An alternative view on the recent pp results

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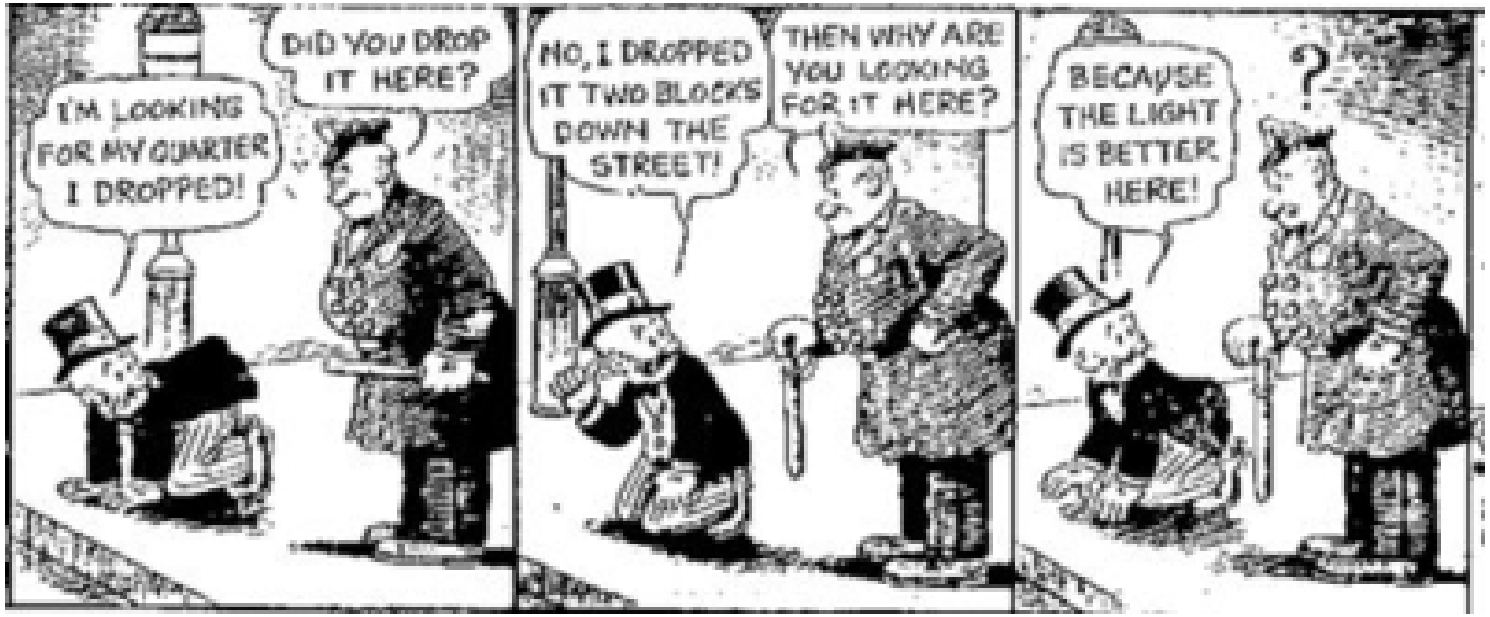
About the origin of the presentation

- It is product of a long chain of woks done, mainly, in the ICN with a number of collaborators:
- A.Ayala, E. Cuautle, A. Ortiz, E. Perez, S. Iga, H.Bello, Y. Maldonado,R. Jimenez, A. Mishra, G. Bencedi and others
- ICN has developed strong presence in the analysis of pp data of ALICE

....a warning!

- From a former student in his tesis
- Al Dr. Guy Paic. Por su manera muy particular de pensar las cosas, es difícil seguir su forma de pensar, lleva tiempo digerir y desenredar lo que tiene en mente, al final, después de pensarlo un rato(a veces un par de semanas), logras entender y te das cuenta que ¡siempre hay una buena idea detrás!
- sometimes it takes much longer !!!
  - The continental drift ideas were known in the 20s but In 1958, Hapgood published *The Earth's Shifting Crust*. It denied the existence of continental drift, an idea that was not supported by mainstream science for another decade. The book included a foreword by Albert Einstein.

Trying to avoid the Streetlight effect



Low pt, azimuthal anisotropies , flow, etc

Introductory comments

- I will not discuss the widely commented features of similarities of pp and heavy ion collisions
- I will present less known, less commented features pondered to my personal view
- I will not limit myself to “official” ALICE figures because I see that there are many interesting results “buried” in theses and other contributions
- I thank specially the discussions I had with M. Petrovici, A. Mishra, G.Barnafoldi and A. Ortiz who had the patience to listen to my “heretical” views and help me forge the present presentation. The conclusions are my sole responsibility!

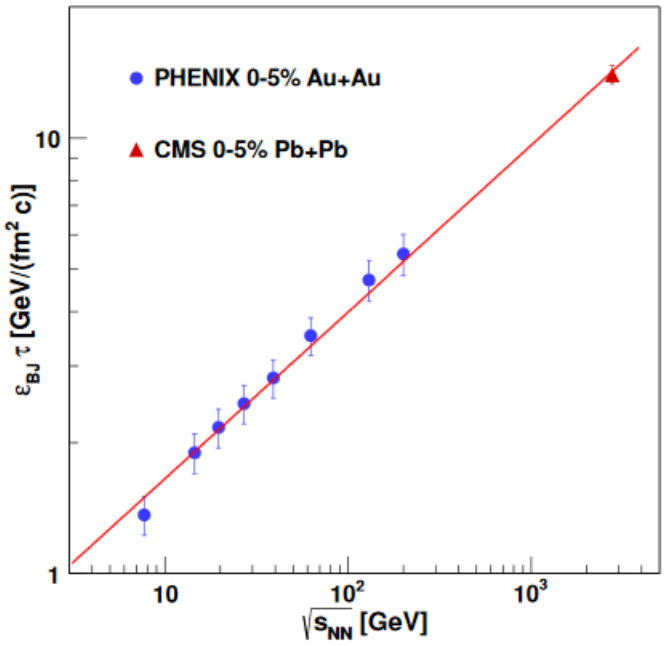
From https://home.cern/science/physics/heavy-ions-and-quark-gluon-plasma

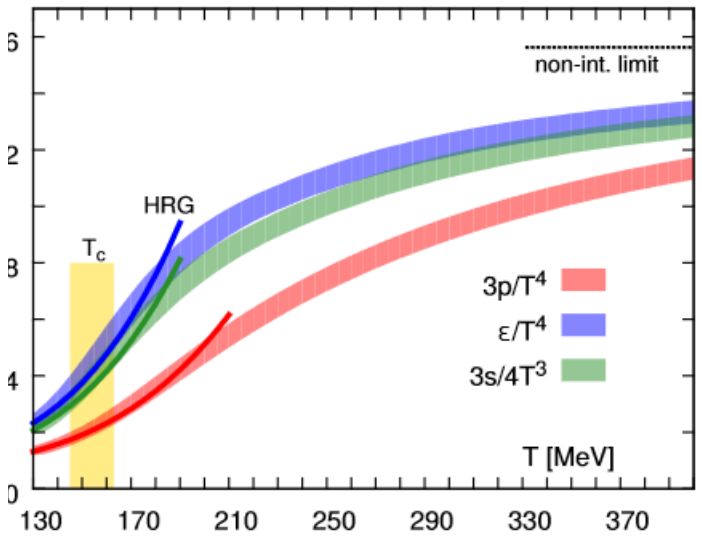
- Recently the ALICE, ATLAS and CMS experiments at CERN's Large Hadron Collider (LHC) have confirmed the phenomenon of jet quenching in heavy-ion collisions. The much greater collision energies at the LHC push measurements to much higher jet energies than are accessible at RHIC, allowing new and more detailed characterization of the quark-gluon plasma. **Theoretical understanding of these measurements is challenging, however, and is one of the most important problems in quantum chromodynamics today**.

What is our core businness

- Quark–gluon plasma (QGP) is a new state of nuclear matter existing at extremely high temperatures and densities when composite states called hadrons (protons, neutrons, pions, etc.) lose their identity. This is due to the so called
- Asymptotic freedom
- at sufficiently high nuclear density or temperature, the average inter-parton distance becomes small, and therefore their interaction strength weakens. Above a critical energy density, of the order of 0.3 GeV/fm3, a gas of hadrons undergoes a deconfinement transition and becomes a system of unbounded quarks and gluons, the so-called quark-gluon plasma (QGP). dissolve into a soup of their constituents—quarks and gluons.

The prediction from LQCD need to be confirmed!





The importance of energy density in pp has now 20 years!

Day one Proton Proton Physics with the ALICE central detector

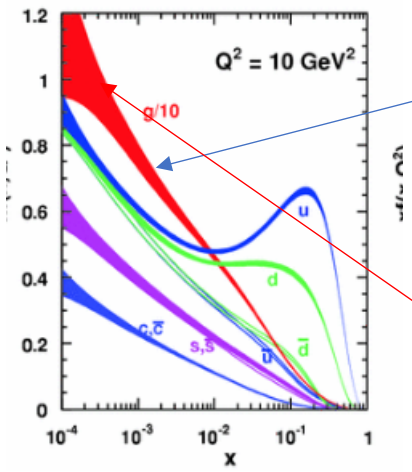
P. Giubellino, S. Kiselev, W. Klempt, A. Morsch, G. Paic, J.P. Revol and K. Safarik, ALICE 2000-28, Internal Note / PHY, 24 November 2000.)

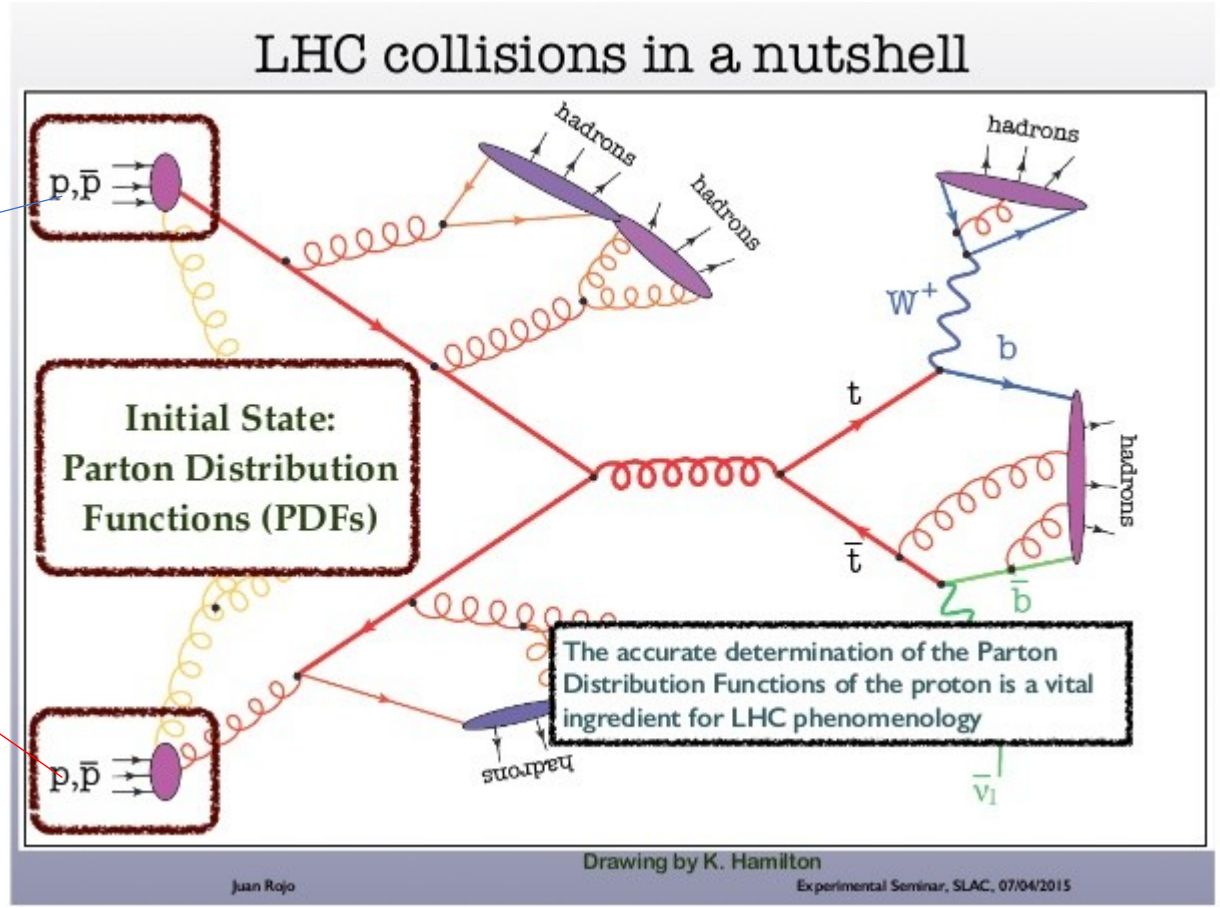
study pp collisions under conditions where they might reach energy densities in excess of what is achieved today in Heavy-Ion (HI) collisions at SPS and comparable to those expected at RHIC. Therefore, the pp data present a considerable interest for the study of the evolution of high energy densities (up to 10 GeV/fm^3) under conditions of small volumes (5 fm^3). Also, these data will be useful to check the nucleon-nucleon predictions of the event generators used in the HI simulation codes. For this particular check, and also for next item, some data taken at the same nucleon-nucleon energy as in HI collisions, i.e. at $\sqrt{s} = 5.5$ TeV, would be very useful;

confirmed! Bjorken energy density in high multiplicity pp collisions at 7 TeV is rather similar with the value in

central Pb-Pb collision at 2.76 TeV

What are we colliding (very simplified)



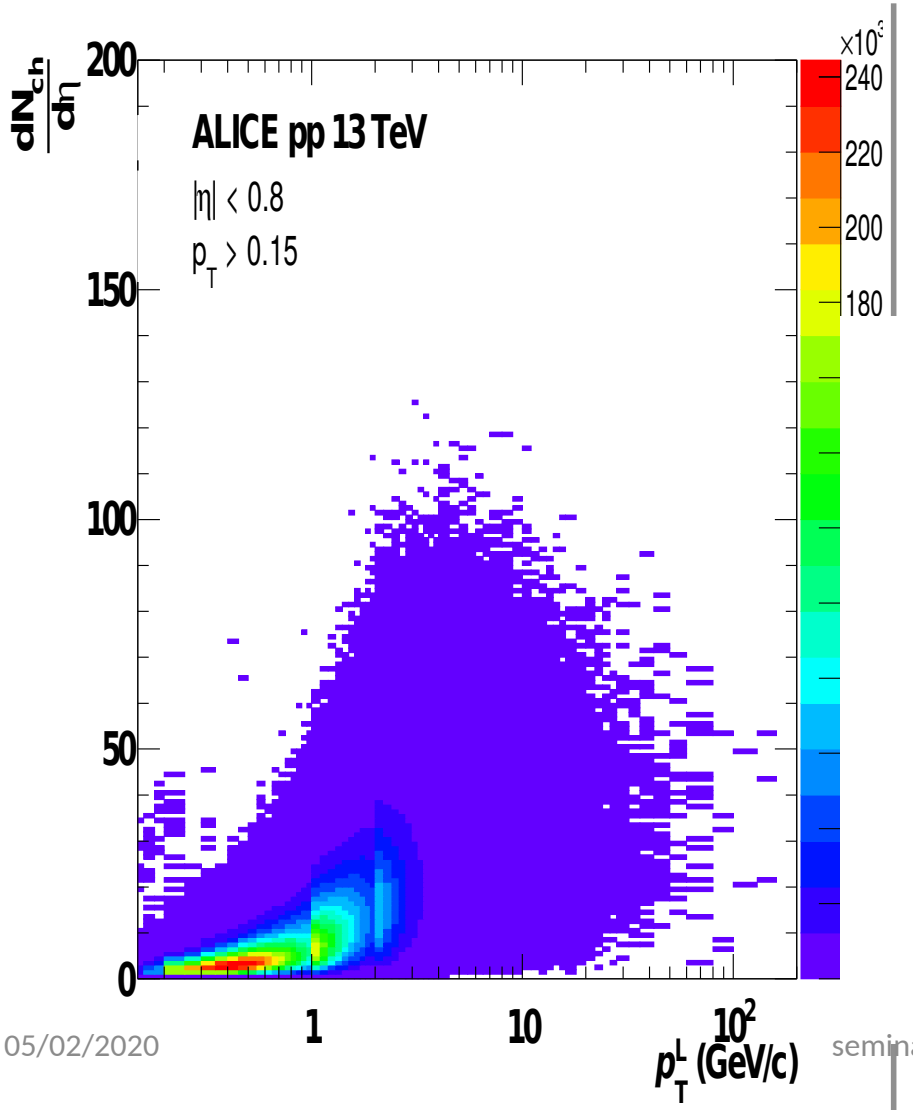


surprise I

- More partons that collide – more probability to get two high pt gluons to collide --✉high p tate?

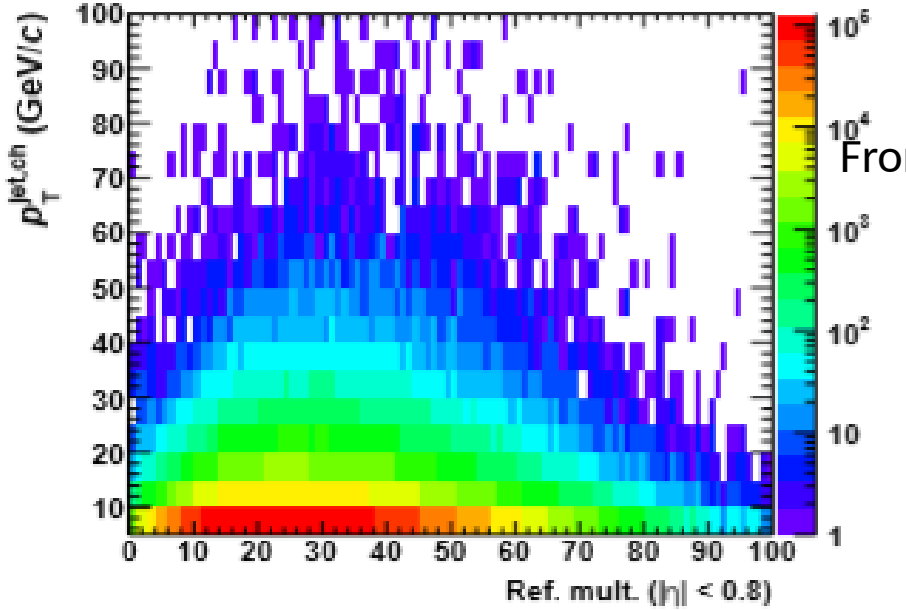
- It not exactly so!

The production of high multiplicities in pp:integral views



The highest multiplicities do not yield the maximum leading pt!

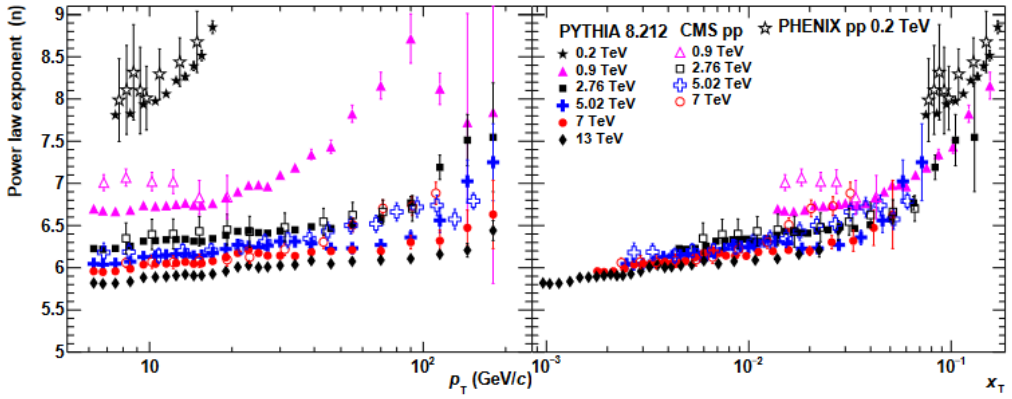
Around multiplicities 40 -60 we observe in the transverse region very strong enhancements of the transverse region pt spectra



From b.hess thesis

ALICE has shown a key feature of transverse momentum spectra in pp and PbPb collisions

- **The slope of the spectra in pp and PbPb collisions diminish with multiplicity up to high momenta (>100 GeV/c)– no theoretical explanation – although Pythia reproduces the trends fairly well.**



The shape of the spectra is pt dependent!

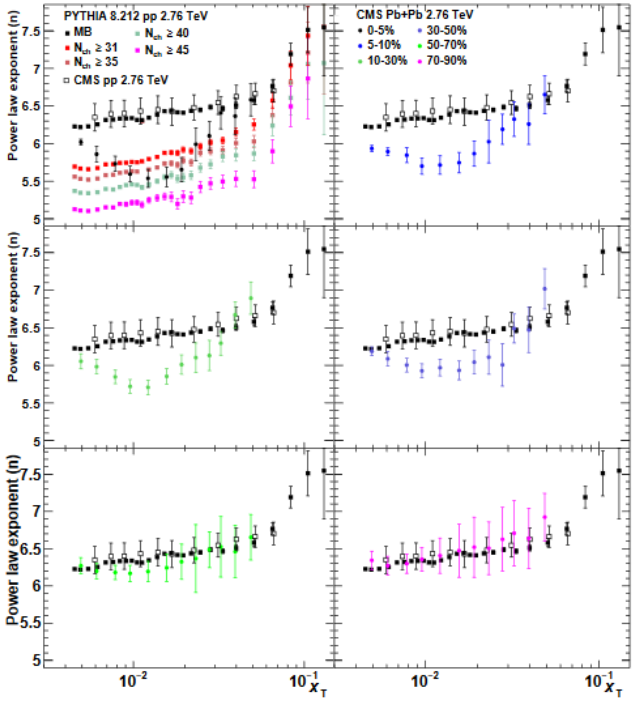


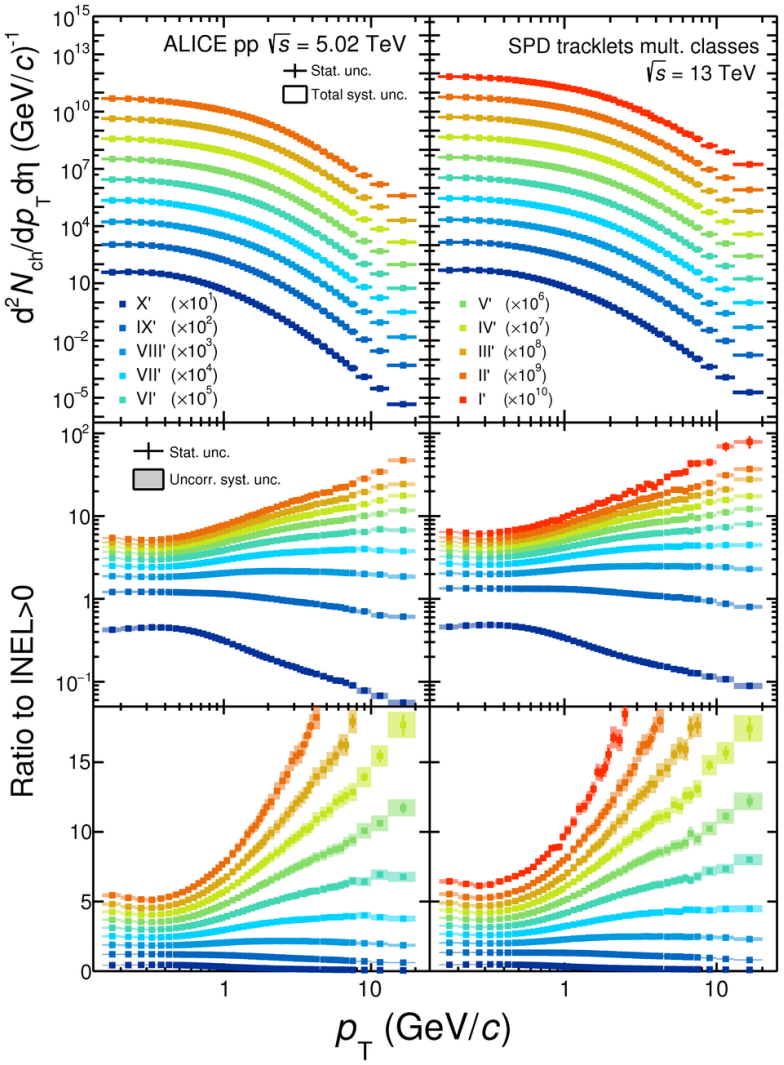
Figure 4: Upper left: Power-law exponent as a function of x_T for central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Heavy-ion data [39] are compared with minimum-bias (MB) CMS data for pp collisions [35] and high multiplicity ($|\eta| < 0.8$) pp collisions at $\sqrt{s} = 2.76$ TeV simulated with PYTHIA 8.212. Other panels show the centrality dependent power-law exponents of Pb-Pb collisions as a function of x_T compared with results from MB pp collisions.

Beautiful and unexpected

Strong rise of the slopes of the pp spectra with multiplicity!

S. Acharya et al.
Eur. Phys. J. C 79 857 (2019)

A similar analysis of the spectra should be done fo the heavy flavors and strange baryon

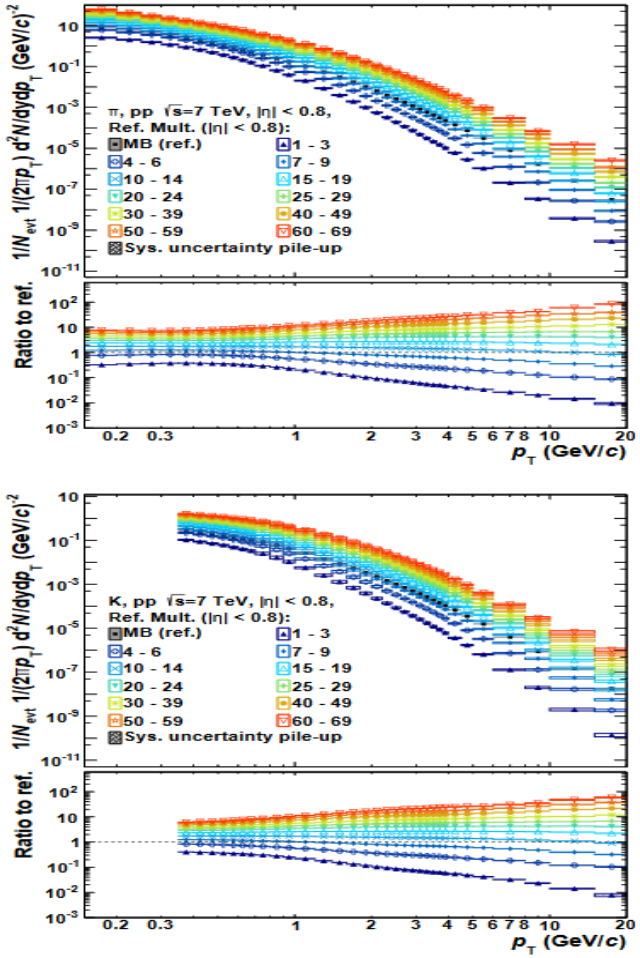


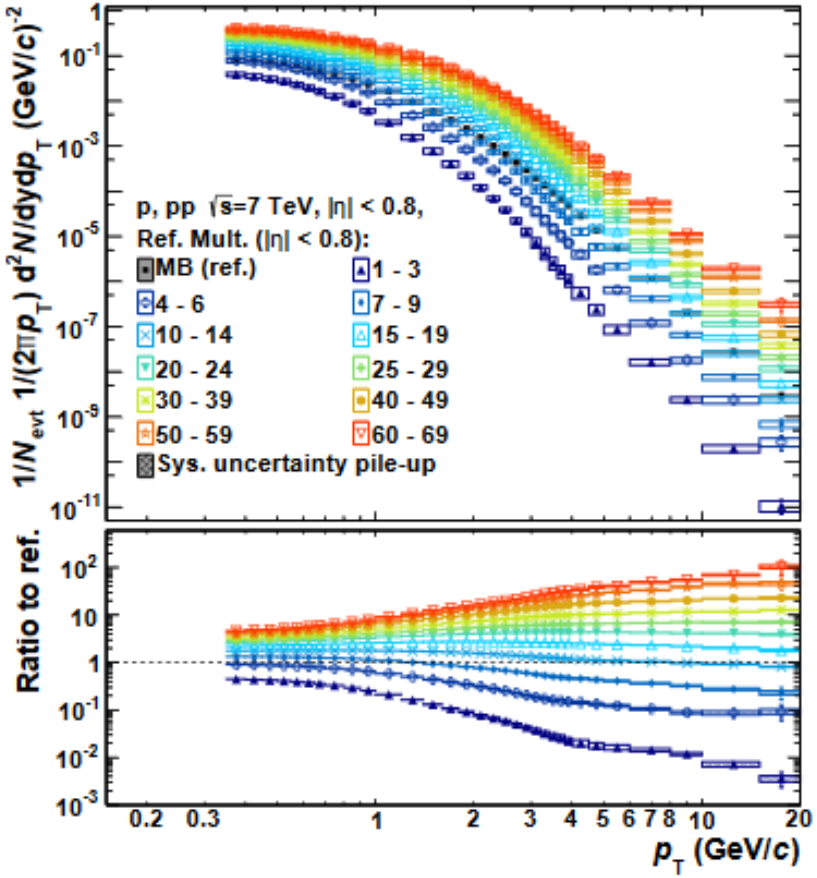
We do also have identified spectra to 20 GeV!

http://inspirehep.net/record/1429564
Benjamin Hess thesis

In the pt range of <20 GeV/c for the highest multiplicity the ratio of proton spectra at 20 GeV/c is >100 to the MB case
Note that the log scale hide the dramatic increase!

To be done: the famous VOM vs central estimator?!
Finalize the analysis





And now for the comparison with PbPb

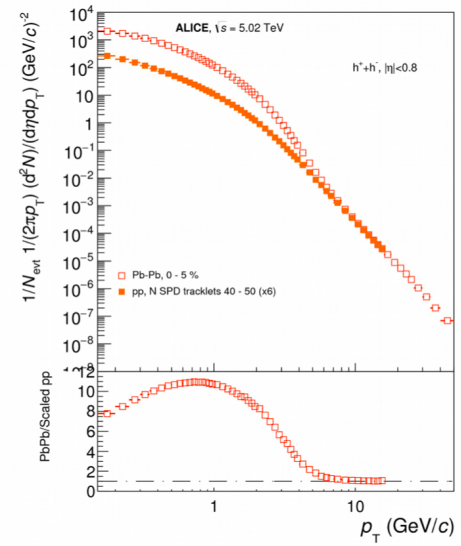
- **The key question: what would be the effect on the shape of the spectra in case of energy loss, in function of the transverse momentum?**

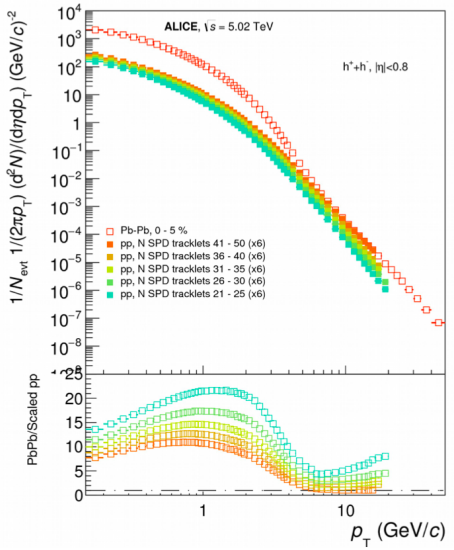
The high pt spectra of PbPb and pp behave in the same way!

For every PBPB spectrum one can find a pp multiplicity with equal high pt behaviour

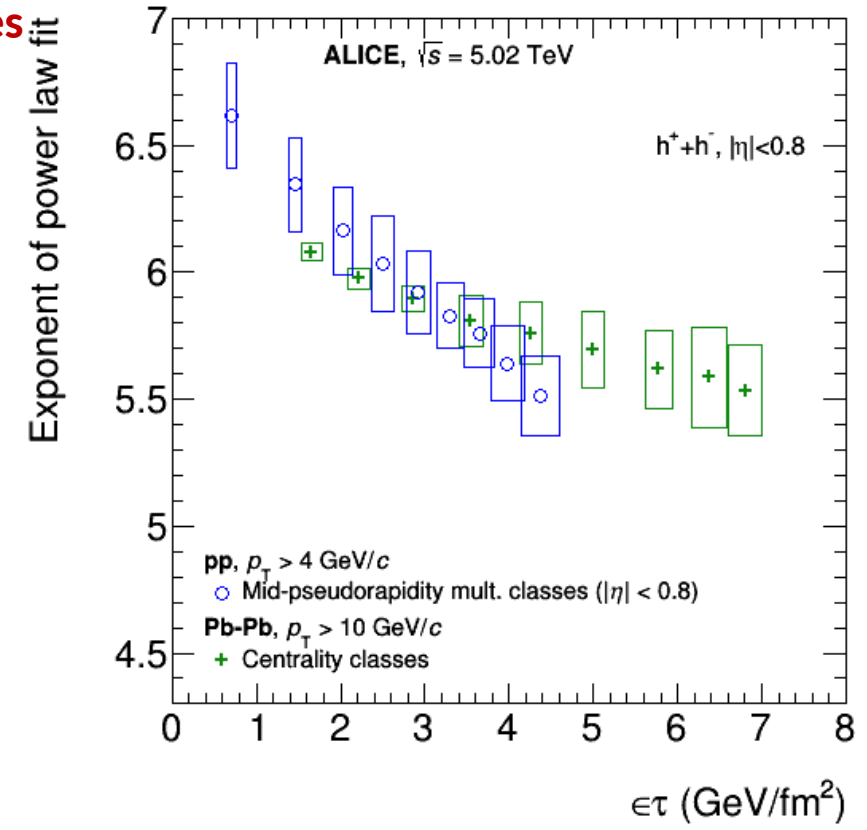
Very sensitive!

S. Iga private communication



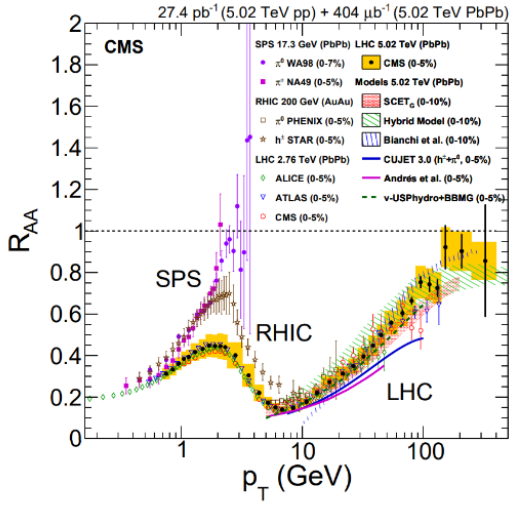


The exponents of the spectra in pp and PbPb have the same trend and ~ same value at comparable enrgy densities



a standard fit curve shows a continuous deviation from PbPb to pp!

Does it have any connection with the famous "Cronin peak that does not move from RHIC to LHC?



Kapil Saraswat et al 2018 J. Phys. Commun.2 035003

The deviations of Tsallis from data are all at the same pt!

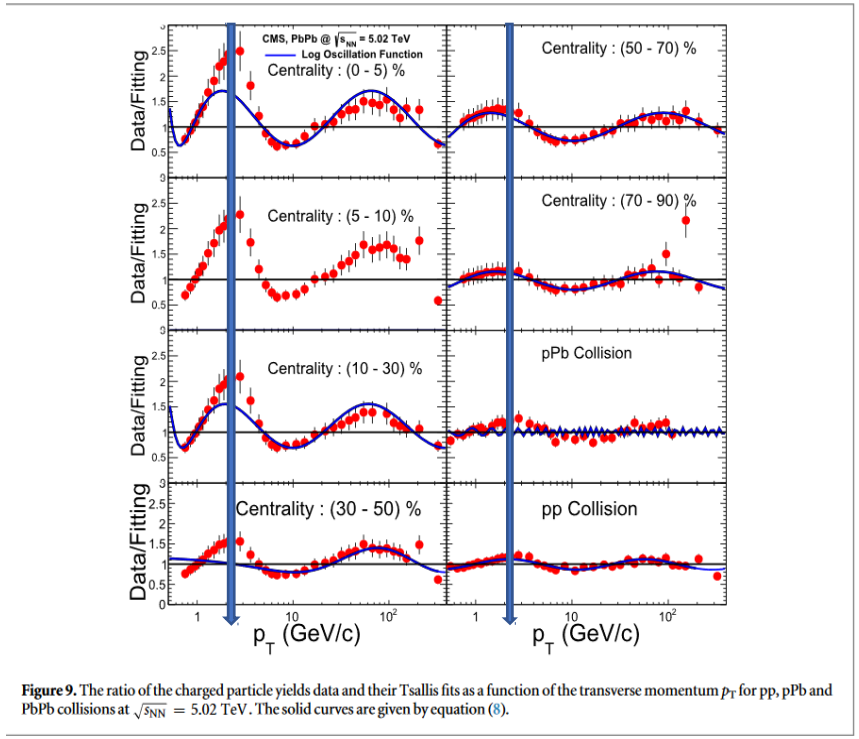


Figure 9. The ratio of the charged particle yields data and their Tsallis fits as a function of the transverse momentum p_T for pp, pPb and PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The solid curves are given by equation (8).

Surprise II – the energy loss

$$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$$

Also A. Ayalaet al.

Jet asymmetry and momentum imbalance from 2→2 and 2→3 partonic processes in relativistic heavy-ion collisions

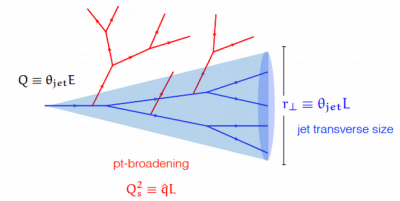
Phys.Rev. C92 (2015) no.4, 044902

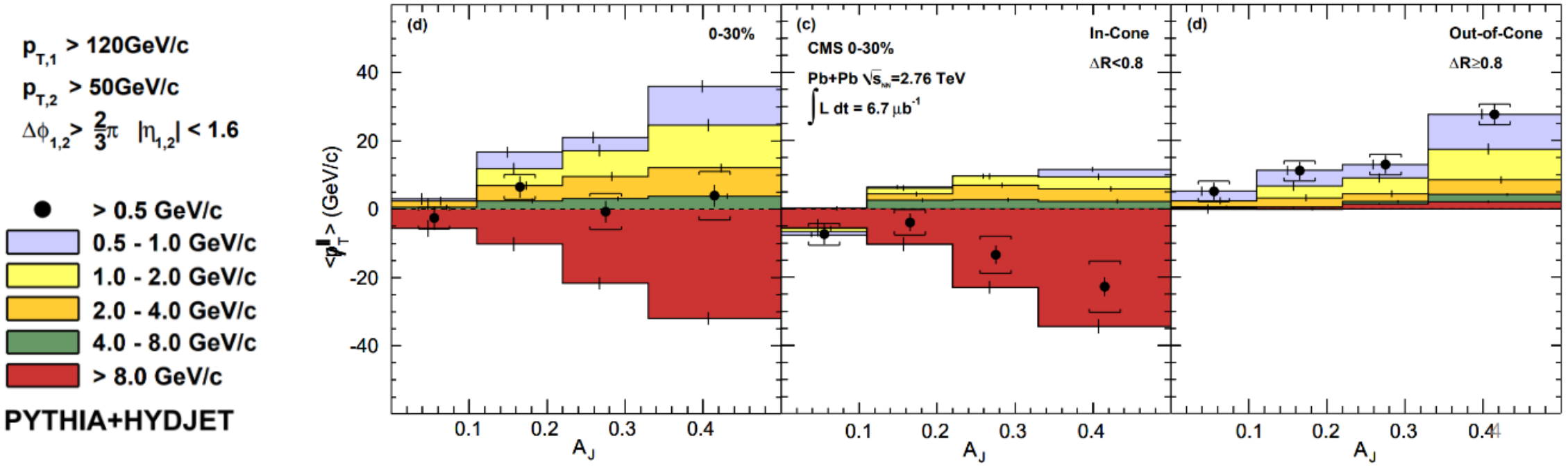
Is the observation of the decreasing slope in the spectra due to “energy loss”?

https://indico.cern.ch/event/792436/contributions/3570543/attachments/1941314/3218961/QM2019_TanLuo.pdf

Caveat: the behaviour of the spectra is reproduced by Pythia wo inclusion of jet quenching!

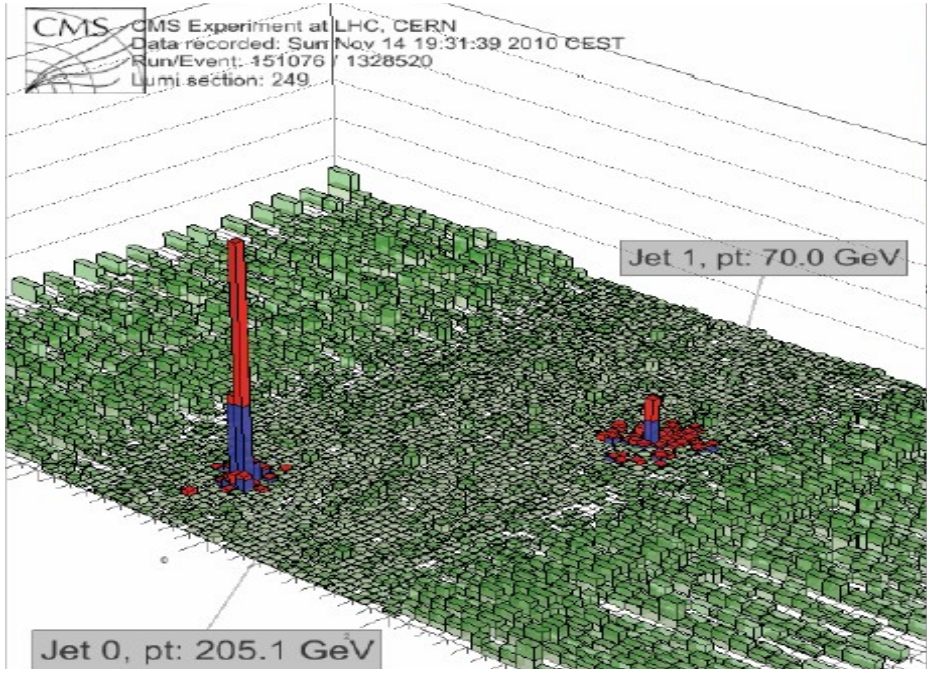
If I have a parton of x GeV/c in an initial state of the collisions I will have in the final state a parton/hadron of x-y GeV/c It means that the hadron will “beef up” the spectra at lower energy and we will get another contribution at low momenta!?





A little reflection:

- If the jet had initially 205 GeV
- The secondary jet “moved” in the pt spectrum much lower -increasing thus the yield of “medium” pt particles. The irradiated gluons hadronise in ~ 100 “low” pt hadrons!!



What about no jet at all?

- If I see jets quenched like in the previous slide – then there should be also events where both jets were “dissolved”
- This the key question and how they affect the spectra
- Fact or fiction?

- As has been mentioned, the interaction of hard jets and the dense nuclear medium usually leads to jet energy loss. One important observable is the sup-pression of the single inclusive hadron yield at highpTin nucleus-nucleus collisions as compared to the expectation from proton-proton collisions.(Guang-You Qin, Xin-Nian Wang arXiv:1511.00790 [hep-ph)

The event shapes- important part possibly a “ forgotten feature”

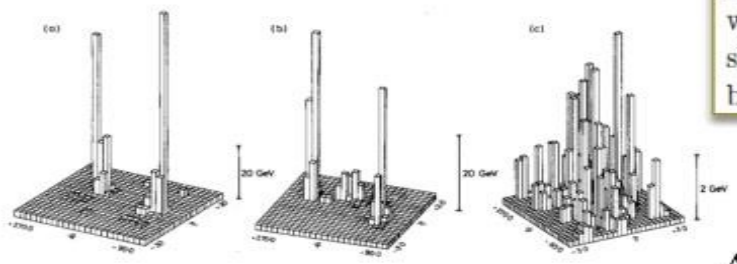
We are focussed to the jets but perhaps should give some action to the hedgehogs

CDF

An interesting example—an *atypical* event observed in $\bar{p}p$ interactions at $\sqrt{s}$ = 1.8 TeV by CDF's Run 1 detector, is shown in Figure 3.([3]) This event was accepted by a $\sum E_\perp$ trigger, without any topological requirement. The LEGO® plot shows many bursts of energy: More than a hundred active towers pass the display threshold of 0.5 GeV. The total transverse energy in the event is 321 GeV, but it is not concentrated in a few sprays, it is everywhere. The central tracking chamber records about sixty charged particles.

I am assured that this "hedgehog" event is authentic; it is not merely coherent noise in the counters. The colleague who selected this specimen estimated similar events to be about as common in the online event stream as Z^0 production and decay into lepton pairs: about one in ten thousand triggers. I include this outlier as a reminder that when we think about the strong interactions outside the realm of a single hard scattering, we should think not only about the large diffractive and "multiperipheral" cross sections, but also about less common phenomena.

Chriss Quigg: arXiv:1004.0975v1 [hep-ph]



UA1

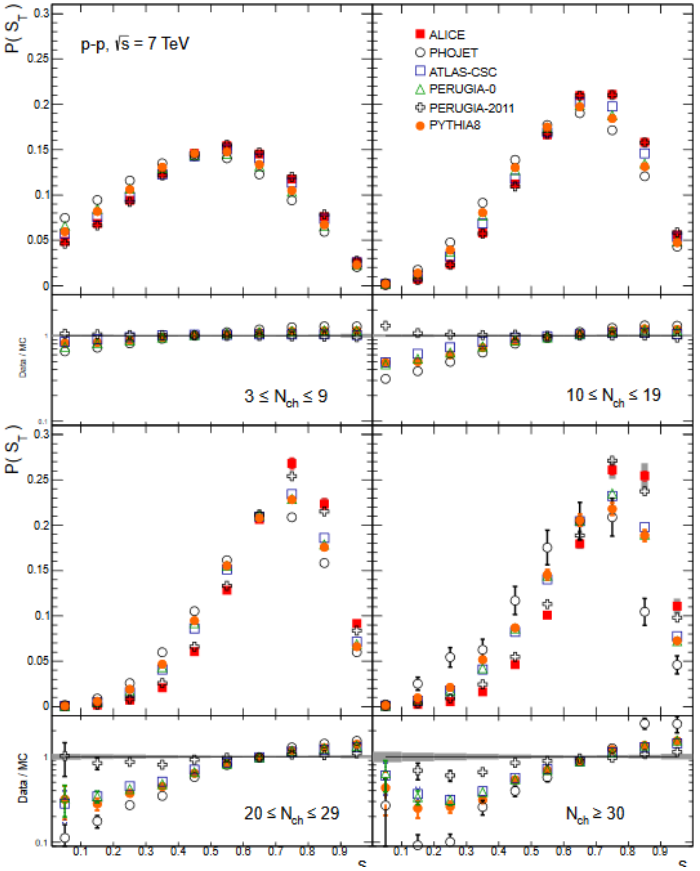
Albajar, C., et al. Analysis of the Highest Transverse Energy Events Seen in the UA1 Detector at the SppS Collider. Z. Phys. C36 (1987)

4

The event shapes in hadron collisions - ICN among the pioneers!

ALICE was the first to use the event shapes!

Eur.Phys.J. C72 (2012) 2124



Isotropic events are not an exception but the norm at high multiplicity!

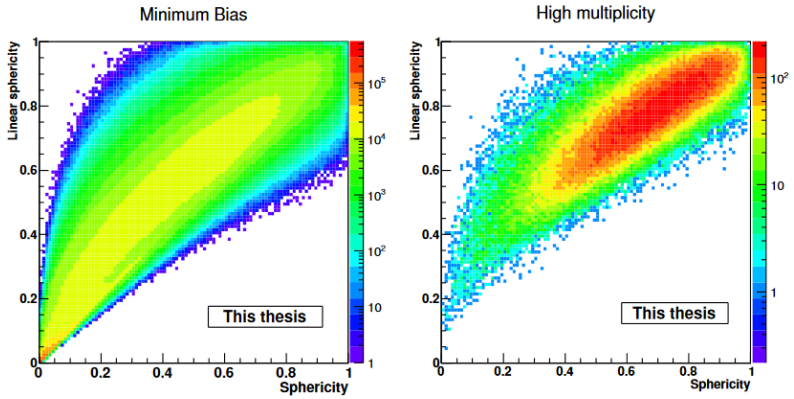
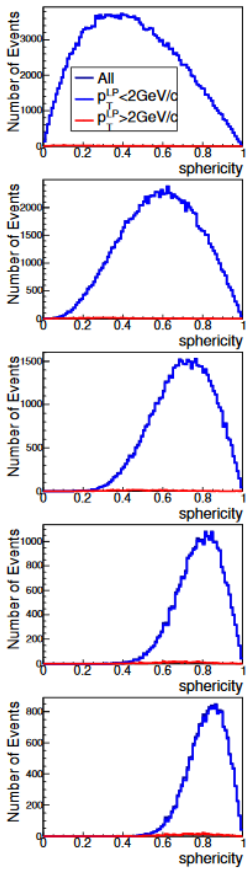


Figure 5.2: Linear sphericity versus sphericity for MB (left) and HM (right) triggers.

Essentially: more multiplicity – less jettiness!

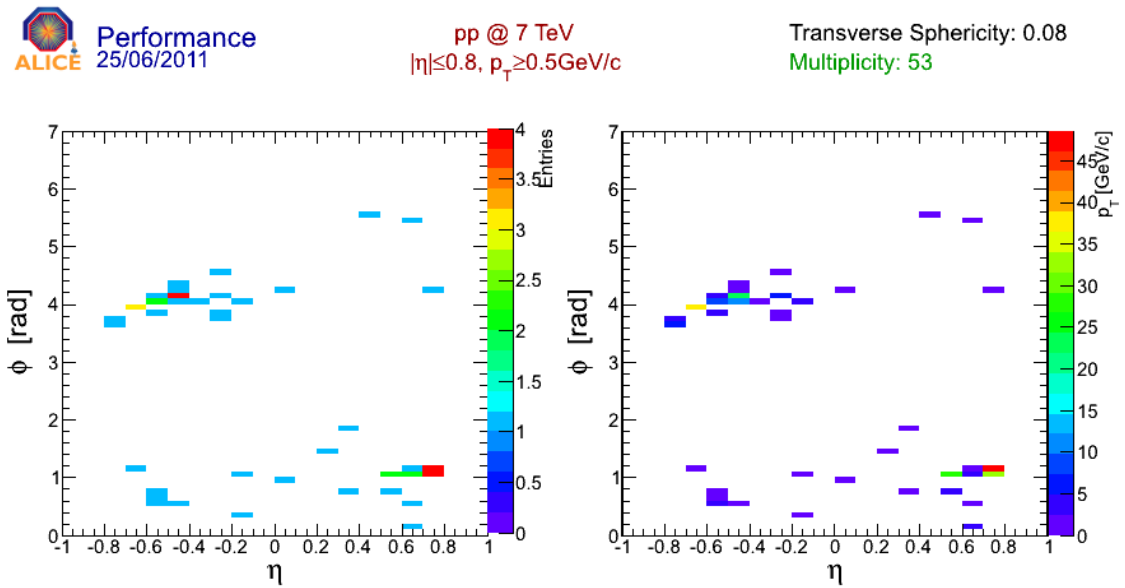


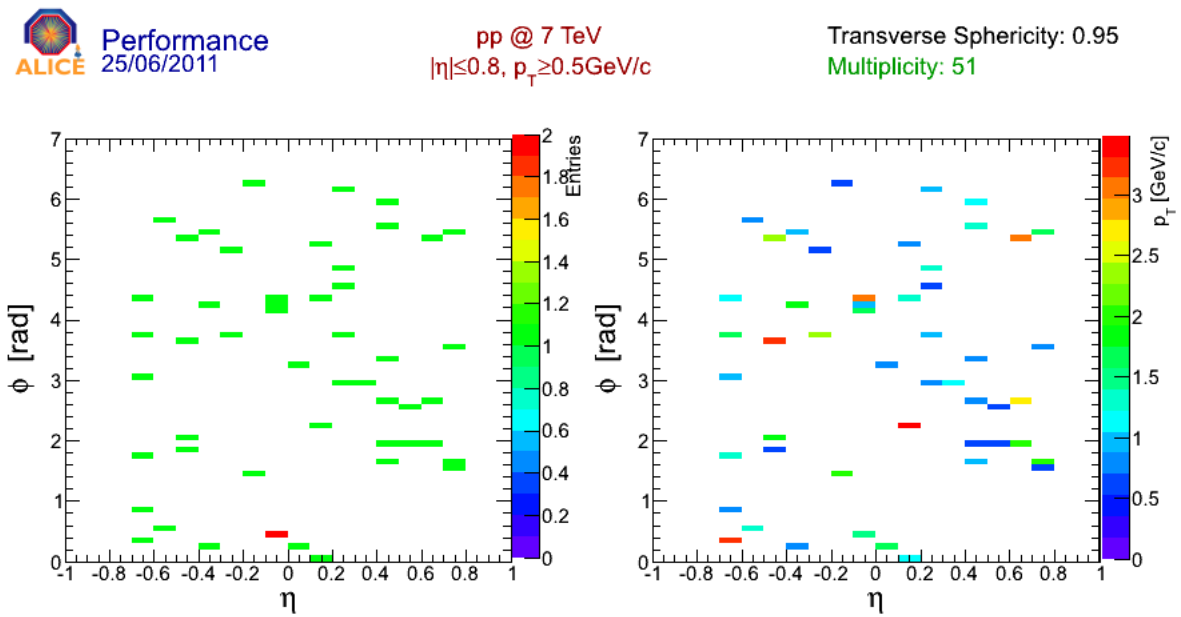
5 10 20 40 60

http://niham.nipne.ro/THESIS_AH.pdf

Andrei Ionut,Herghelegiu

Jetty and hedgehog events in ALICE (thesis A. Ortiz)



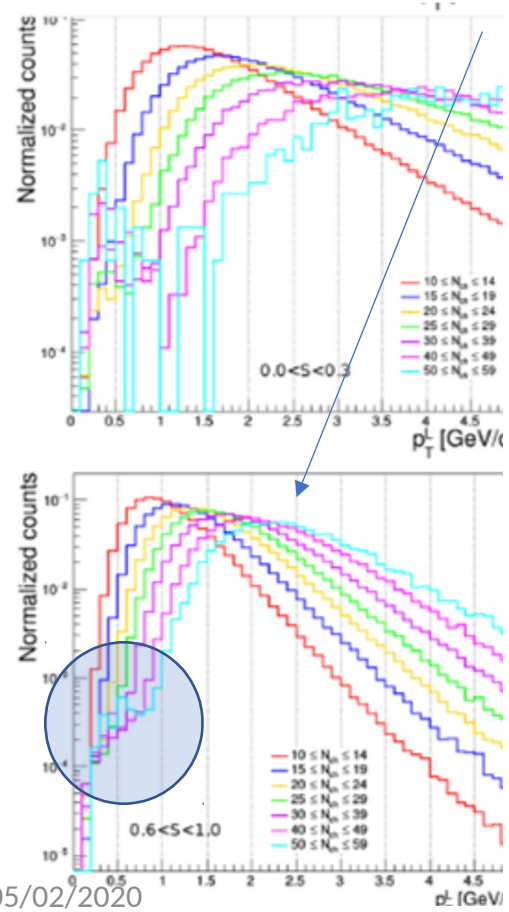


The high sphericity/spherocity events are a challenge!

More surprises!

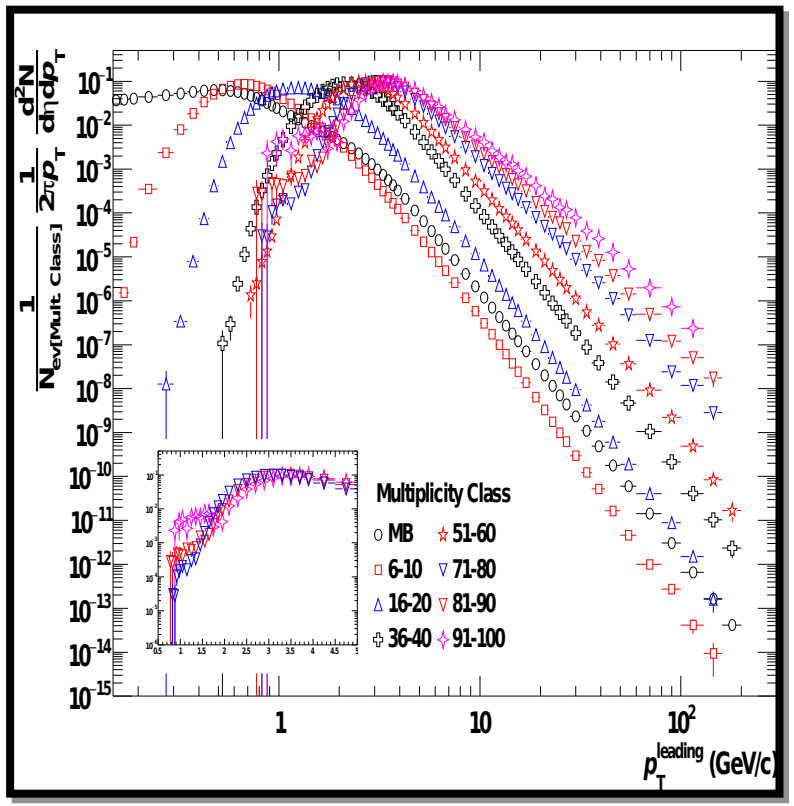
The behaviour of the leading pt in function of the sphericity

Bucarest analysis - data



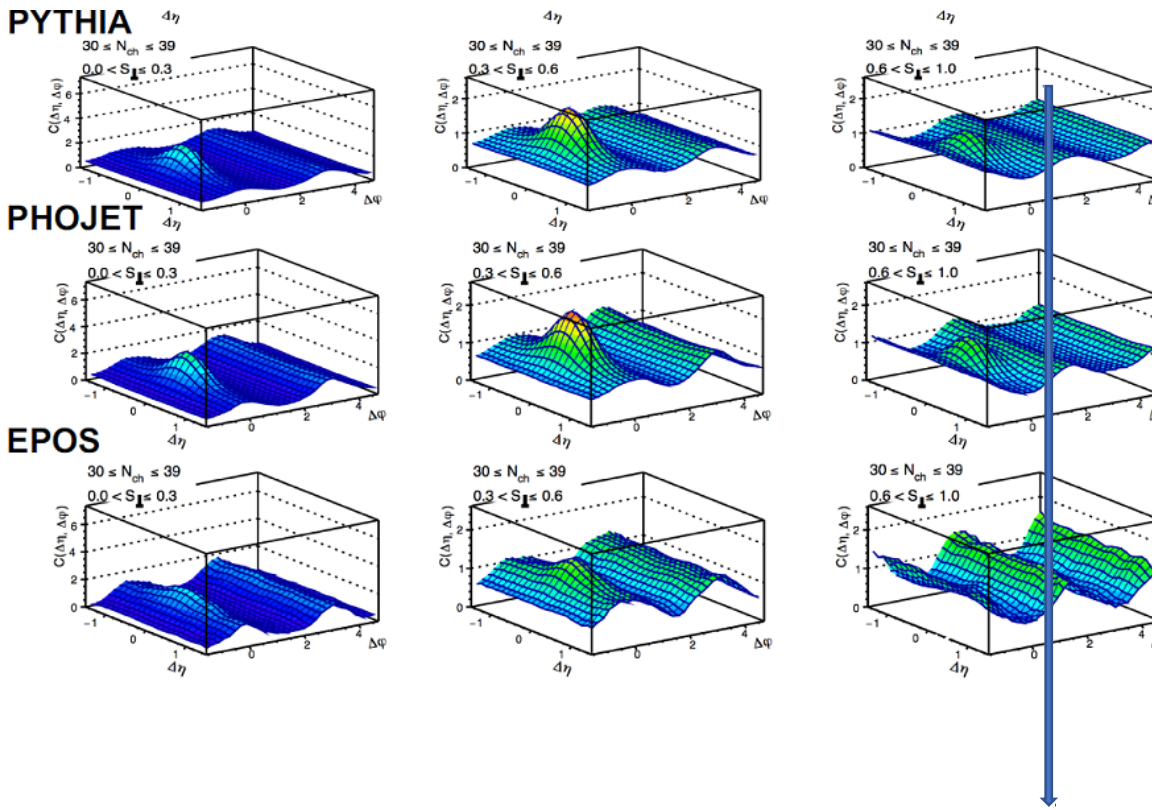
Pythia A. Mishra, G.P

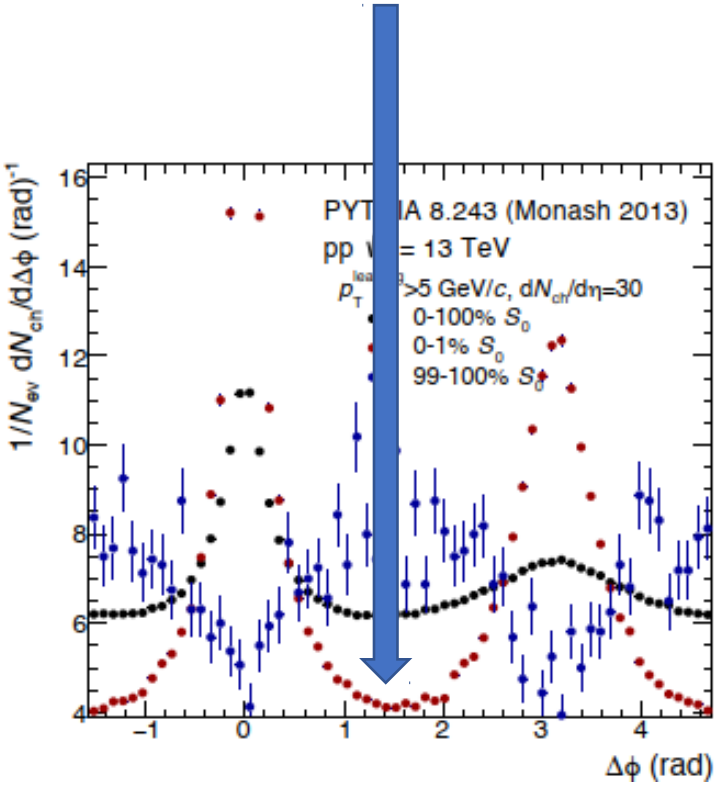
As we increase the multiplicity & the sphericity the leading particle spectra develop a shift at low leading pt!



Clear transfer of particles to the transverse side! At high multiplicity the near side peak disappears as in MC generators

M. Petrovici private comm

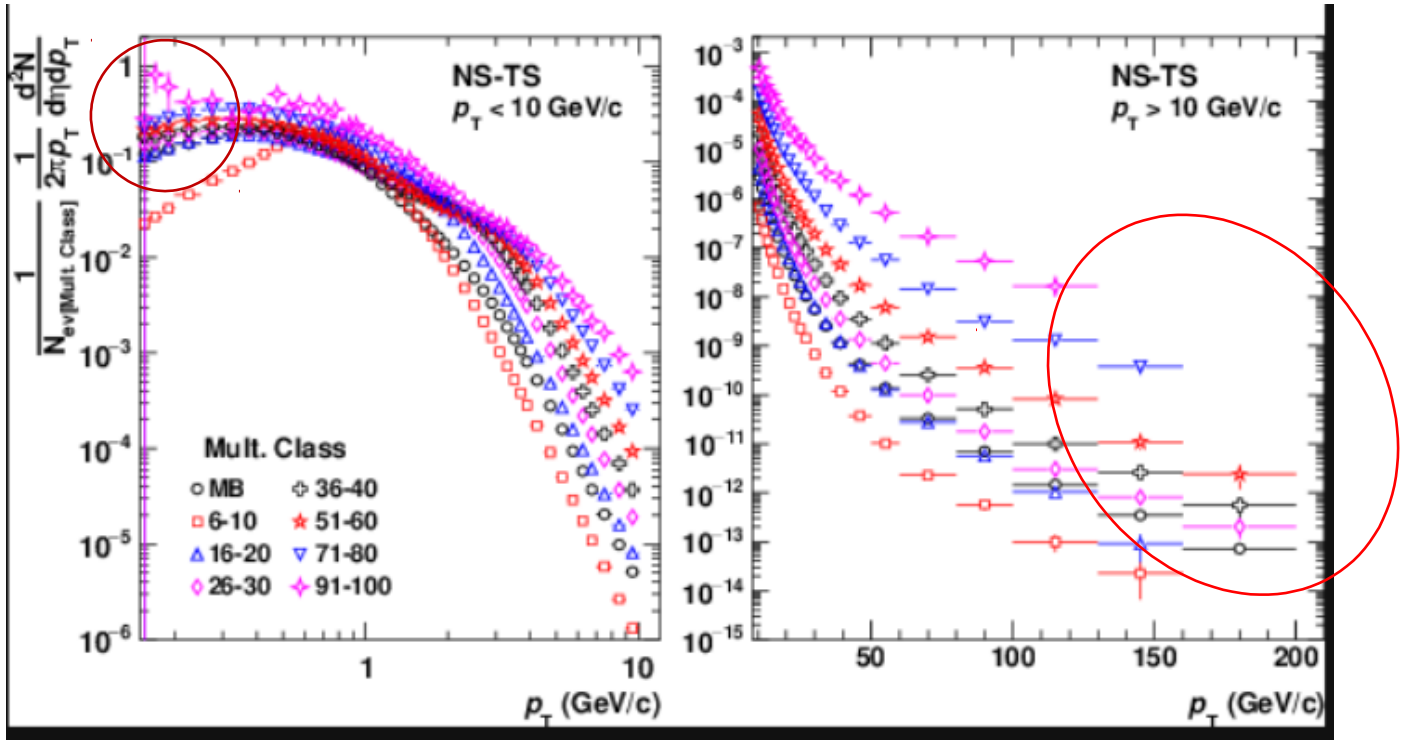




A. Ortiz MPI 2019

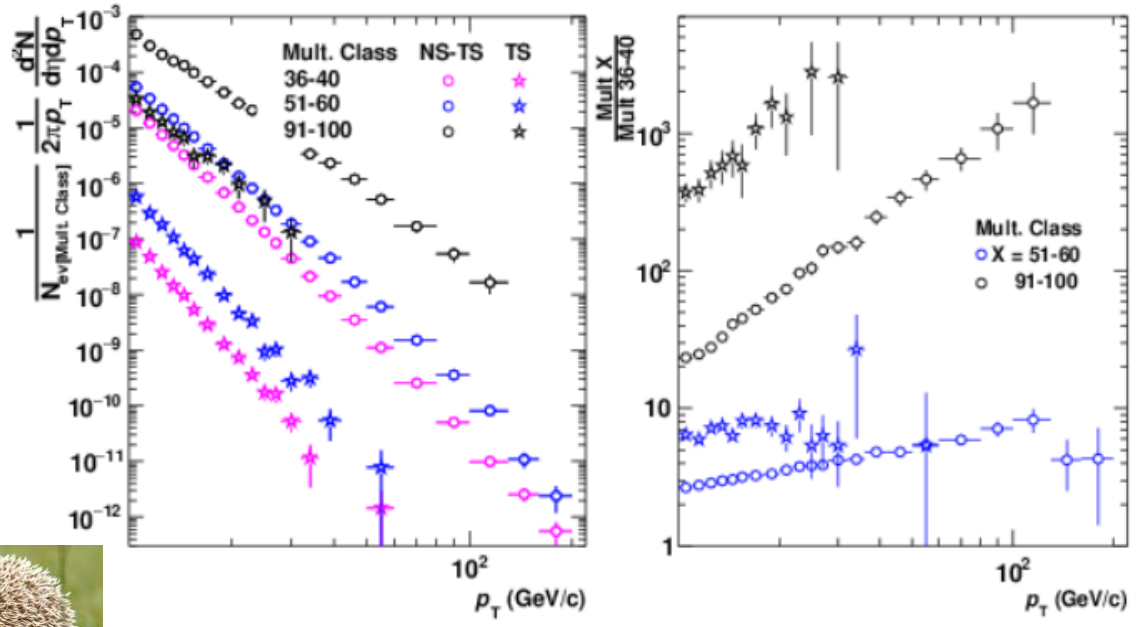
observation

- We generate spectra resulting from the subtraction of the Transverse side spectrum (T from the Near side (NS) ones) The spectrum labeled NS-TS which is obtained by subtracting the TS spectrum from the NS spectrum.
- **The spectra exhibit a hardening with multiplicity.**
- At higher multiplicities the slope of the spectra continues decreasing without producing higher momentum particles!



The TS spectra are strongly correlated with multiplicity!

- Transverse spectra above pt =10 GeV/c
- The spectral slopes rise much faster for the TS spectra then for the NS-TS spectra
- **Enormous rise of TS!**
- **Essentially we see the isotropisation of the dihadron correlation**



arXiv:1905.0691 G.P and A. Mishra

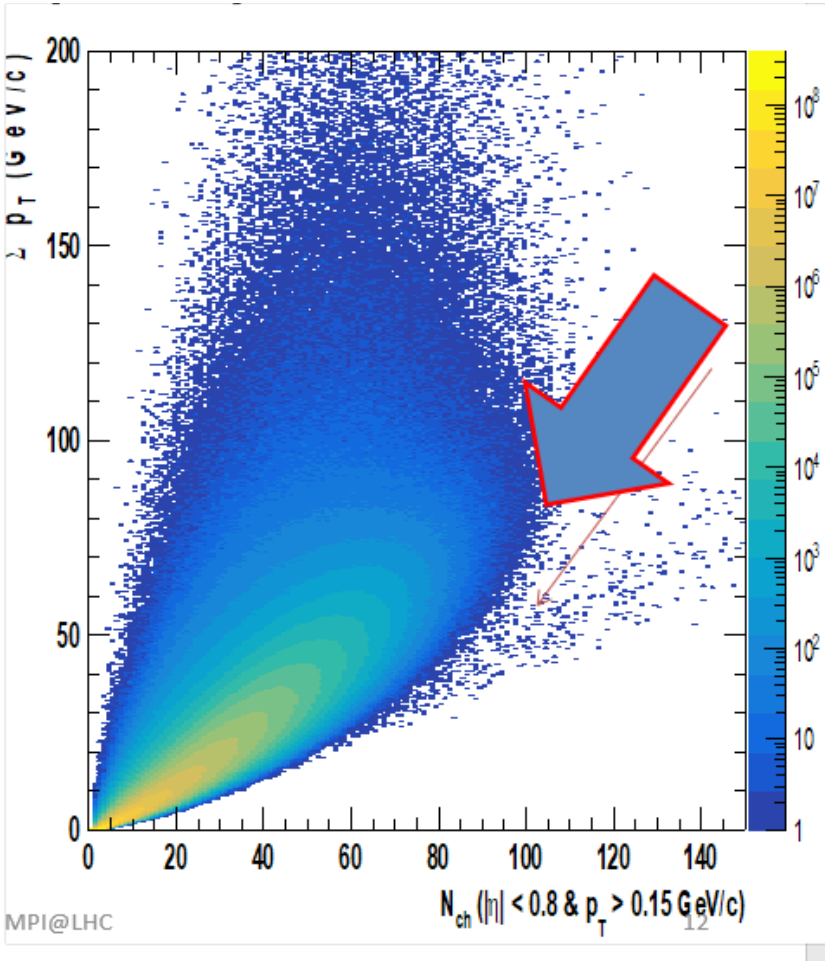
Pythia

The sum pT! could be used as observable

- The $\sum p_T$ is the largest for the 40-50 multiplicity.
- **The highest multiplicities have not the highest $\sum p_T$.**

Do we see the change of momentum into mass?

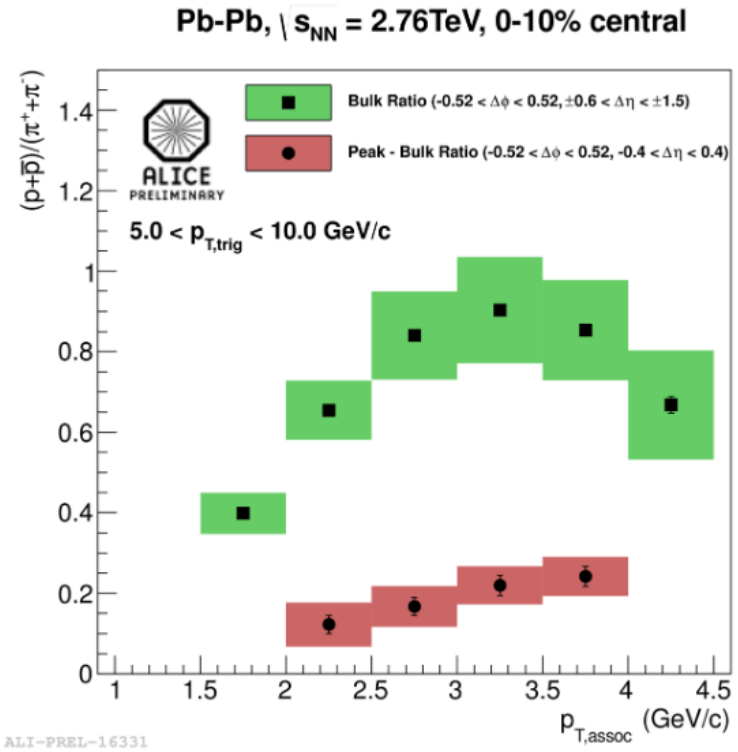
We know that the hadrochemistry of the underlying events and the jets is not the same!



A nice way to study the hadrochemistry without PID!!

A possible experimental proof

- M. Veldhoen [ALICE Collaboration], arXiv:1207.7195.



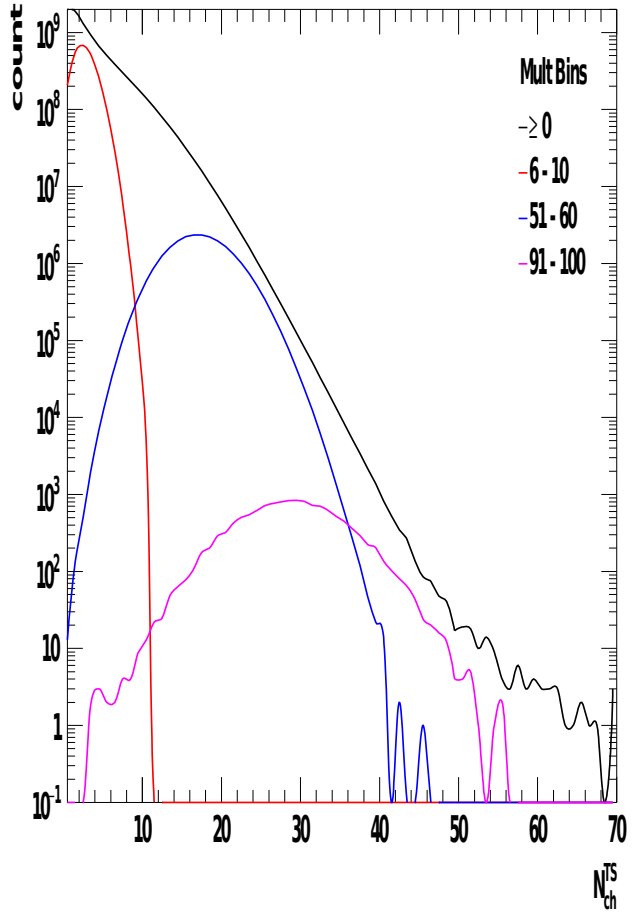
When the p/π ratio in the peak is corrected for bulk effects using an η gap one finds that the ratio is dominated by the bulk.
So the ratio does not seem to be driven by hard physics.

What about the situation in PbPb?

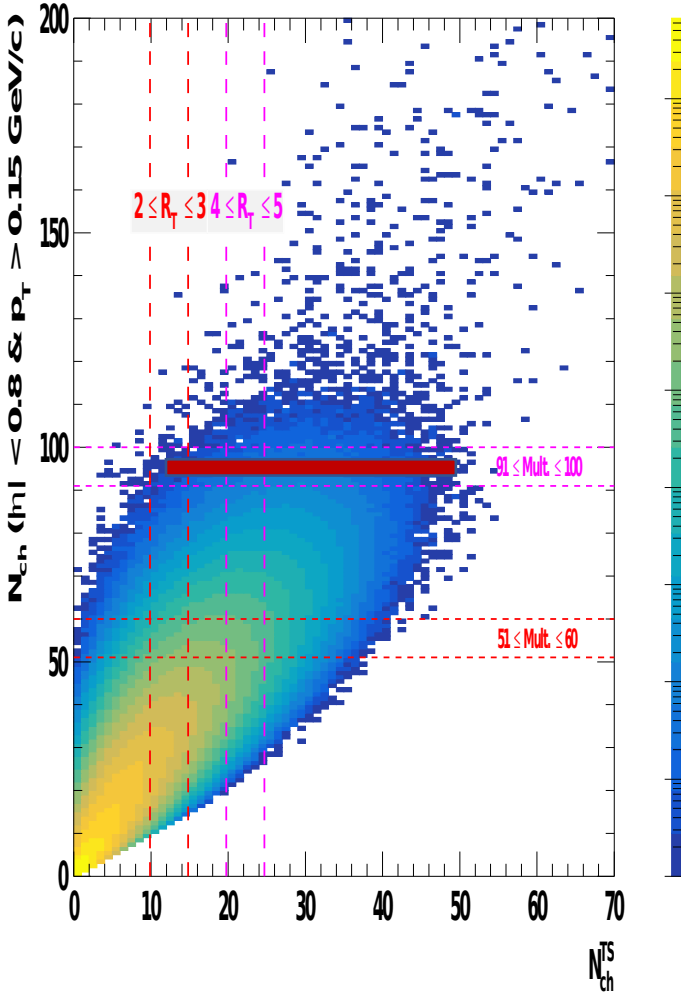
This is definitely a significant result of ALICE should be pursued in many different manner

Another way of characterising the events - RT

What does RT tell us?



At a given multiplicity there is wide range of RT values – it means that some particles in the jetty part move to the transverse side and other less so as if it would be associated with a pathlength which is not

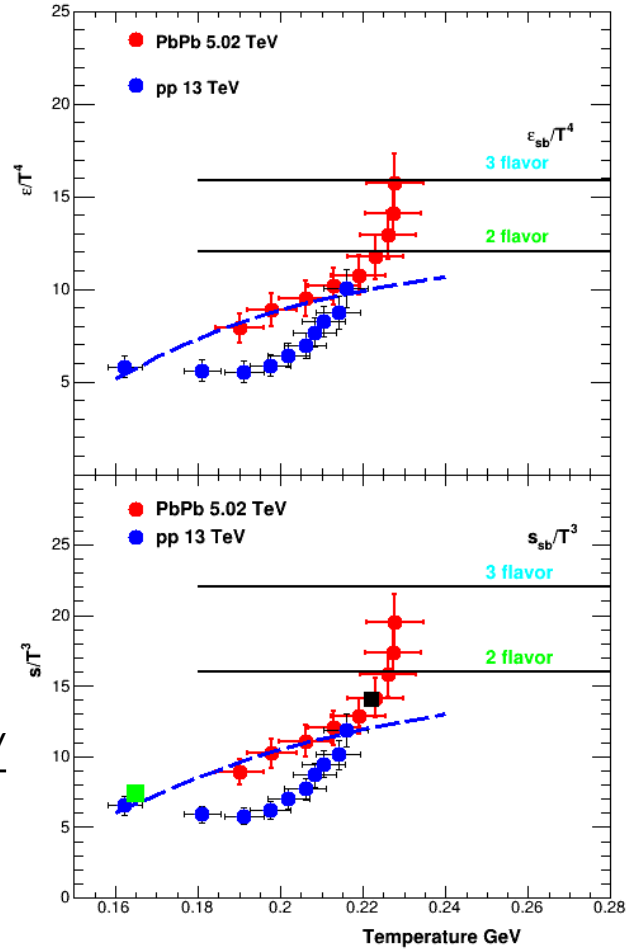


Multiplicity or energy density?

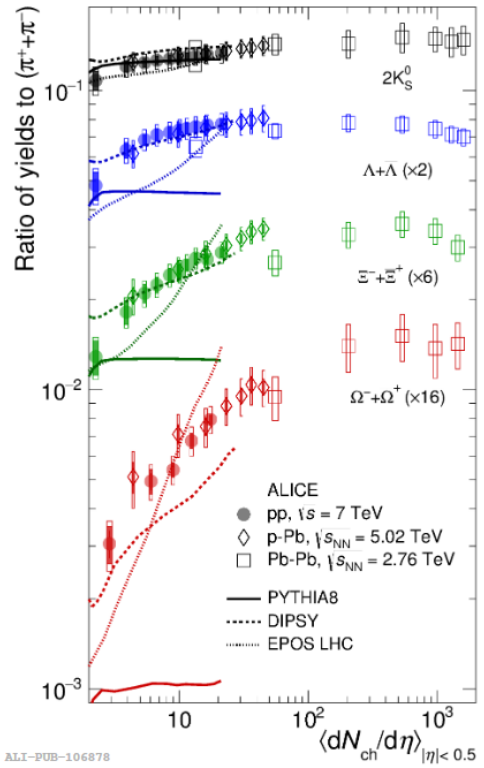
- A lost battle?
- Int.J.Mod.Phys. E25 (2016) no.07, 1642009 ● ArXiv:1608.02101
- Our Basic creed is the LQCD

Are we really unable to give any kind of answer on our “core business”?

https://indico.cern.ch/event/792436/contributions/3535661/attachments/1935119/3213905/QM2019_Ollitrault.pdf
the black point!



B. Srivastava private communication based on the percolation approac



Conclusions

- During the years we have made a number of observations – we need now to put them together to get a real picture.
- The spectra of charged particles offer a beautiful playing ground to study the energy loss of partons in dense media.
- To be able to compare heavy ion and pp we should try to apply the same criteria and analysis to heavy ion collisions – event shapes, Rt, underlying events
- As exposed here there is material to expect that in pp collisions we are also confronted with some sort of parton energy loss coupled to an interesting behaviour of the accompanying hadrochemistry
- We actually propose a two stage energy influence of partons – one diminishing the ‘leading parton “ momentum and the contribution of the “debris “ to the very low part of the spectrum – it is supported by data
- The attempts to really reproduce the LQCD results are few and not very successful
- We have data, not yet processed, that indicate important processes in pp (disappearance of the near side peak in high multiplicity events

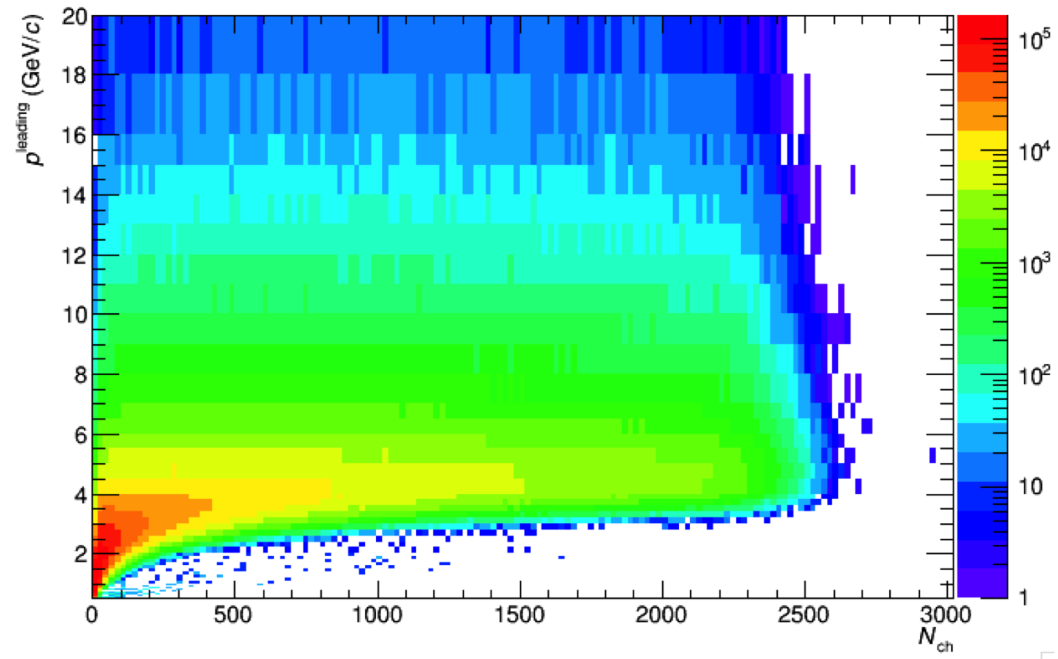
Conclusions II

- **The results reproduced by Pythia open an interesting questions is what we see a QGP or some other manifestation?**
- **This should in my mind be the basis of our paper and of a strong interaction with theorists to explain WHY they reproduce the data without temperature, equilibration etc**
- **I believe that we should**
- **a)b treat the comparisons of pp with heavy ions using an energy density approach**
- **b) try to exploit to the maximum the high multiplicities**

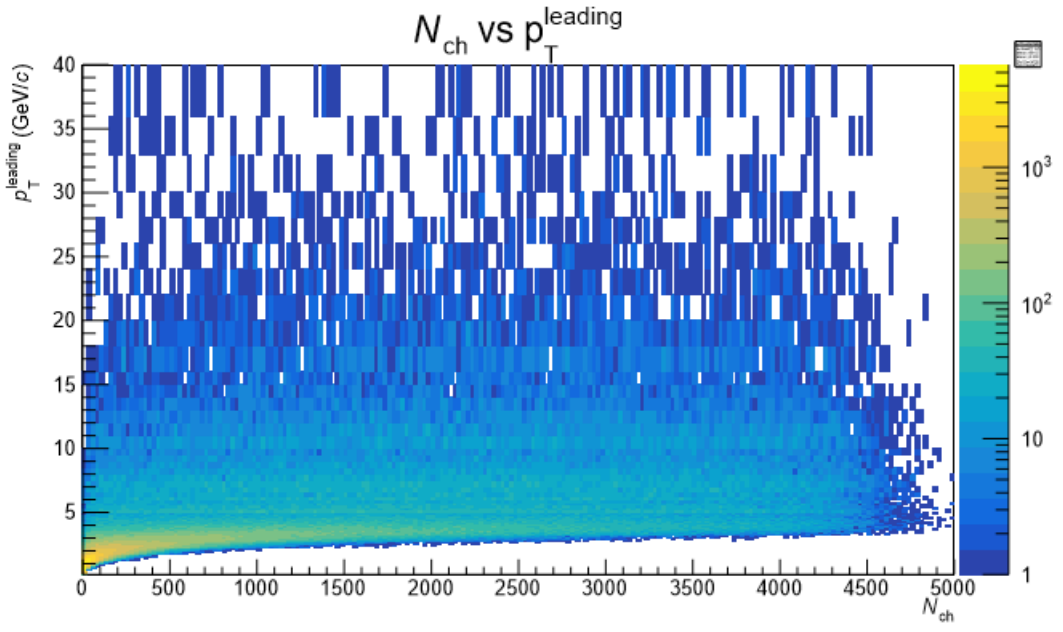
backup

S. Chatrchyan *et al.* (CMS Collaboration) Phys. Rev. Lett. 109, 152303 –

- For the top 5% most central colli-sions, this formula give14 GeV=fm3at a time 1fm=cand for a transverse surface ofA¼ð7fmÞ2[22]. This is a factor of 2.6 times larger than the energy
- http://niham.nipne.ro/mp_summer_school_2014.pdf petrovici
- With the canonical assumption of a 1 fm/cformation time, weestimate that the energy density in 0%–5% central Pb-Pb collisions at√sNN=2.76 TeV is 12.3±1.0 GeV/fm3and that the energy density at the most central 80 fm2of the collision is at least 21.5±1.7 GeV/fm3
- *https://link.aps.org › pdf › PhysRevC.94.034903*
- -

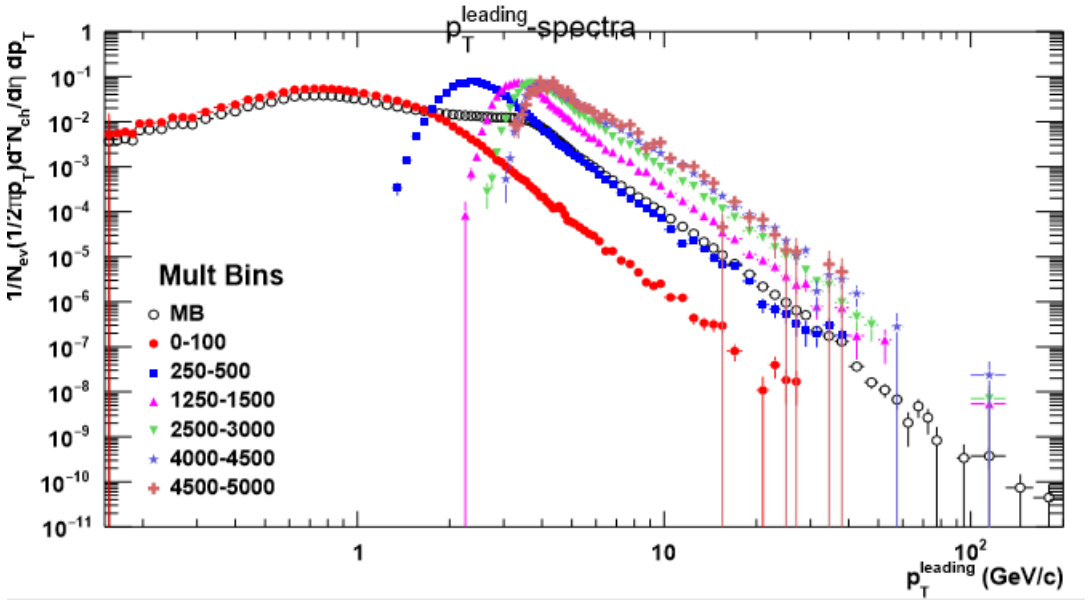


From Antonio - private



AMPT Aditya

AMPT leading particle



Baryon puzzle in high multiplicity events

From thesis B. hess

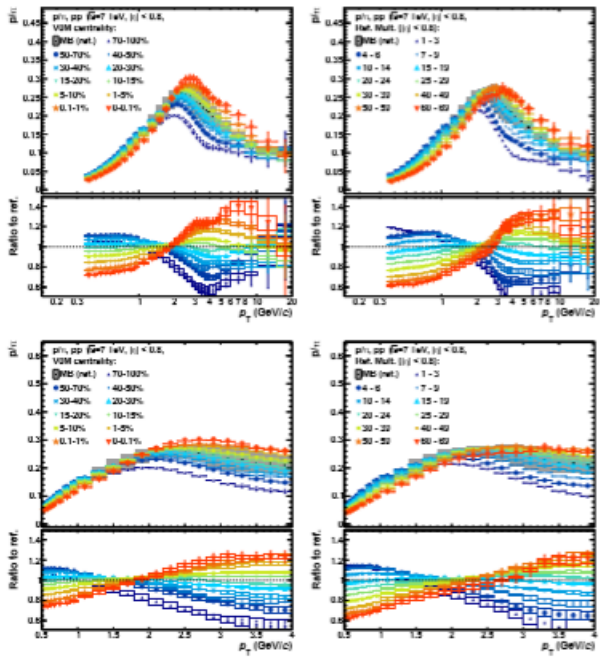


Figure 6.30.: p/π ratios for different bins of V0M (left) and reference multiplicity (right). For better visibility, only the systematic uncertainties of the MB data points are plotted in the upper panel of each row. The lower panel of each row shows the ratio to MB including the corresponding systematic uncertainties. The bottom row shows a zoom to the crossing point with linear p_T scale.

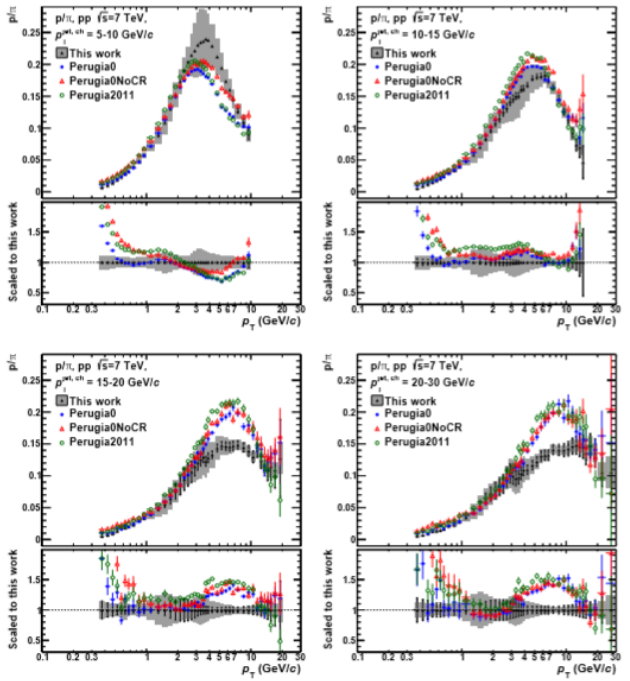


Figure 6.40.: Comparison of corrected p/π ratios in jets to different MC predictions as a function of p_T. The p_T^{jet} increases from the upper left to the lower right panel.

First implementation of transverse spherocity analysis for heavy-ion collisions at the Large Hadron Collider energies

arXiv:2001.06849

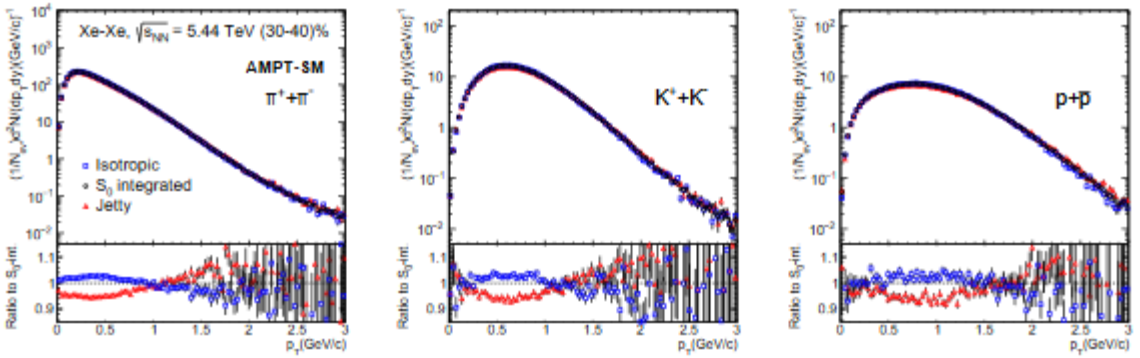


FIG. 3: (Color Online) Top plot: p_T-spectra for pions, kaons and protons in Xe-Xe collisions at (30-40)% centrality with isotropic, S_0-integrated and jetty events. Bottom plot: Ratio of p_T-spectra for isotropic and jetty events to the S_0-integrated events.

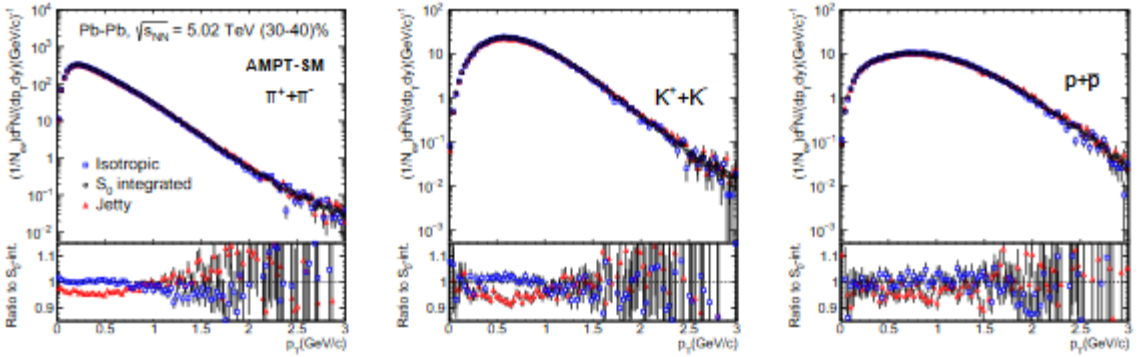


FIG. 4: (Color Online) Top plot: p_T-spectra for pions, kaons and protons in Pb-Pb collision at (30-40)% centrality with isotropic, S_0-integrated and jetty events. Bottom plot: Ratio of p_T-spectra for isotropic and jetty events to the S_0-integrated

First implementation of transverse spherocity analysis for heavy-ion collisions at the Large Hadron Collider energies

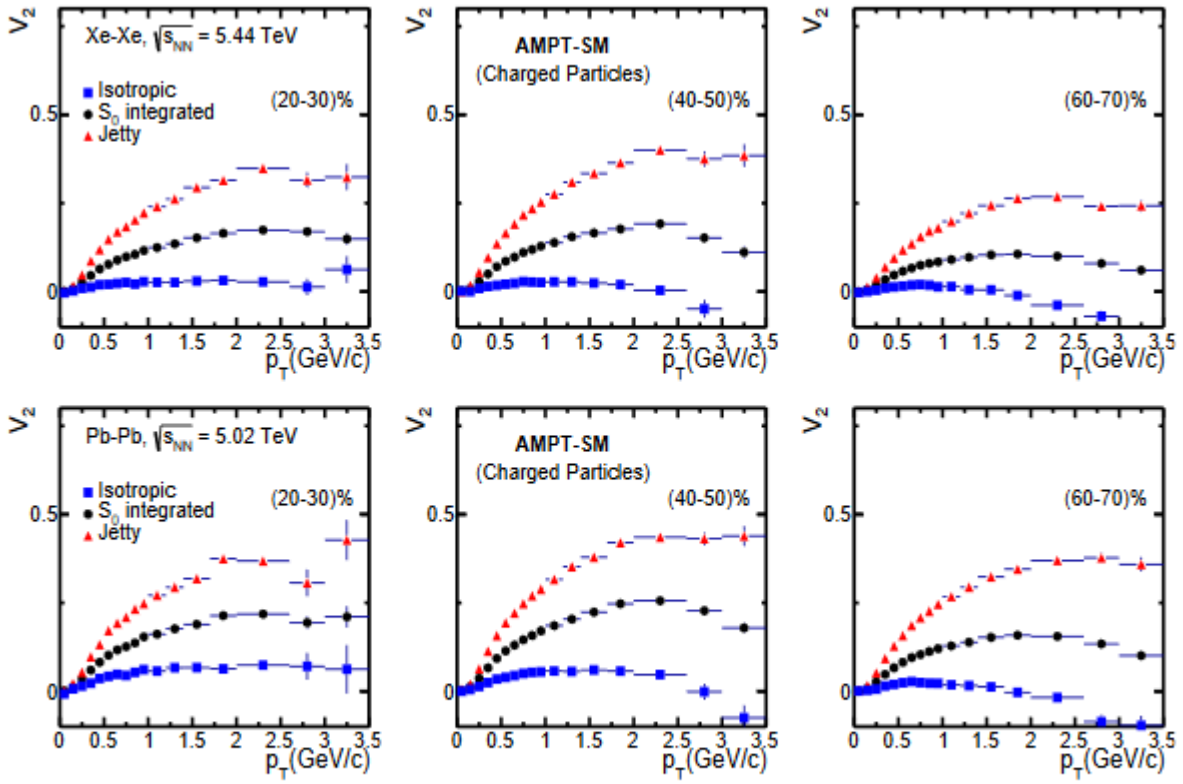
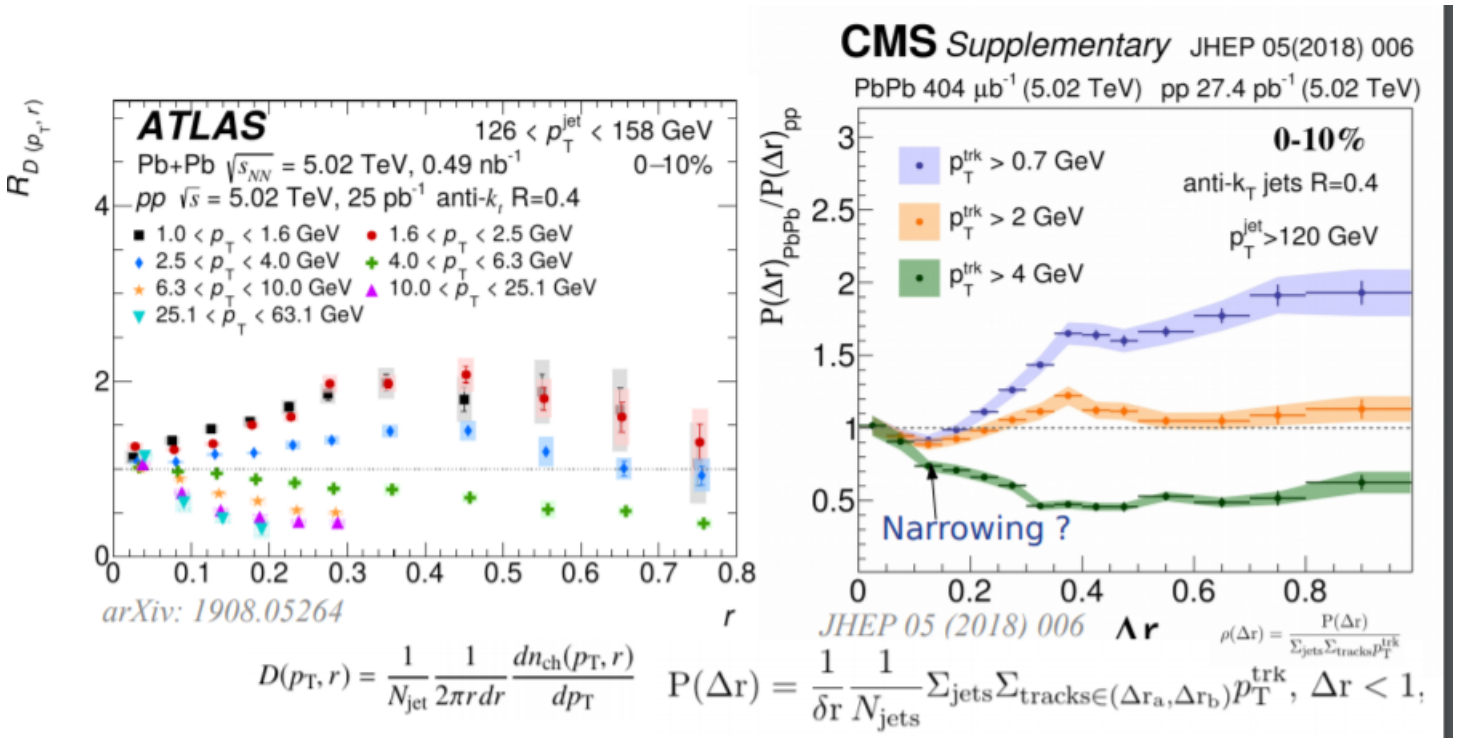


FIG. 7: (Color Online) Centrality dependence of elliptic flow for Xe-Xe and Pb-Pb collisions at different centralities using AMPT-SM model. Event shape dependencies are shown for various centralities.

Everybody sees the same thing

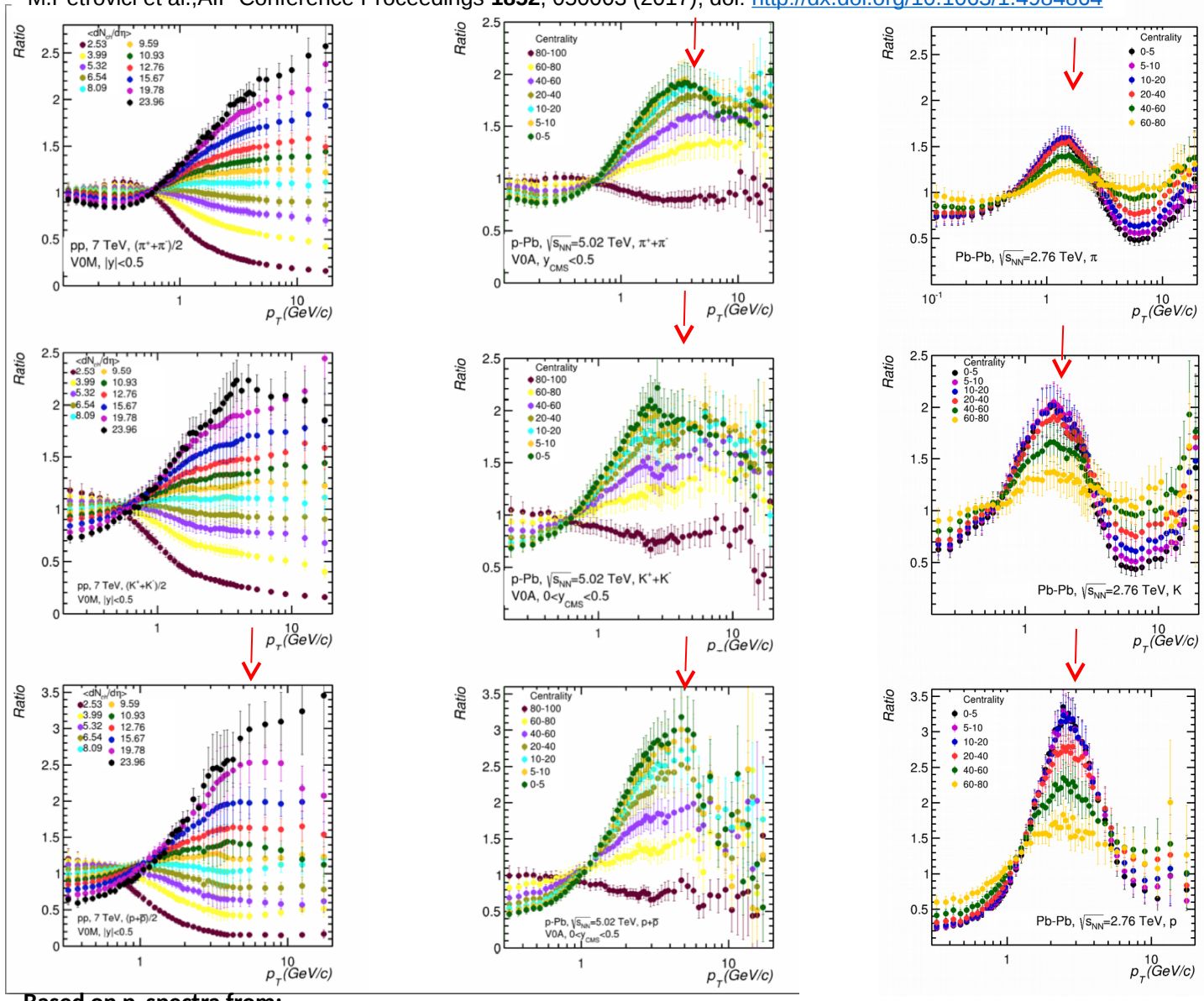
- https://indico.cern.ch/event/792436/contributions/3570537/attachments/1941406/3219169/1_HFLFJetsQuenching_BTrzeciak_QM19_v3.pdf



$$\frac{[\frac{d^2\sigma}{dydp_T} / < dN_{ch}/d\eta >]^{(\%bin)}}{[\frac{d^2\sigma}{dydp_T} / < dN_{ch}/d\eta >]^{(p+p)^{MB}}}$$

Normalized p_T distributions relative to MB p+p as a fuction of charged particle multiplicity-centrality for p+p (7 TEV), p+Pb (5.02 TeV) and Pb+Pb (2.76 TeV)

M.Petrovici et al.,AIP Conference Proceedings **1852**, 050003 (2017); doi: http://dx.doi.org/10.1063/1.4984864



Based on p_T spectra from:

V.Vislavicius , ALICE Coll. QM2015

J.Adam et al., ALICE arXiv:[nucl-ex]1601.03658

B.Abelev et al., ALICE Phys.Lett. B720(2013)52

Facts:

1. *depletion at low p_T values in all three systems*
2. *- for π the ratios go through 1 at ~ the same p_T - for all systems - for all mult.*
   - for K is less evident
   - for p - multiplicity dependence
3. *followed by steep increase*
   - all systems
4. *Up to a:*
   - sharp maximum in Pb+Pb at ~ the same p_T for a given specie
   - saturation towards broader maximum in p+Pb with multiplicity
   - tendency towards saturation at high multiplicity in p+p, especially for heavier species
5. *Pb+Pb a minimum followed by an increase towards values larger than 1*

Possible explanations:

1. *boost type signature*
2. *particle mass dependence of boosted p_T spectra*
3. *boost + ???*
4. *Pb+Pb: - Cronin*
   - jet radiation<->suppression
   p+Pb: - Cronin, UE
   p+p: - UE
5. *Compatible with the outcome of CMS study of the "softening of fragmentation pattern of the away-side jet" !!! - larger p_T values*
   - no p_T dependence observed