Fluctuations and Selection Bias in 5 and 13 TeV *p-p* Collisions: *Where are the jets*?

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ISMD 2021 via ZOOM

Agenda

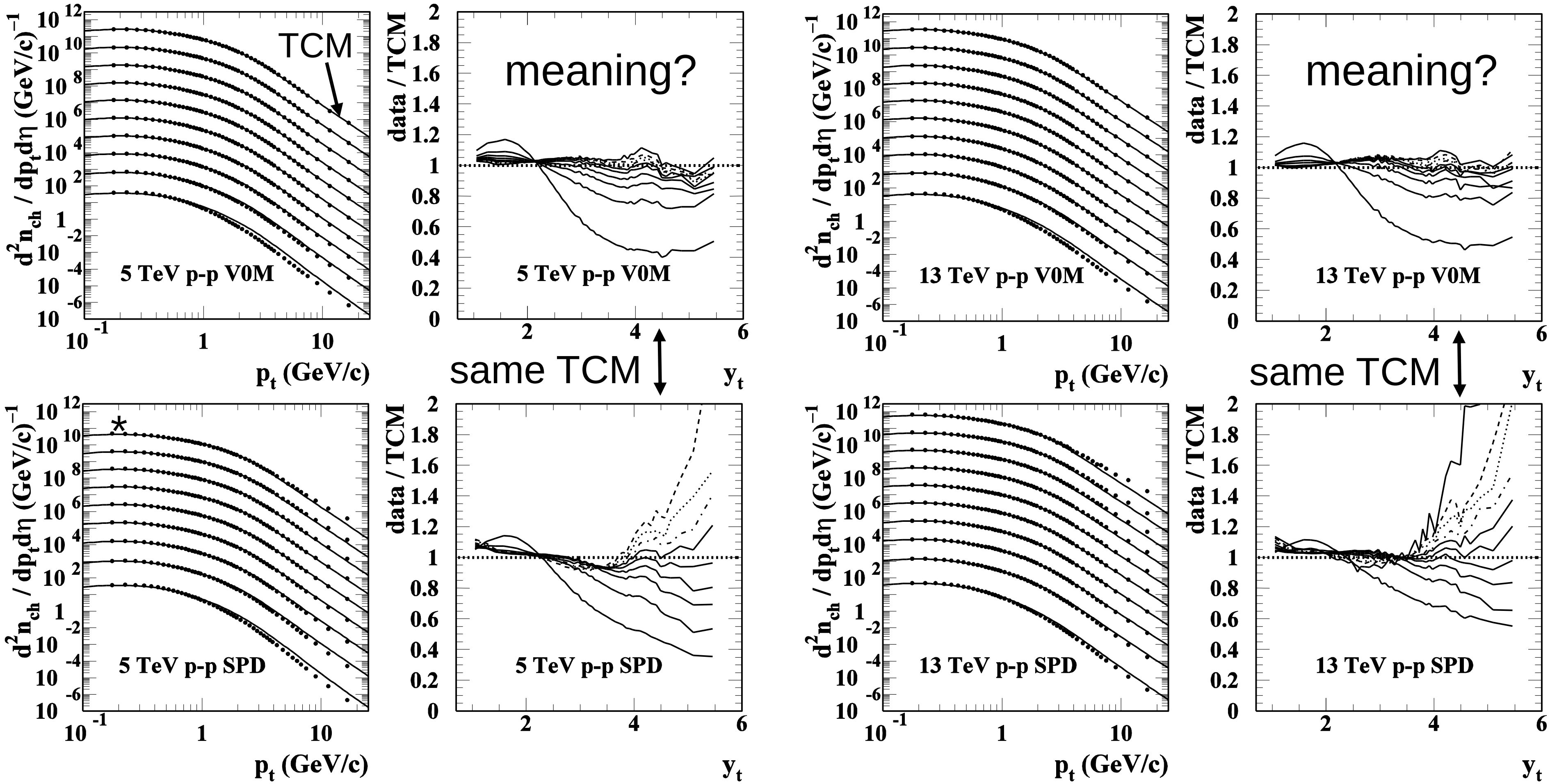
collectivity in small systems?

study jets in 5 and 13 TeV p-p p_t spectra

two-component model of hadron production

ALICE *p-p* p_t Spectrum Data

105M events Eur. Phys. J. C **79**, 857 (2019), arXiv:1905.07208 **60M events**



13 TeV V0M: $n_{ch} \in [2.5,26.6]$ (*ten event classes*[*]) 13 TeV SPD: $n_{ch} \in [2.9,54.1]$

"The aim…is to investigate the importance of jets in high-multiplicity pp collisions and their *contribution to charged-particle production at low* p_T"

Two-Component Model – Fixed TCM

hadron production in *p-p* collisions near midrapidity

$y_{ti} = \ln\left[(m_{ti} + p_t)/m_i\right]$ hadron species *i*

Pancheri and Srivastava, 1985

charge densities: $\bar{\rho}_0(y_t, n_{ch}) = \bar{\rho}_s(y_t, n_{ch}) + \bar{\rho}_h(y_t, n_{ch})$ **soft + hard**

soft component: projectile-nucleon dissociation (~PDF)

participant low-*x* gluons $\propto \bar{\rho}_s$ $\bar{\rho}_{sNSD} \approx 0.81 \log(\sqrt{s} / 10\ \text{GeV})$

hard component: large-angle scattered gluons → dijets

hard vs soft $\Rightarrow$ **MB jet fragments:** $\bar{\rho}_h \approx \alpha \bar{\rho}_s^2$ $\alpha \approx O(0.01)$

predictive model

factorized: $\bar{\rho}_s(y_t, n_{ch})$ $\bar{\rho}_h(y_t, n_{ch})$

$$\bar{\rho}_0(y_t, n_{ch}) \approx \bar{\rho}_s \hat{S}_0(y_t) + \bar{\rho}_h \hat{H}_0(y_t)$$

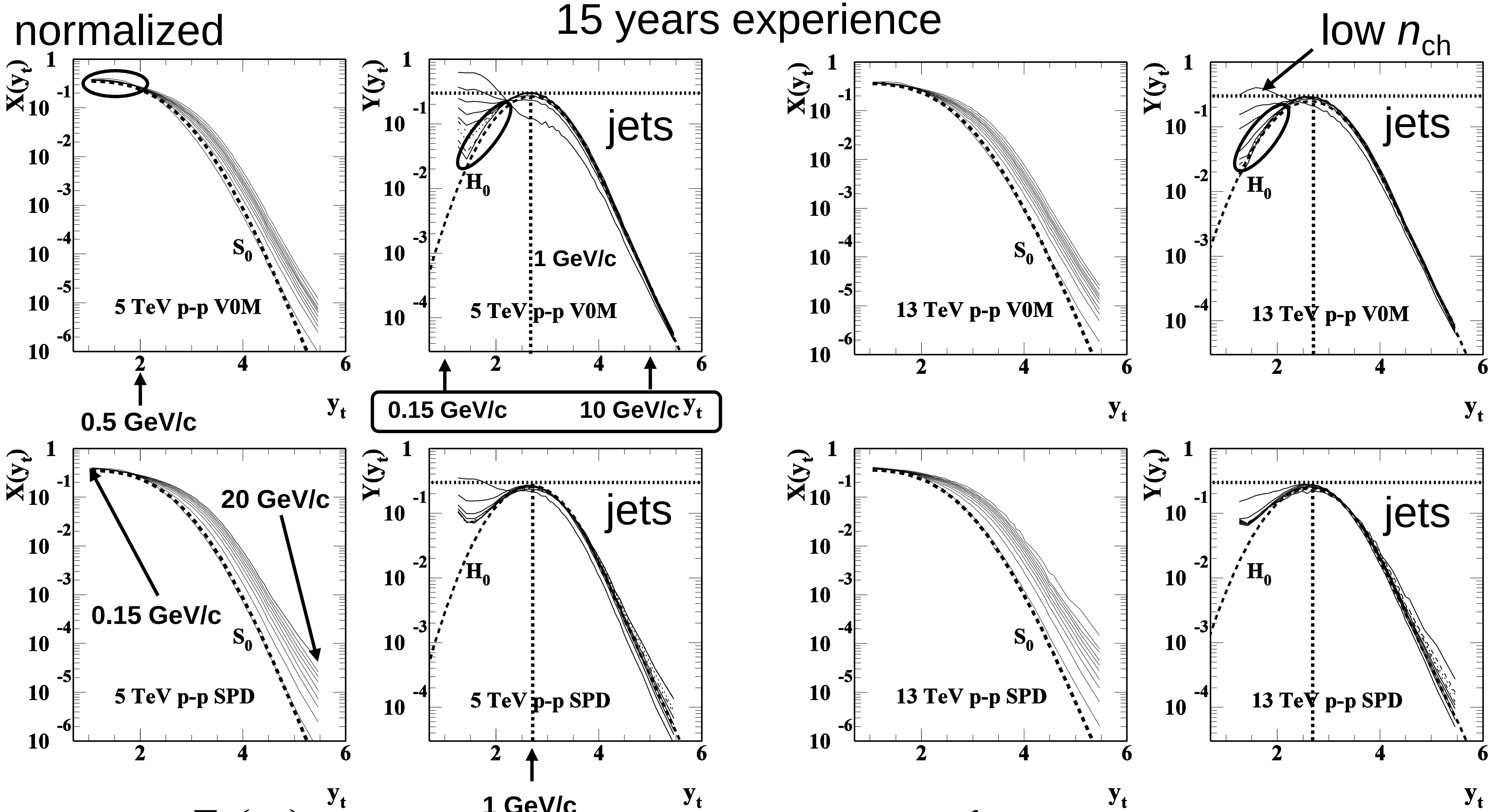
$$x(n_s) \equiv \frac{\bar{\rho}_h}{\bar{\rho}_s} \approx \alpha\left(\sqrt{s}\right)\bar{\rho}_s$$

root of quadratic equation: $\bar{\rho}_0(y_t, n_{ch}) \approx \bar{\rho}_s + \alpha \bar{\rho}_s^2$

TCM unit-normal fixed model function

TCM p_t Spectrum *Fixed* Model

15 years experience



$$X(y_t) \equiv \frac{\bar{\rho}_0(y_t)}{\bar{\rho}_s} \approx \hat{S}_0(y_t) + x(n_s)\hat{H}_0(y_t)$$

data — model

$$Y(y_t) \equiv \frac{1}{x(n_s)}\left[X(y_t) - \hat{S}_0(y_t)\right] \approx \hat{H}_0(y_t)$$

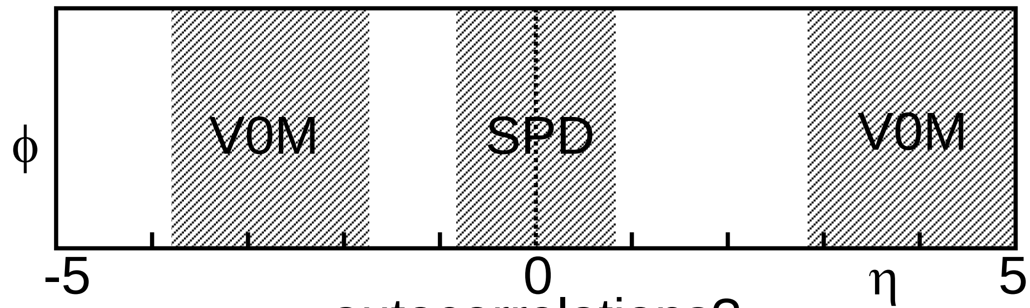
data — model

$$x(n_s) \equiv \alpha\bar{\rho}_s$$

Event-Selection Bias

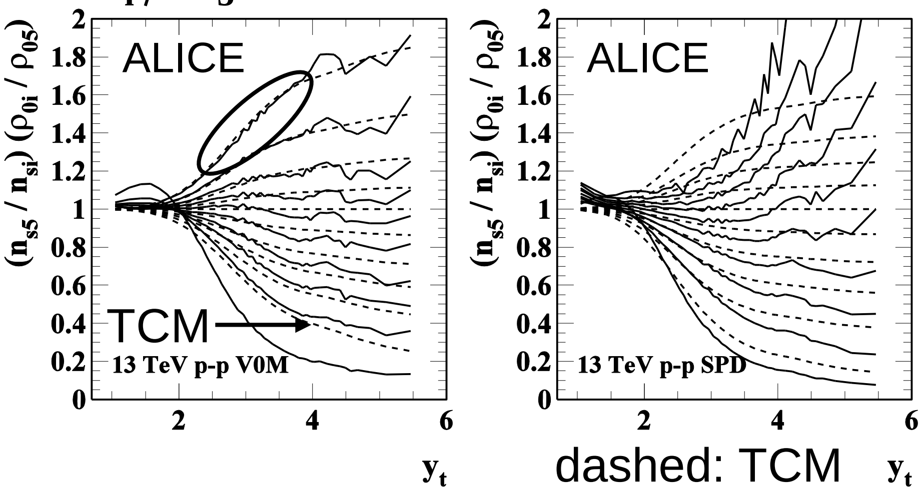
event selection based on two angular acceptances:

the *same event ensemble* partitioned in two ways

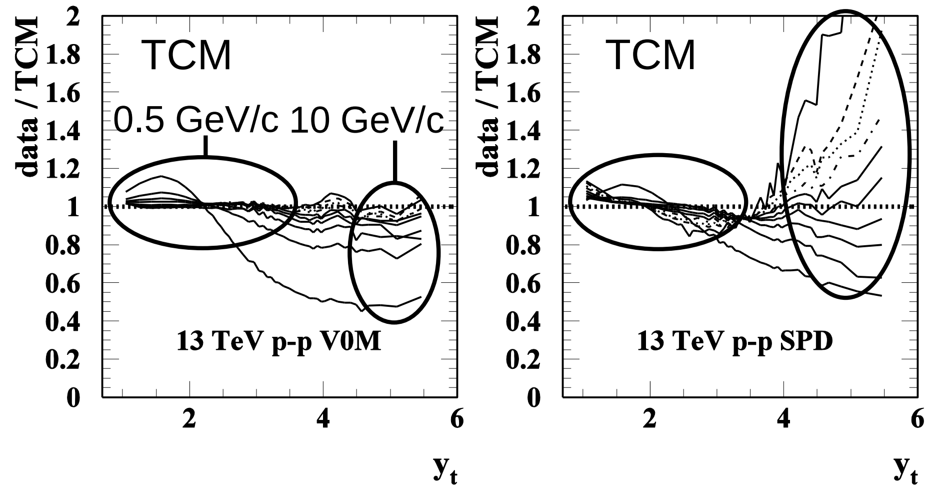


autocorrelations?

X_i / X_5 V0M vs SPD



p_t spectra in ratio to TCM event class 5 (normalized by soft charge densities)



data in ratio to fixed TCM
what does this mean?

bias relative to mean-value trends (e.g. TCM) due to *fluctuations*

different bias trends at lower p_t and higher p_t

Z scores and Significance

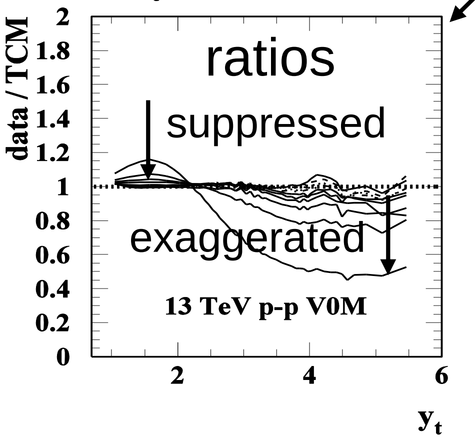
spectrum ratio: $\frac{\text{data}}{\text{model}} - 1 \approx \frac{\text{data - model}}{\text{error}} \times \frac{\text{error}}{\text{data}}$

Z scores **extraneous factor**

STATISTICS 101

$$\chi^2 = \sum_i Z_i^2$$

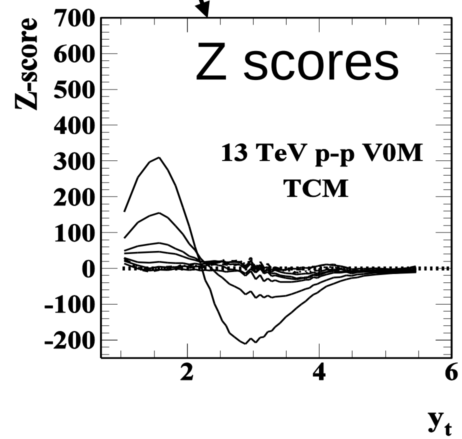
ratios hide significant low-p_t structure:

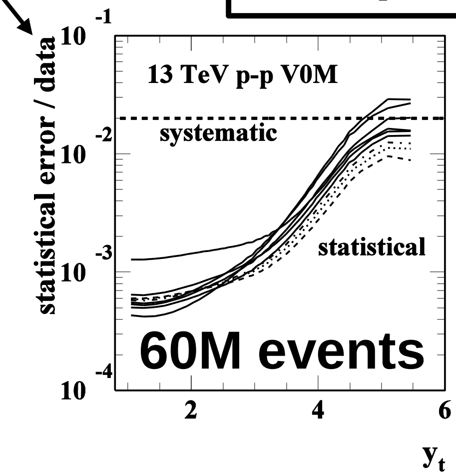


same data

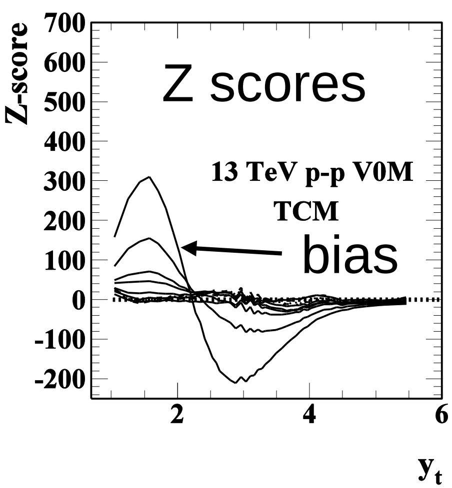
vs TCM

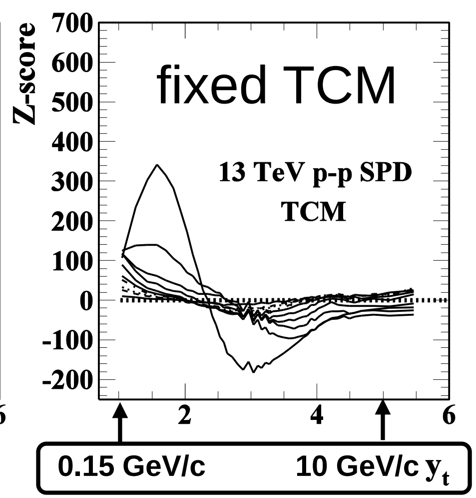
Z_i

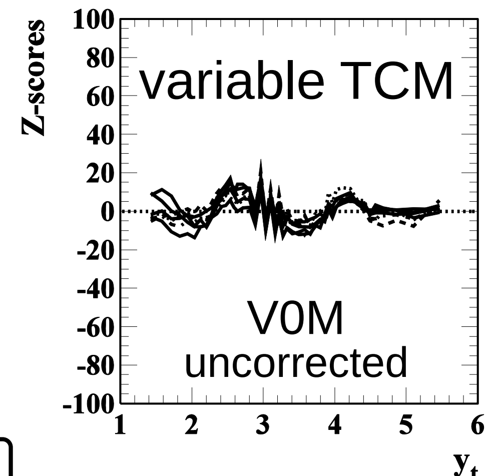


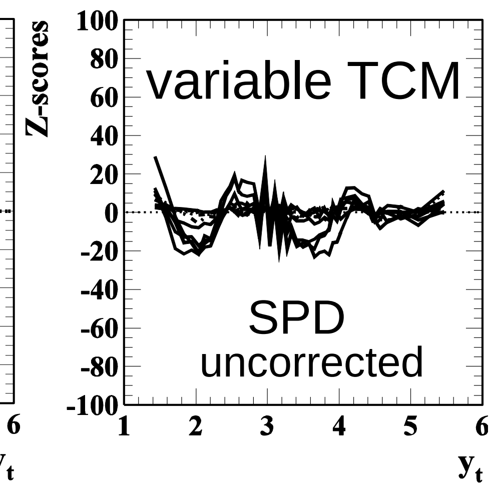


biases produce *highly significant* deviations at low p_t

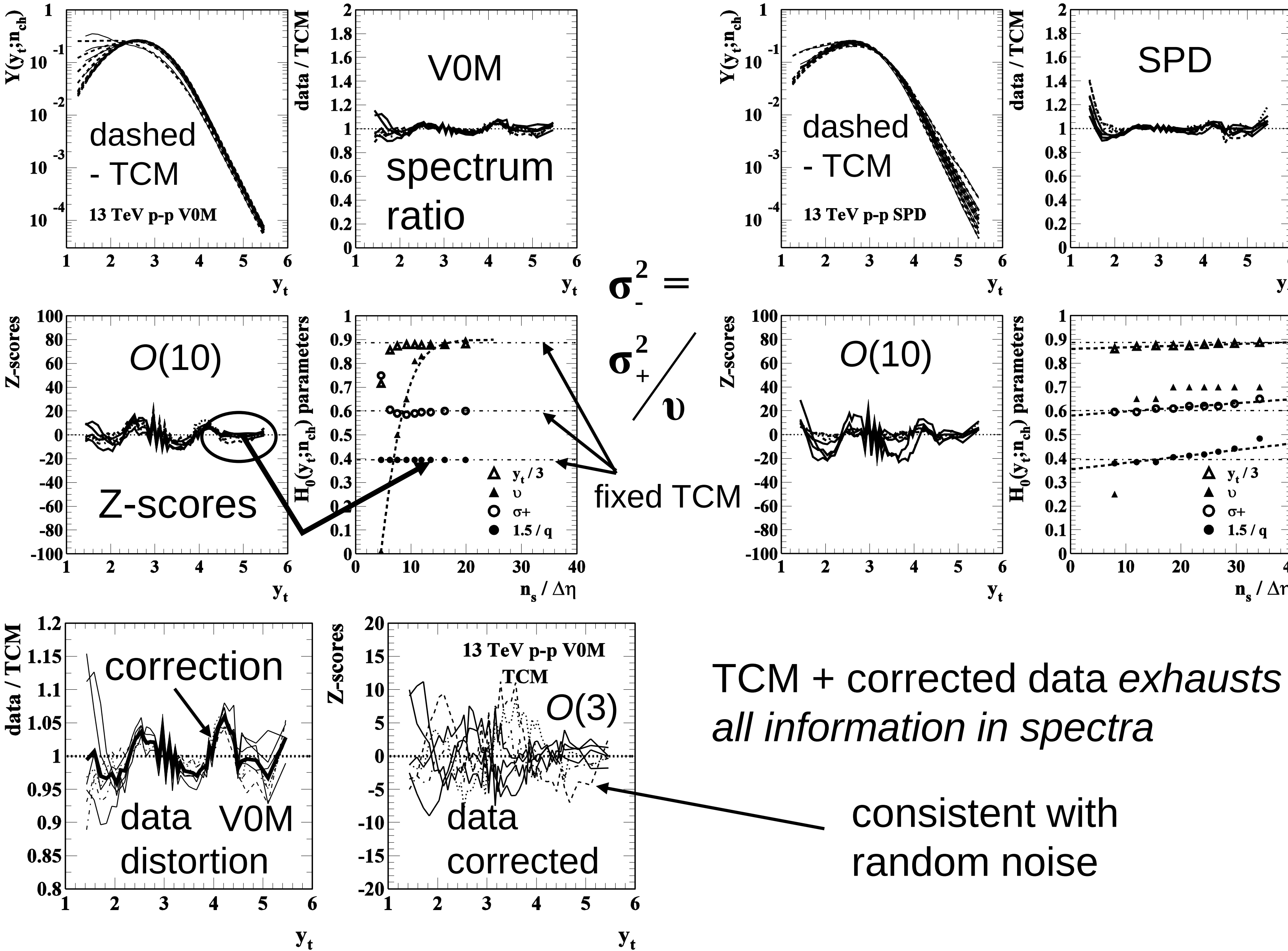








TCM p_t Spectrum *Variable* Model



$\sigma_-^2 = \sigma_+^2 / \upsilon$

TCM + corrected data *exhausts all information in spectra*

consistent with random noise

Alternative Model: Tsallis

J. Phys. G **47**, 055111 (2020), arXiv:1908.04208

<u>Modified</u> Tsallis spectrum model:

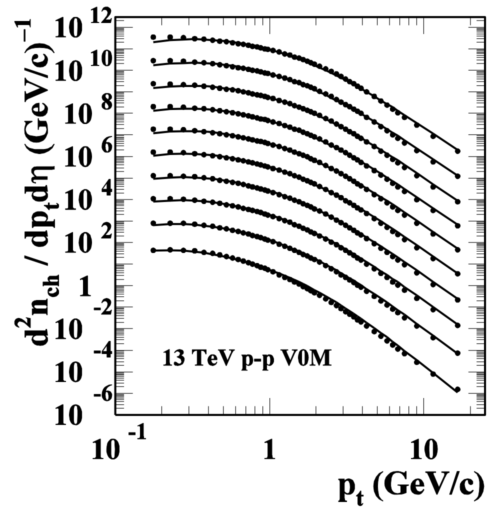
?

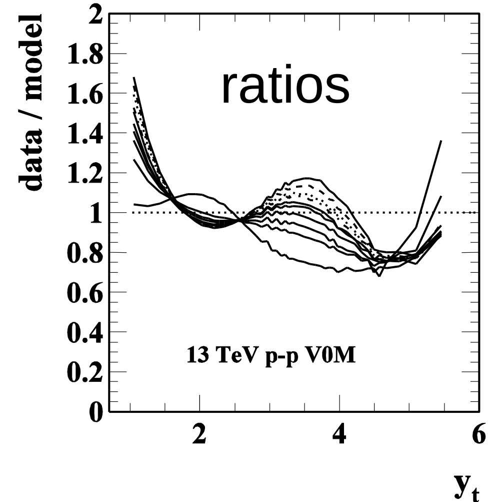
$$\frac{d^2 n_{ch,i}}{dp_t\, d\eta} = w_i \bar{\rho}_0 \left[\frac{p_t^2 A}{\left(1 + m_{t,i} / nT\right)^{n+1}} \right]$$

1/n = q-1 (Tsallis *q*)

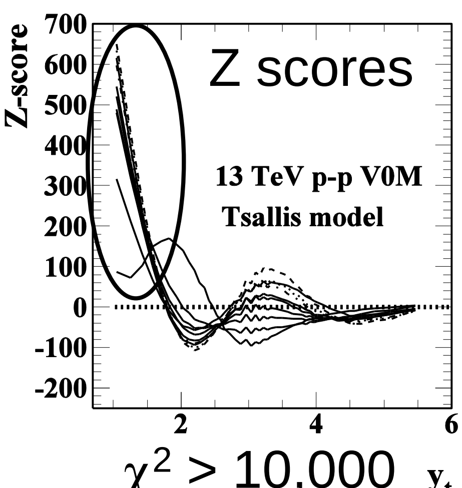
w_i is statistical weight of species i

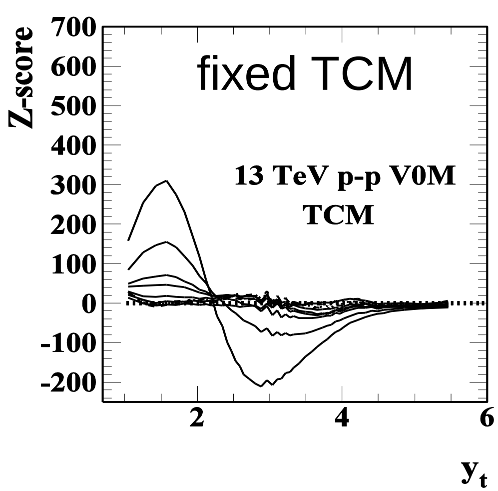
fit parameters *q, T*

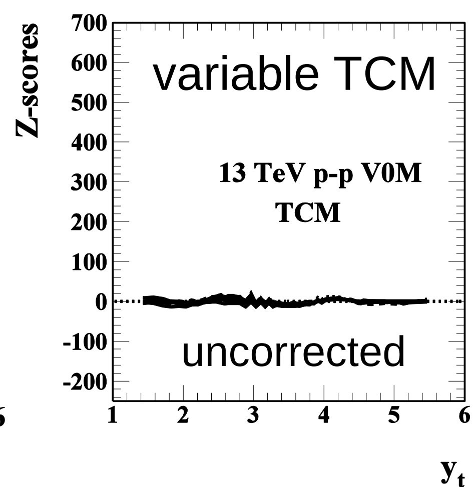


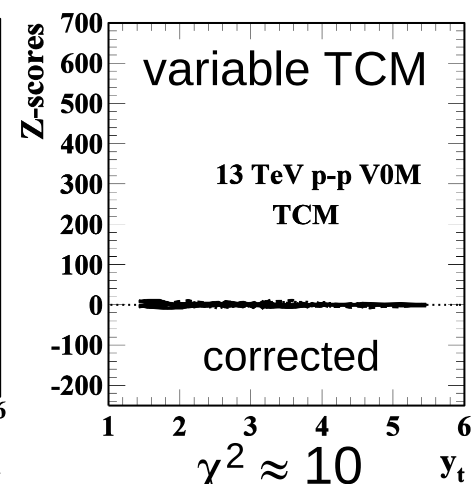


Tsallis model fails below y_t = 4 (≈ 4 GeV/c)





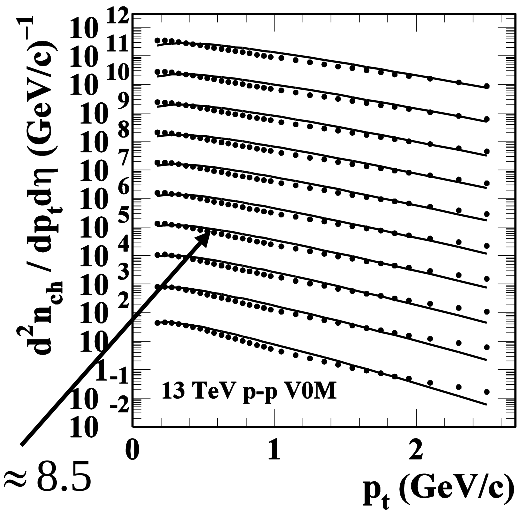


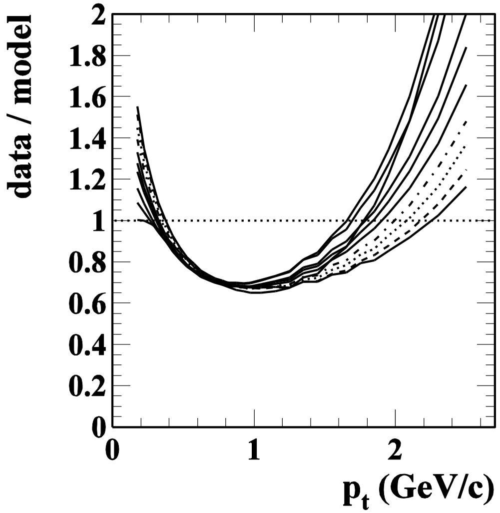


Alternative Model: Blast Wave

$[p_t m_t]$ - missing factors   J. Phys. G **47**, 055111 (2020)

$$\frac{d^2N}{dp_t dy} = D[p_t m_t]\int_0^{R_0} r\,dr\, K_1\left[\frac{m_t\cosh(\rho)}{T}\right] I_0\left[\frac{p_t\sinh(\rho)}{T}\right]$$

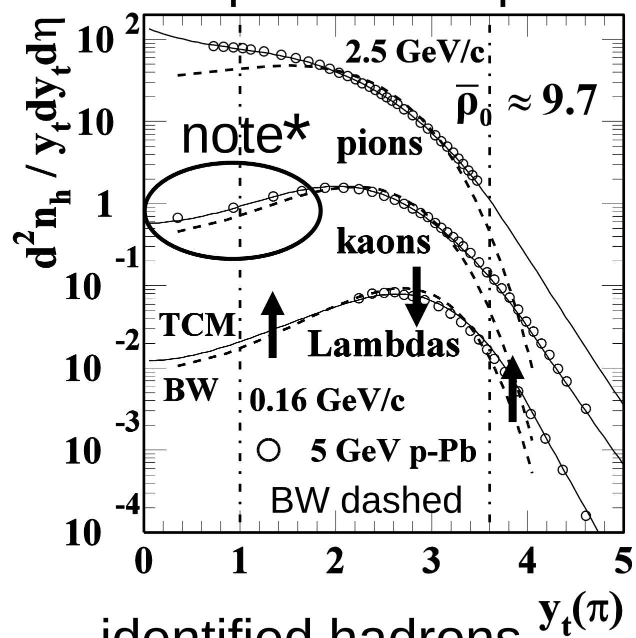




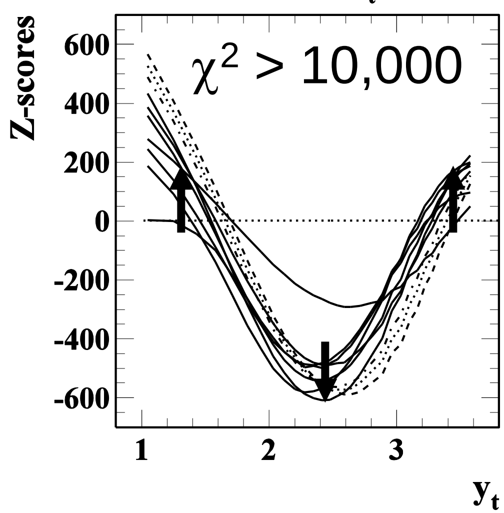
$\bar{\rho}_0 \approx 8.5$

J. Phys. G **47**, 045104 (2020)

equivalent to p-N



identified hadrons
- p-Pb data fit details



$\bar{\rho}_{0NSD} \approx 6.4$

blast-wave fits always deviate from spectrum data in the same way

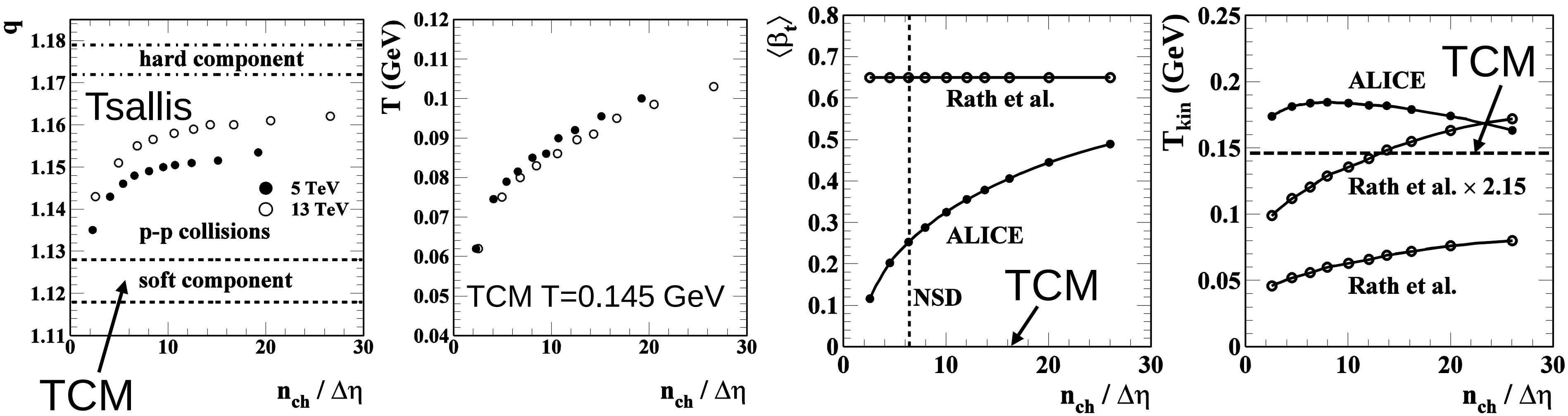
* TCM (solid) describes K_s^0 data down to $y_t = 0$

Model Parameters vs TCM

J. Phys. G **47**, 055111 (2020) (Rath. *et al*.)

Tsallis $\mathbf{q = 1 + 1/n}$ **n** is a "power-law" exponent

Tsallis fit parameters V0M data blast-wave fit parameters V0M data



Tsallis as a one-component model attempts to describe two components

Blast-wave model (hydro) attempts to accommodate jet fragments

dramatic inconsistencies between individual applications

p-value for model with $\chi^2 \sim 10{,}000$?

Summary

- *Fixed* TCM accurately separates jets from nonjet contributions
- Selection bias: (a) V0M vs SPD η acceptance, (b) spherocity $\Leftrightarrow$ azimuthal asymmetry (not shown)
- Z-scores – deviation *significance* – model validity
- *Variable* TCM describes *p-p* spectra within their uncertainties
- Tsallis and blast-wave models dramatically falsified

p-p collectivity?