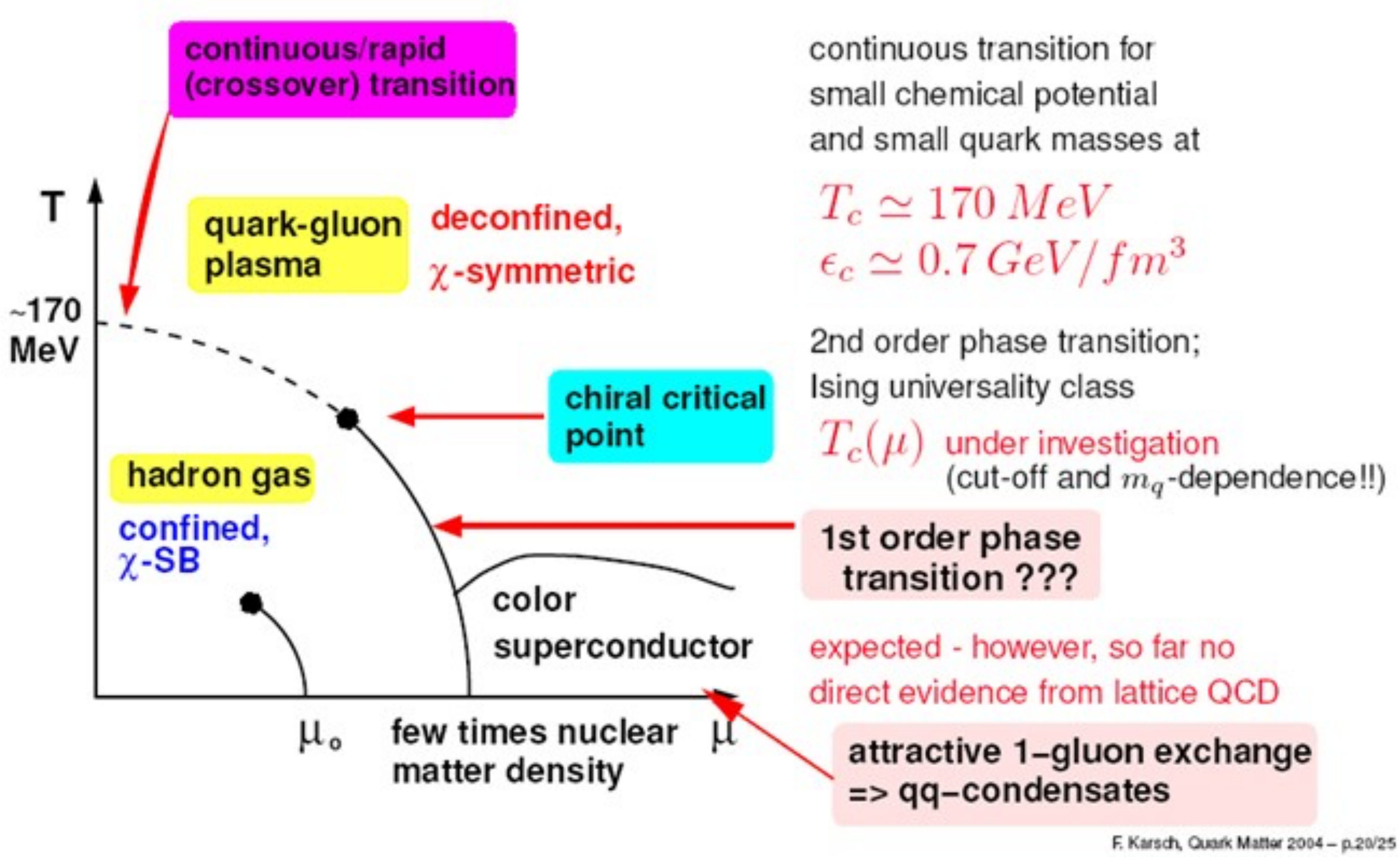
3ra Reunión Anual RED-ALICE

Señales de colectividad en p-Pb y p-p a energías de LHC

Irais Bautista
Cátedra CONACYT -FCFM BUAP

21-10- 2016



continuous transition for small chemical potential and small quark masses at

$$T_c \simeq 170\ MeV$$
$$\epsilon_c \simeq 0.7\ GeV/fm^3$$

2nd order phase transition; Ising universality class

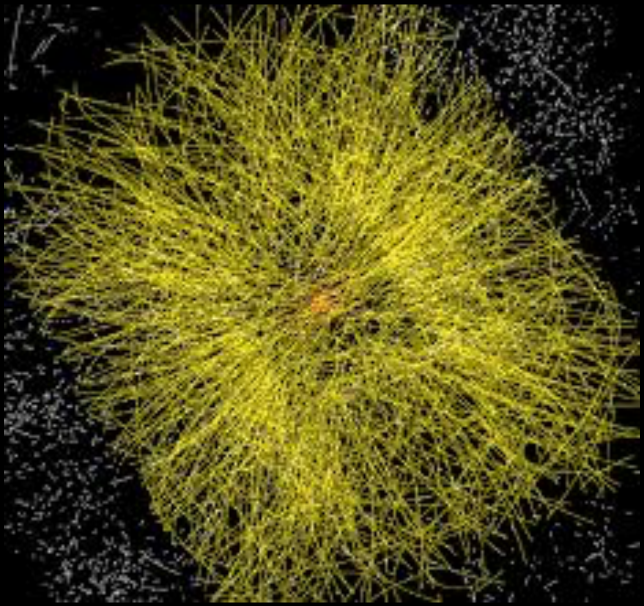
$T_c(\mu)$ under investigation (cut-off and m_q-dependence!!)

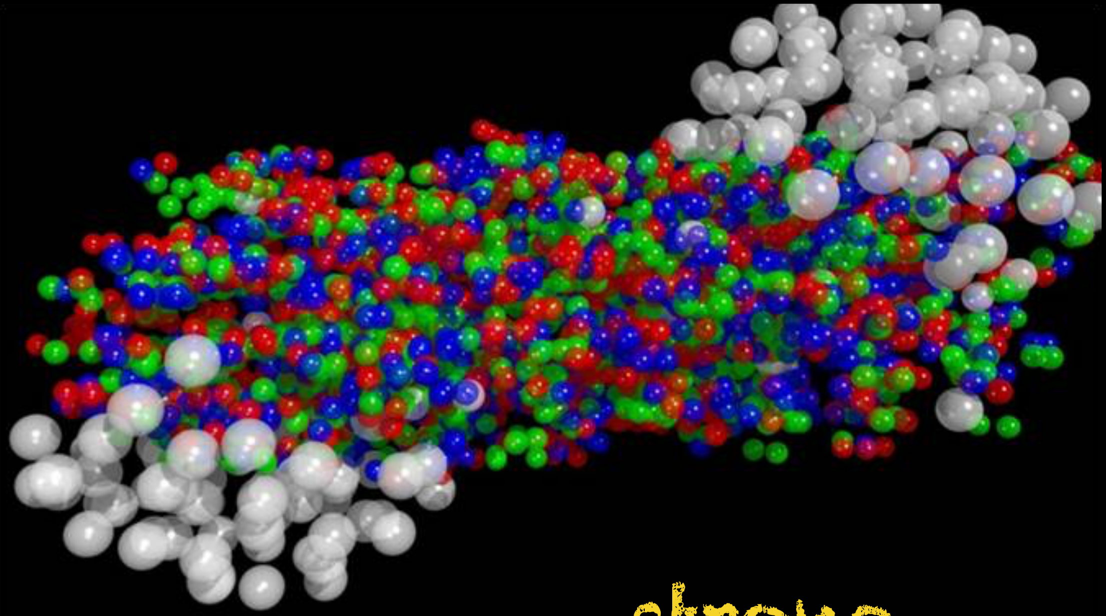
expected - however, so far no direct evidence from lattice QCD

F. Karsch, Quark Matter 2004 – p.20/25

Quark Gluon Plasma

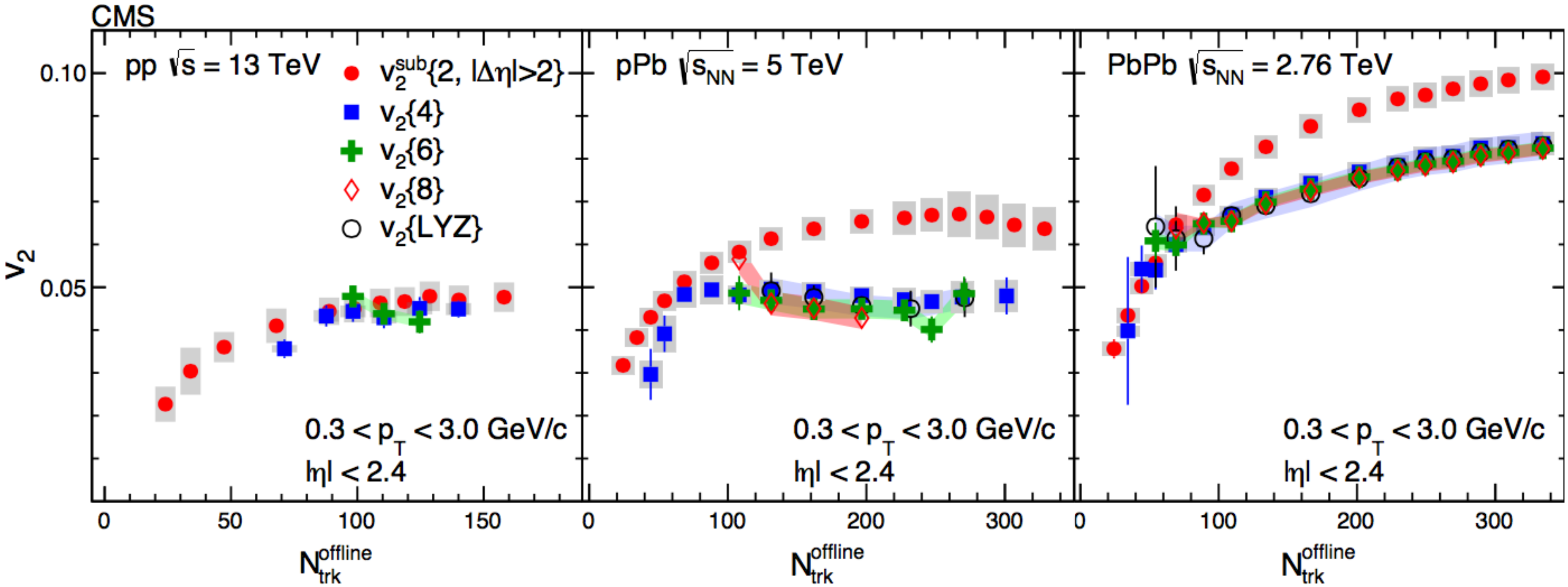
sQGP





small

strong



The elliptic-flow harmonic v₂ extracted using two- and multi-particle correlations, as a function of particle multiplicity in pp, pPb and PbPb collisions.
Reported by CMS arXiv:1606.06198.

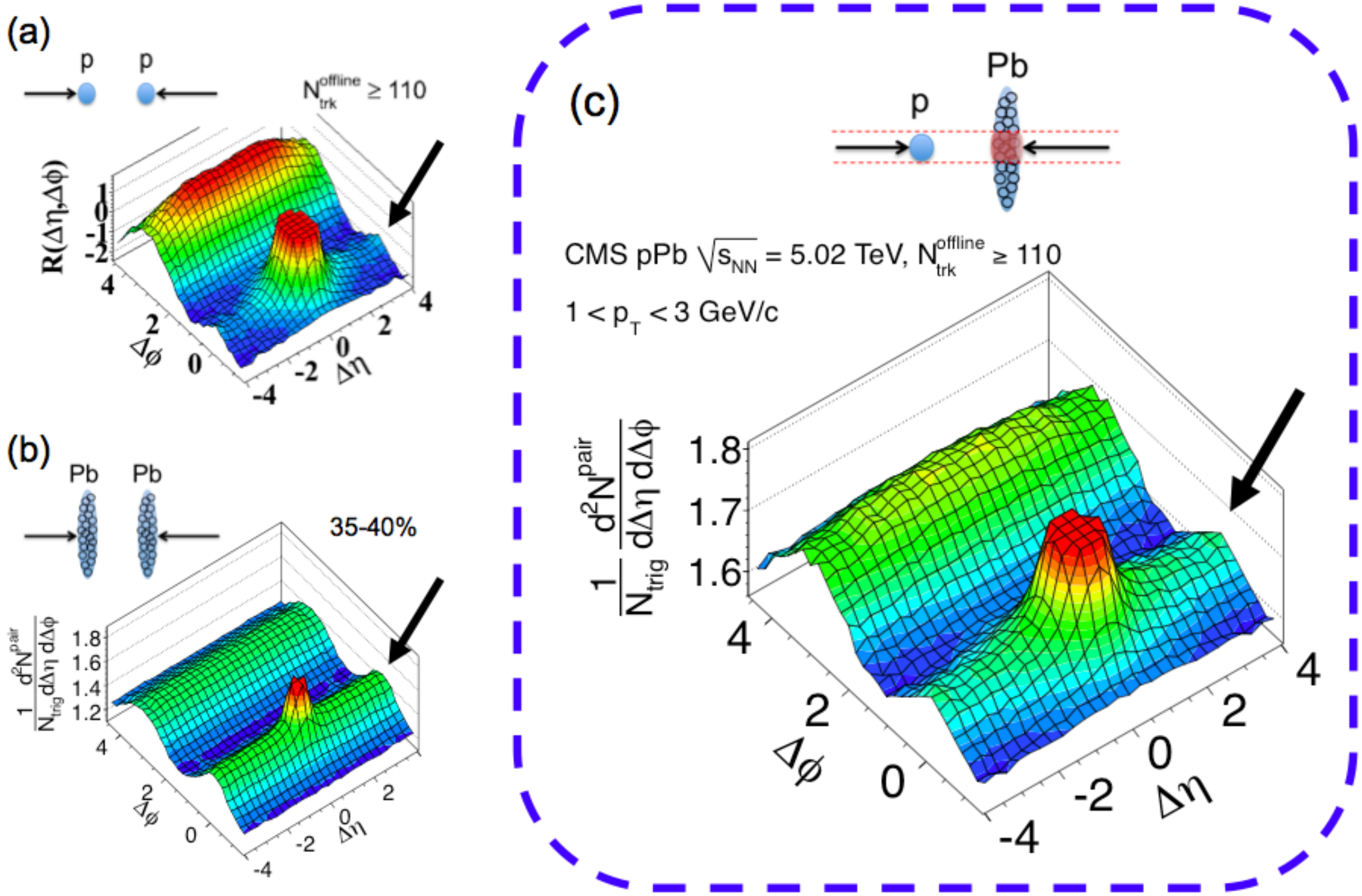
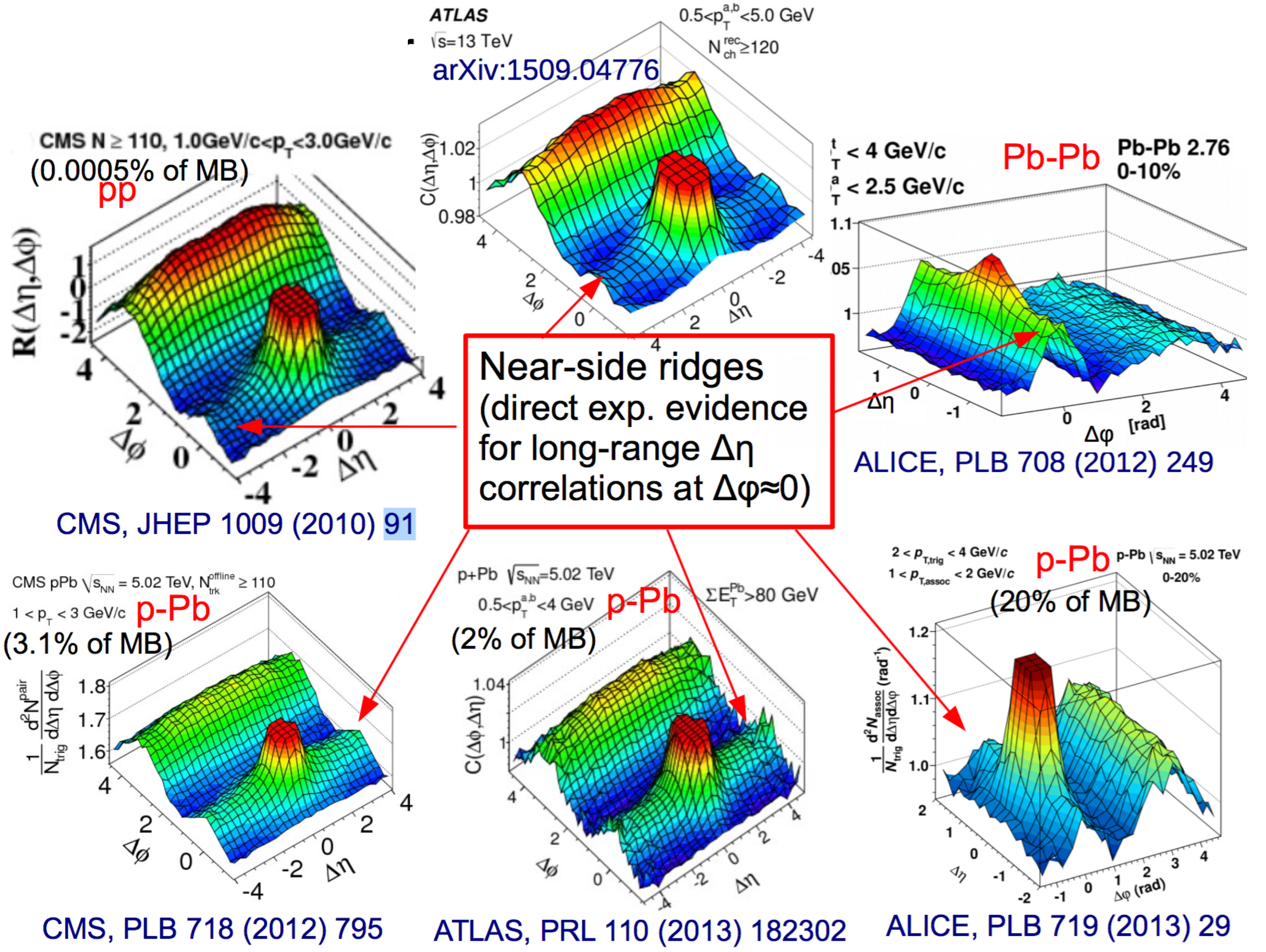


Figure from: 2nd Conference on Heavy Ion Collisions in the LHC Era and Beyond, Quy Nhon, Vietnam, 27 Jul – 02 Aug, 2015



arXiv:1509.04776

Near-side ridges (direct exp. evidence for long-range Δη correlations at Δφ≈0)

CMS, JHEP 1009 (2010) 91

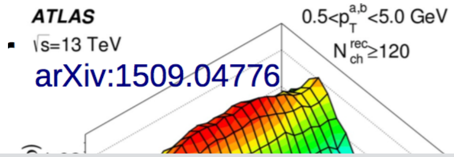
ALICE, PLB 708 (2012) 249

CMS, PLB 718 (2012) 795

ATLAS, PRL 110 (2013) 182302

ALICE, PLB 719 (2013) 29

Figure from: 2nd Conference on Heavy Ion Collisions in the LHC Era and Beyond, Quy Nhon, Vietnam, 27 Jul – 02 Aug, 2015



arXiv:1509.04776

Posible explanations:
(collectivity QGP formation)

Hydrodinamics

Li Yan and Jean-Yves Ollitrault. Phys. Rev. Lett. 112, 082301 – 25 February 2014

Color Glass

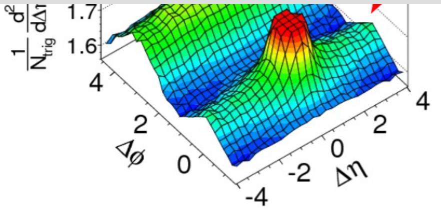
J. Orjuela Koop, A. Adare, D. McGlinchey, J. L. Nagle, arXiv:1501.06880.

SPM

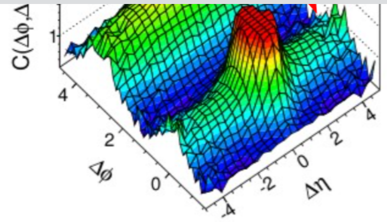
Bautista, A. Fernandez, P. Ghosh, Phys. Rev D 92 (2015) 7, 0172504
L.J. Gutay, A.S. Hirsch, et al. 2 pp. Published in Int.J.Mod.Phys. E24 (2015) no.12, 1550101

Color reconnection

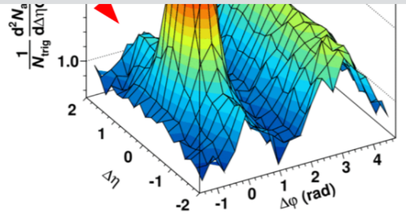
Antonio Ortiz, Peter Christiansen, Eleazar Cuautle, Ivonne Maldonado, Guy Paic Phys. Rev. Lett. 111, 042001 (2013)



CMS, PLB 718 (2012) 795



ATLAS, PRL 110 (2013) 182302



ALICE, PLB 719 (2013) 29

Figure from: 2nd Conference on Heavy Ion Collisions in the LHC Era and Beyond, Quy Nhon, Vietnam, 27 Jul – 02 Aug, 2015

Work on progress

- **Phase change signals in small systems on SPM p-Pb, p-p high multiplicity (Phenomelogy) (Thesis 2 Students: Pablo Fierro, Ricardo Alvarado)**

- **Study Jet/bulk evolution as a function of event multiplicity on p-p; Mean transverse momentum event by event fluctuations in collaboration of Antonio Ortiz, Pablo Fierro (Analysis +Phenomenology) (Discussions with Group ICN-UNAM)**

Phase change signals in small systems on SPM p-Pb, p-p high multiplicity (Phenomelogy)

(Thesis 2 Students: Pablo Fierro, Ricardo Alvarado)

String Percolation Model

- Macroscopic system where we have the formation of related structures, which each time goes bigger by a random addition of links process between the components.

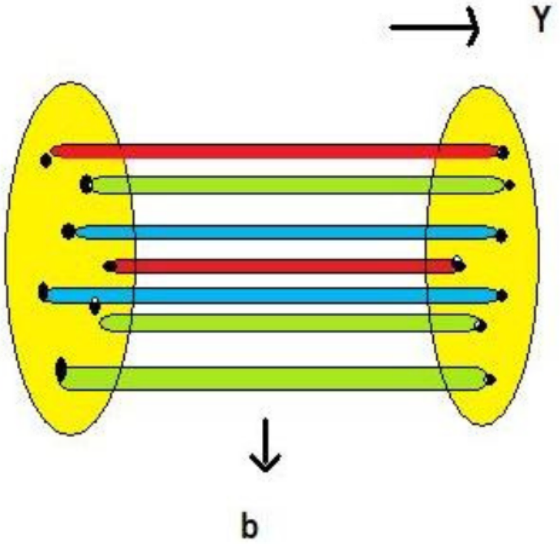
- For a given critical density of links one gets a macro-structure called cluster (dimension of the order of the total system).

String Percolation Model

- In the transverse impact parameter plane the strings look like discs (2 dimensional percolation theory)

Increases with:

$\sqrt{s},\ N_{part}$

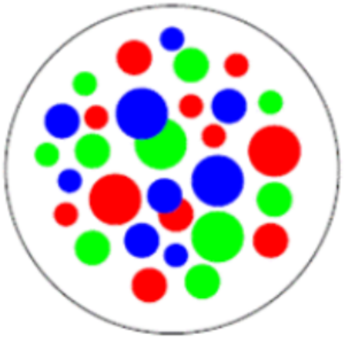


$r_0 \sim 0.25$ fm

$S_1 = \pi r_0^2$

String Percolation Model

- **At the critical density a macroscopic cluster appears and marks a geometrical phase transition.**



String Percolation Model

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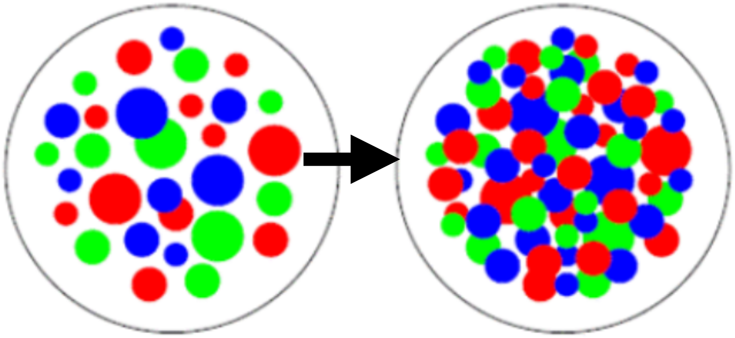
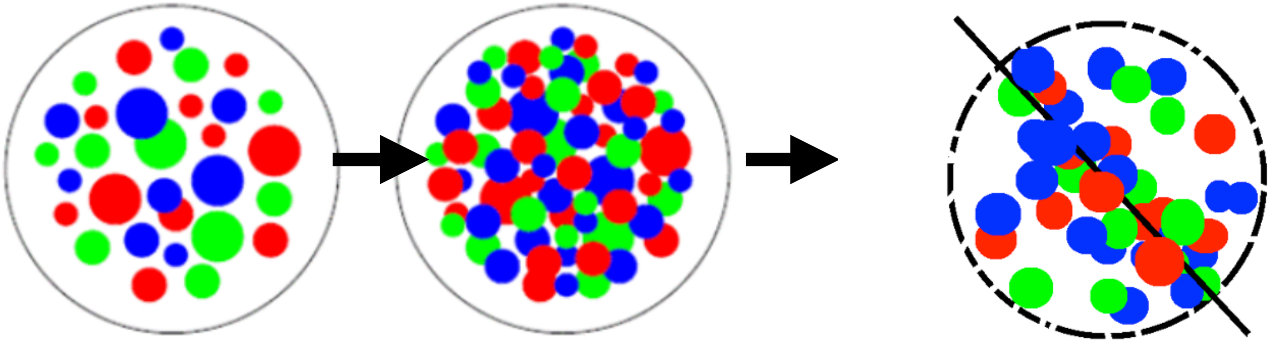


String Percolation Model

- At the critical density a macroscopic cluster appears and marks a geometrical phase transition



- Due to the color random summation of the color charges SU(3) the total change generates a reduction in multiplicity and an increase in the string tension

- The stretched strings between the partons decay into new pairs of partons and so new strings are formed. Subsequently, particles are produced from interaction of partons by the Schwinger Mechanism

String Percolation Model

- The critical parameter is the string density.

$$\xi = N_s \frac{S_1}{S_A}, \; \xi_c = 1.1 - 1.5$$

- The area cover when a critical value is reached is given by

$$1 - e^{-\xi}$$

- We asume that a cluster behaves as a single string but with higher momentum and color

- In the n large limit the multiplicities and the transverse momentum can be express as:

$$< \mu_n > = \sqrt{\frac{nS_n}{S_1}} < \mu_1 > \; , \; < p_{Tn}^2 > = \sqrt{\frac{nS_1}{S_n}} < p_{T1}^2 >$$

multiplicity → $\frac{dn}{dy} \sim F(\xi)\bar{N}_s$

color reduction factor → $F(\xi) = \sqrt{\frac{1-e^{-\xi}}{\xi}}$

number of strings → $N_p^s = 2+4\left(\frac{r_0}{R_p}\right)^2\left(\frac{\sqrt{s}}{m_p}\right)^{2\lambda}$

string density
in pp collisions → $\xi = N_p^s(\frac{r_0}{R_p})^2$

multiplicity → $\frac{dn}{dy} \sim F(\xi)\bar{N}_s$

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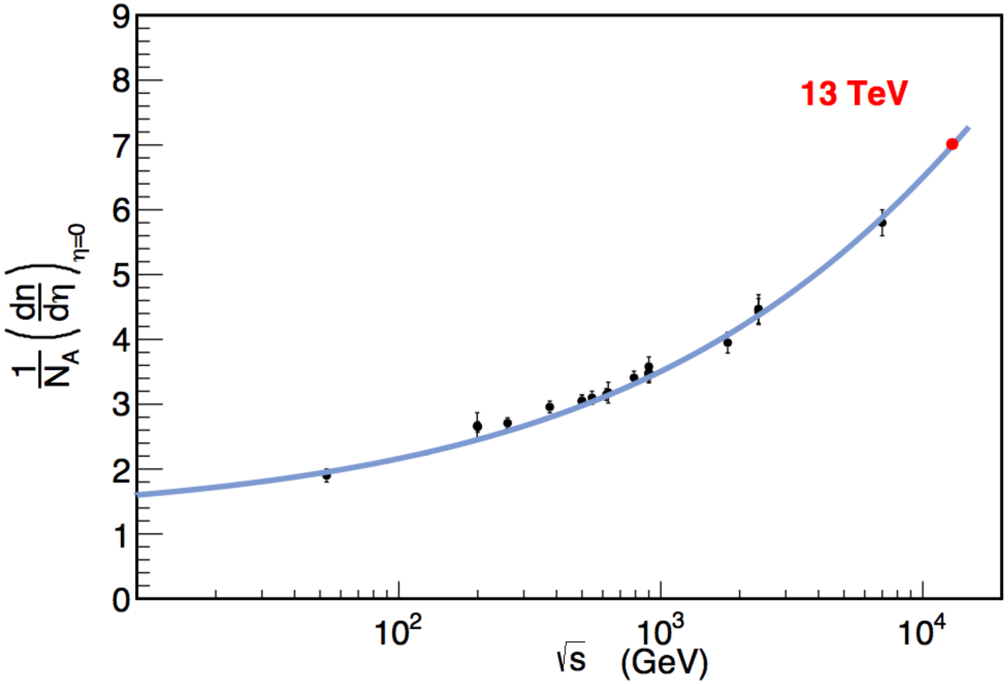
string density
in pp collisions → $\xi = N_p^s\left(\frac{r_0}{R_p}\right)^2$

$\lambda = .201$

proton mass

proton radius

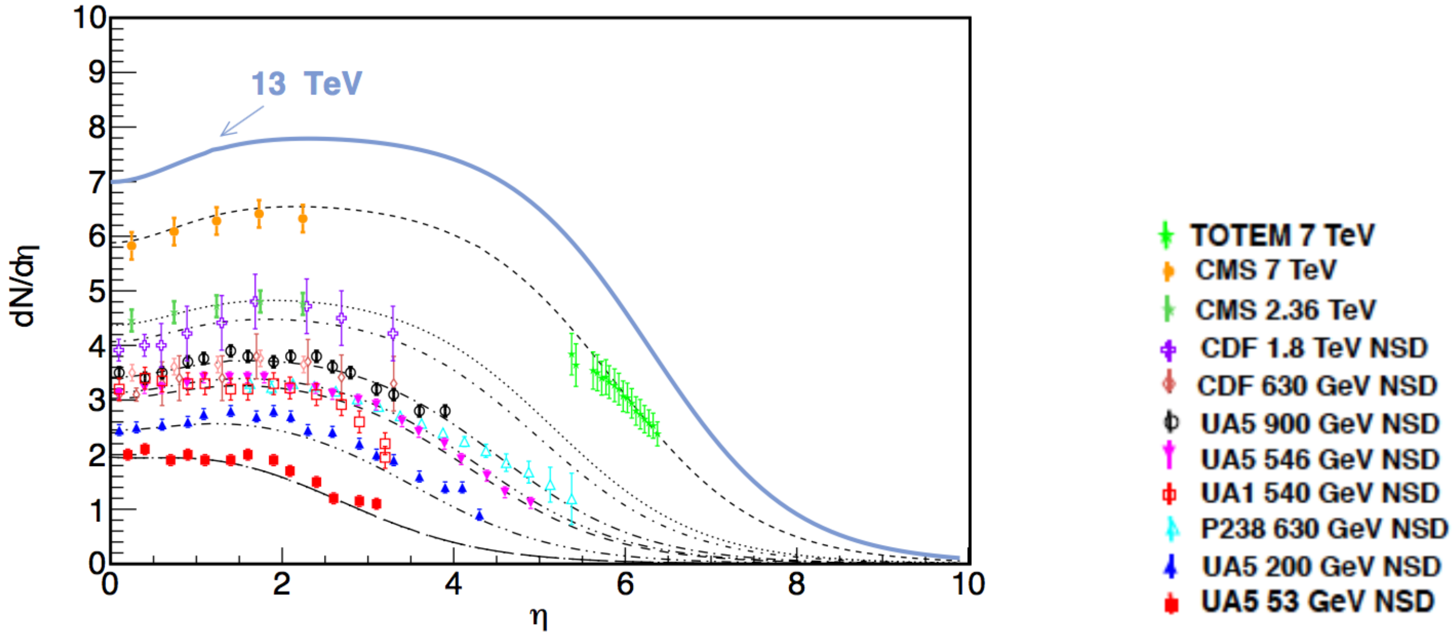
- $dn_{ch}^{pp}/dy|_{y=0} = \kappa F(\xi) N_p^s$ with $\kappa = .63$



Multiplicity dependence on $\sqrt{s}$. Data from $p-p$ PDG,

I. Bautista, J. G. Milhano, C. Pajares and J. Dias de Deus, Phys. Lett. B715, 230 (2012).

- $dn_{ch}^{pp}/d\eta|_{\eta} = \kappa' J F(\xi) N_p^s \frac{1}{\exp\left(\frac{\eta-(1-\alpha)Y}{\delta}\right)+1}$



Comparison of the results from the evolution of the $\frac{dn_{ch}}{d\eta}$ with dependence in pseudorapidity for $p-p$ collisions at different energies (lines).

I. Bautista,J. Dias de Deus, C. Pajares, Phys.Rev. C86 (2012) 034909.

Transverse momentum distribution

$$\frac{d^2N}{dp_T^2} = \omega(\alpha, p_0, p_T) = \frac{(\alpha-1)(\alpha-2)}{2\pi p_0^2}\frac{p_0^\alpha}{[p_0+p_T]^\alpha}$$

$$\frac{d^2N}{dp_T^2} = \frac{(\alpha-1)(\alpha-2)\left(p_0\sqrt{\frac{F(\zeta_{pp})}{F(\zeta_{HM})}}\right)^{\alpha-2}}{2\pi\left[p_0\sqrt{\frac{F(\zeta_{pp})}{F(\zeta_{HM})}}+p_T\right]^\alpha}$$

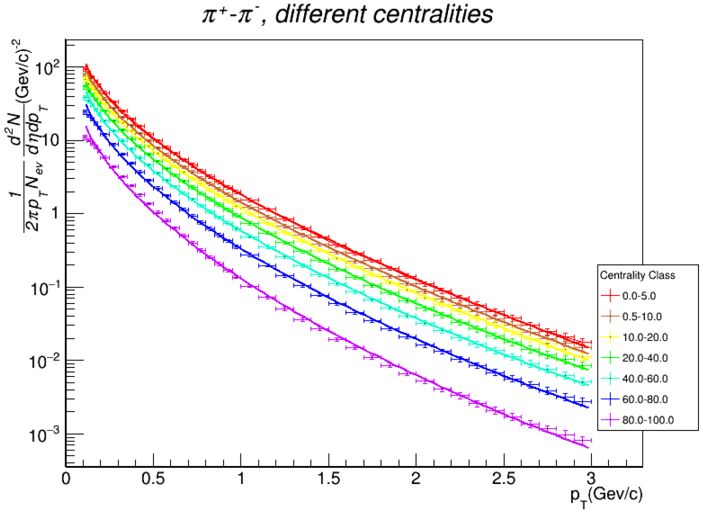
$$\frac{1}{N}\frac{d^2N}{d\eta\, dp_T} = a'(\sqrt{s})\frac{dN}{d\eta}\Big|^{pp}_{\eta=0}(\sqrt{s})\,\omega(\alpha, p_0, p_T) = \frac{a\left(p_0\frac{F(\zeta_{pp})}{F(\zeta_{HM})}\right)^{\alpha-2}}{\left[p_0\sqrt{\frac{F(\zeta_{pp})}{F(\zeta_{HM})}}+p_T\right]^{\alpha-1}}$$

Shear viscosity / entropy

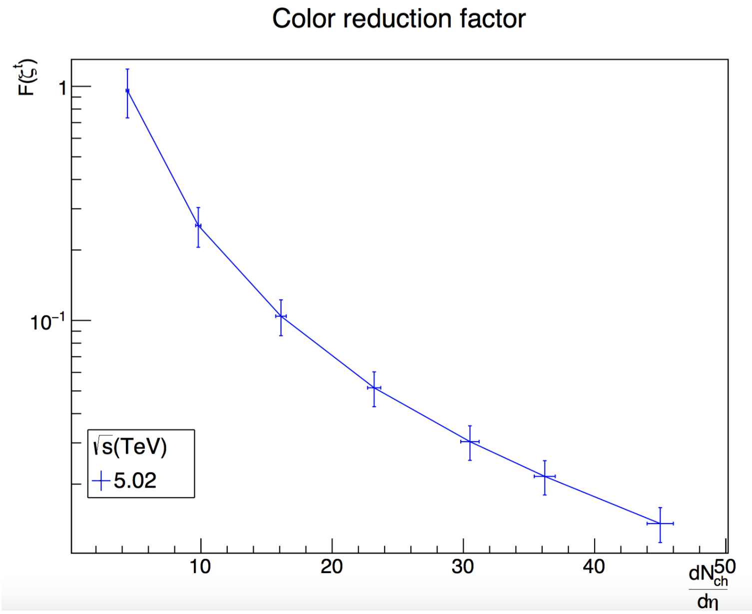
- In the relativistic kinetic theory $\frac{\eta}{s} \simeq \frac{T\lambda_{fp}}{5}$
- $\lambda_{fp} \sim \frac{1}{n\sigma_{tr}}$ is the mean free path
- $n = \frac{N_{sources}}{S_N L}$ is the density of the effective number of sources per unit volume
- We considered $\frac{N_{sources}}{S_N L}\sigma_{tr} = (1-e^{-\zeta^t})/L$, and L=1fm the longitudinal extension of the source.

$$\frac{\eta}{s} = \frac{TL}{5(1-e^{-\zeta^t})}$$

p-Pb at 5.02 TeV

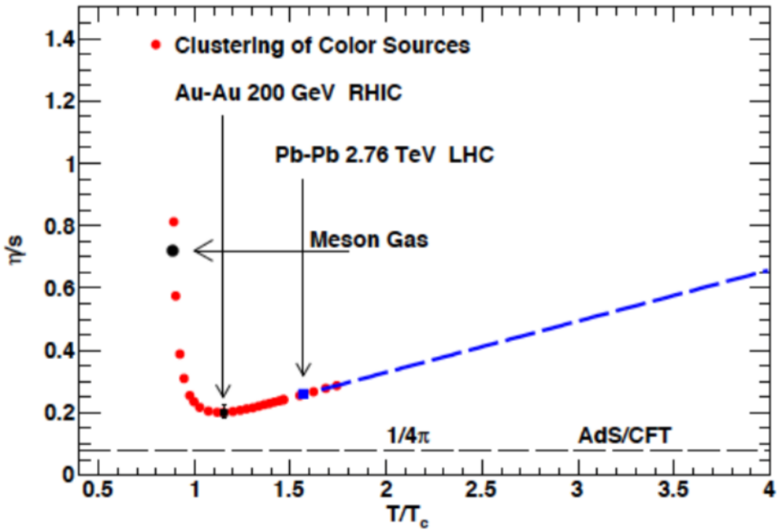


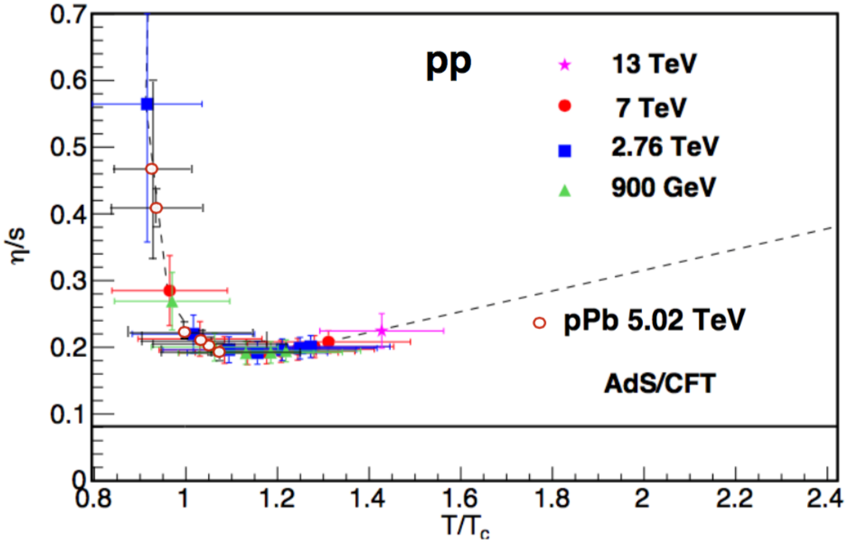
Transverse momentum spectra fits to SPM. Data taken from: Data taken from: http://hepdata.cedar.ac.uk/view/ins1244523



Color reduction factor and Temperature as a function of the charge multiplicity on p-Pb collisions at 5.02 TeV results from the SPM model.

Shear viscosity / entropy





On the right Shear viscosity over entropy ratio for 7 TeV high multiplicity classes corresponding to $N_{track} = 40$ to $N_{track} = 131$, with the $T_c = 154 \pm 9$. In here we have plot the corresponding value corresponding to an approximate number of tracks $\sim 155 \pm 7$ corresponding to high multiplicity event in 13 TeV. Left side calculations the T_c value was taken as 167 MeV for heavy ion B. K. Srivastava, Eur. Phys. J. C72.

Now we need to calculate the bulk viscosity contribution (Thesis: Ricardo Alvarado)

On small systems the initial state geometry effects become relevant on SPM (work in progress with: J. Eredi Cancino, Arturo Fernández)

Study Jet/bulk evolution as a function of event multiplicity on p-p and p-Pb

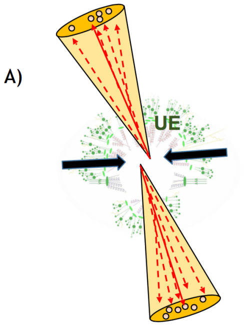
How to?

- By using spherocity as an event shape tool to select events by their topology we select the contribution from jet like events from the isotropic ones corresponding to the bulk.

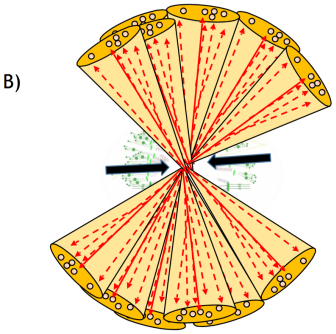
- By studying different acceptance on the Multiplicity estimator.

- A complementary study can be made in order to ensure accuracy in the jet contribution by implementing a jet finder routine which is based on the anti kT ordering.

Why to use ES?



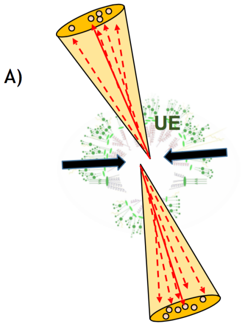
One pp collision with one partonic scattering



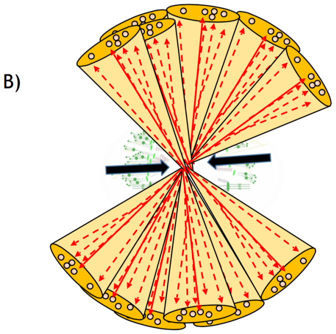
One pp collision with five partonic scattering

(ES=Event Shape)

Why to use ES?



One pp collision with one partonic scattering



One pp collision with five partonic scattering

(ES=Event Shape)

- They measure the geometrical properties of energy flow in QCD events
- Event by event classification of event with hard and soft topology

Spherocity

Transverse spherocity is used to characterize the events through the geometrical distribution of the p_T's of the charged hadrons, which is by definition collinear and infrared safe.

Avoids the bias from the boost along the beam axis

It's defined for a unit transverse vector which minimizes the ratio

$$S_0 = \frac{\pi^2}{4}\left(\frac{\sum_i |\vec{p}_{\mathrm{T}i} \times \hat{\mathbf{n}}|}{\sum_i p_{\mathrm{T}i}}\right)^2$$

A. Ortiz, G. Paić and E. Cuautle, Nucl. Phys. A 941 (2015) 78.
E. Cuautle, R. Jimenez, I. Maldonado, A. Ortiz, G. Paic and E. Perez, arXiv:1404.2372.

Spherocity

We use spherocity as a tool to split the sample in soft and hard

$$S_0 = \begin{cases} 0 & \text{“pencil-like” limit (hard events)} \\ 1 & \text{“isotropic” limit (soft events)} \end{cases}$$

ES characterize the distribution of the outgoing particle energy from high energy collision. In hadron-hadron collision they are restricted to the transverse component w.r.t. beam axis (avoid the bias from the boost)

A. Ortiz. et al : Nuclear Physics A Volume 941, September 2015, Pages 78–8

ES good tool to study observables with multiplicity and hardness on p-p collisions.

- Fluctuations: average pT

Event by event mean pT fluctuations

Physics Goals:

Study of $\sqrt{C_m}/M(p_T)$ vs N_{ch} event by event on p-p collisions at 13 TeV, looking at the independent evolution in multiplicity for the contribution coming from jets and the bulk.

Separation of the contribution from jets (which gives a bias on high multiplicity data), leading to a more clean bulk evolution in high multiplicity events on such small collisions systems.

Event by event mean pT fluctuations

Why?

We need to understand the contribution from the jet bias on the high multiplicity on the event by event mean transverse momentum fluctuations on p-p or p-Pb collisions.

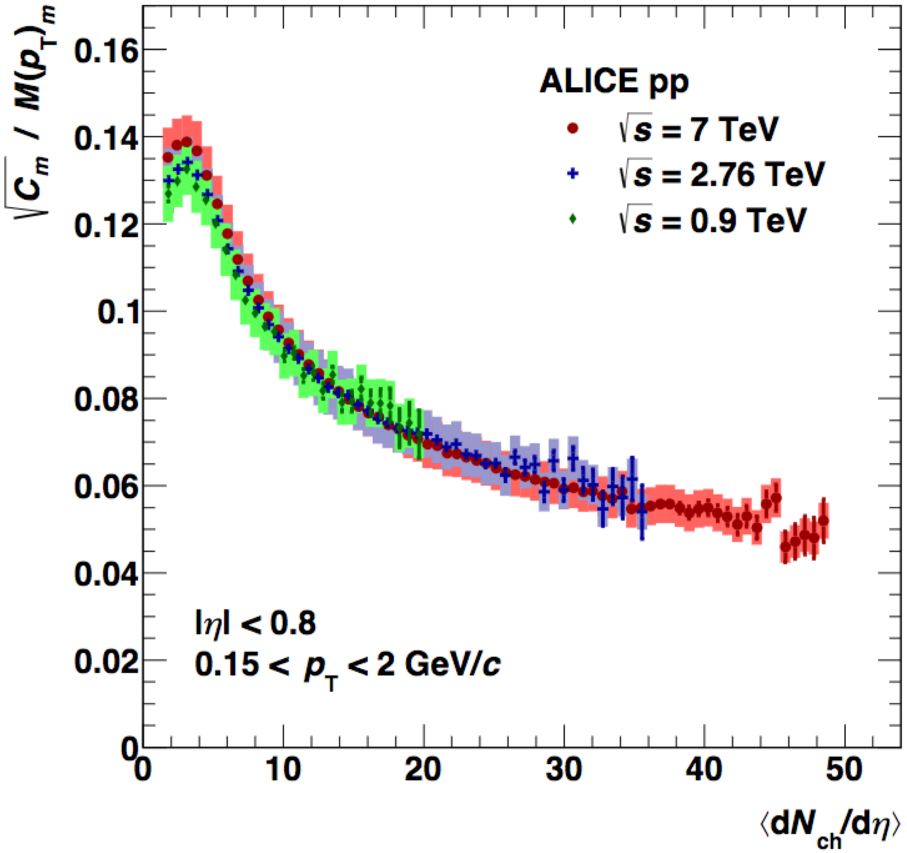
Knowing the contribution to the mean pT fluctuation from jets will allow to distinguish from possible medium effects if there are any.

Compare fluctuations in events with jets switched off.

Look at the power-law index for the multiplicity dependence of M(pT) fluctuations in pp.

Event by event mean pT fluctuations

- To understand better the origin of the mean pT fluctuations at high multiplicit
- In the ALICE publication, the behavior of the fluctuations is attributed to multiple-partonic interactions, but no more information is added:
    - Small drop of QGP?



Event by event mean pT fluctuations

Dynamical fluctuations

(scale independent approach: integrating over short and long range contributions)

- To measure the event-by-event fluctuations, we use the dynamical fluctuation $\sigma^2_{p_\mathrm{T},\mathrm{dyn}}$ defined as:

$$\sigma^2_{p_\mathrm{T},\mathrm{dyn}} = \left\langle \left(M(p_\mathrm{T}) - \mu_{M(p_\mathrm{T})} \right)^2 \right\rangle - \frac{\left\langle \left(p_\mathrm{T} - \mu_{p_\mathrm{T}} \right)^2 \right\rangle}{\langle N_\mathrm{ch} \rangle}$$

which is derived from:

  - variance of the inclusive single particle p_T distribution $\left\langle \left(p_\mathrm{T} - \mu_{p_\mathrm{T}} \right)^2 \right\rangle$,
  - variance of the event-by-event mean transverse momentum distribution $\left\langle \left(M(p_\mathrm{T}) - \mu_{M(p_\mathrm{T})} \right)^2 \right\rangle$ and
  - the average number of charged particles per event $\langle N_\mathrm{ch} \rangle$

- By definition $\sigma^2_{p_\mathrm{T},\mathrm{dyn}}$ is zero if all fluctuations are purely statistical

CERES, Nucl. Phys. **A811** (2008) 179–196

Event by event mean pT fluctuations

Dynamical fluctuations

(scale dependent approach)

- More details about the origin of the non-statistical fluctuations can be obtained by the study of their scale dependence
- Non-statistical fluctuations go along with correlations among the particles p_T. For this purpose the two-particle p_T correlator (C_m) is used:

$$C_m = \frac{1}{\sum_{k=1}^{n_{ev,m}} N_k^{\text{pairs}}} \sum_{k=1}^{n_{ev,m}} \sum_{i=1}^{N_{\text{acc},k}} \sum_{j=i+1}^{N_{\text{acc},k}} \left(p_{\text{T}}^{i} - M(p_{\text{T}})_m\right)\left(p_{\text{T}}^{j} - M(p_{\text{T}})_m\right)$$

- It can be shown that $C_m \sim \sigma^2_{p_{\text{T}},\text{dyn}}$, and this can be calculated for different classes of particles after the application of single particle cuts:
  - cuts on p_T, $\Delta\phi$, $\Delta\eta$, charge sign

Event by event mean pT fluctuations

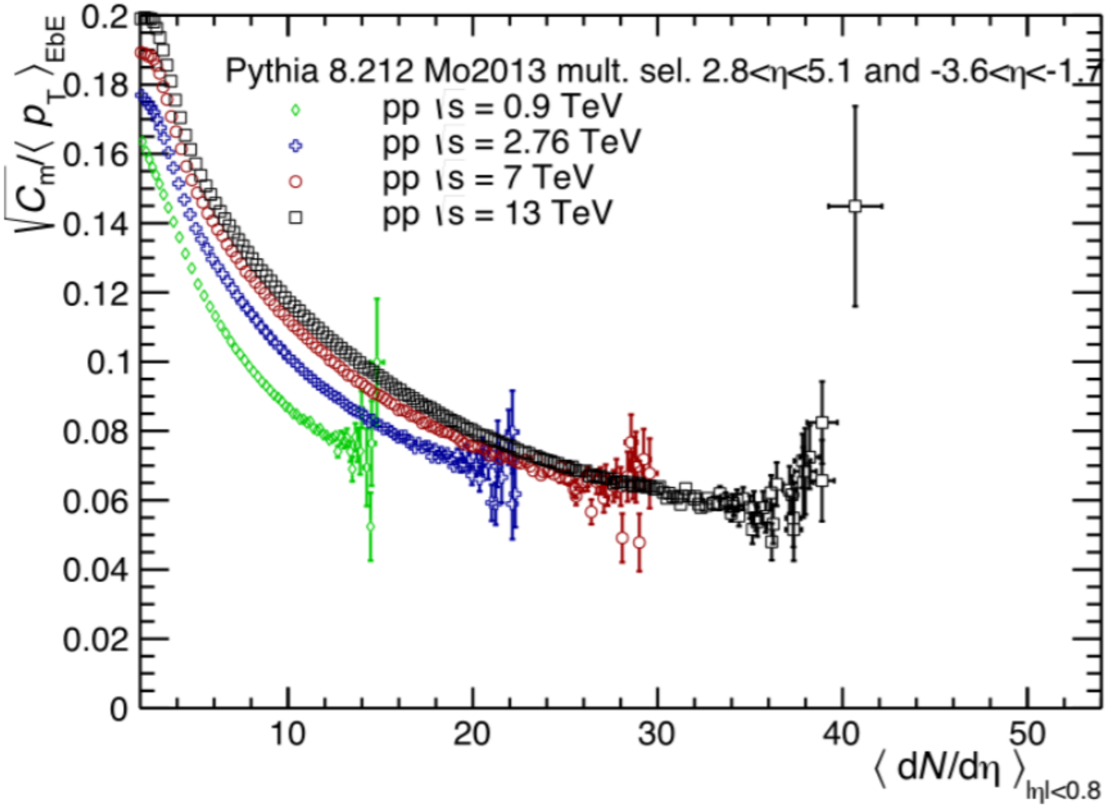
Simulations

- pp collisions at $\sqrt{s}$ = 13 TeV
- 400 M events
- Tune: Monash 2013 Pythia 8.212
- Events were selected using three criteria:
  - N_{ch} counted at mid-rapidity, $|\eta| < 0.8$
  - N_{ch} counted at forward+backward η, $2.8 < \eta < 5.1$ & $-3.6 < \eta < -1.7$
  - Number of multi-partonic interactions, N_{mpi}
- The relative dynamical fluctuation, $\sqrt{C_m}/M(p_T)_m$, is studied as a function of $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.8}$

Event by event mean pT fluctuations

- To be more sensitive to MPI one can use a different set of particles for multiplicity and mean p_T fluctuations
  - e.g. |eta|<0.8 for fluctuations and ALICE VZERO acceptance for determining the event multiplicity

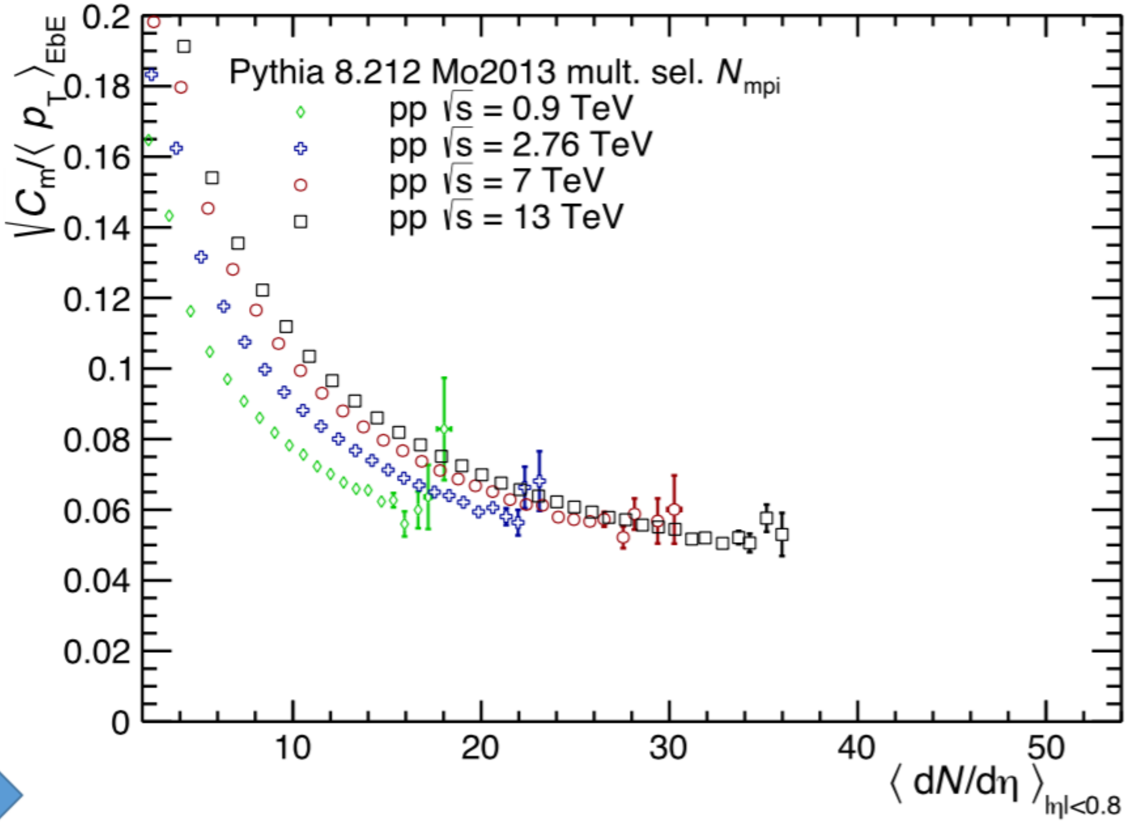
WE SEE THE SAME DEPENDENCE SELECTING ON MPI (SEE NEXT SLIDE)



Event by event mean pT fluctuations

- To be more sensitive to MPI one can use a different set of particles for multiplicity and mean p_T fluctuations
  - e.g. |eta|<0.8 for fluctuations and ALICE VZERO acceptance for determining the event multiplicity

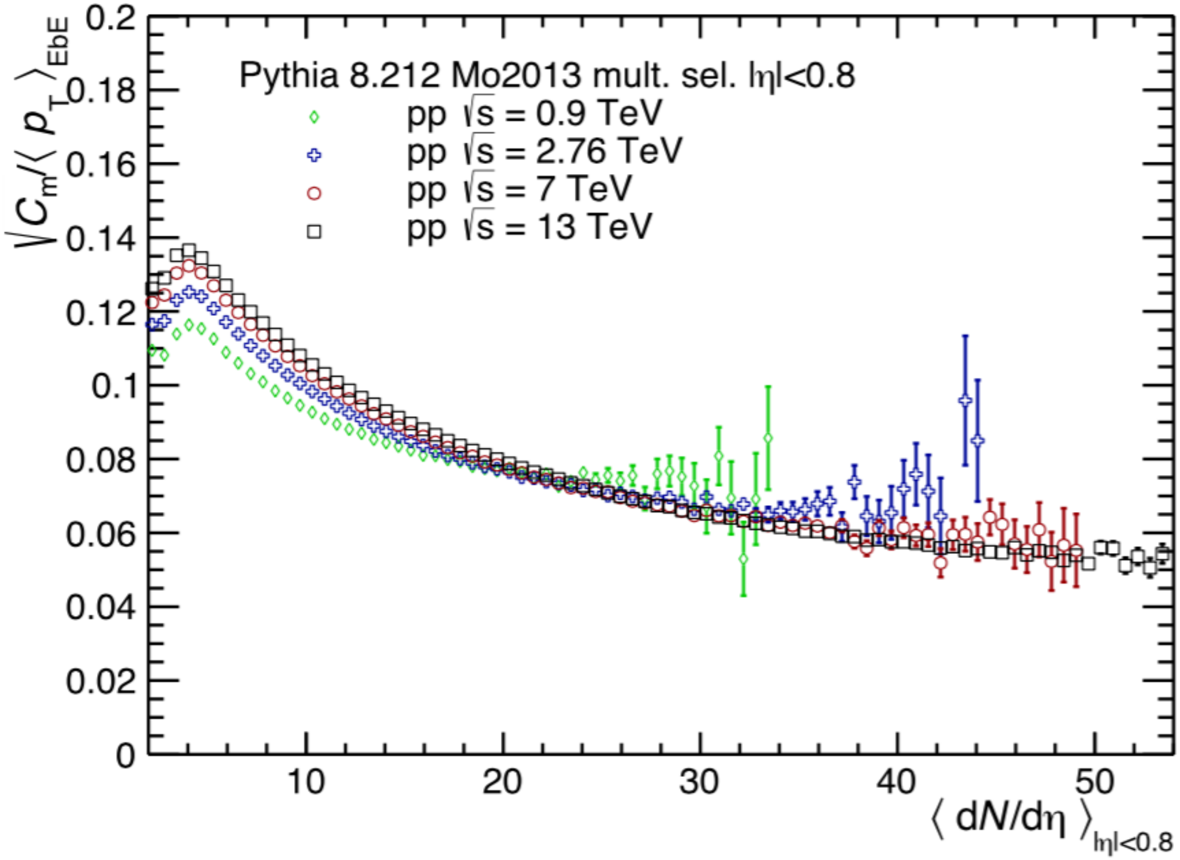
BUT NOT WHEN WE COMPUTE THE MULTIPLICITY AT MID-ETA (SEE NEXT SLIDE)



Event by event mean pT fluctuations

- To be more sensitive to MPI one can use a different set of particles for multiplicity and mean p_T fluctuations
  - e.g. |eta|<0.8 for fluctuations and ALICE VZERO acceptance for determining the event multiplicity

OTHER BIAS POPS UP WHEN CONSIDERING MID-ETA MULTIPLICITY



Event by event mean pT fluctuations

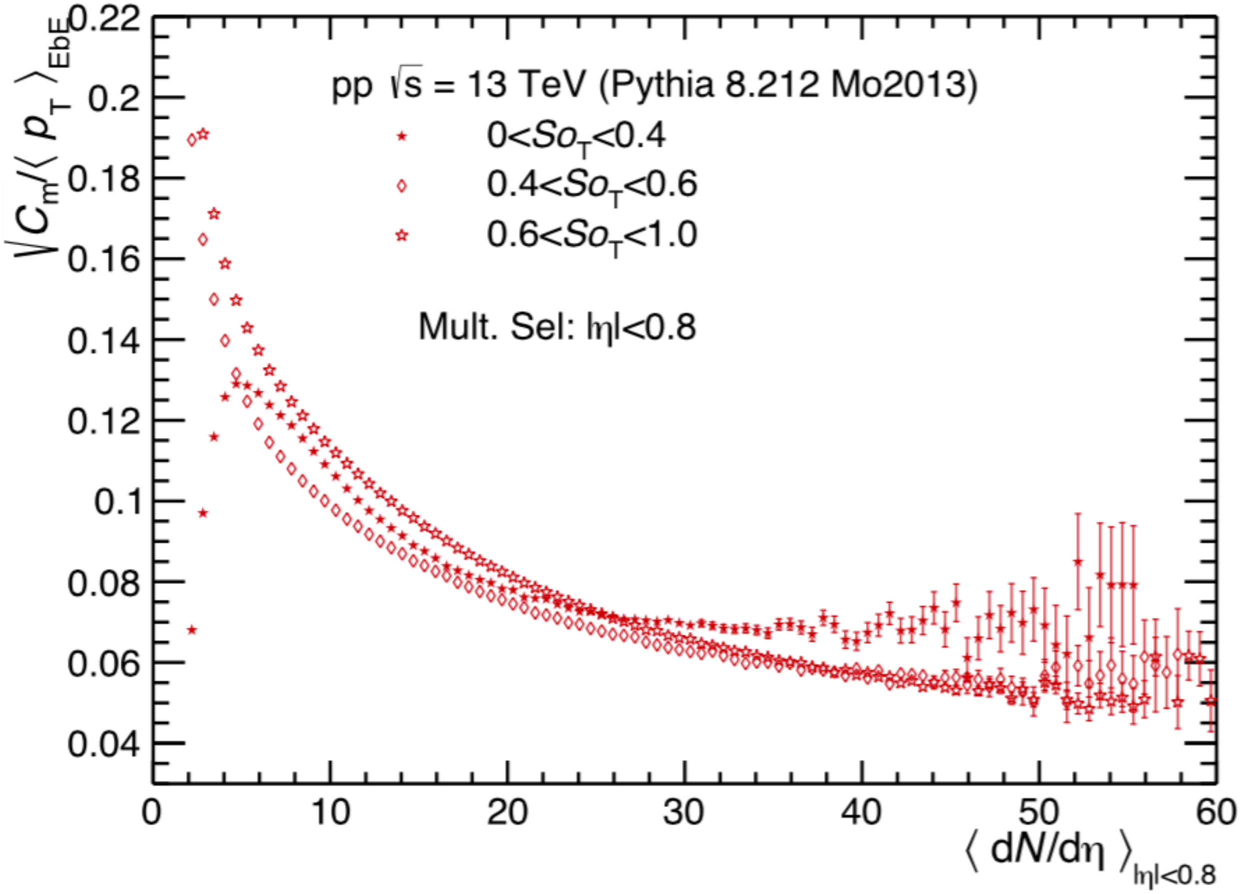
SELECTION BASED ON EVENT SHAPES:

- High multiplicities and jetty-like structure allows to study the jet contribution to the fluctuations

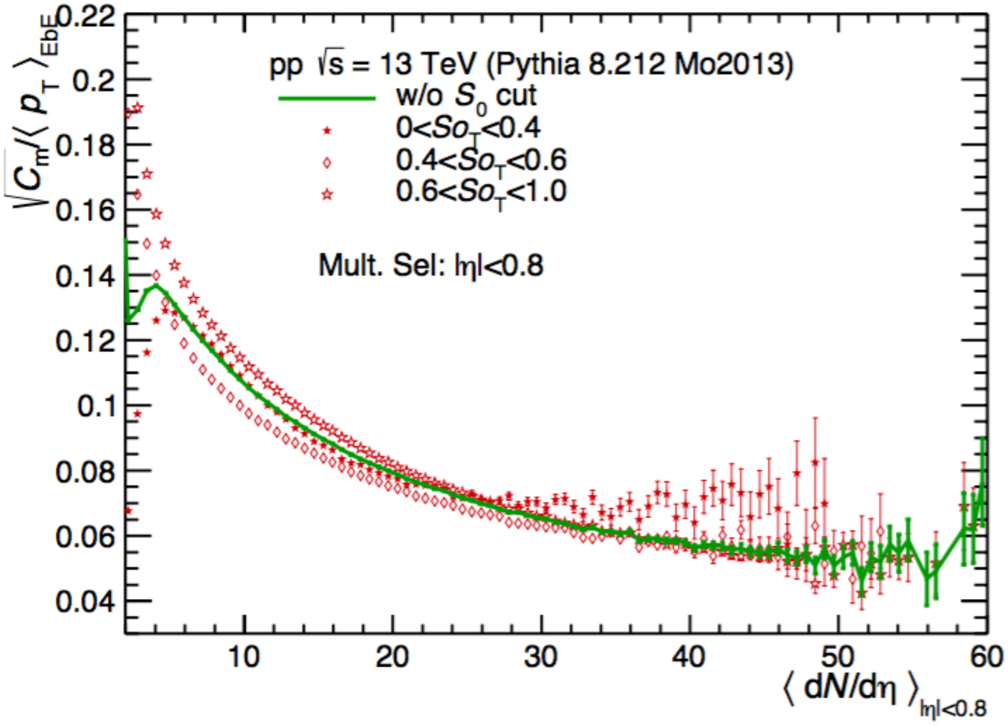
- For isotropic events (no jet structure) we can remove the jet bias and learn more about the role of soft physics

- In Pythia different behaviors are found for jetty and isotropic events

- Comparisons with EPOS 3 are needed



Event by event mean pT fluctuations



We already discussed about the bias of this selector. Using spherocity, we see that for high multiplicity jetty-like events larger fluctuations are obtained

Data analysis

- pp data @ 13 TeV
- Period: LHC15f pass2
- Runs: 225031 225576 225757 226476 225035 225578 225762 226483 225037 225579 225763 226495 225041 225580 225766 226500 225043 225582 225768 225050 225586 226062 225051 225587 226170 225052 225707 226220 225106 225708 226225 225305 225709 226444 225307 225710 226445 225309 225716 226452 225313 225717 226466 225314 225719 226468 225322 225753 226472
- 48 M events were analyzed

NEW

- Software: AliRoot::v5-08-13a-1, AliPhysics::vAN-20160716-1
  - According with Evgeny's talk: https://indico.cern.ch/event/489470/, using recent software version: physics selection now implements: new background + pileup cuts
- kINT7 trigger, isIncompleteDAQ
- We use the recommended vertex selection for 13 TeV pp analyses:

https://twiki.cern.ch/twiki/bin/view/ALICE/PWGPPEvSelRun2pp

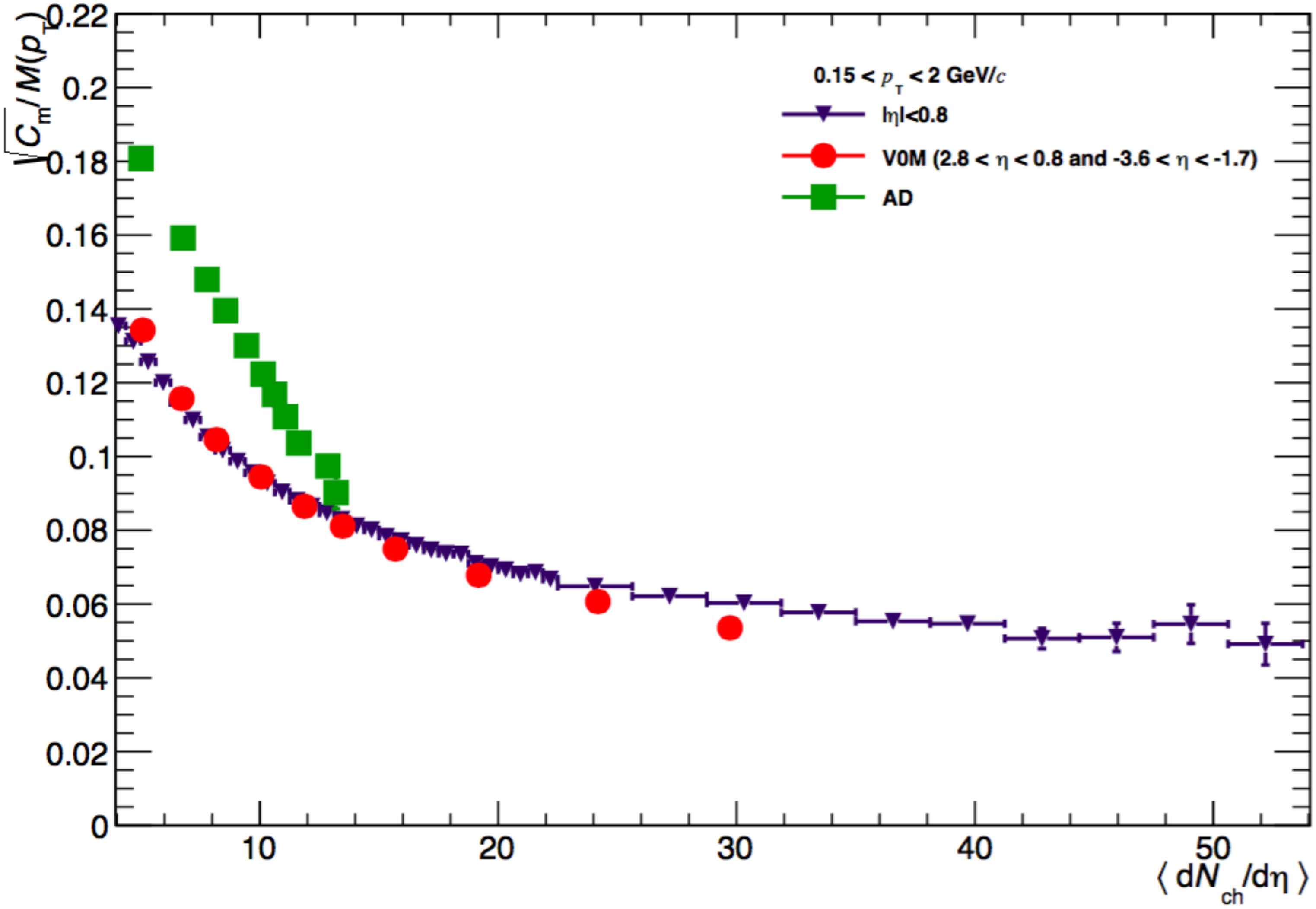
Data analysis (II)

- ❑Track selection for mean p_T fluctuation:
  - ❑0.15<p_T<2.0 GeV/c, $|\eta|$<0.8 (as done in the already published results, but we want to explore more p_T bins)
  - ❑GetStandardTPCOnlyTrackCuts()+TPCrefit

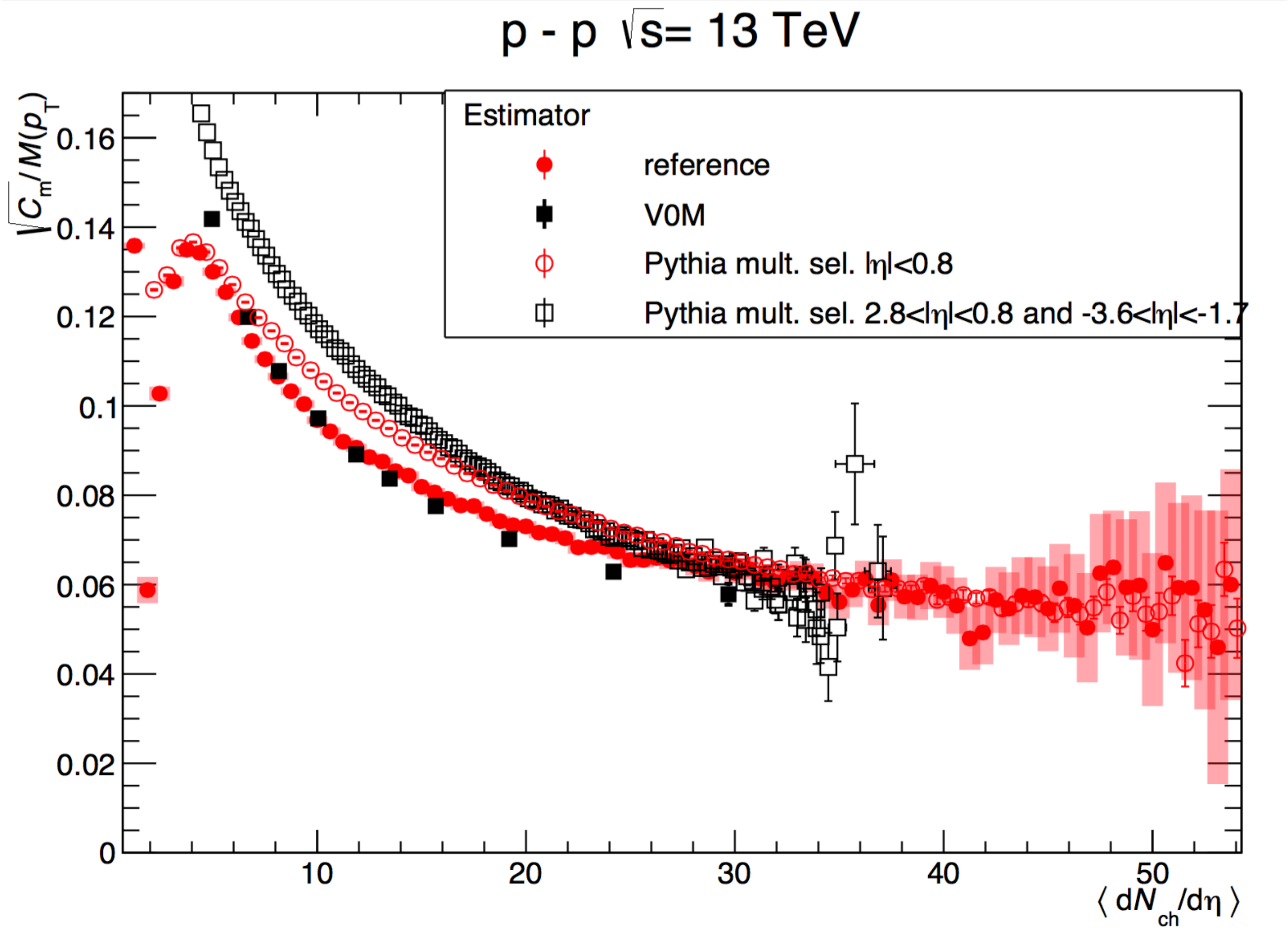
- ❑Measurement of transverse spherocity
  - ❑GetStandardTPCOnlyTrackCuts(), at least 3 tracks
  - ❑0.15<p_T<10 GeV/c, $|\eta|$<0.8

  (Know issues: low tracking efficiency at 0.15 GeV/c, secondary contamination affect the reconstruction of spherocity. This improves using: a) hybrid track cuts, b) increasing the minimum p_T and c) the minimum multiplicity, all this is being documented by ICN group)

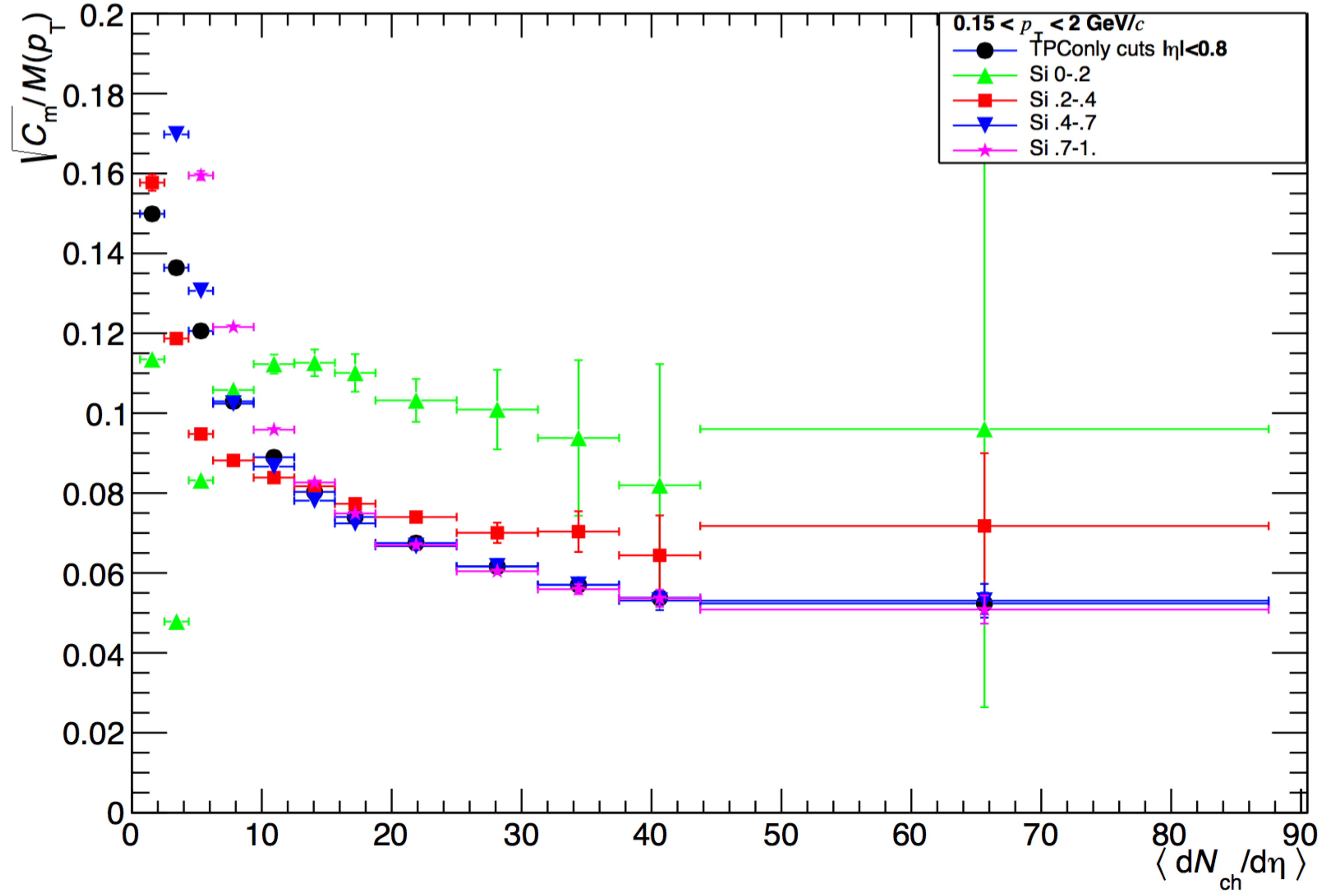
p-*p* $\sqrt{s}$= 13 TeV.



Event by event mean pT fluctuations

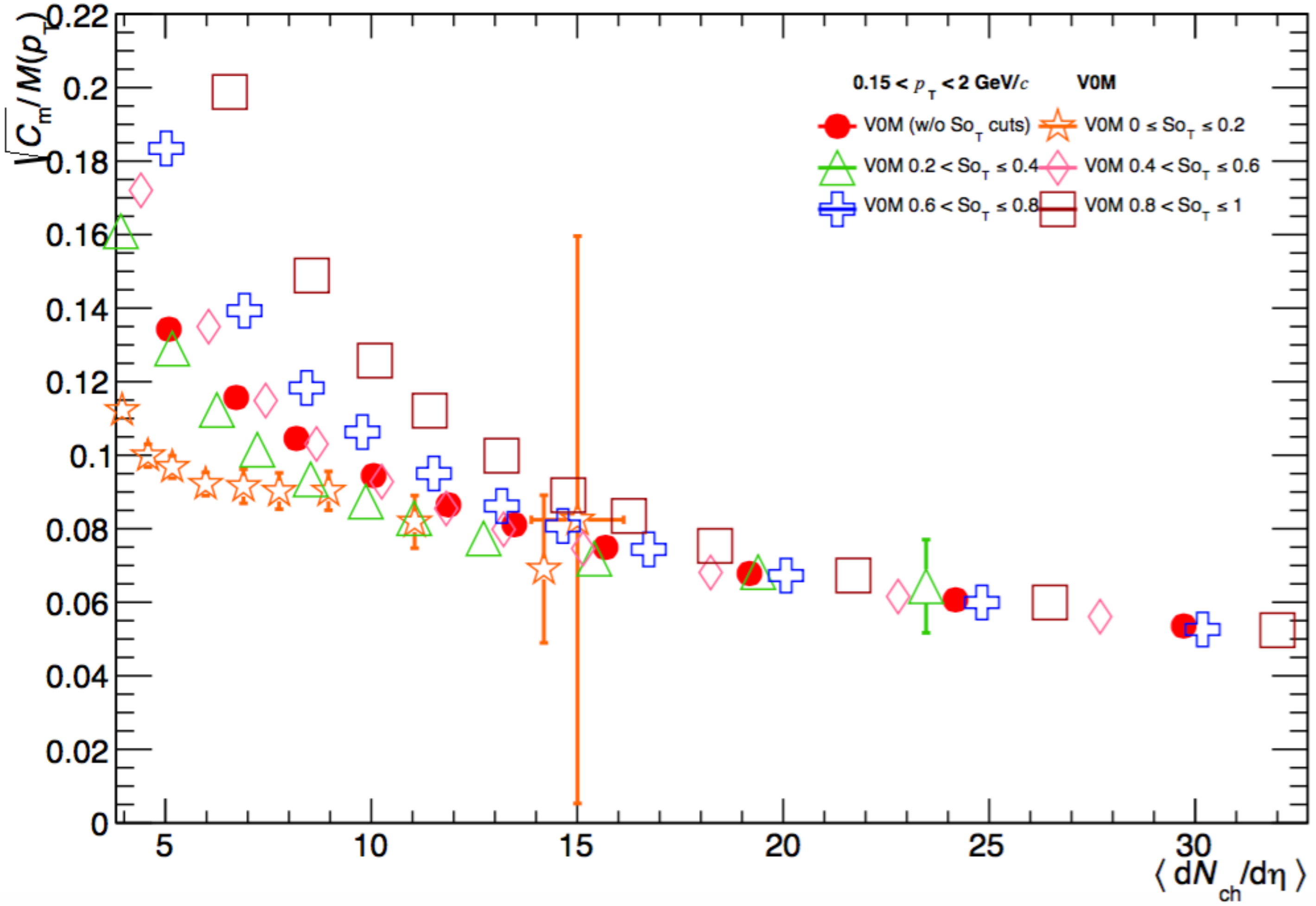


Event by event mean pT fluctuations

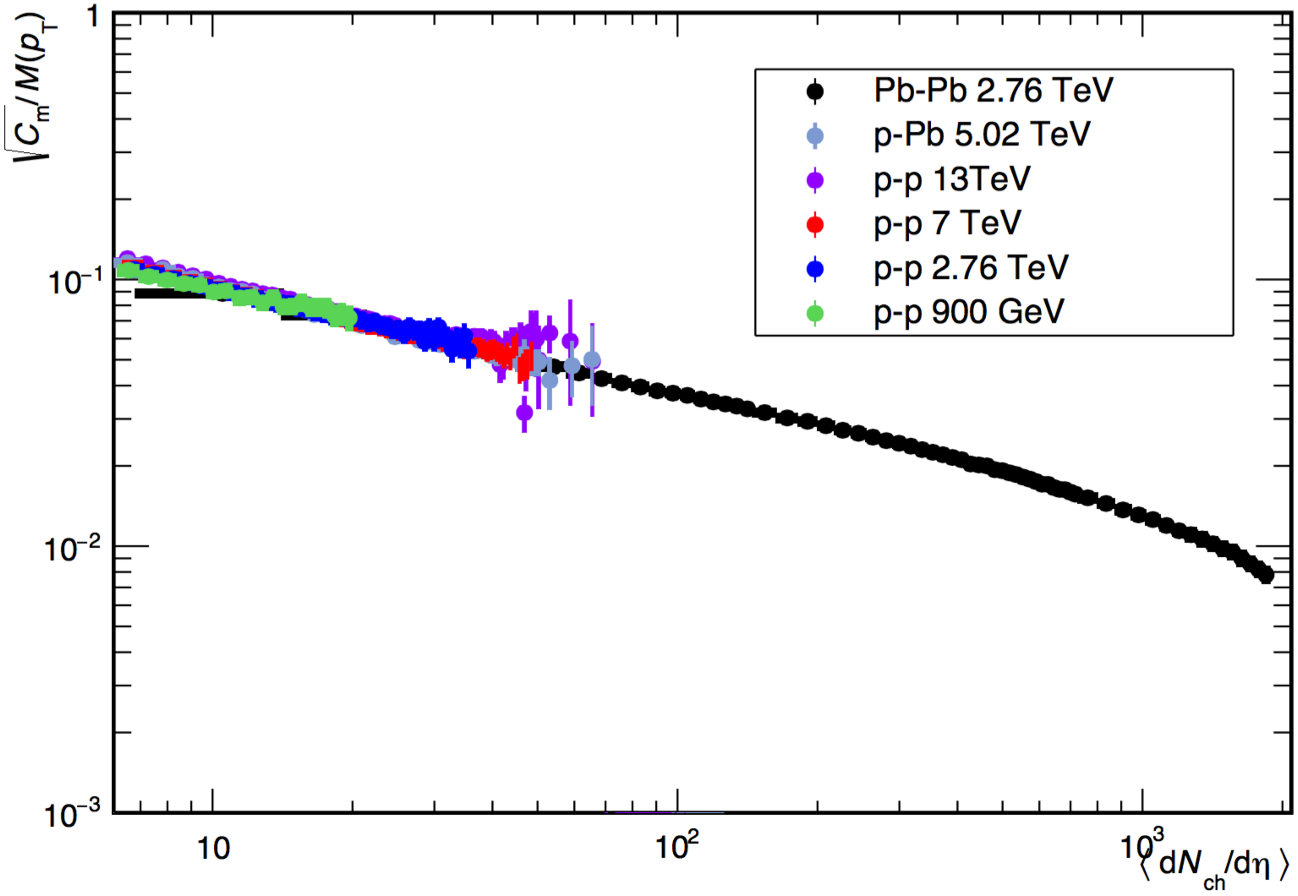


Event by event mean pT fluctuations

p-p $\sqrt{s}$= 13 TeV. 46,443,000 events



Event by event mean pT fluctuations

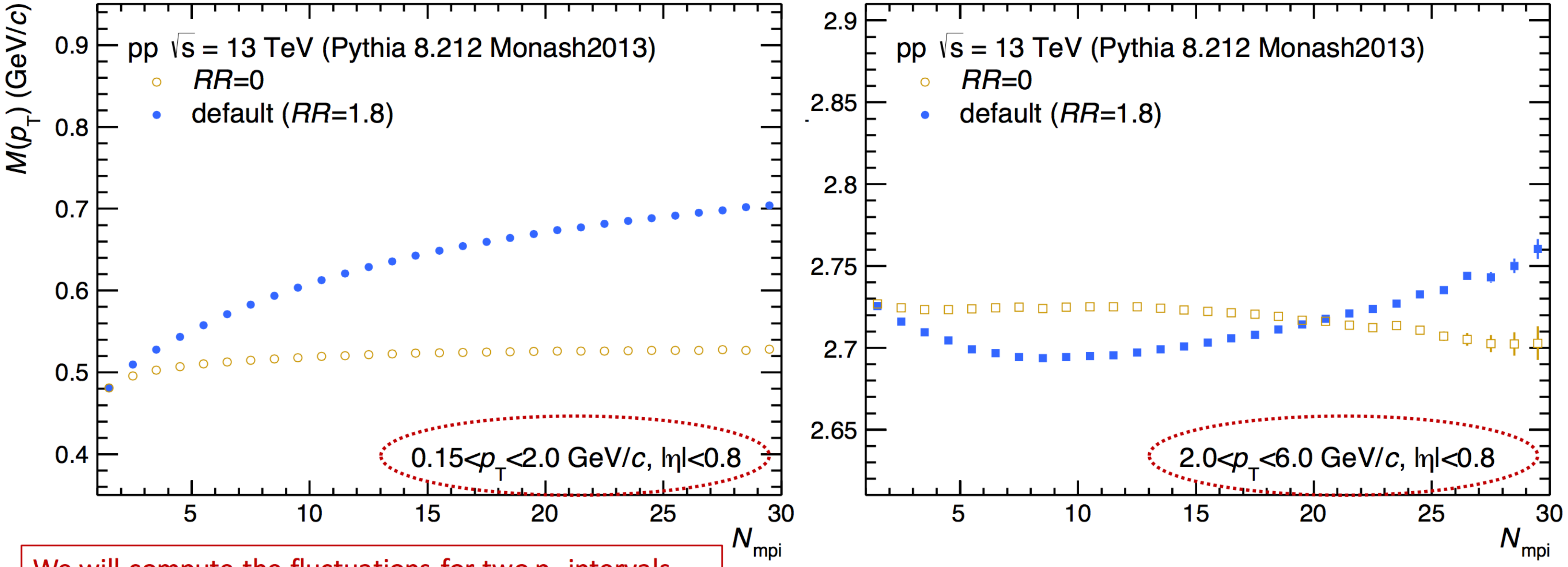


Event by event mean pT fluctuations

- pp collisions at 13 TeV simulated with Pythia 8.212
- 400 M events were generated for two cases:
  - Reconnection range (RR): 0
  - Reconnection range: 1.8 (default in Monash2013 tune)
  - Since same random seeds were used, therefore the events just before color reconnection should be identical
  - The best comparison between both RR cases is in terms of the number of multi-partonic interactions (N_{mpi})
- Details about the average pT fluctuations can be found in this ALICE paper:
  - The ALICE collaboration, Eur. Phys. J. C 74 (2014) 3077

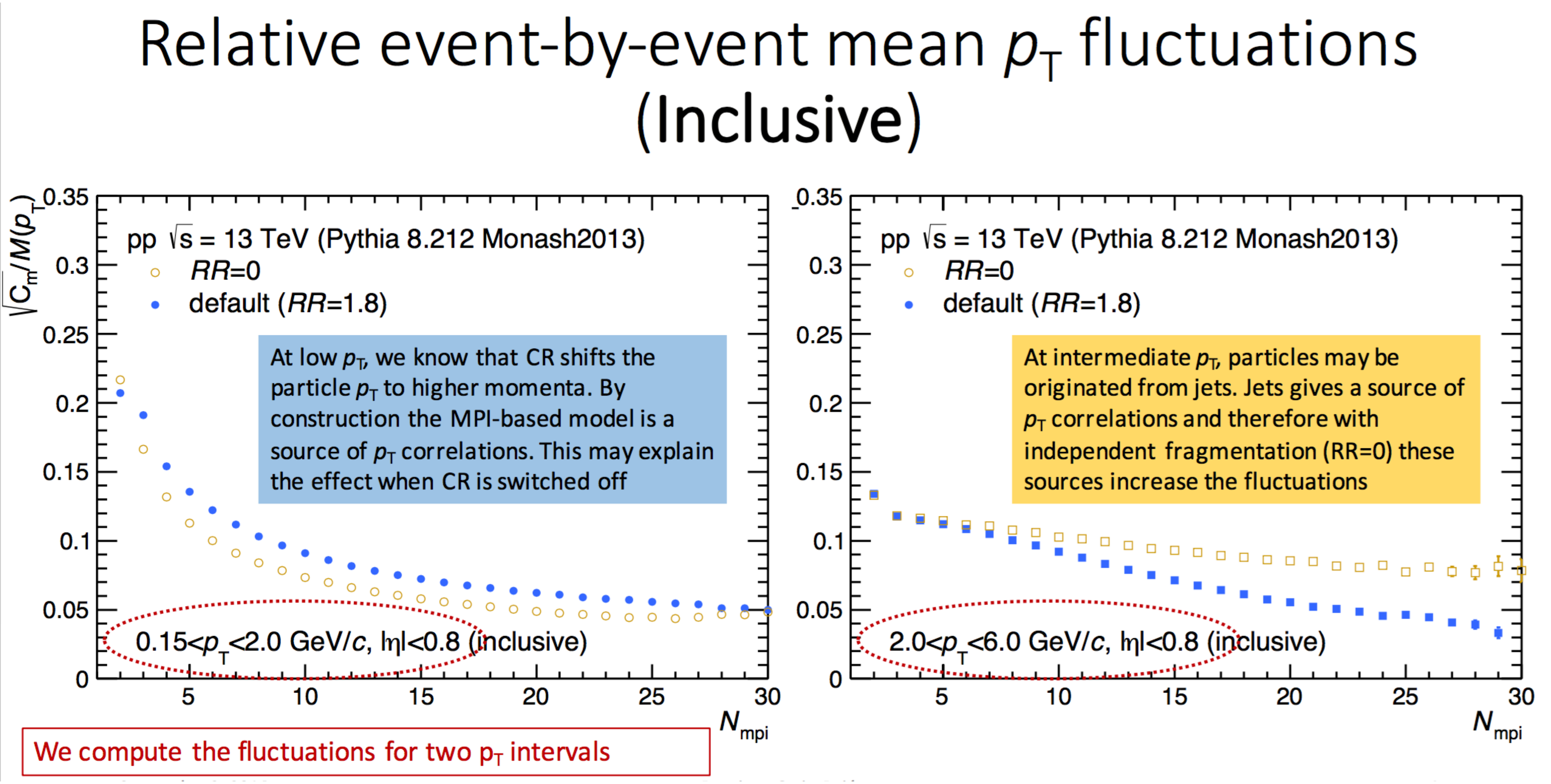
Event by event mean pT fluctuations

The fluctuations are calculated with respect to the event-by-event average p_T, $M(p_T)$



We will compute the fluctuations for two p_T intervals

Event by event mean pT fluctuations



Relative event-by-event mean p_T fluctuations (Inclusive)

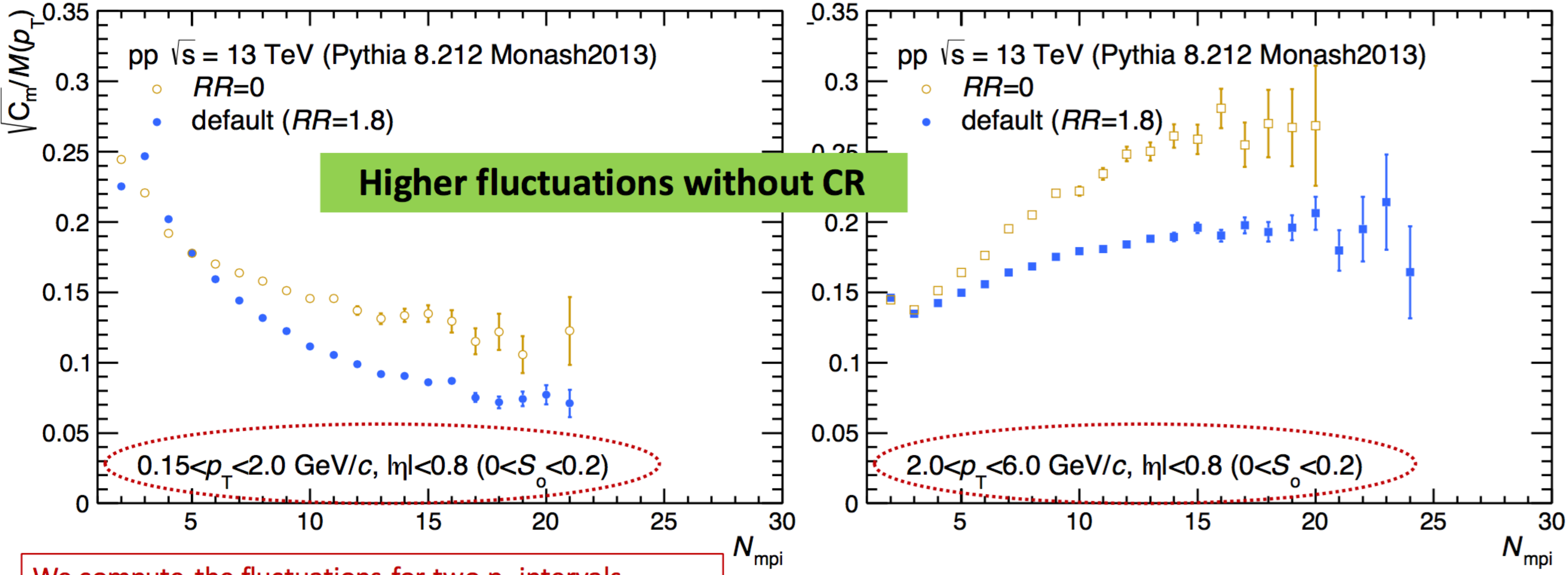
At low p_T, we know that CR shifts the particle p_T to higher momenta. By construction the MPI-based model is a source of p_T correlations. This may explain the effect when CR is switched off

At intermediate p_T, particles may be originated from jets. Jets gives a source of p_T correlations and therefore with independent fragmentation (RR=0) these sources increase the fluctuations

We compute the fluctuations for two p_T intervals

Event by event mean pT fluctuations

Relative event-by-event mean p_T fluctuations (Pencil-like events)

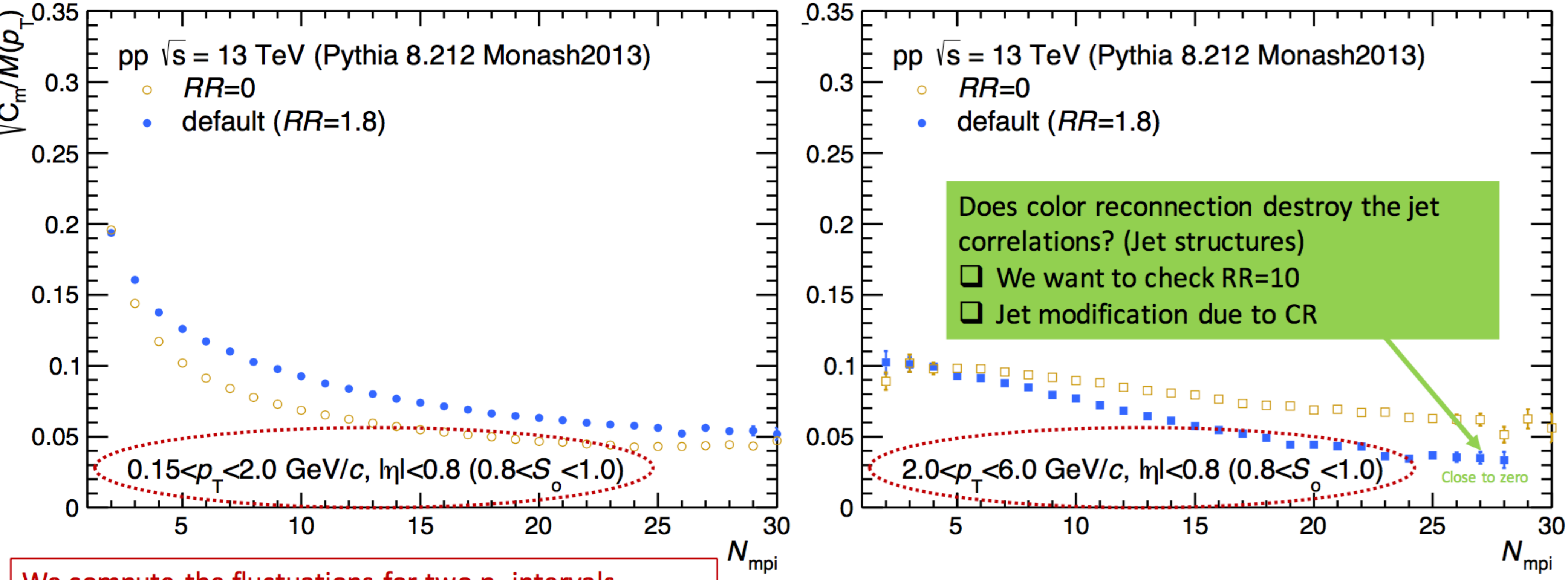


Higher fluctuations without CR

We compute the fluctuations for two p_T intervals

Event by event mean pT fluctuations

Relative event-by-event mean p_T fluctuations (Hedgehog-like events)



Does color reconnection destroy the jet correlations? (Jet structures)

- ❑ We want to check RR=10
- ❑ Jet modification due to CR

We compute the fluctuations for two p_T intervals

Event by event mean pT fluctuations

Remaks

- ❑Results on event shape spherocity cuts show that jetty like events have a different evolution on multiplicity (at high multiplicity they give a higher value on fluctuations). Need to explore other ES.
- ❑CR decreases fluctuations on isotropic like events.
- ❑When using color reconnection jet correlations are decreased. (Jet modification due to CR?)
- ❑Would be interesting to have a further extension of the this study can be done for more energies and also (p-Pb)
- ❑Comparison of the event by event mean pT fluctuations with SPM (Thesis: Pablo Fierro)

GRACIAS !!!

Event by event mean pT fluctuations

(Color reconnection RC)

The colour flows in the separate subprocesses defined in the multiparton-interactions scenario are tied together via the assignment of colour flow in the beam remnant.
The colour flow is reconstructed by how a PS could have constructed the configuration.

Partons are classified by which MPI system they belong to. The colour flow of two such systems can be fused, and if so the partons of the lower-pT system are added to the strings defined by the higher-pT system in such a way as to give the smallest total string length. The bulk of these lower-pT partons are gluons, and this is what the scheme is optimized to handle.

An MPI system with a scale pT of the hard interaction (normally 2 → 2) can be merged with one of a harder scale with a probability that is pT0_Rec^2 / (pT0_Rec^2 + pT^2), where pT0_Rec is range times pT0, the latter being the same energy-dependent dampening parameter as used for MPIs. Thus it is easy to merge a low-pT system with any other, but difficult to merge two high-pT ones with each other.

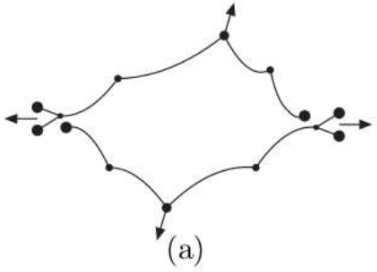
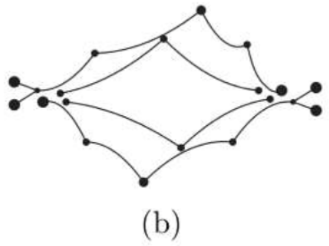
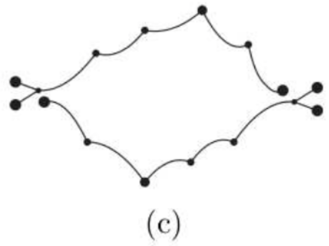




FIG. 2. Illustration of the color reconnection in the string fragmentation model (picture taken from [14]). The outgoing gluons color connected to the projectile and target remnants (a). The second hard scattering (b). Color reconnected string(c).

AD (4.8<eta< 6.3, -7<eta<- 4.9)