STUDY OF DE-CONFINEMENT PHASE TRANSITION IN THE COLOR STRING PERCOLATION APPROACH IN ALICE AT LHC

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Introduction: Color Strings

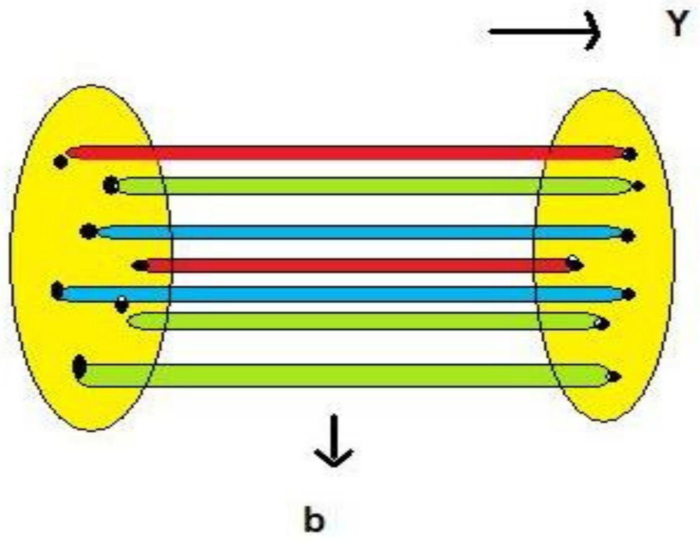
- Multiparticle production at high energies is currently described in terms of color strings stretched between the projectile and target.
- These strings decay into new ones by production and subsequently hadronize to produce the observed hadrons.
- The number of strings and the string density grows with energy and with the number of participating nucleons.
- As the no. of strings grow, they start to overlap and form clusters.
- At a critical density a macroscopic cluster appears and marks the percolation phase transition.
- Particles are produced by the Schwinger mechanisms.

Introduction: Color Strings

- In the case of a nuclear collisions, the density of disks - elementary strings:

$$\xi = \frac{N^s S_1}{S_N}$$

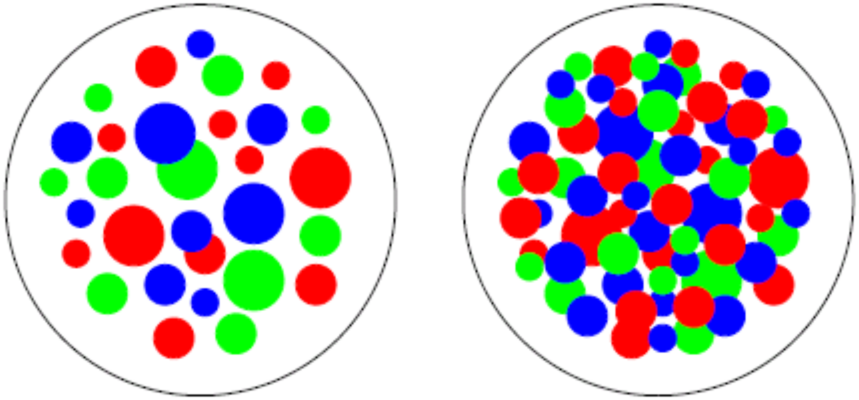
N^s = Number of strings
S_1 = Single string area
S_N = total nuclear overlap area



Introduction: Clustering of Color Sources

- De-confinement is expected when the density of quarks and gluons becomes so high that it no longer makes sense to partition them into color-neutral hadrons, since these would overlap strongly.

- We have clusters within which color is not confined : De-confinement is thus related to cluster formation very much similar to cluster formation in percolation theory and hence a connection between percolation and de-confinement seems very likely.



Parton distributions in the transverse plane of nucleus-nucleus collisions

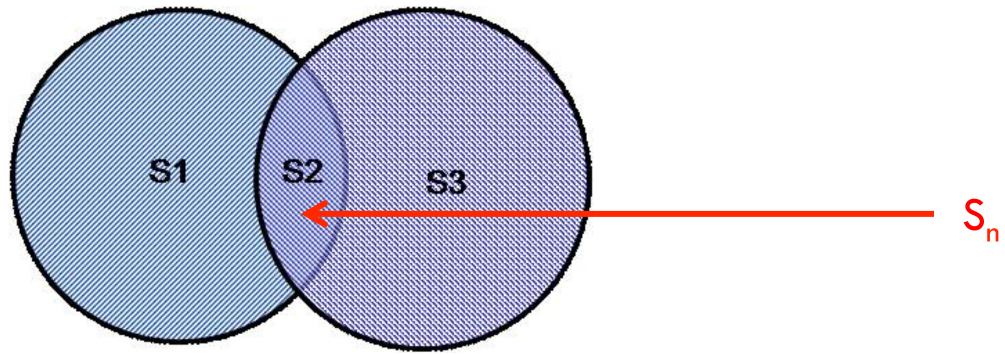
H. Satz, Rep. Prog. Phys. 63, 1511(2000).
H. Satz , hep-ph/0212046

In two dimensions, for uniform string density, the percolation threshold for overlapping discs is:

$$\xi_c = 1.18$$

Critical Percolation Density

Introduction: Clustering of Color Sources



- The transverse space occupied by a cluster of overlapping strings split into a number of areas in which different number of strings overlap, including areas where no overlapping takes place.

- A cluster of n strings that occupies an area **S_n** behaves as a single color source with a higher color field $\vec{Q}_n$ corresponding to vectorial sum of color charges of each individual string $\vec{Q}_1$

$$\vec{Q}_n^2 = n\vec{Q}_1^2$$ If strings are fully overlap

$$\vec{Q}_n^2 = n\frac{S_n}{S_1}\vec{Q}_1^2$$ Partially overlap

Introduction: Clustering of Color Sources

Multiplicity and <p_T^2> of particles produced by a cluster of *n* strings

Multiplicity (μ_n)

$$\mu_n = F(\xi) N^s \mu_1$$

Average Transverse Momentum

$$< p_T^2 >_n = < p_T^2 >_1 / F(\xi)$$

$$\xi = \frac{N^s S_1}{S_N}$$

$$F(\xi) = \sqrt{\frac{1 - e^{-\xi}}{\xi}}$$

Color suppression factor
(due to overlapping of discs).

N^s = # of strings
S_1 = disc area
S_N = total nuclear overlap area

ξ is the string density parameter

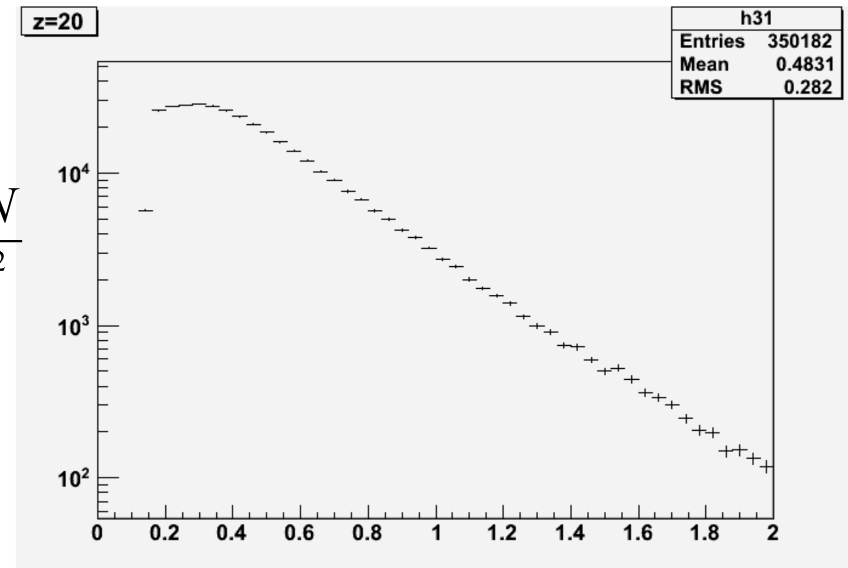
M. A. Braun and C. Pajares, Eur. Phys. J. C16,349 (2000)
M. A. Braun et al, Phys. Rev. C65, 024907 (2002)

Methodology

- Using the p_T spectrum to calculate F(ξ) The experimental p_T distribution from pp data is used

$$\frac{d^2N}{dp_T^2} = \frac{a}{(p_0 + p_T)^n}$$

Here, a, p_0 and n are fit parameters to the proton-proton data.



$$\frac{d^2N}{dp_t^2}$$

p_T (GeV/c)

For parameterizations, pp data from UA1 200, 500 and 900 GeV & ISR 53 and 23 GeV are used.
p_0 = 1.71 and n = 12.42

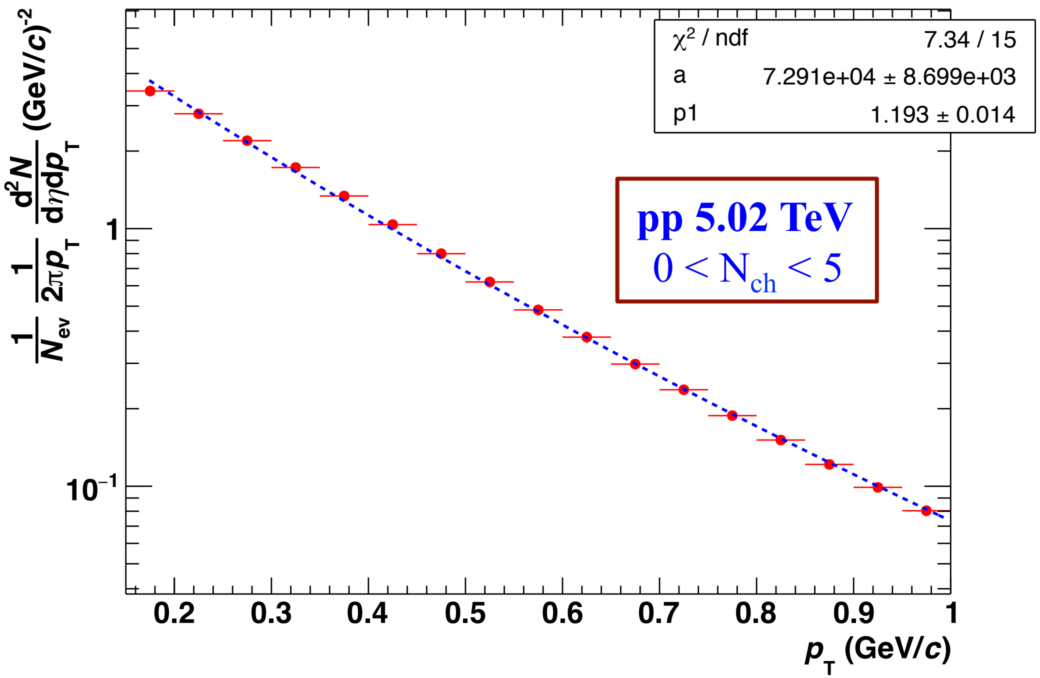
Nucl. Phys. A698, 331 (2002)

Methodology

- This parameterization can be used for high multiplicity events in pp and Heavy-ion collisions to account for the clustering :

$$\frac{d^2N}{dp_T^2} = \frac{b}{\left(p_0 \sqrt{\frac{F(\xi_{pp})}{F(\xi_{pp})_{HM}}} + p_T \right)^n}$$

$$F(\xi_{pp}) = 1$$



M. A. Braun and C. Pajares, Eur. Phys. J. C16,349 (2000)
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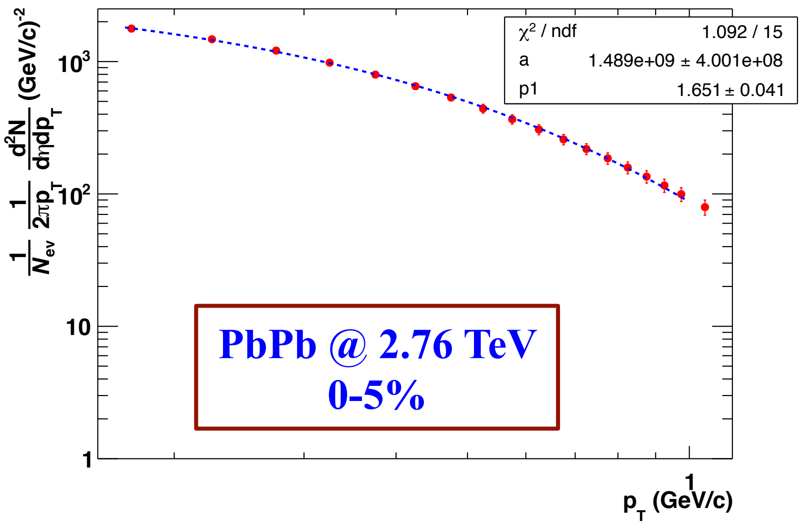
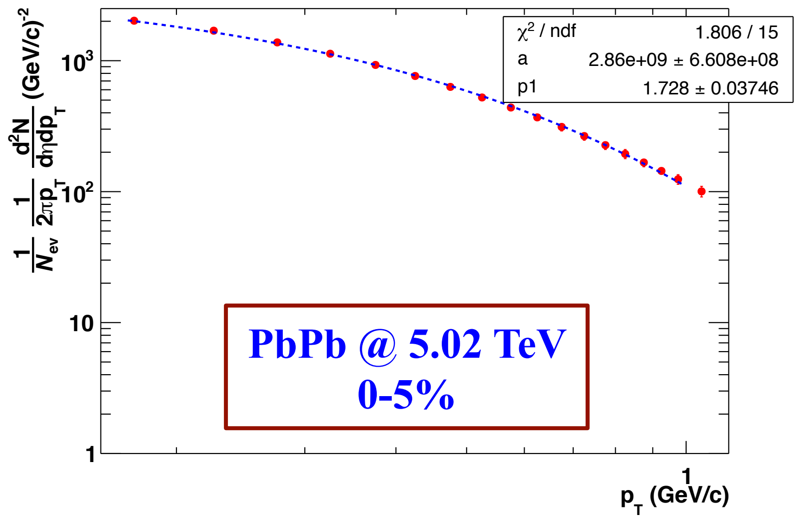
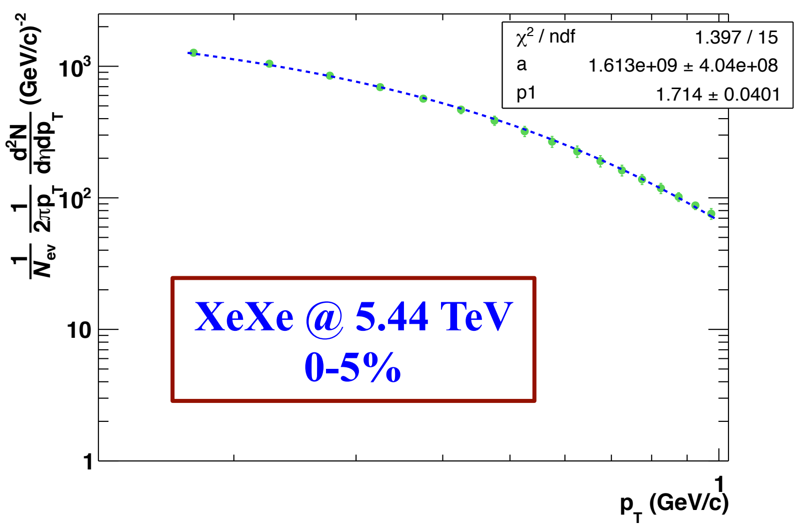
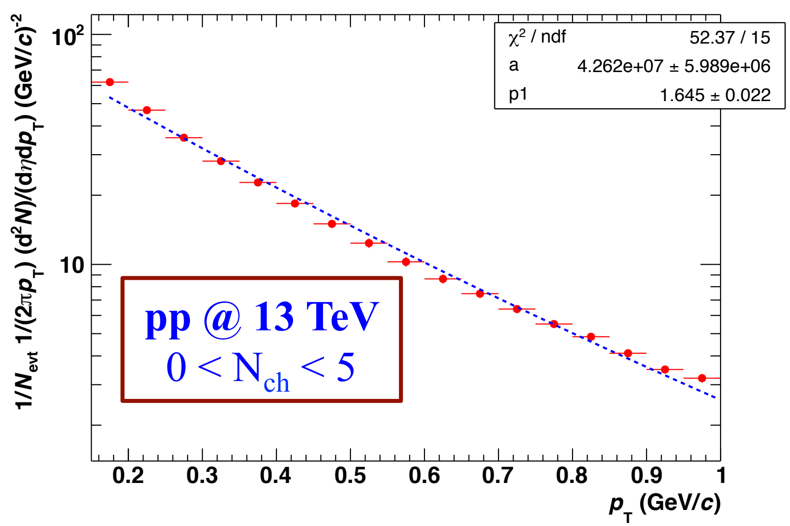
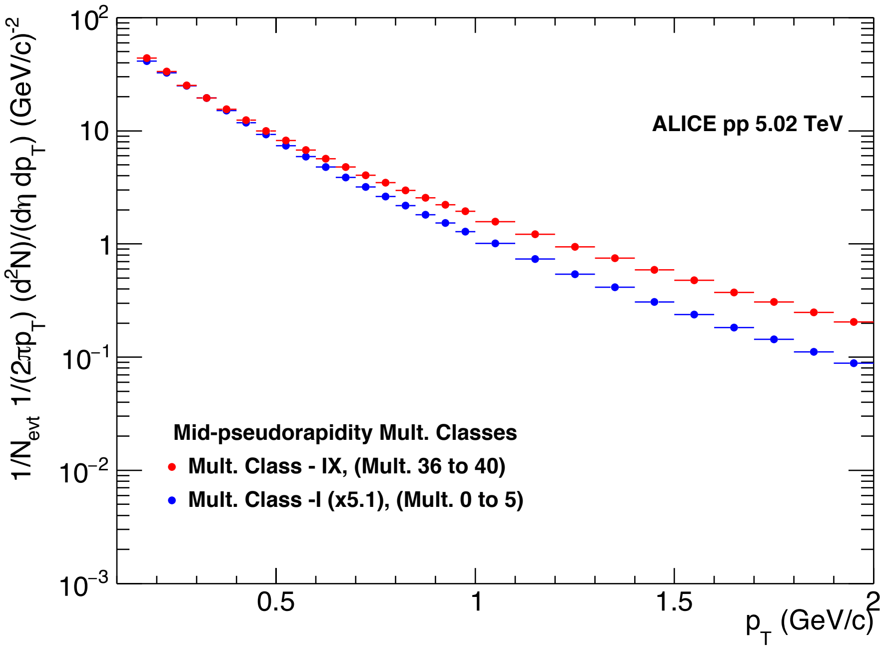


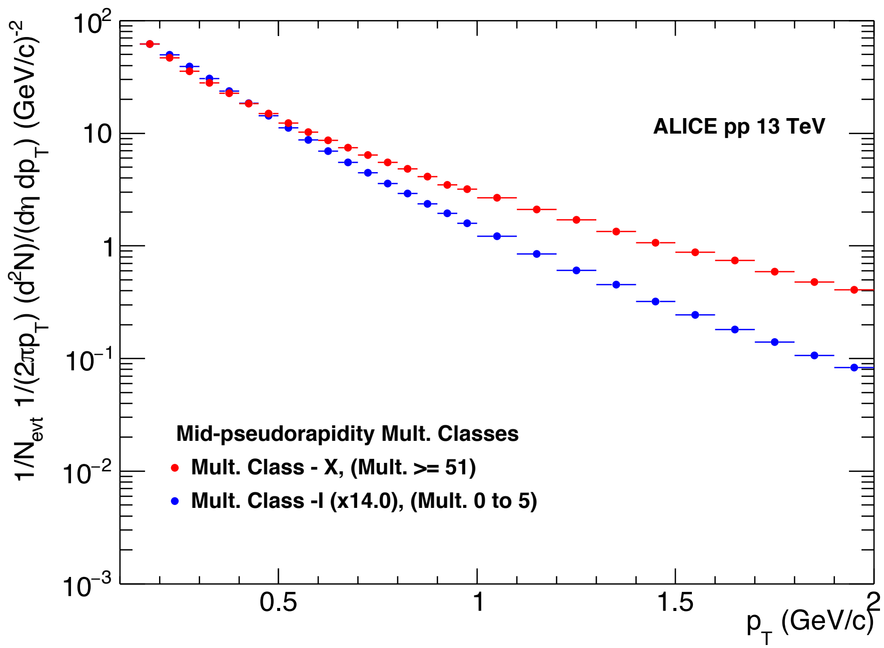






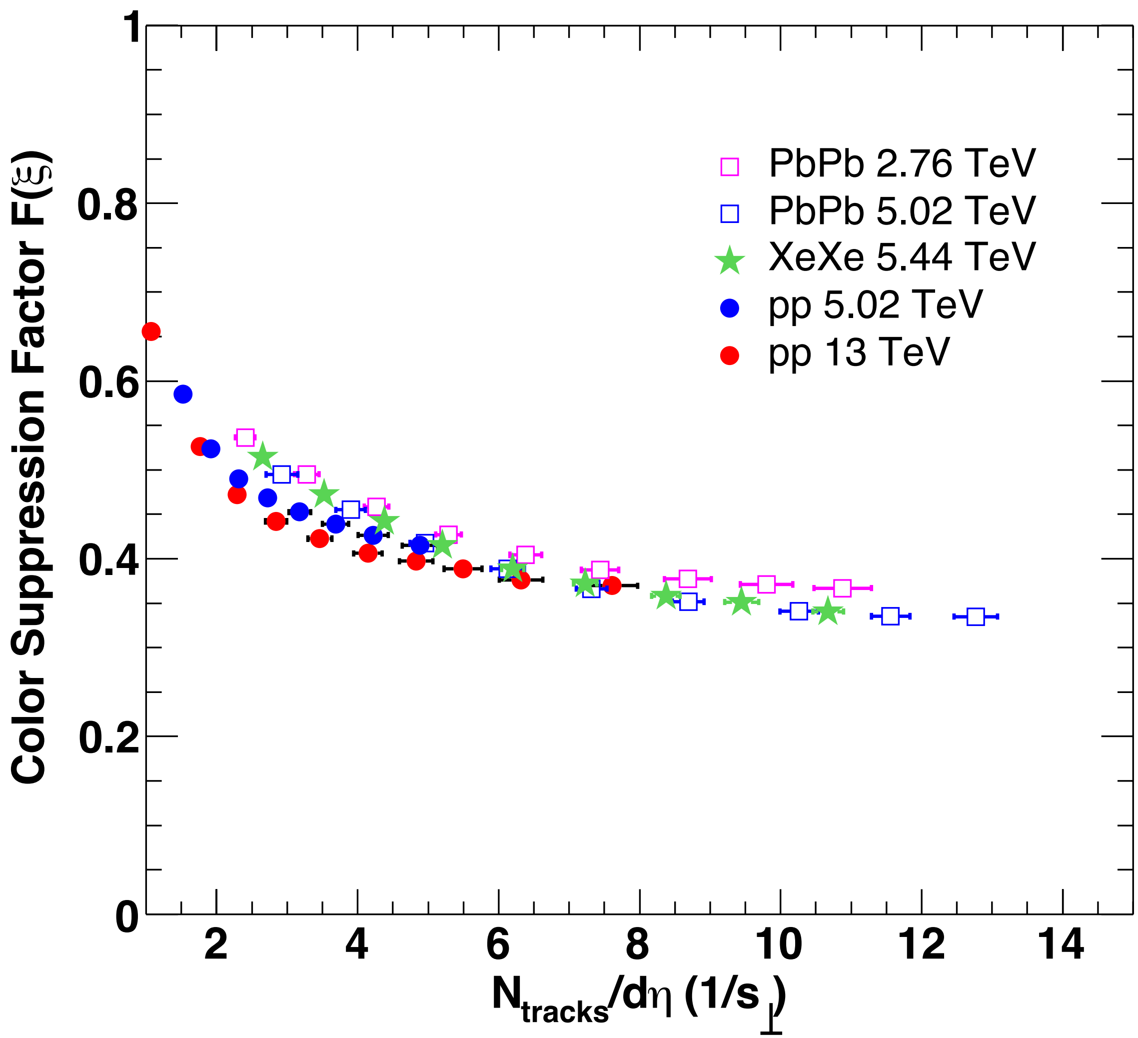
Analysis: p_T Spectra



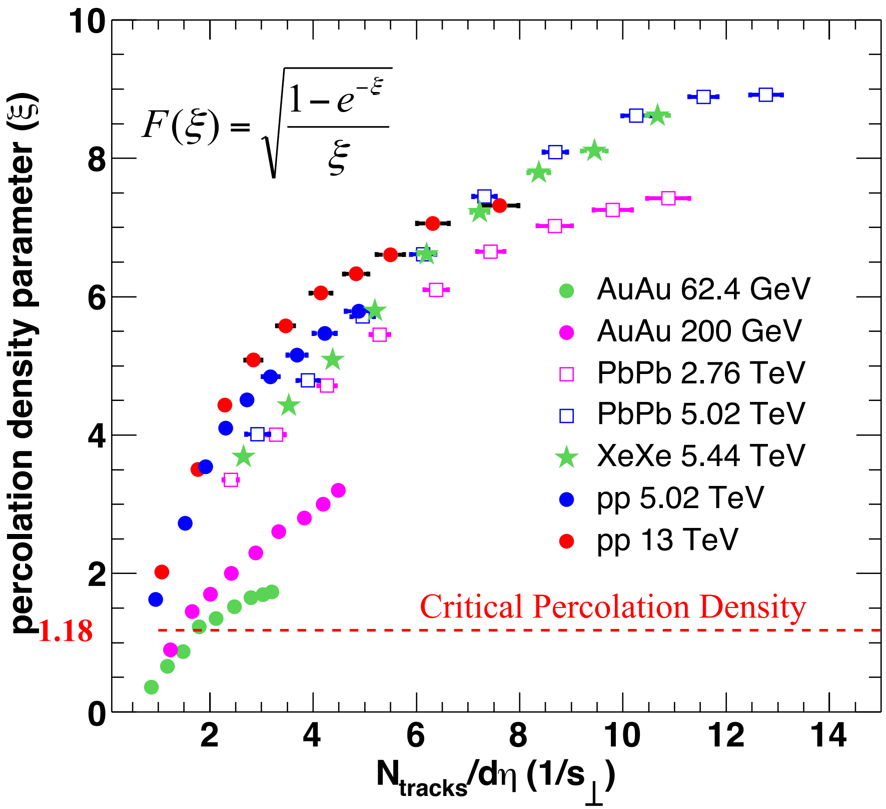


- p_T spectra for two different multiplicity classes to show that for higher multiplicity p_T spectra gets harder which results a lower value of **Color Suppuration Factor "F(ξ)"** and higher values of **Temperature.**

Analysis: Color Suppression Factor



Results: Percolation Density Parameter



➢ **ξ value for AuAu 62.4 GeV collisions:** Almost all centralities, except for the three most peripheral bins, lie above the critical percolation density.

➢ **ξ value for AuAu 200 GeV collisions:** All centralities, except for the most peripheral bin, lie above the critical percolation threshold.

➢ For all the ALICE data shown here, **ξ values are well above than the critical percolation threshold.**

Results: Cluster/Initial Temperature

$$T = \sqrt{\frac{\langle p_t^2 \rangle_1}{2F(\xi)}}$$

At the critical percolation density
$\xi = 1.2$ ➔ $T_c = 167$

PHENIX:

For Au+Au @200 GeV
0-10% centrality

$\xi = 2.88$ ➔ $T \sim 195$ MeV

Direct Photon Measurement
$T = 220 \pm 19^{(stat)} \pm 19^{(syst)}$ MeV
Phys. Rev. Lett. 104, 132301 (2010)

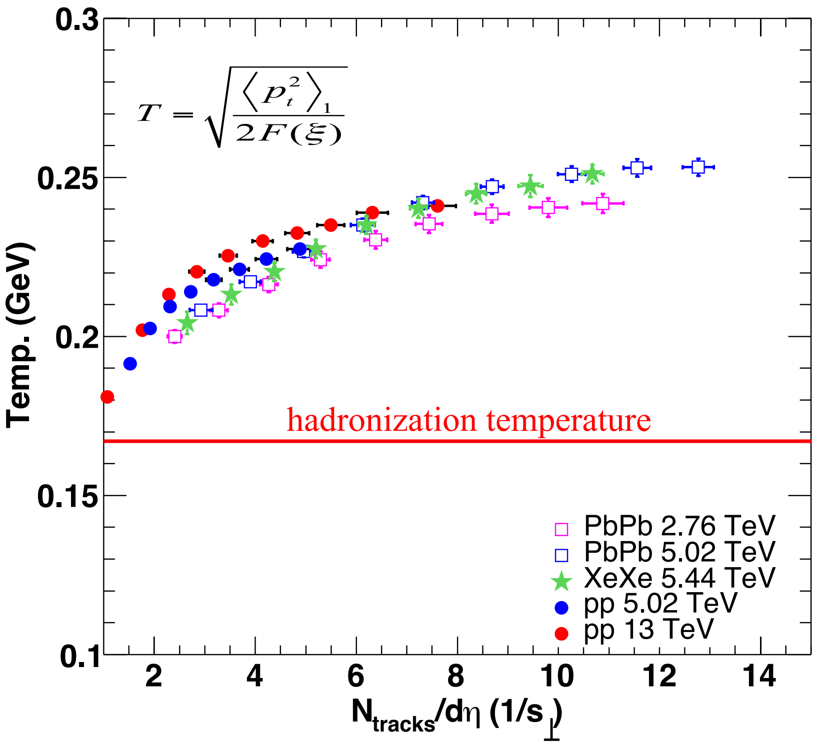
ALICE:

For Pb+Pb @ 2.76 TeV
0-5% centrality

$\xi = 10.56$ ➔ $T \sim 262 \pm 13$ MeV

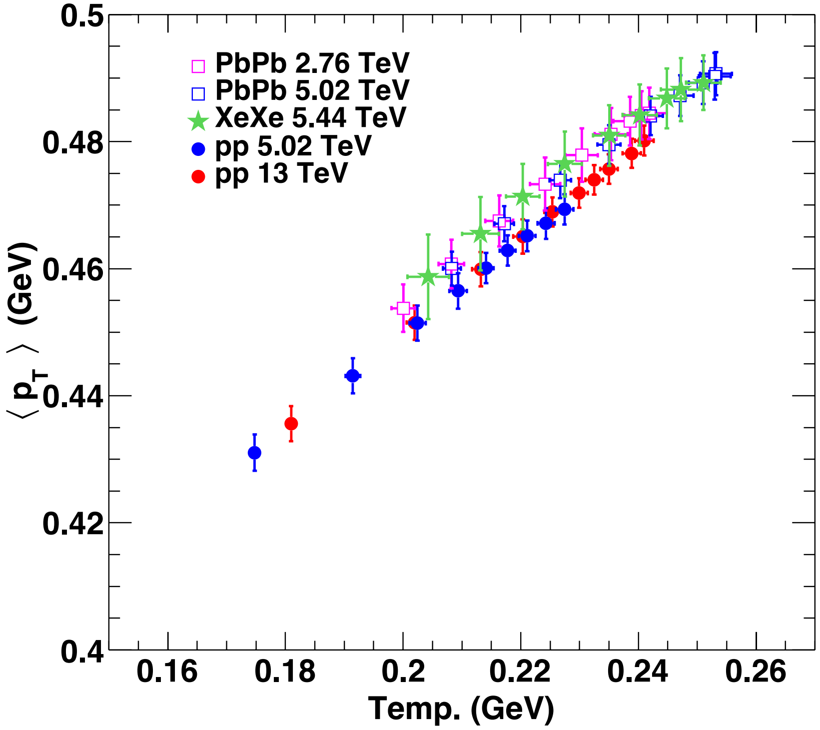
Direct Photon Measurement
$T = 297 \pm 12^{(stat)} \pm 41^{(syst)}$ MeV
Phys. Lett. B 754 (2016) 235-248

Results: Cluster/Initial Temperature



- Temperature from hadron-hadron and nucleus-nucleus collisions fall doesn't show a clear scaling multiplicity is scaled by the transverse interaction area.
- All the temperatures are above the universal hadronization temperature (165 MeV)
- The obtained temperatures indicate the creation of de-confined matter in pp collisions at $\sqrt{s}$ = 5.02 and 13 TeV even at very low multiplicity.

Results: Mean Transverse Momentum

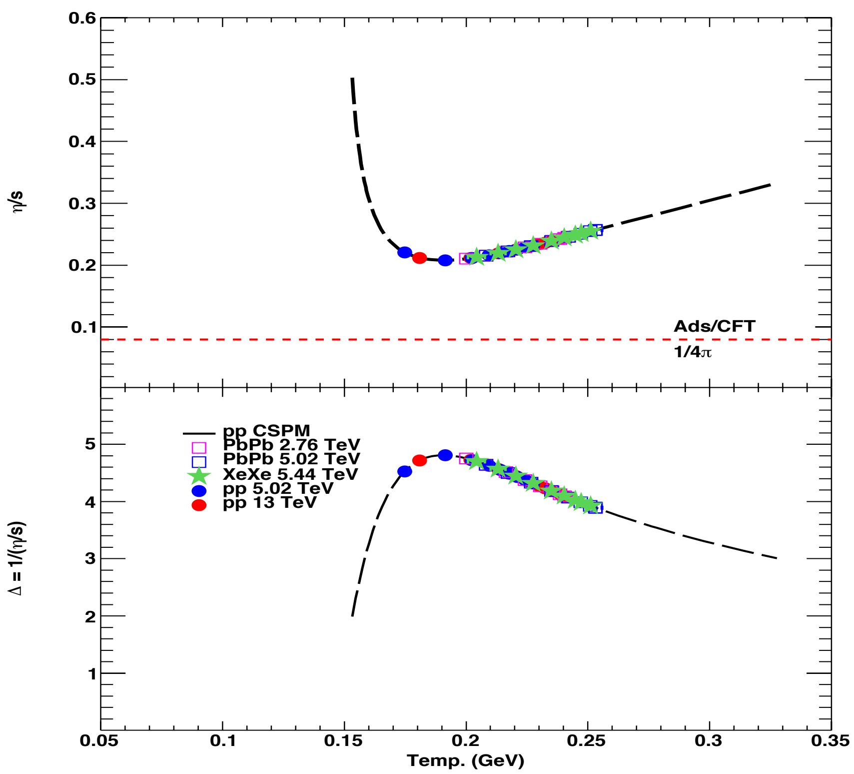


For an ultrarelativistic ideal gas $\langle p_T \rangle \propto T$. When the transverse momentum is exponentially distributed with inverse slope T in a given event, $\langle p_T \rangle = 2T$**. Using this relation one can predict the $\langle p_T \rangle$ for upcoming collision energies.

***H. Heiselberg Phys. Rep. 351 (2001) 161.*

Results: eta/s

- η/s was obtained in the framework of kinetic theory and the string percolation with the following expression:



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

where T is the temperature and L is the longitudinal extension of the source ~1 fm.

- The inverse of η/s also measures how strong are the interactions in the medium.

- Both Δ and η/s describe the transition from a strongly coupled QGP to a weakly coupled QGP.

Results: Energy Density

Bjorken 1D expansion

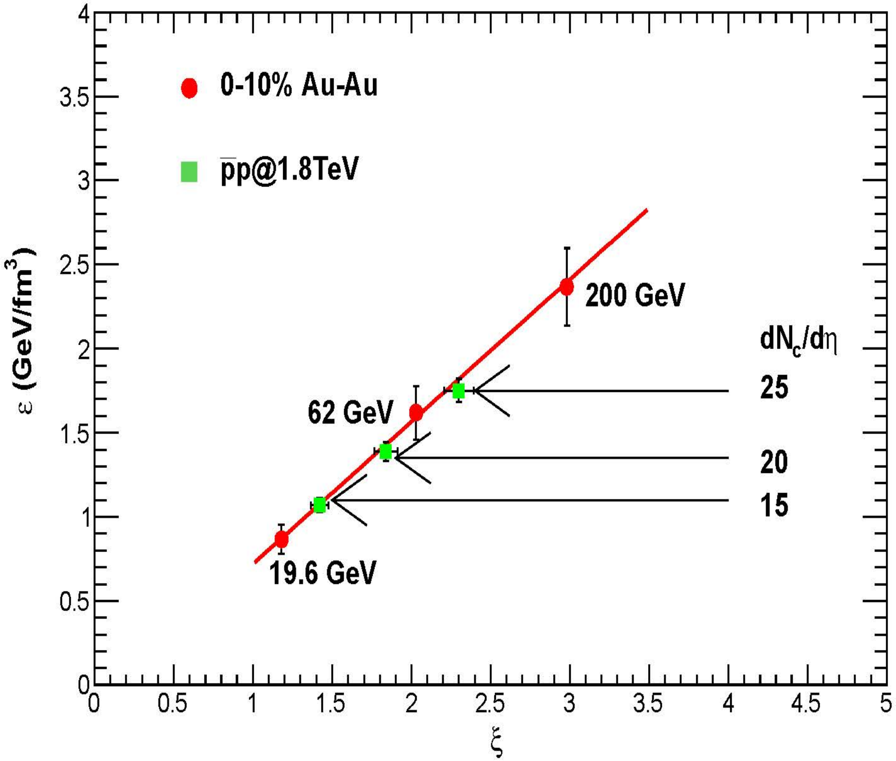
$$\varepsilon = \frac{3}{2}\frac{dN_c}{dy}\frac{<m_t>}{A}\frac{1}{\tau_{pro}} GeV/fm^3$$

Transverse overlap area (A)

Proper Time (τ_{pro})

τ_{pro} is the QED production time for a boson which can be scaled from QED to QCD and is given by

$$\tau_{pro} = \frac{2.405\hbar}{<m_t>}$$



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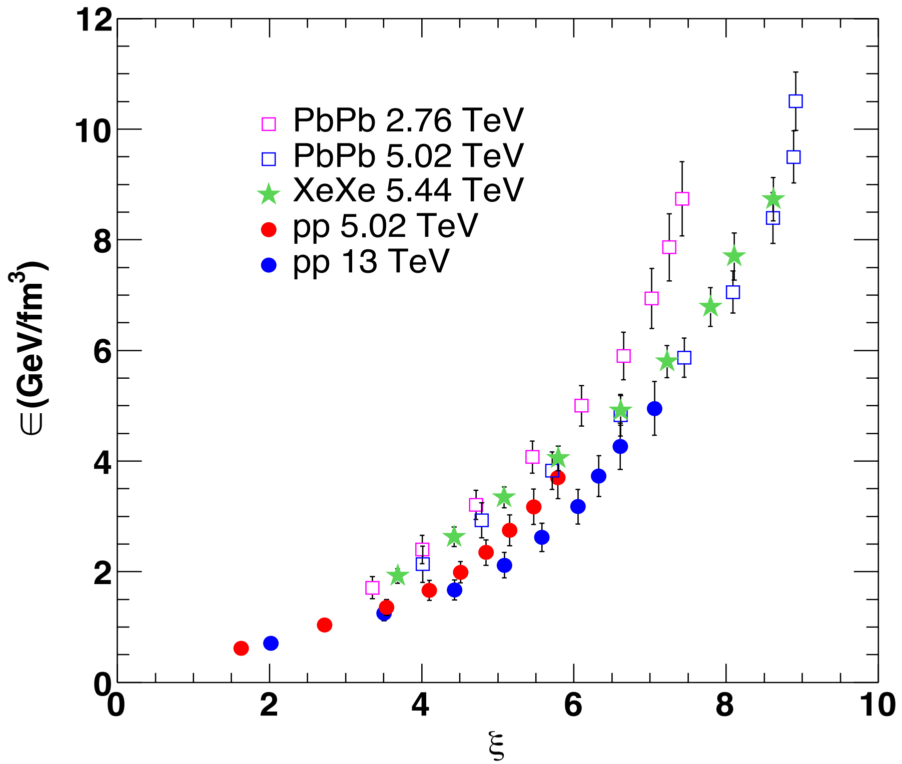


We find the non-linear relationship between Energy density and percolation density parameter.

Introduction to high energy heavy ion collisions: C. Y. Wong

Summary

- Color string percolation concept has been explored to study the de-confinement in nuclear collisions

- Energy density obtained at LHC energies show a different behaviour than at RHIC energy.

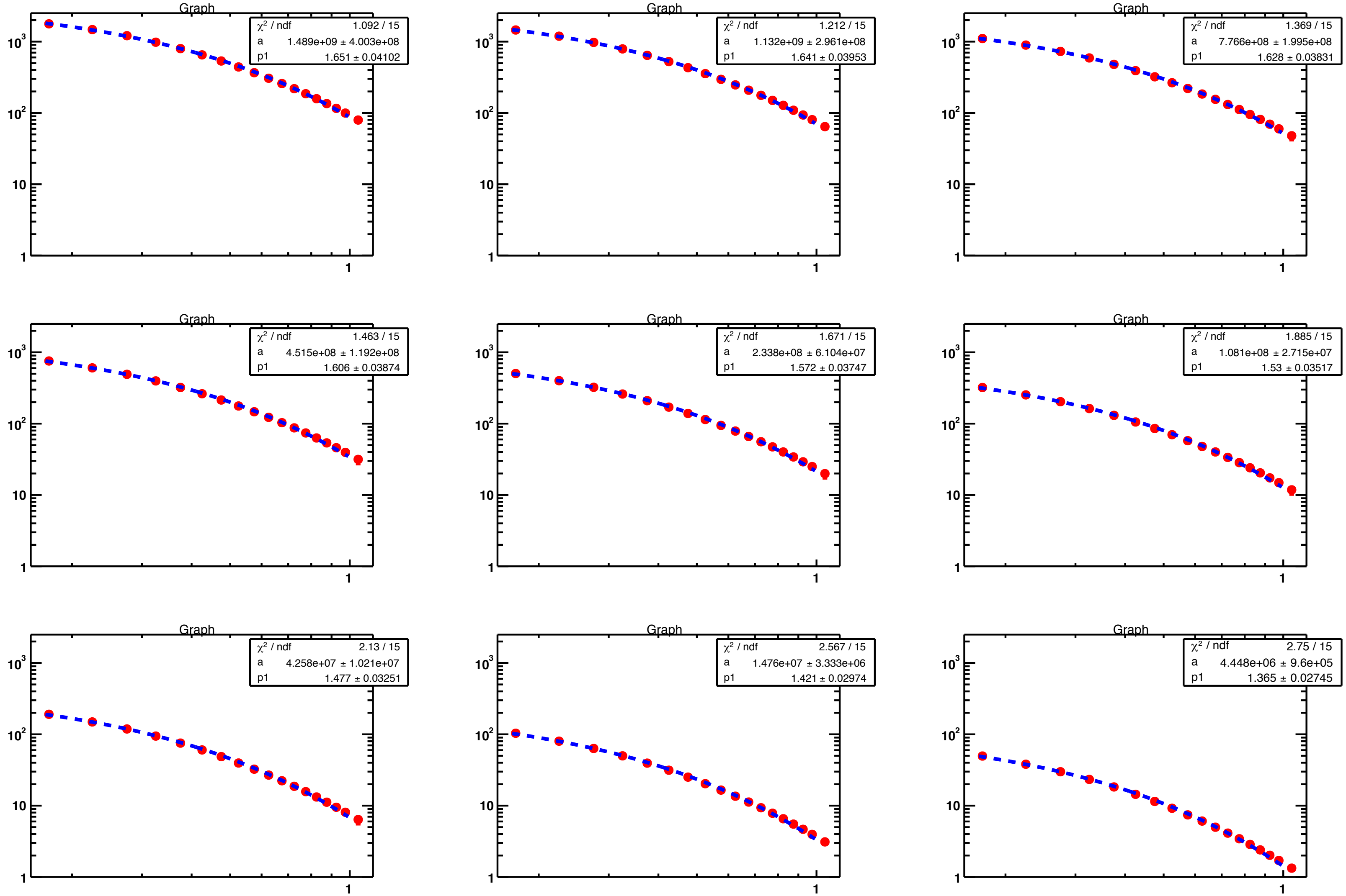
- We are to understand the non-linear behaviour of the energy density as a function of percolation density parameter.

- Initial temperature obtained using percolation for all considered LHC energies are above the universal hadronization temperature (165 MeV) .

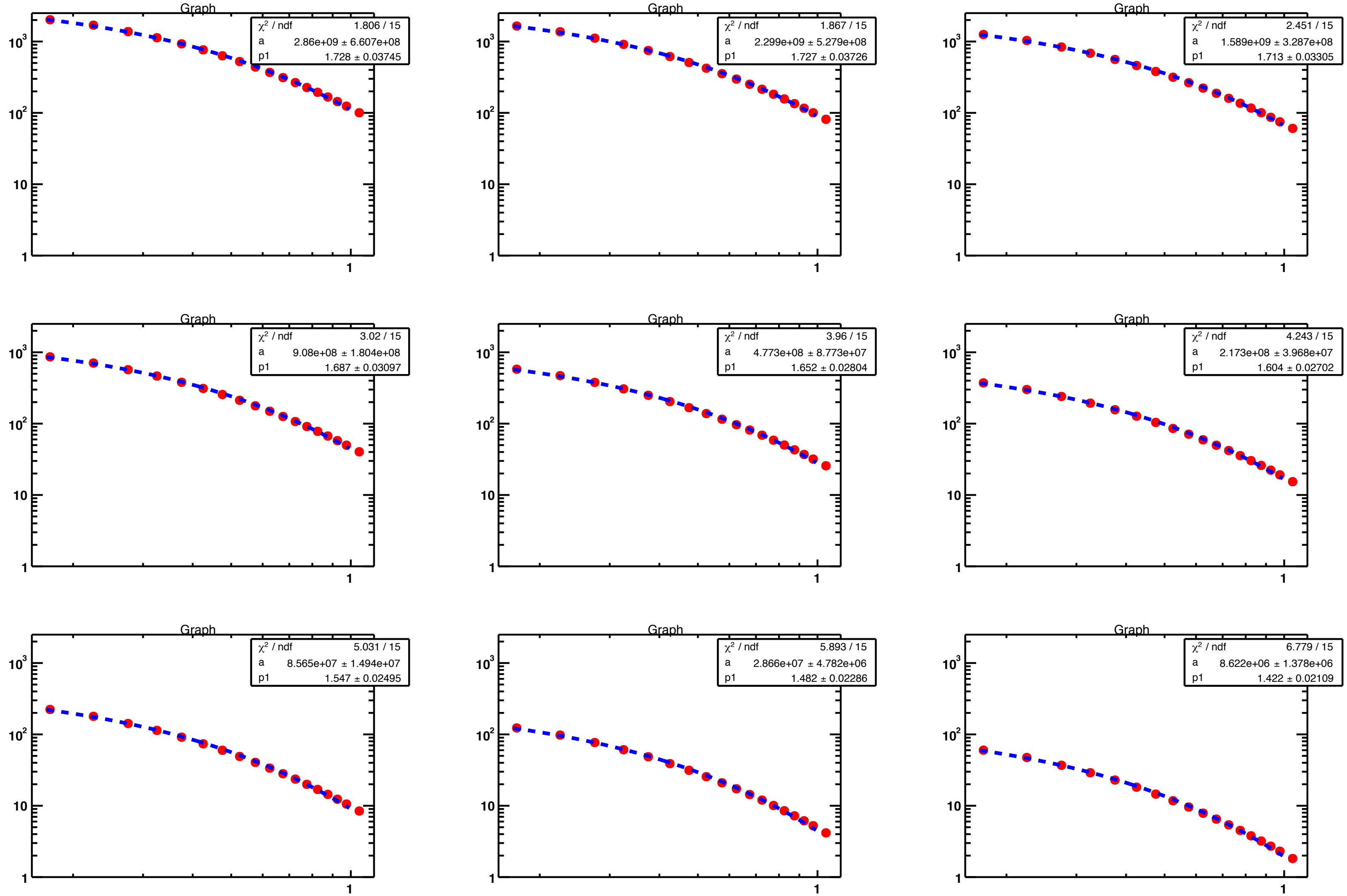
Thank you

Backup Slides

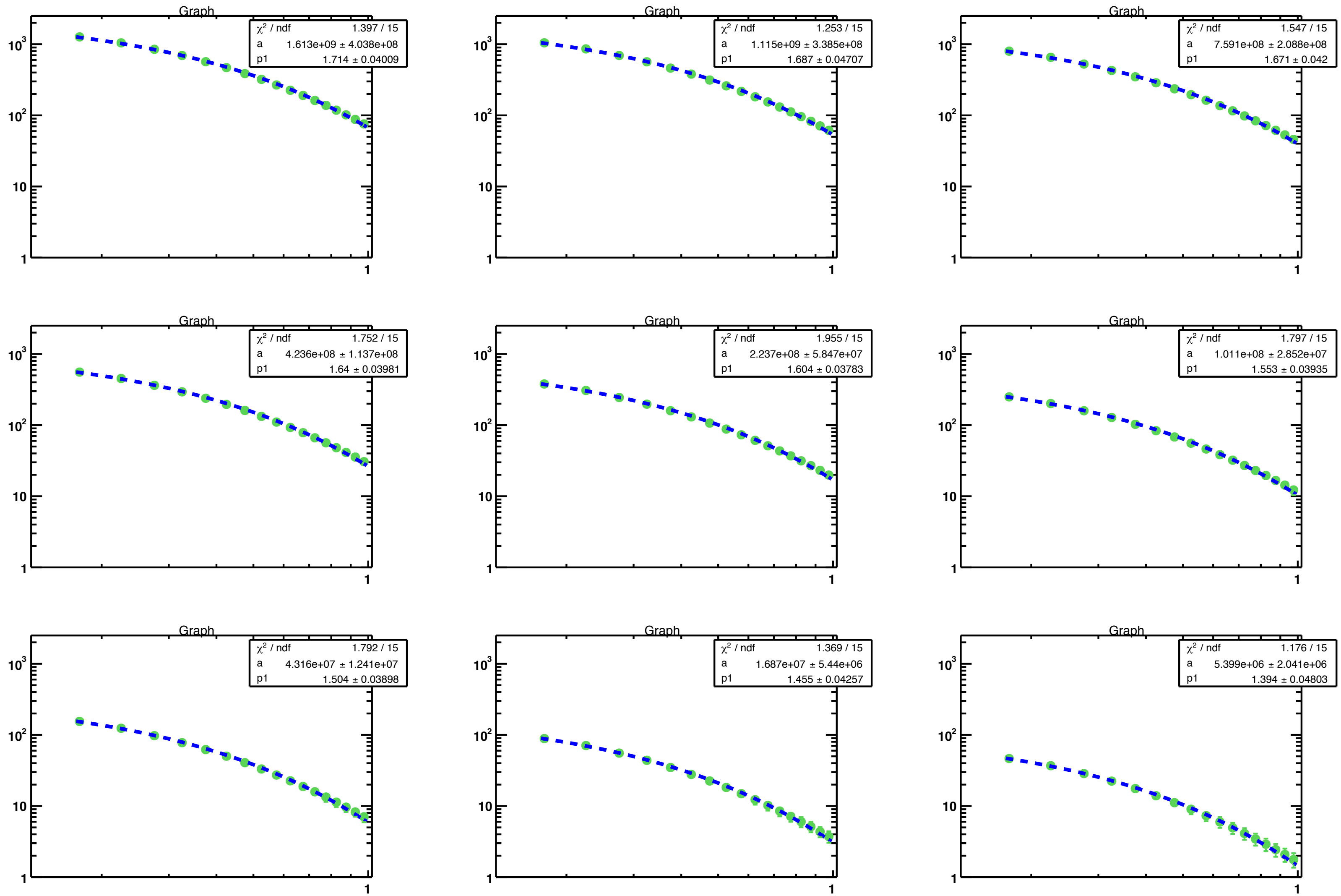
PbPb @ 2.76 TeV


Graph
χ2 / ndf 1.092 / 15
a 1.489e+09 ± 4.003e+08
p1 1.651 ± 0.04102
Graph
χ2 / ndf 1.212 / 15
a 1.132e+09 ± 2.961e+08
p1 1.641 ± 0.03953
Graph
χ2 / ndf 1.369 / 15
a 7.766e+08 ± 1.995e+08
p1 1.628 ± 0.03831
Graph
χ2 / ndf 1.463 / 15
a 4.515e+08 ± 1.192e+08
p1 1.606 ± 0.03874
Graph
χ2 / ndf 1.671 / 15
a 2.338e+08 ± 6.104e+07
p1 1.572 ± 0.03747
Graph
χ2 / ndf 1.885 / 15
a 1.081e+08 ± 2.715e+07
p1 1.53 ± 0.03517
Graph
χ2 / ndf 2.13 / 15
a 4.258e+07 ± 1.021e+07
p1 1.477 ± 0.03251
Graph
χ2 / ndf 2.567 / 15
a 1.476e+07 ± 3.333e+06
p1 1.421 ± 0.02974
Graph
χ2 / ndf 2.75 / 15
a 4.448e+06 ± 9.6e+05
p1 1.365 ± 0.02745

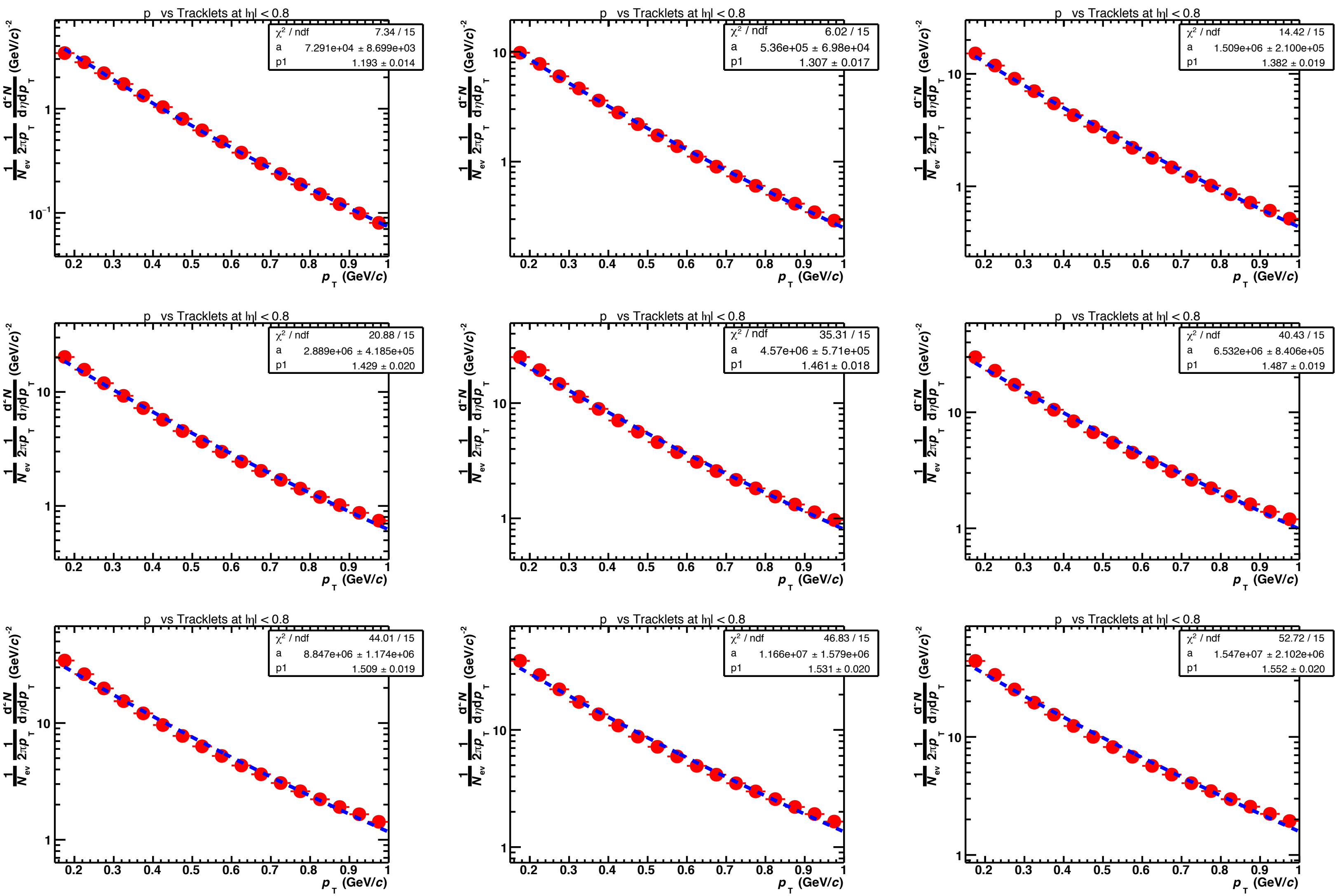
PbPb @ 5.02 TeV


Graph
χ2 / ndf 1.806 / 15
a 2.86e+09 ± 6.607e+08
p1 1.728 ± 0.03745
Graph
χ2 / ndf 1.867 / 15
a 2.299e+09 ± 5.279e+08
p1 1.727 ± 0.03726
Graph
χ2 / ndf 2.451 / 15
a 1.589e+09 ± 3.287e+08
p1 1.713 ± 0.03305
Graph
χ2 / ndf 3.02 / 15
a 9.08e+08 ± 1.804e+08
p1 1.687 ± 0.03097
Graph
χ2 / ndf 3.96 / 15
a 4.773e+08 ± 8.773e+07
p1 1.652 ± 0.02804
Graph
χ2 / ndf 4.243 / 15
a 2.173e+08 ± 3.968e+07
p1 1.604 ± 0.02702
Graph
χ2 / ndf 5.031 / 15
a 8.565e+07 ± 1.494e+07
p1 1.547 ± 0.02495
Graph
χ2 / ndf 5.893 / 15
a 2.866e+07 ± 4.782e+06
p1 1.482 ± 0.02286
Graph
χ2 / ndf 6.779 / 15
a 8.622e+06 ± 1.378e+06
p1 1.422 ± 0.02109

XeXe @ 5.44 TeV

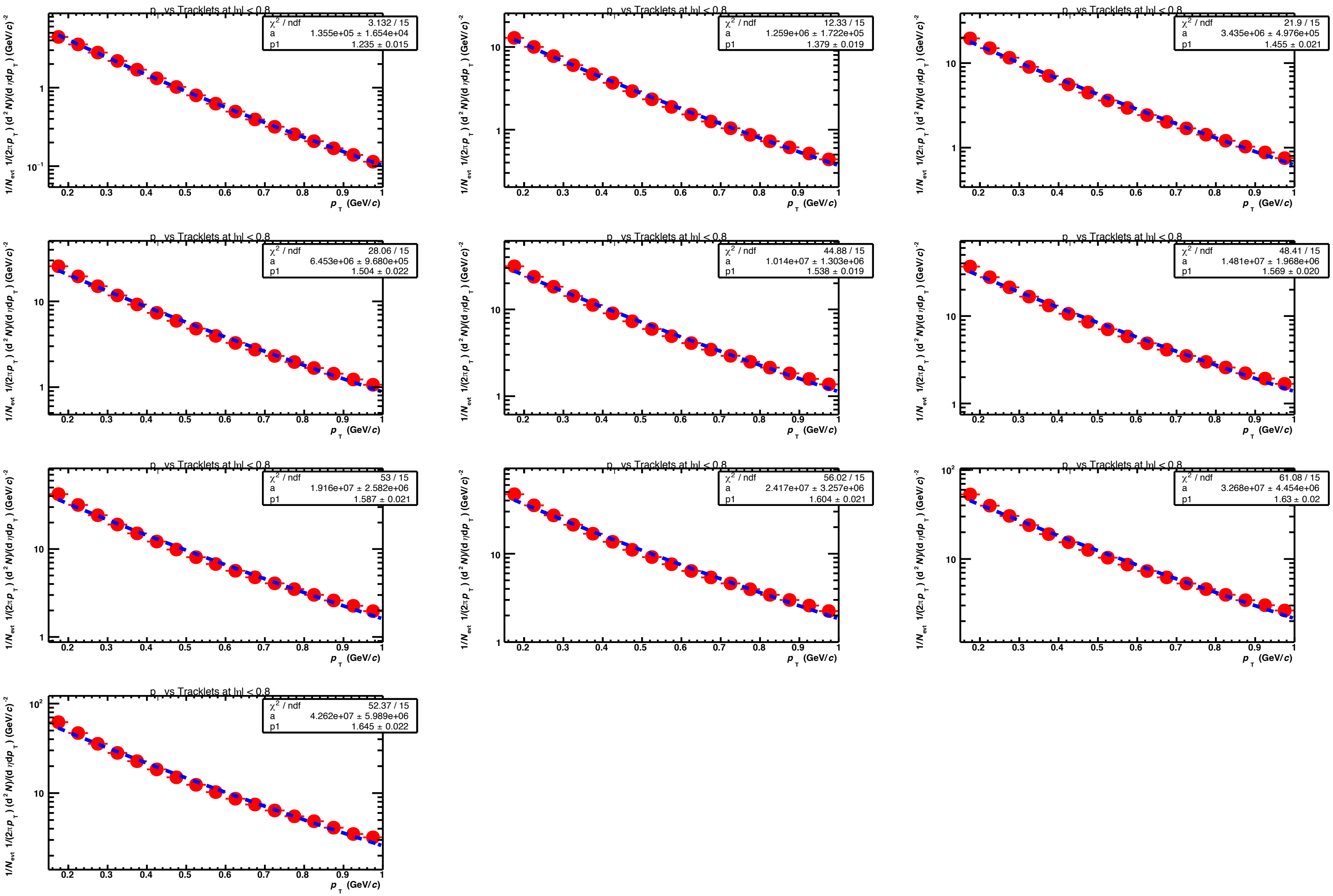

Graph
χ² / ndf 1.397 / 15
a 1.613e+09 ± 4.038e+08
p1 1.714 ± 0.04009
Graph
χ² / ndf 1.253 / 15
a 1.115e+09 ± 3.385e+08
p1 1.687 ± 0.04707
Graph
χ² / ndf 1.547 / 15
a 7.591e+08 ± 2.088e+08
p1 1.671 ± 0.042
Graph
χ² / ndf 1.752 / 15
a 4.236e+08 ± 1.137e+08
p1 1.64 ± 0.03981
Graph
χ² / ndf 1.955 / 15
a 2.237e+08 ± 5.847e+07
p1 1.604 ± 0.03783
Graph
χ² / ndf 1.797 / 15
a 1.011e+08 ± 2.852e+07
p1 1.553 ± 0.03935
Graph
χ² / ndf 1.792 / 15
a 4.316e+07 ± 1.241e+07
p1 1.504 ± 0.03898
Graph
χ² / ndf 1.369 / 15
a 1.687e+07 ± 5.44e+06
p1 1.455 ± 0.04257
Graph
χ² / ndf 1.176 / 15
a 5.399e+06 ± 2.041e+06
p1 1.394 ± 0.04803
10³
10²
10
1

pp @ 5.02 TeV



p vs Tracklets at |η| < 0.8
χ² / ndf 7.34 / 15
a 7.291e+04 ± 8.699e+03
p1 1.193 ± 0.014
p vs Tracklets at |η| < 0.8
χ² / ndf 6.02 / 15
a 5.36e+05 ± 6.98e+04
p1 1.307 ± 0.017
p vs Tracklets at |η| < 0.8
χ² / ndf 14.42 / 15
a 1.509e+06 ± 2.100e+05
p1 1.382 ± 0.019
p vs Tracklets at |η| < 0.8
χ² / ndf 20.88 / 15
a 2.889e+06 ± 4.185e+05
p1 1.429 ± 0.020
p vs Tracklets at |η| < 0.8
χ² / ndf 35.31 / 15
a 4.57e+06 ± 5.71e+05
p1 1.461 ± 0.018
p vs Tracklets at |η| < 0.8
χ² / ndf 40.43 / 15
a 6.532e+06 ± 8.406e+05
p1 1.487 ± 0.019
p vs Tracklets at |η| < 0.8
χ² / ndf 44.01 / 15
a 8.847e+06 ± 1.174e+06
p1 1.509 ± 0.019
p vs Tracklets at |η| < 0.8
χ² / ndf 46.83 / 15
a 1.166e+07 ± 1.579e+06
p1 1.531 ± 0.020
p vs Tracklets at |η| < 0.8
χ² / ndf 52.72 / 15
a 1.547e+07 ± 2.102e+06
p1 1.552 ± 0.020
p_T (GeV/c)

pp @ 13 TeV



p_T vs Tracklets at |η| < 0.8
1/N_evt 1/(2π p_T) (d² N)/(d η dp_T) (GeV/c)^-2
p_T (GeV/c)
χ² / ndf 3.132 / 15
a 1.355e+05 ± 1.654e+04
p1 1.235 ± 0.015
χ² / ndf 12.33 / 15
a 1.259e+06 ± 1.722e+05
p1 1.379 ± 0.019
χ² / ndf 21.9 / 15
a 3.435e+06 ± 4.976e+05
p1 1.455 ± 0.021
χ² / ndf 28.06 / 15
a 6.453e+06 ± 9.680e+05
p1 1.504 ± 0.022
χ² / ndf 44.88 / 15
a 1.014e+07 ± 1.303e+06
p1 1.538 ± 0.019
χ² / ndf 48.41 / 15
a 1.481e+07 ± 1.968e+06
p1 1.569 ± 0.020
χ² / ndf 53 / 15
a 1.916e+07 ± 2.582e+06
p1 1.587 ± 0.021
χ² / ndf 56.02 / 15
a 2.417e+07 ± 3.257e+06
p1 1.604 ± 0.021
χ² / ndf 61.08 / 15
a 3.268e+07 ± 4.454e+06
p1 1.63 ± 0.02
χ² / ndf 52.37 / 15
a 4.262e+07 ± 5.989e+06
p1 1.645 ± 0.022