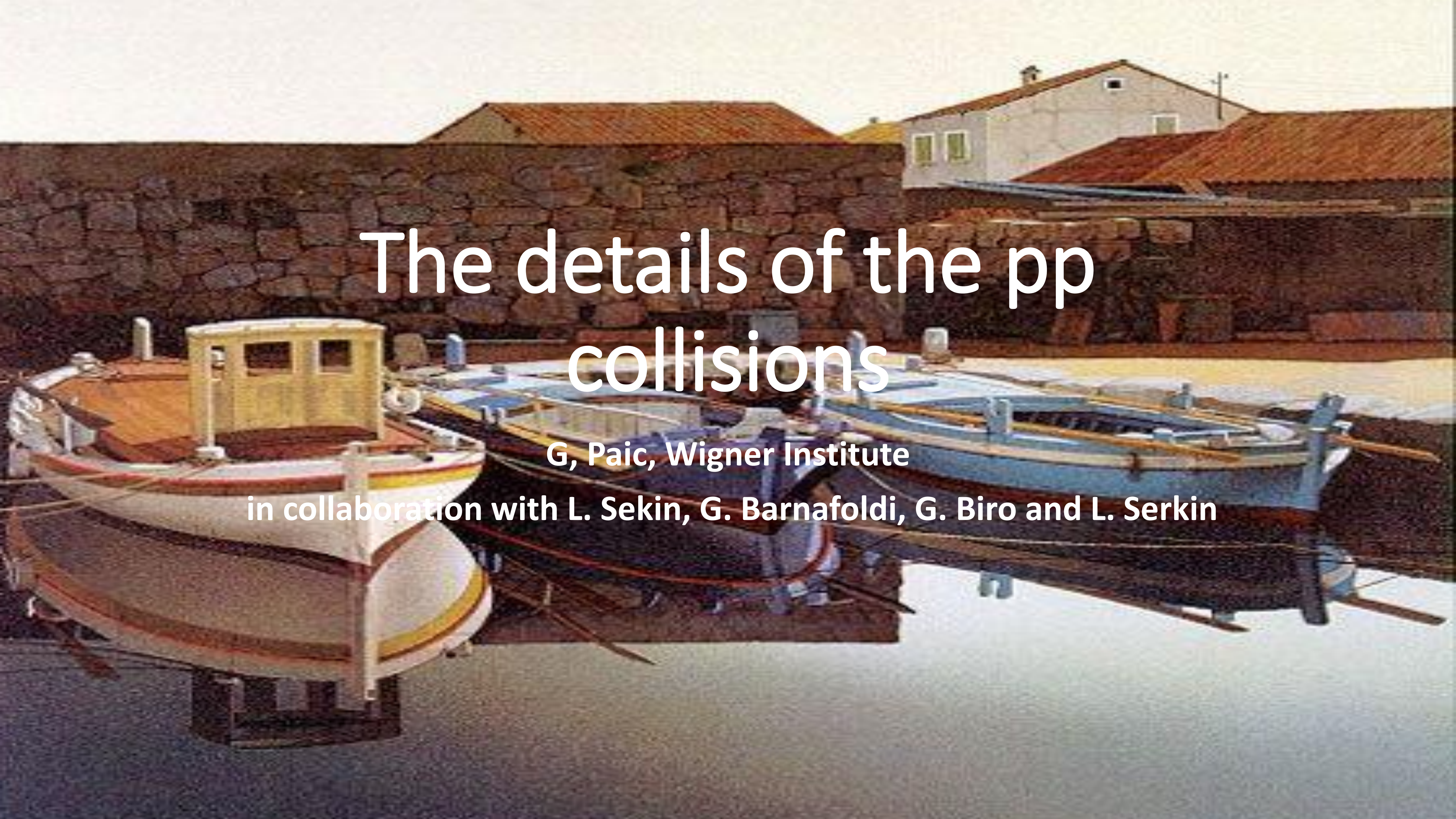


The details of the pp collisions

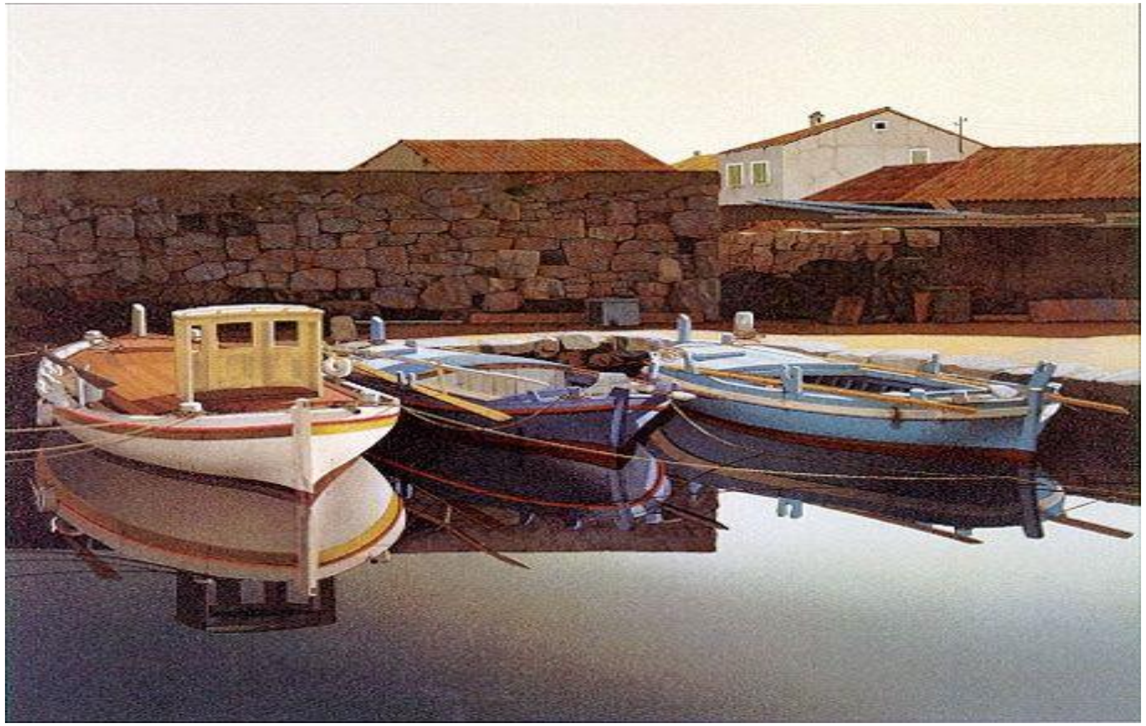
G, Paic, Wigner Institute

in collaboration with L. Sekin, G. Barnafoldi, G. Biro and L. Serkin

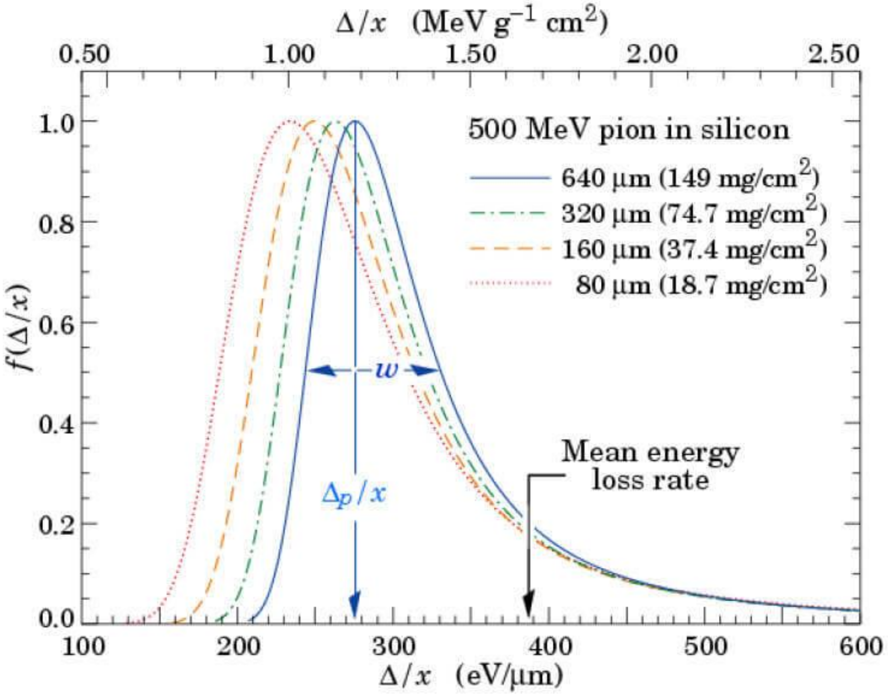
why study the details?

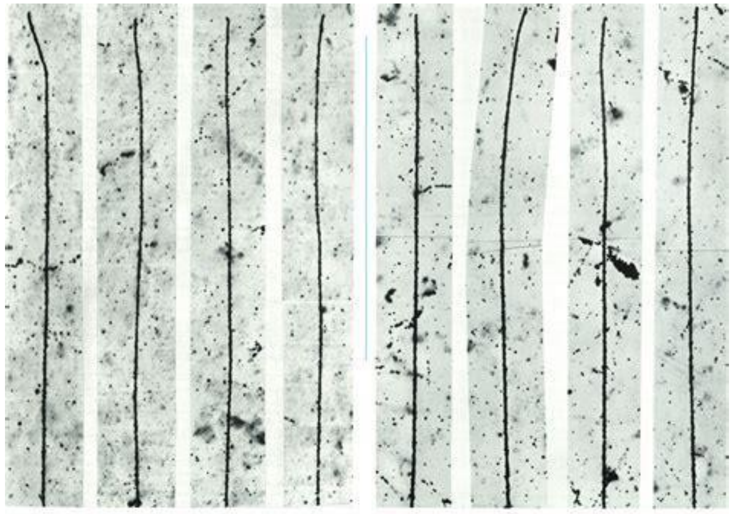
- possible answers:
- Because the mean values are never representing the whole truth…
- because we are searching for surprises that will move our knowledge farther,
- Because the devil is in the details!

Science is about details!



A classical example of the importance to understand the details of the results – the Landau curve




Tracks of tritons at the end of their range

Tracks of alpha particles at the end of their range

The LHC - powerful super microscope!

- The LHC allows us to study the details of the interaction among particles.
- The question I am asking: are the possibilities fully exploited?
- The talk is a call to investigate the interactions in more details than we are doing now with the firm conviction that specific approaches may lead us to discoveries!
- Most probably the understanding of the mechanism in play will pass thru more experimental puzzles for the theorists

The present methodology

- Measure a large number of data and compare the mean values with state of the art models.
- Draw the conclusion from the agreement/disagreement of the “mean values”
- Typically for successful model the agreement is “fair”….
- One may ask if I display the model and the full distribution will I observe the parts where the agreement is not fair or where it is good
- The means are dangerous!

the pp collisions as the first guinea pig of the approach

Why pp collisions?

- Clean (or so we believe!)
- Has been reputed for having collective effects similar to the ones observed in heavy ion collisions
- The interest due to the intriguing theoretical predictions about the possibilities of observing “mini QGPs “in the pp collisions

- The knowledge is the aim of science – there is no permanent Truth

A long history - tempting for theorists and experimentalists

Van Hove 1982

Alexopoulos et alhttps://doi.org/10.1016/S0370-2693(02)01213-3,

P. Levai and B.MullerPRL 67,12, 1519 (1991)

CERN-Heidelberg-Lund Collaboration Charged Particle Spectra in ~ and ~p Collisions at the CERN ISR . W. Bell et al

Presently, it is widely believed that in pp collisions in the studied energy range a hot QCD matter is not produced in the typical inelastic minimum bias events due to small energy density. But in high multiplicity (HM) pp events the energy density may be comparable to that in AA collisions at RHIC and LHC energies. And if the thermalization time, τ0, is small enough, say τ0 ∼ < 0.5 fm, the mini-QGP with size of ∼ 2 − 3 fm should be formed quite likely to the large-size plasma in AA collisions

B.G Zakharov https://doi.org/10.48550/arXiv.1311.1159
Parton energy loss in the mini quark-gluon plasma and jet quenching in proton-proton collisions - We evaluate the medium suppression of light hadron spectra in pp collisions at RHIC and LHC energies in the scenario with formation of a mini quark-gluon plasma

P. Jacobs Search for jet quenching effects in high multiplicity pp collisions at $\sqrt{\mathrm{s}}$=13 Tev

arXiv:2001.09517 [nucl-ex]

M. Mangano and B Nachman Observables for possible QGP signatures in central pp collisions
https://doi.org/10.48550/arXiv.1708.08369

We consider observables such as jet energy loss and jet shapes, which could point to the possible existence of an underlying quark-gluon plasma, or other new dynamical effects related to the presence of large hadronic densities. Eur. Phys. J. C 78 (2018) 343

And ALICE also!

Alice note 2000-28!!

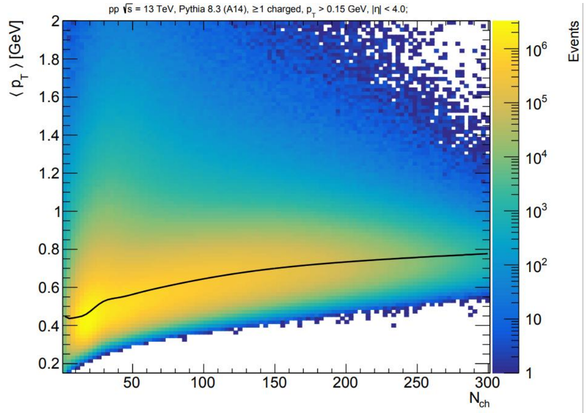
Day One Proton-Proton Physics with the ALICE Central Detector

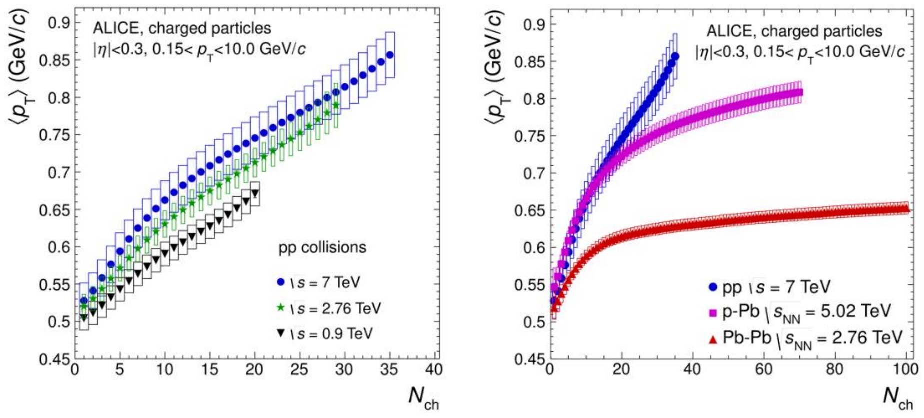
P. Giubellino, S. Kiselev, W. Klempt, A. Morsch, G. Paic, J.-P. Revol and K. Safarik

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;

Where to look – are the “means“sufficient?

- For different reasons the observations we are doing and the accompanying theories are based on “means” – mean multiplicity, transverse momentum, anisotropy, strangeness…
- There is much more than means
- The models can get the most prominent features but never all the details of the interactions if there are multiple sources that contribute
- IMHO they serve to compare models and measurements in a very crude manner.





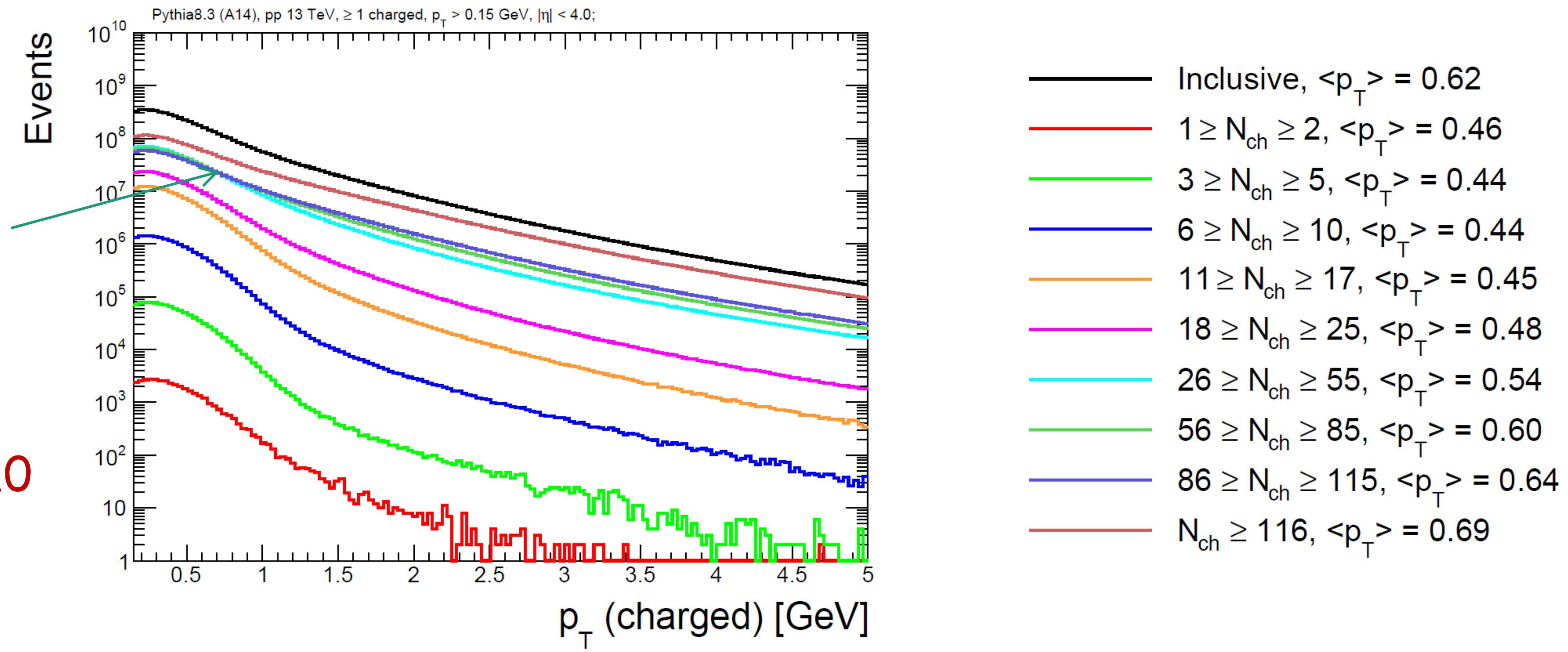
B. Abelev et al. (ALICE Collaboration)
Phys.Lett. **B727** (2013) 371

Going into the details

Instead of plotting the mean pt in function of multiplicity we compare the pt spectra for each multiplicity bin! The simulation shows interesting behavior

Note the evolution in shape of the spectra !

Pythia8.3, pT > 0.15 GeV, |η| < 4.0



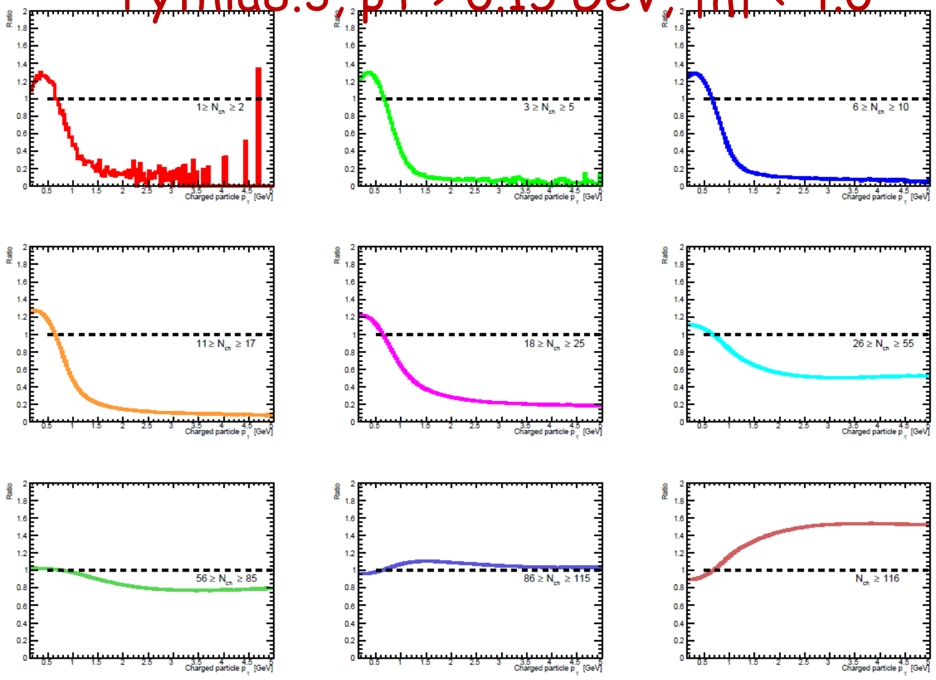
A lot of details appearing while and smalle the change in the mean pt is very gradual

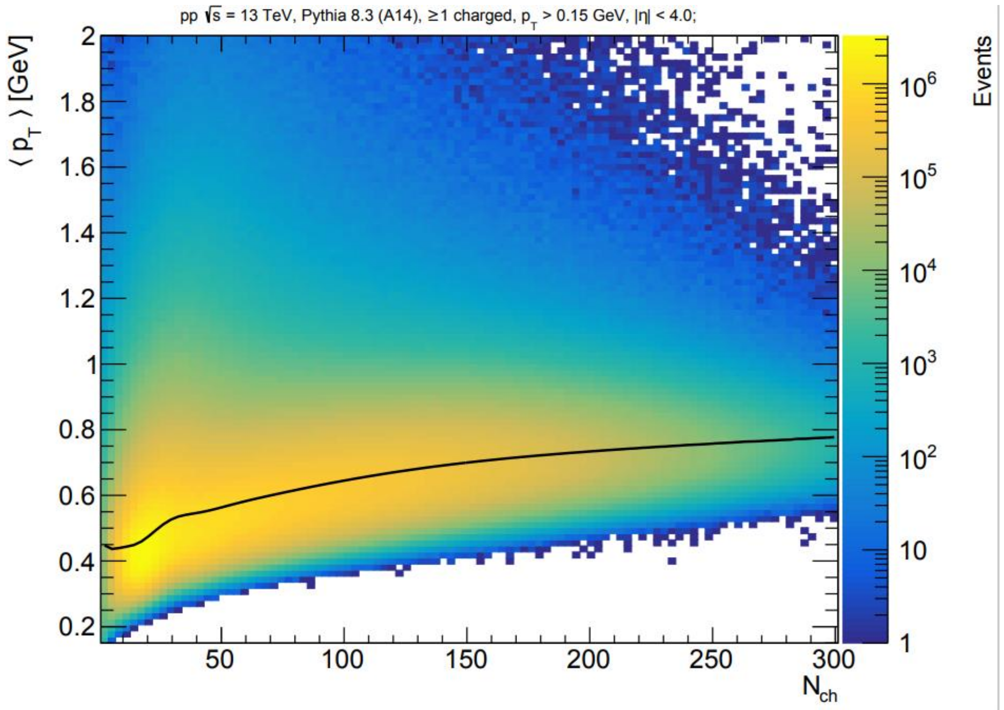
Ratio to inclusive in 9 bins of Nch – rapid changes

We observe clearly two components evolving. One at small pt and one at Pt

Pythia8.3, pT > 0.15 GeV, |η| < 4.0

Within a small multiplicity range important change of shape!

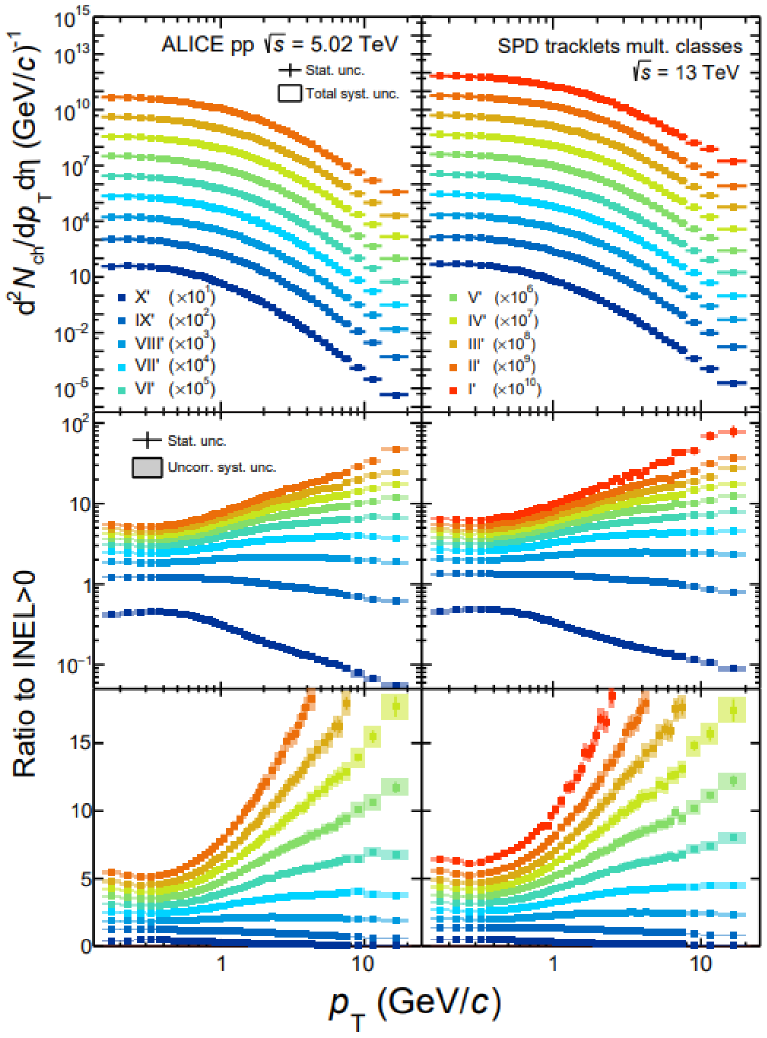




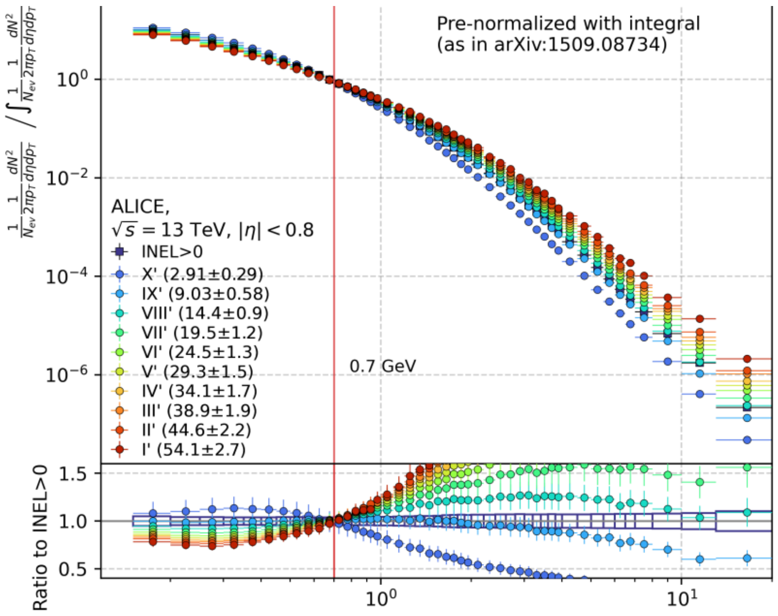
And now with data

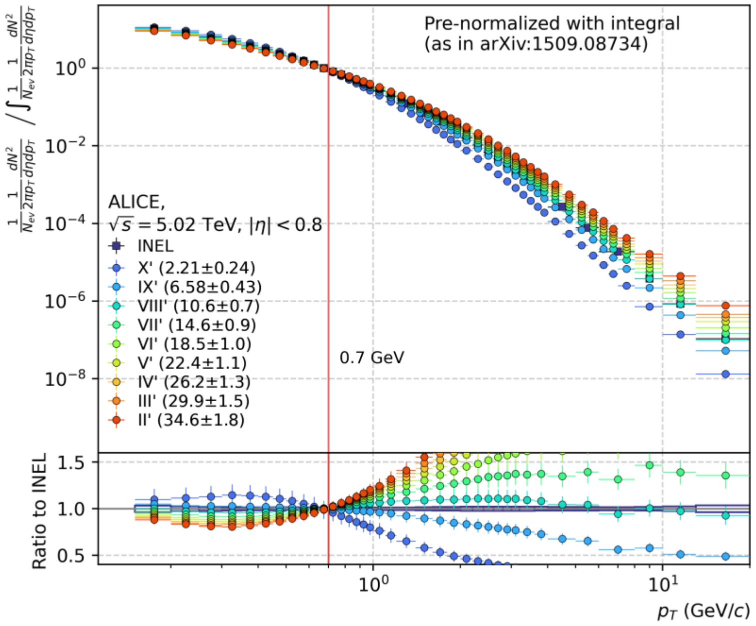
- Charged particle production as a function of multiplicity and transverse spherocity in pp collisions at 5.02 and 13 teV

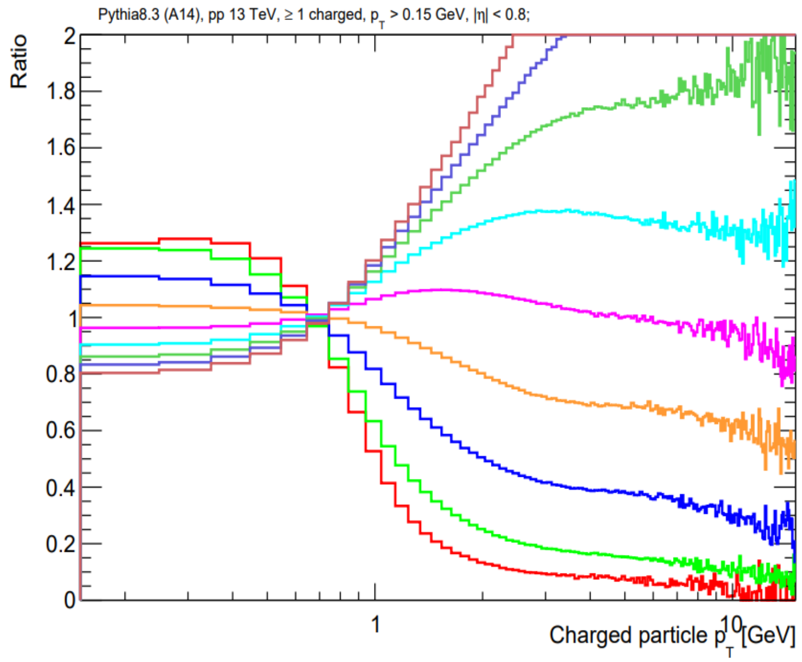
- Eur.Phys.J.C. (2019)79:857



We change slightly the way of representing







Very specific behavior – possibly a way to compare and tune MC

Do we see something that has been also encountered in earlier works at ISR?

Charged Particle Spectra in ~ and ~p Collisions at the CERN ISR CERN-Heidelberg-Lund Collaboration W. Bell 1, K. Braune 2'",

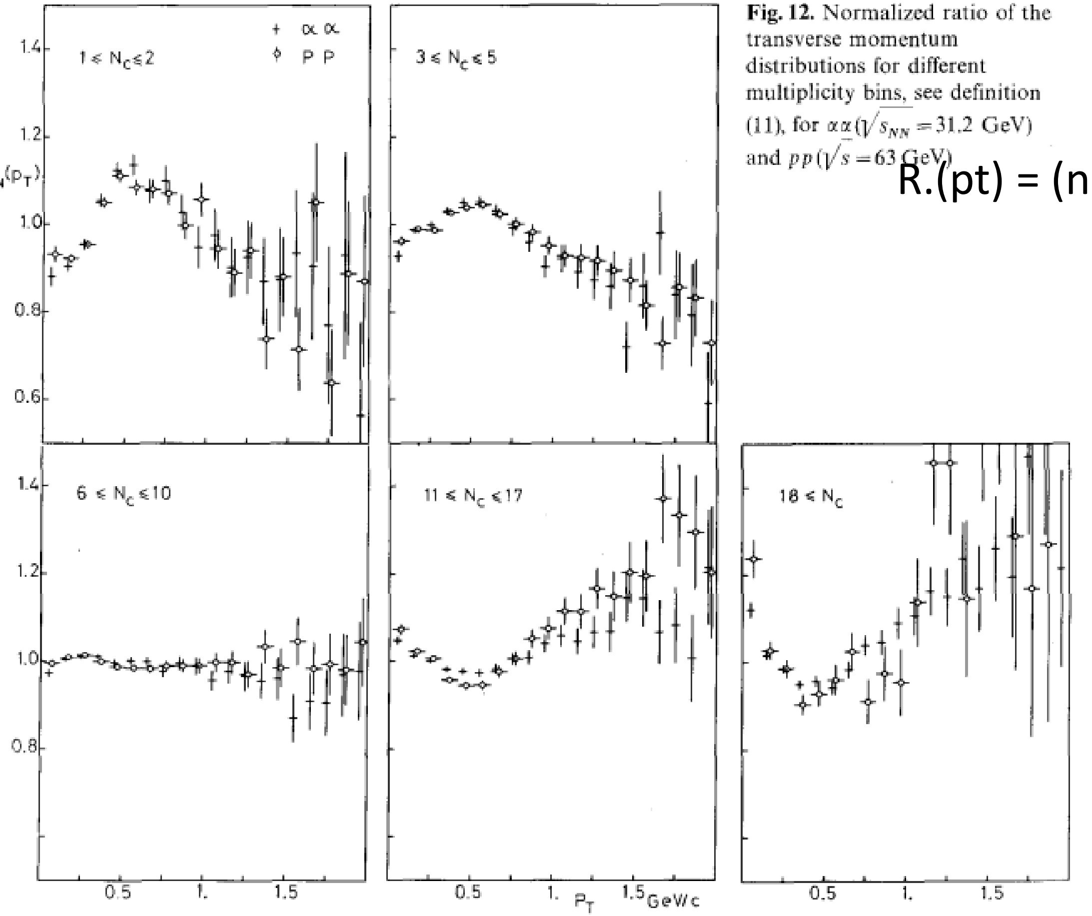
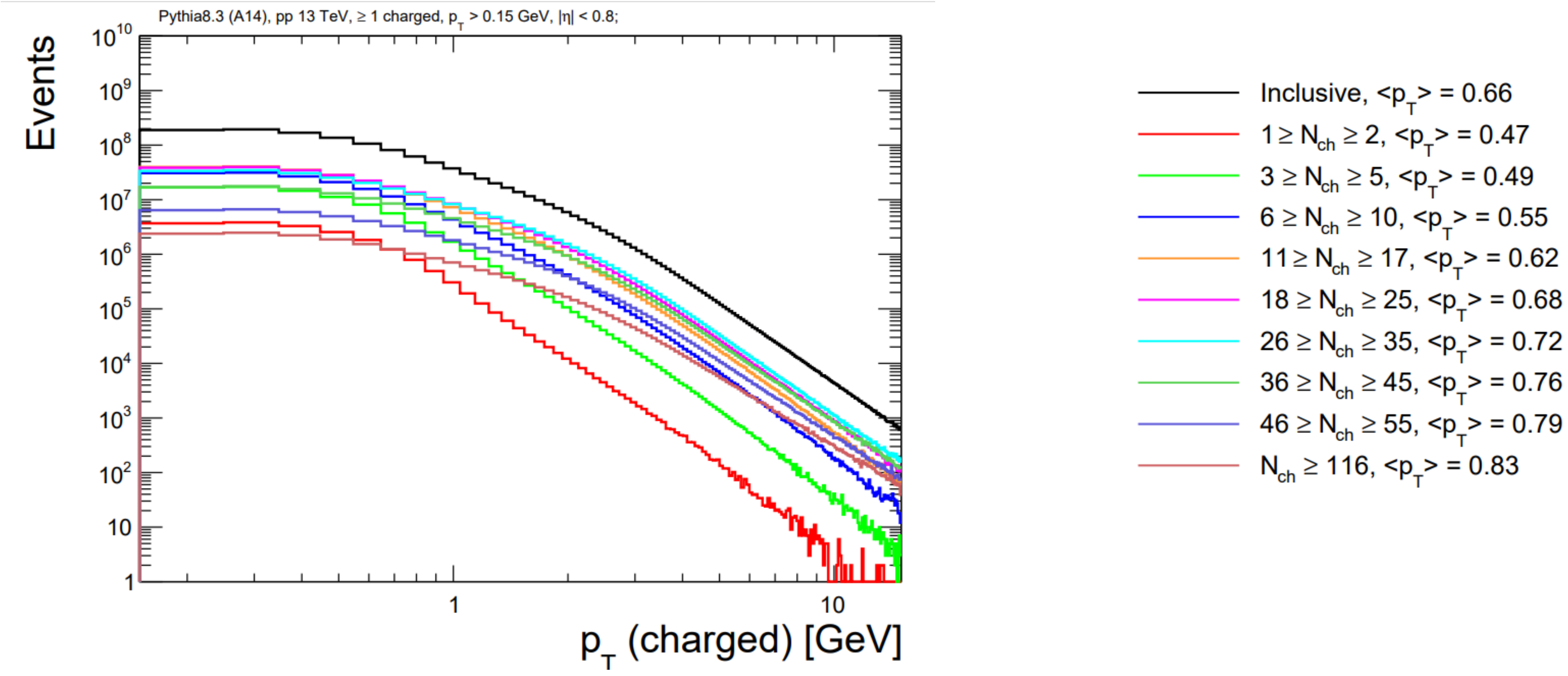


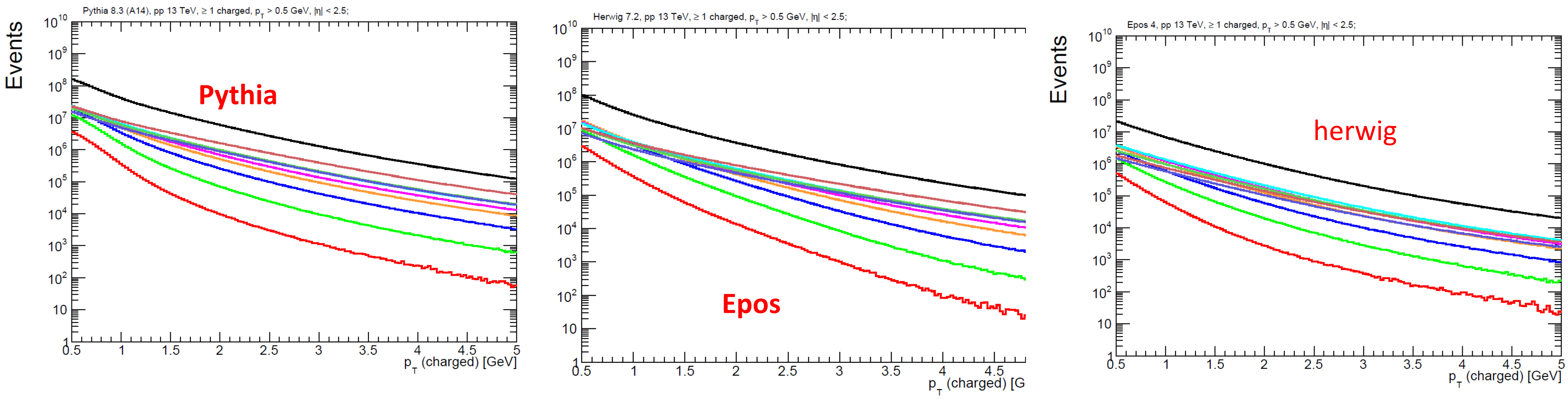
Fig. 12. Normalized ratio of the transverse momentum distributions for different multiplicity bins, see definition (11), for $\alpha\alpha$ ($\sqrt{s_{NN}} = 31.2$ GeV) and pp ($\sqrt{s} = 63$ GeV)

R.(pt) = (n^-1dn/dpt)./<n>^-1<dn/dpt>).

Small changes in the mean but very different in shape of the spectra



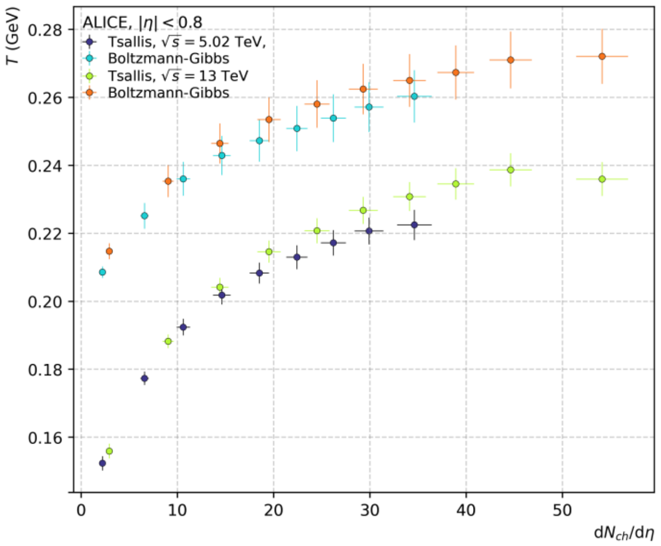
Pythia vs Herwig vs Epos in the pT distribution

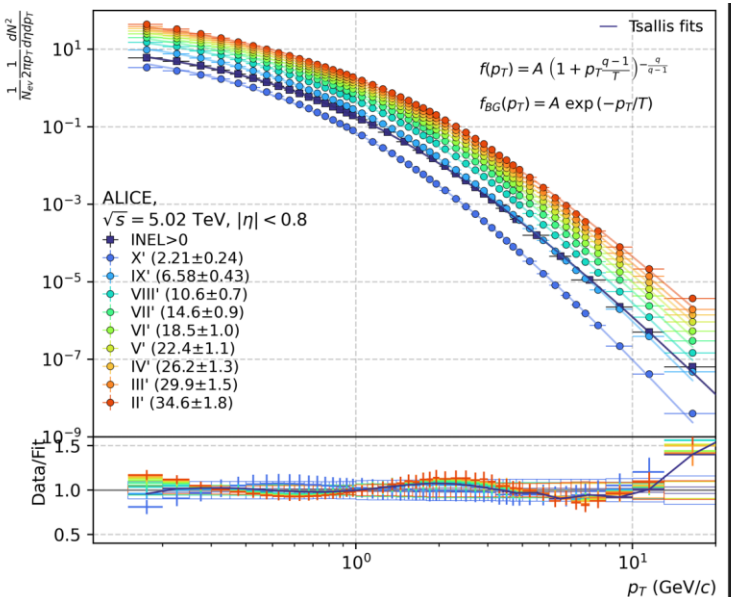


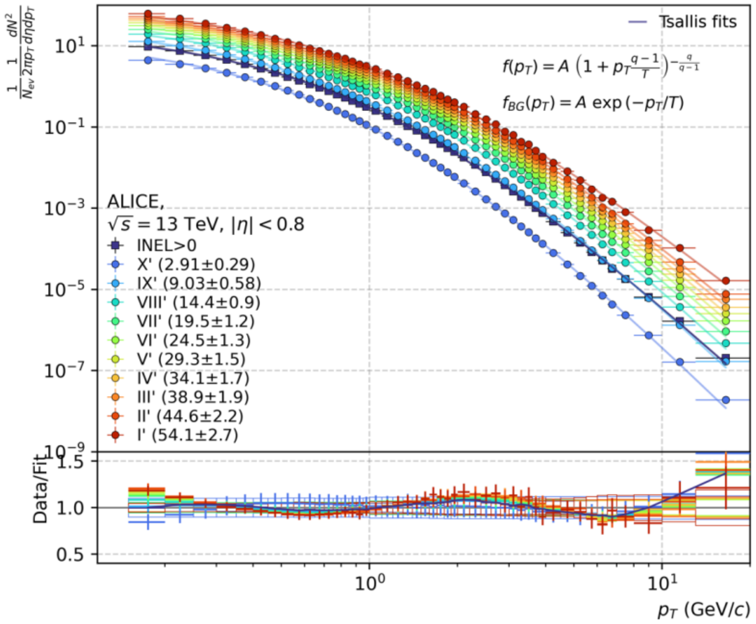
Small differences in the mean pt's but important differences in the spectra!

Pythia	Herwig	Epos
Inclusive, $\langle p_T \rangle$ = 0.98	Inclusive, $\langle p_T \rangle$ = 0.99	Inclusive, $\langle p_T \rangle$ = 1.02
$1 \geq N_{ch} \geq 2$, $\langle p_T \rangle$ = 0.72	$1 \geq N_{ch} \geq 2$, $\langle p_T \rangle$ = 0.76	$1 \geq N_{ch} \geq 2$, $\langle p_T \rangle$ = 0.77
$3 \geq N_{ch} \geq 5$, $\langle p_T \rangle$ = 0.77	$3 \geq N_{ch} \geq 5$, $\langle p_T \rangle$ = 0.82	$3 \geq N_{ch} \geq 5$, $\langle p_T \rangle$ = 0.85
$6 \geq N_{ch} \geq 10$, $\langle p_T \rangle$ = 0.84	$6 \geq N_{ch} \geq 10$, $\langle p_T \rangle$ = 0.87	$6 \geq N_{ch} \geq 10$, $\langle p_T \rangle$ = 0.91
$11 \geq N_{ch} \geq 17$, $\langle p_T \rangle$ = 0.90	$11 \geq N_{ch} \geq 17$, $\langle p_T \rangle$ = 0.92	$11 \geq N_{ch} \geq 17$, $\langle p_T \rangle$ = 0.98
$18 \geq N_{ch} \geq 25$, $\langle p_T \rangle$ = 0.95	$18 \geq N_{ch} \geq 25$, $\langle p_T \rangle$ = 0.97	$18 \geq N_{ch} \geq 25$, $\langle p_T \rangle$ = 1.01
$26 \geq N_{ch} \geq 35$, $\langle p_T \rangle$ = 1.00	$26 \geq N_{ch} \geq 35$, $\langle p_T \rangle$ = 1.02	$26 \geq N_{ch} \geq 35$, $\langle p_T \rangle$ = 1.05
$36 \geq N_{ch} \geq 45$, $\langle p_T \rangle$ = 1.03	$36 \geq N_{ch} \geq 45$, $\langle p_T \rangle$ = 1.06	$36 \geq N_{ch} \geq 45$, $\langle p_T \rangle$ = 1.07
$46 \geq N_{ch} \geq 55$, $\langle p_T \rangle$ = 1.07	$46 \geq N_{ch} \geq 55$, $\langle p_T \rangle$ = 1.10	$46 \geq N_{ch} \geq 55$, $\langle p_T \rangle$ = 1.09
$N_{ch} \geq 56$, $\langle p_T \rangle$ = 1.11	$N_{ch} \geq 56$, $\langle p_T \rangle$ = 1.15	$N_{ch} \geq 56$, $\langle p_T \rangle$ = 1.11

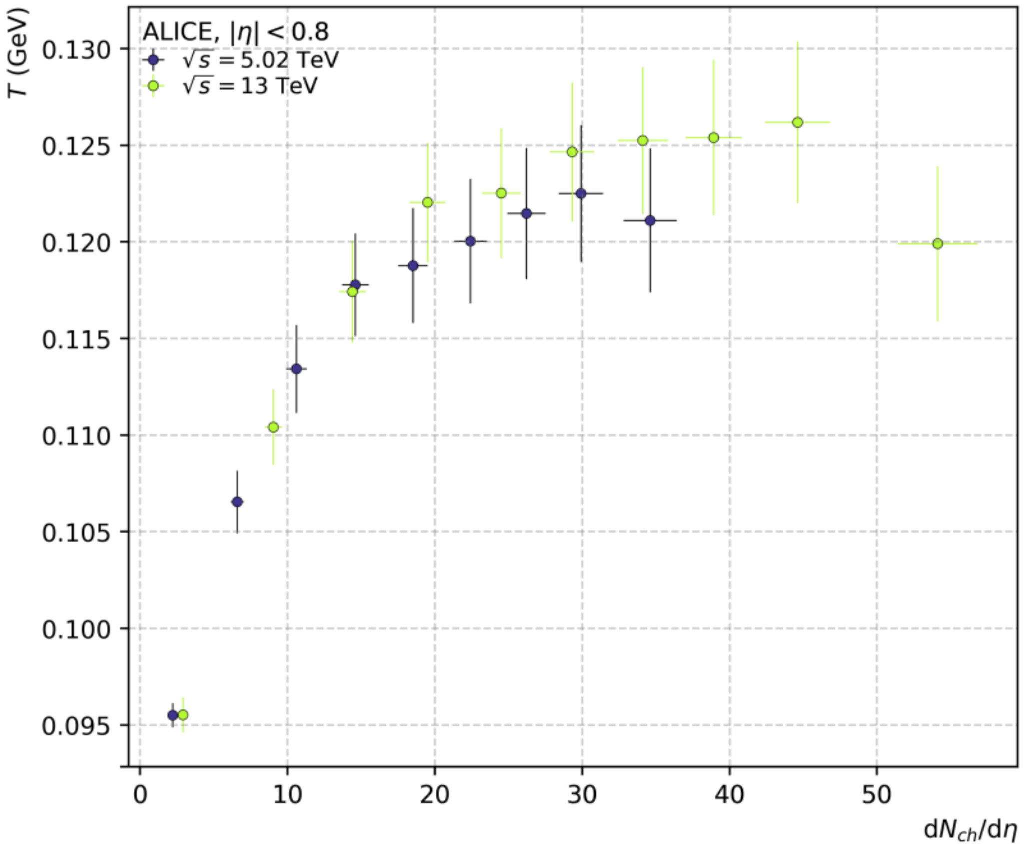
Comparison with Tsallis fit

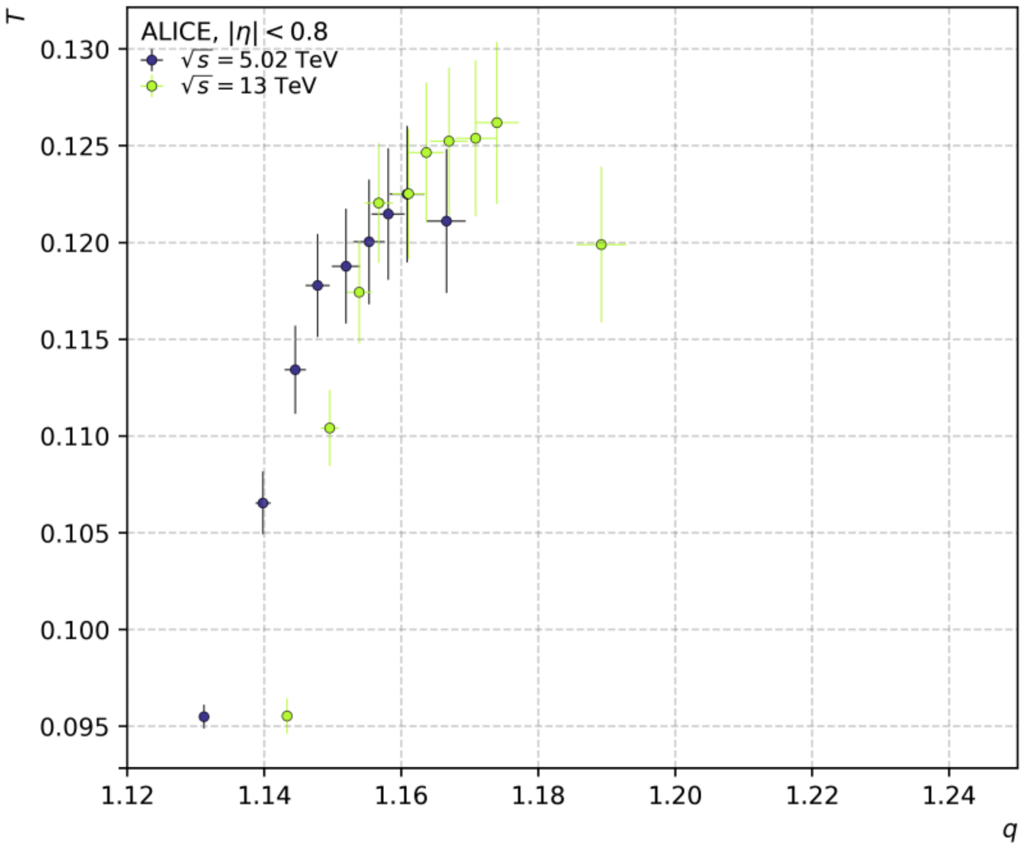






Tsallis parameters varation





The tsallis entropy

Given a discrete set of probabilities $\{p_i\}$ with the condition $\sum_i p_i = 1$, and q any real number, the **Tsallis entropy** is defined as

$$S_q(p_i) = \frac{k}{q-1}\left(1 - \sum_i p_i^q\right),$$

where q is a real parameter sometimes called *entropic-index* and k a positive constant. In the limit as $q \to 1$, the usual Boltzmann–Gibbs entropy recovered, namely

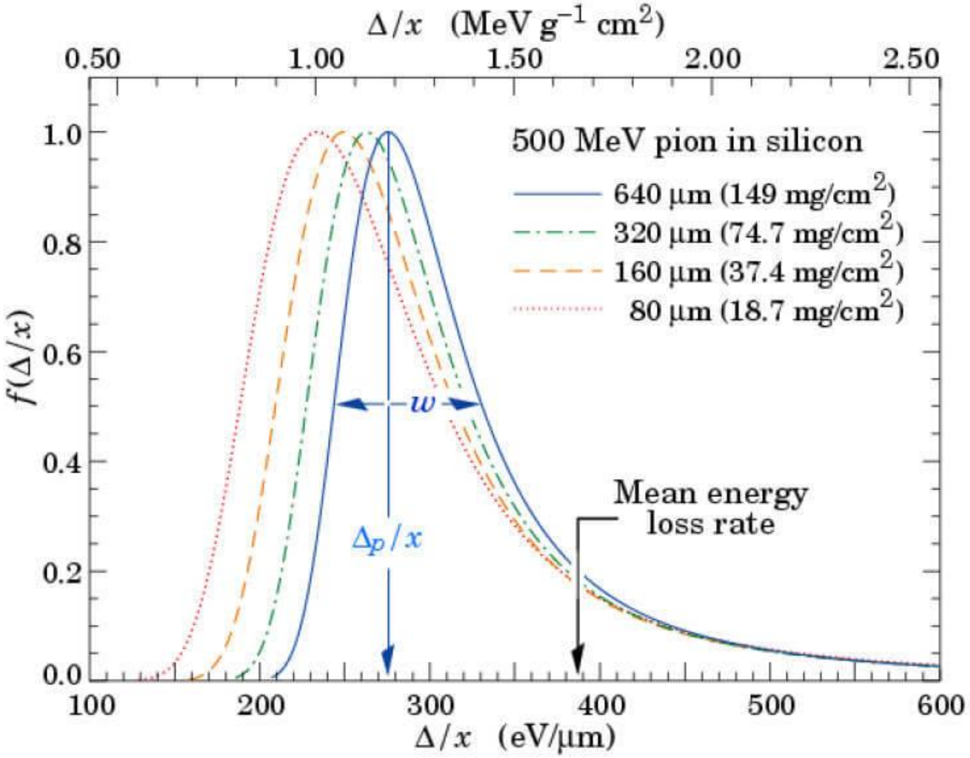
$$S_{\mathrm{BG}} = S_1(p) = -k \sum_i p_i \ln p_i,$$

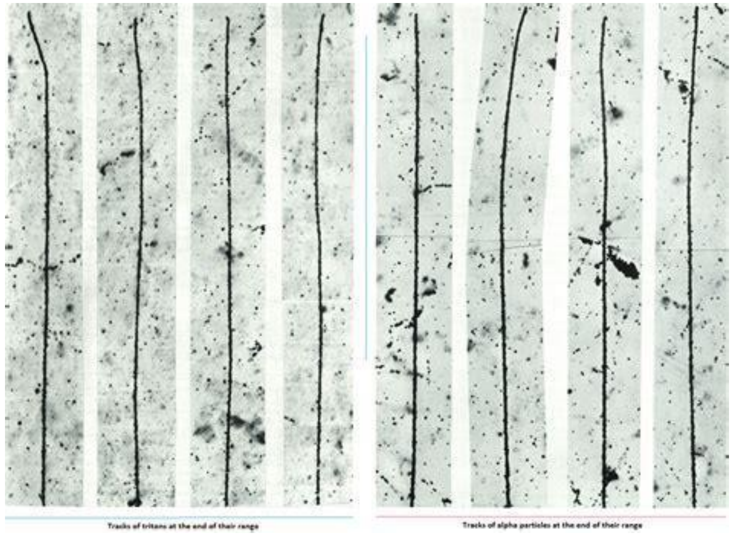
where one identifies k with the Boltzmann constant k_B.

Conclusion

- The detailed investigation of the spectra in function of pt has a larger sensitivity than the mere means.
- The means **do not** reflect completely the situation!
- We should try to push for more details!

The meaning of the “means”





Deta rays around a track@

- **Take the example of the “landau”curve for energy loss in a medium!**

QGP or strings?

- The experimental facts especially those on pp collisions are also at the heart of an important debate:
  - The models based on strings (Pythia etc), and the hydro models (CGC etc) are about equally successful in describing the experimental results!
  - The question has also political overtones - dangerous in science!