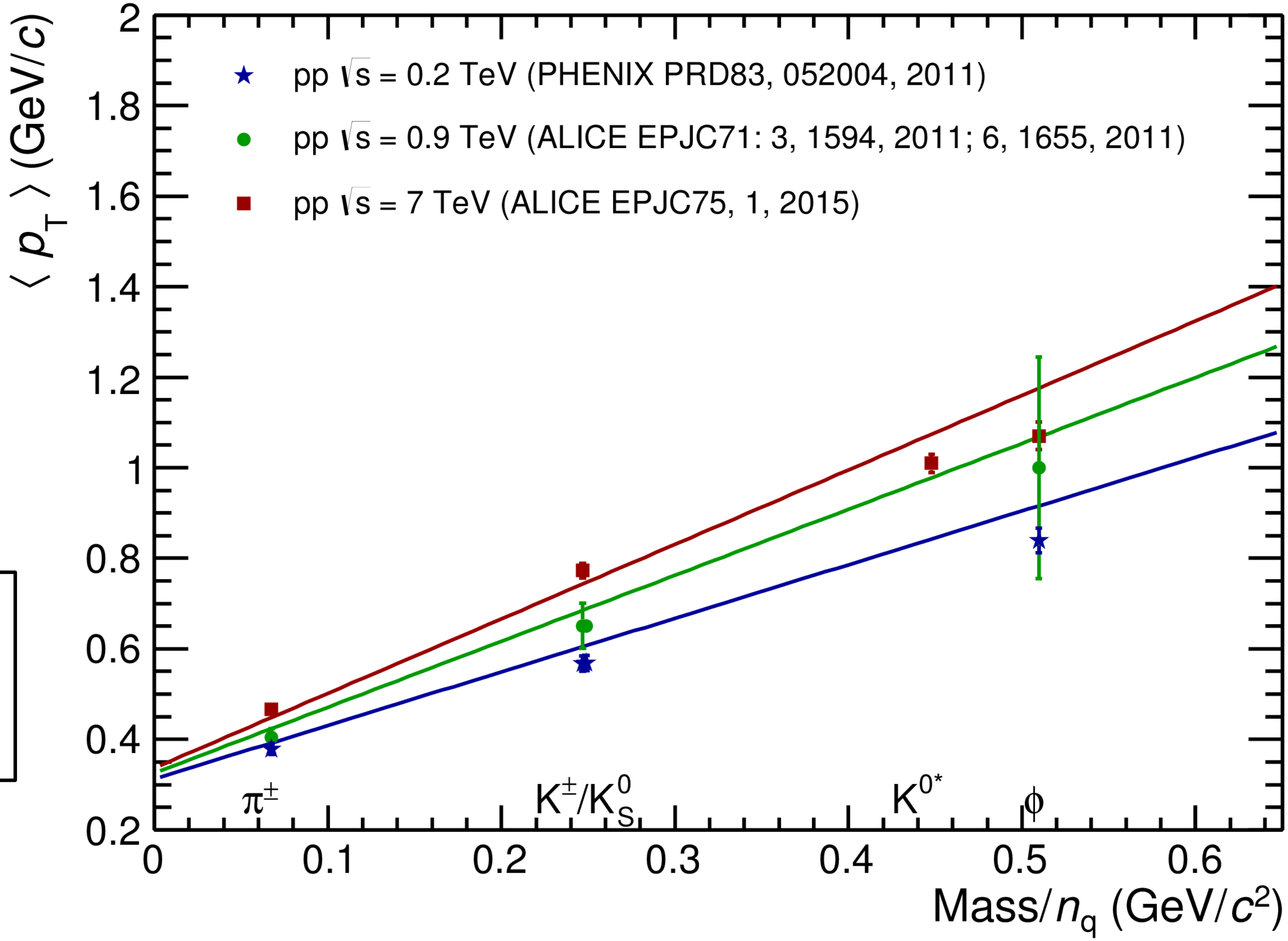


Comparison with data

$$\boxed{\langle p_T \rangle = \alpha_0 x^{\alpha_1} + \alpha_2 \log(x)\, y}$$

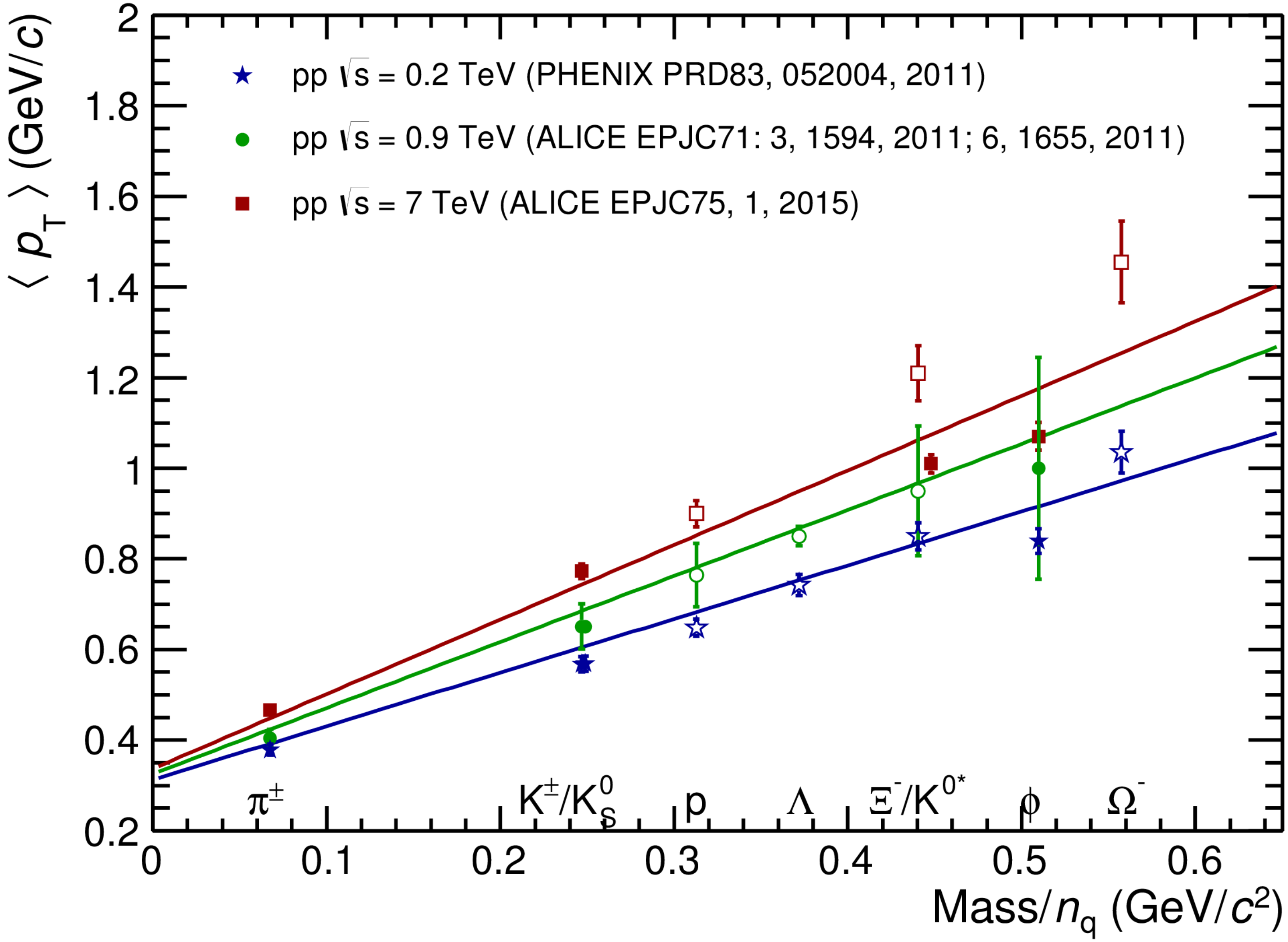
$$x = \frac{dN_{ch}}{d\eta} \qquad y = \frac{m}{n_q}$$

The multiplicity-based parametrization describes qualitatively well the behavior of data.



Adding baryons

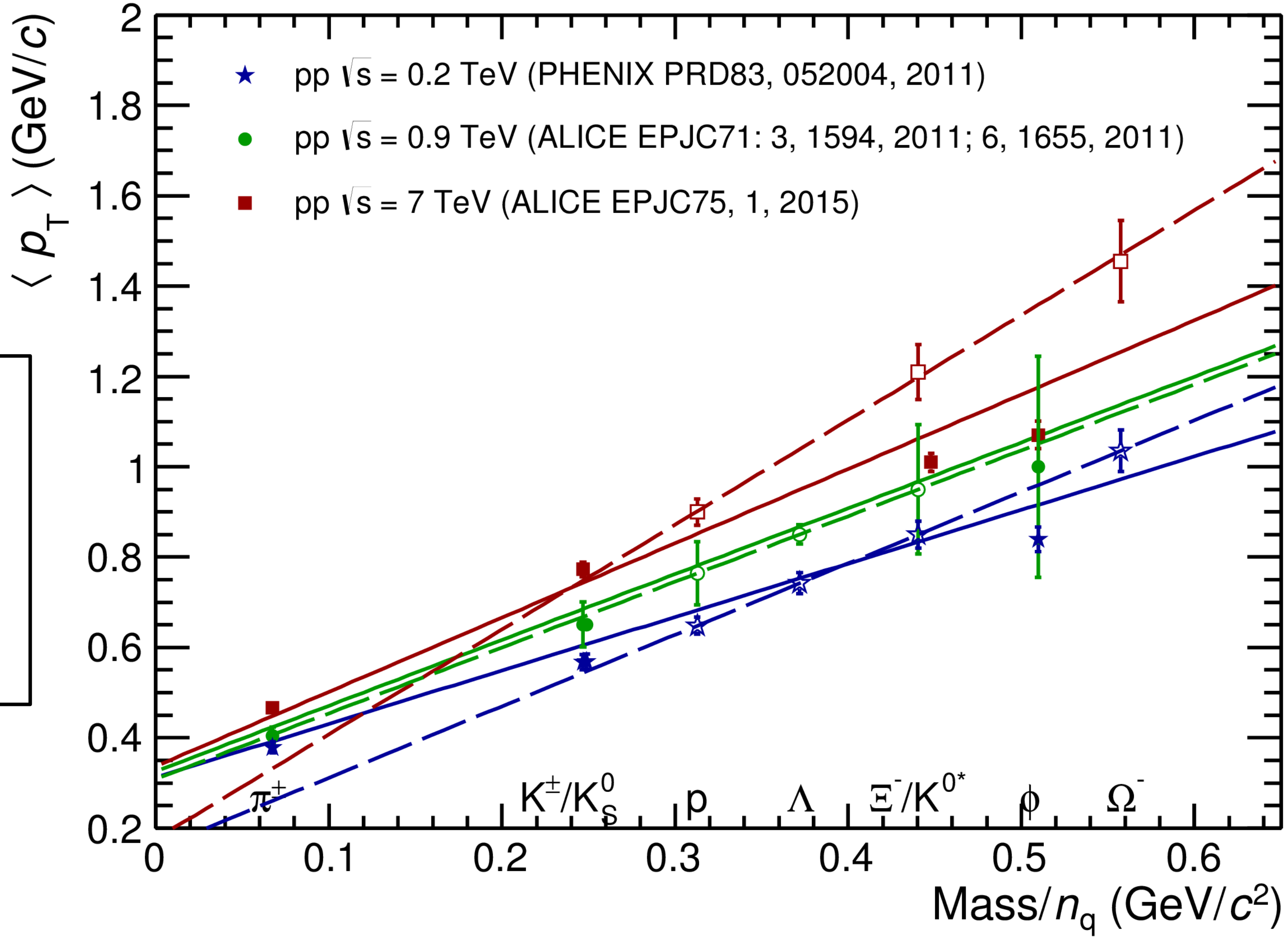
The large uncertainties on the baryon $<p_T>$ measured in p-Pb data do not allow to extract the parametrization. Here we only show the behavior of pp data.



taken from S

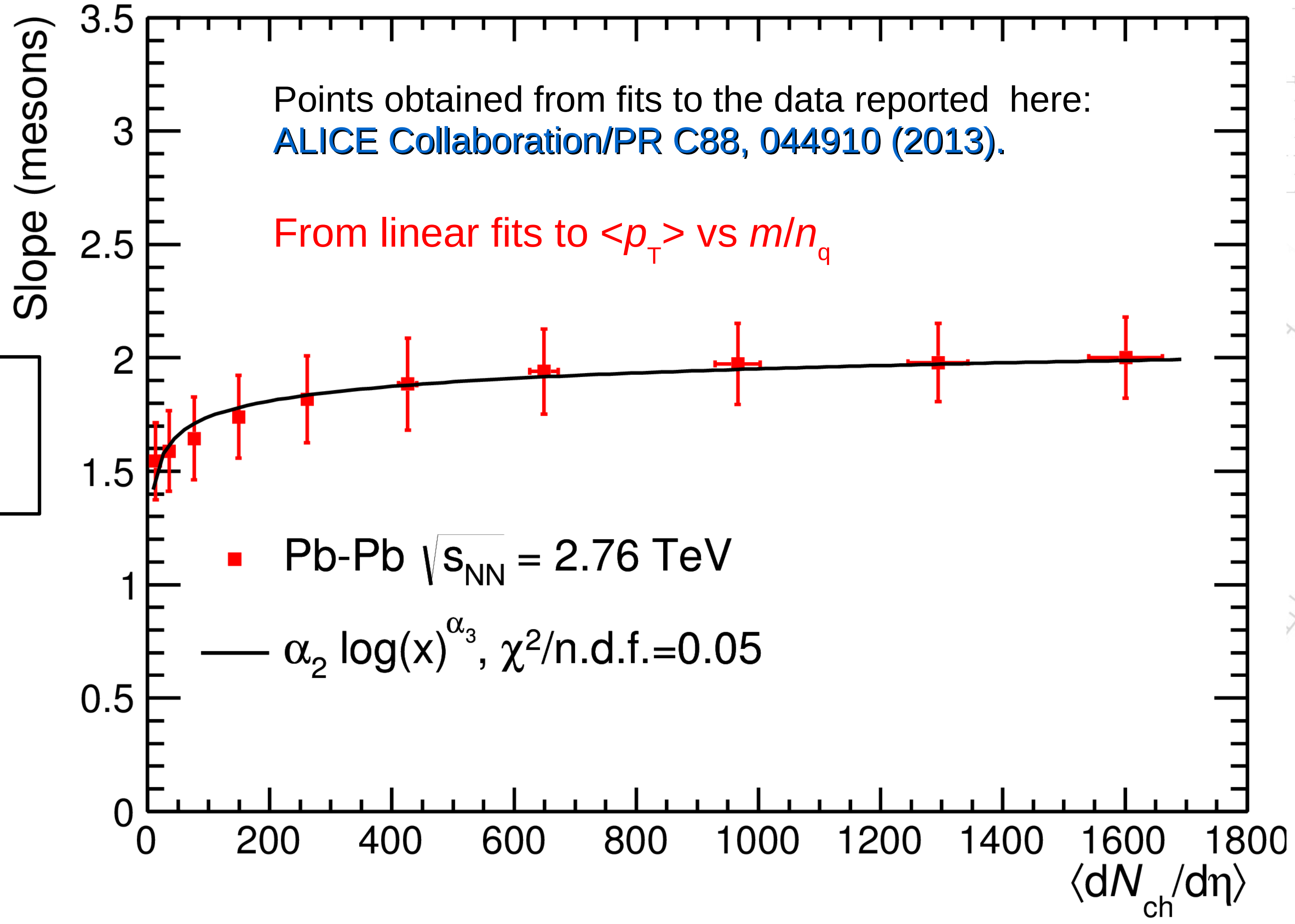
Adding baryons

As seen in low multiplicity p-Pb collisions, baryons are described by a linear function with a larger slope than the one obtained for mesons.



taken from S

Slope vs N_{ch} (mesons)



Points obtained from fits to the data reported here: ALICE Collaboration/PR C88, 044910 (2013).

From linear fits to $<p_T>$ vs m/n_q

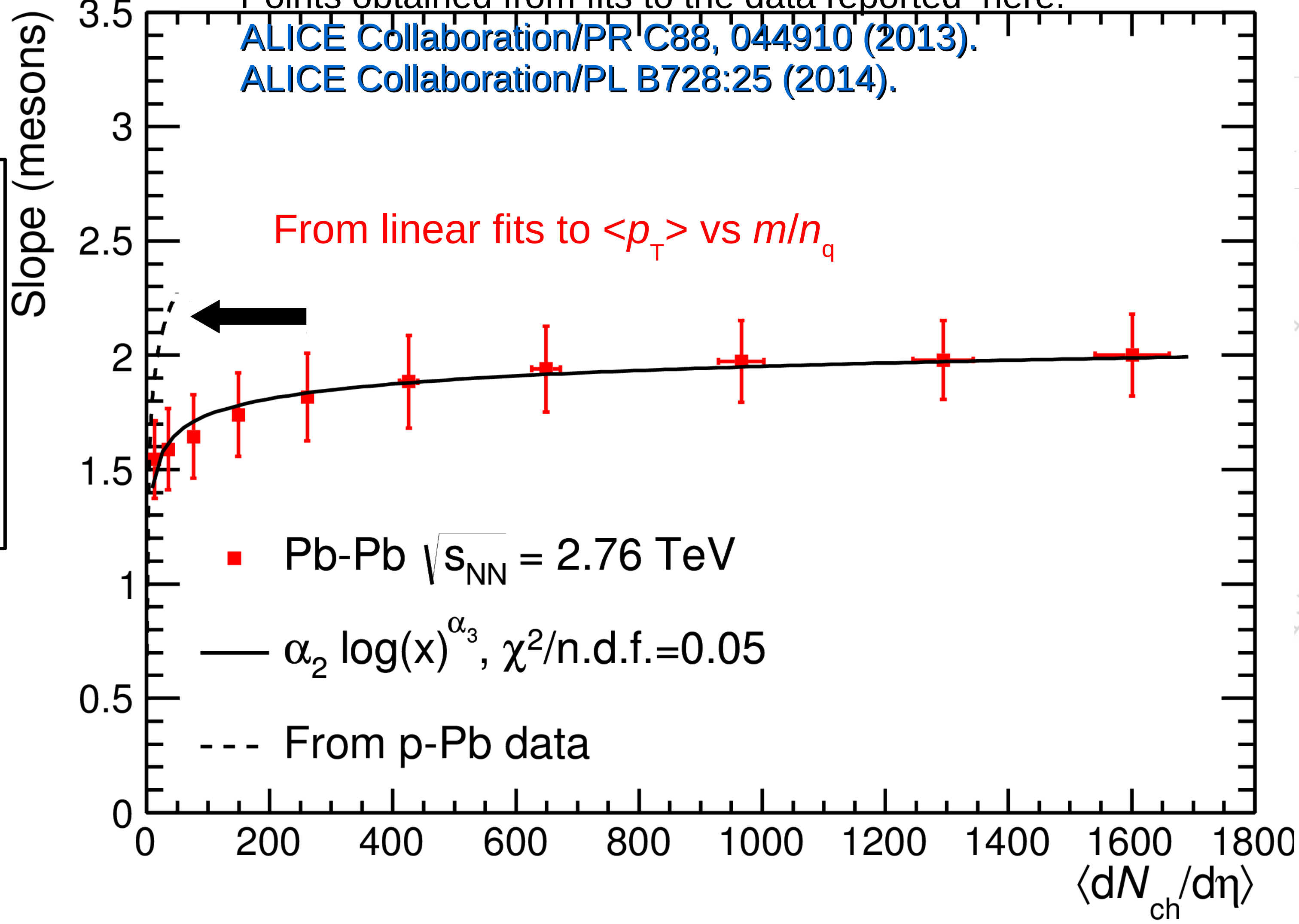
Data are well described by a logarithmic function.

Slope vs N_{ch} (mesons)

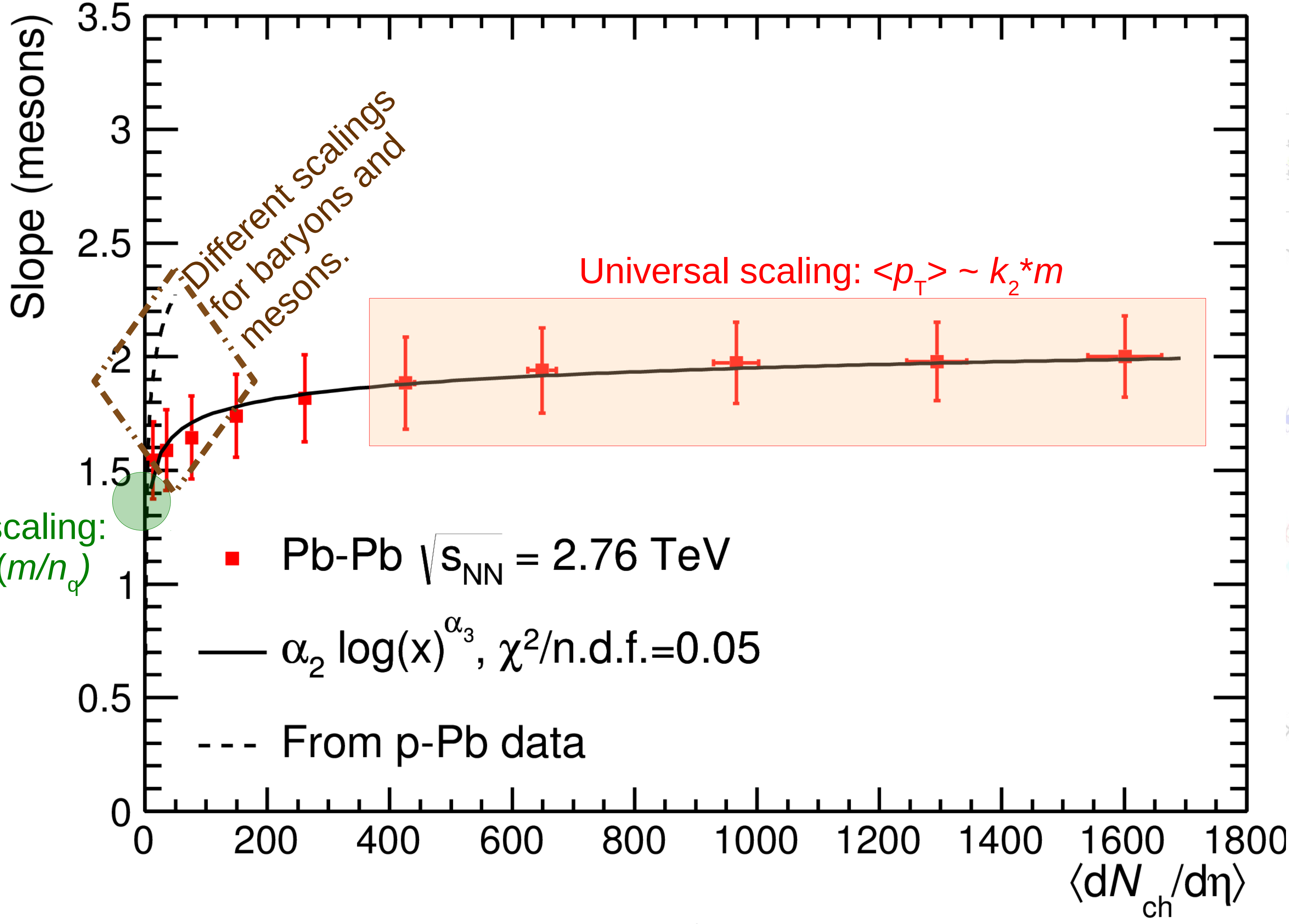
Points obtained from fits to the data reported here:
ALICE Collaboration/PR C88, 044910 (2013).
ALICE Collaboration/PL B728:25 (2014).

A larger slope is obtained for p-Pb data.

The Pb-Pb parametrization fails to reproduce the MB pp results.



Thanks!



Different scalings for baryons and mesons.

Universal scaling: $\langle p_T \rangle \sim k_2 {*} m$

Universal scaling: $\langle p_T \rangle \sim k_1 {*} (m/n_q)$