Collectivity and manifestations of minimum-bias jets in high-energy nuclear collisions

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Agenda

- What is collectivity?
- The two-component (soft + hard) model (TCM)
- *p*-*p* jets, spectra, correlations and the TCM

- *p*-*p* $\bar{p}_t$ TCM
- *p*-Pb $\bar{p}_t$ TCM
- Pb-Pb $\bar{p}_t$ TCM

arXiv:1708.09412

- Naïve Glauber model of *p*-Pb collisions
- PYTHIA – *p*-*p* model assumptions *vs* reality

What is Collectivity?

collectivity ⇒ countable collection,   <u>any</u> correlations ⇒ collectivity

e.g. dijets = collective phenomenon!

several mechanisms may produce correlations

our task is to identify them via data analysis

Two-component Model – TCM

hadron production in *p-p* collisions near midrapidity

charge densities: $\bar{\rho}_0 = \bar{\rho}_s + \bar{\rho}_h$ **soft + hard**

soft component SC: projectile-nucleon dissociation

participant low-*x* gluons $\propto \bar{\rho}_s \propto$ **log(√s/10 GeV)**

hard component HC: large-angle scattered gluons → dijets

MB jet fragments: $\bar{\rho}_h \approx \alpha\, \bar{\rho}_s^2$ **(noneikonal)** $\alpha = O(0.01)$

hadron production in A-B collisions follows suite:

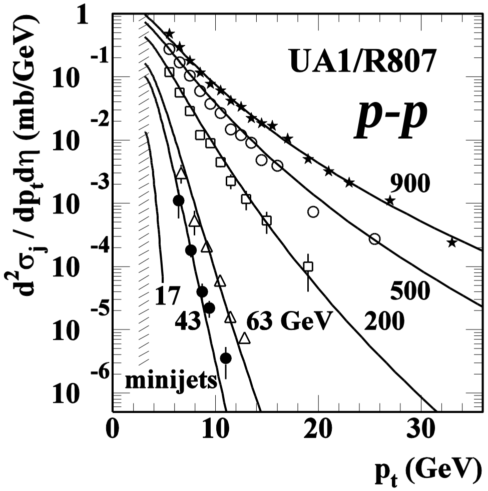
extensive $\bar{P}_t = (N_{part}/2)\, n_{sNN}\, \bar{p}_{tsNN} + N_{bin}\, n_{hNN}\, \bar{p}_{thNN}$

$$\bar{P}_t / n_s = \bar{p}_{ts} + x(n_s)\, \nu(n_s)\, \bar{p}_{thNN}(n_s)$$

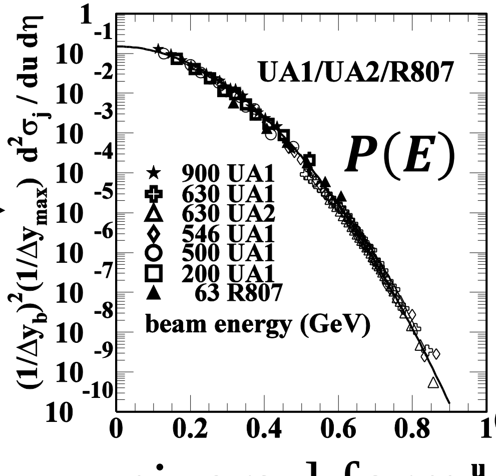
QCD Jets and p-p p_t Spectra

$P(E)$

$P(p|E)$



JS – jet spectra

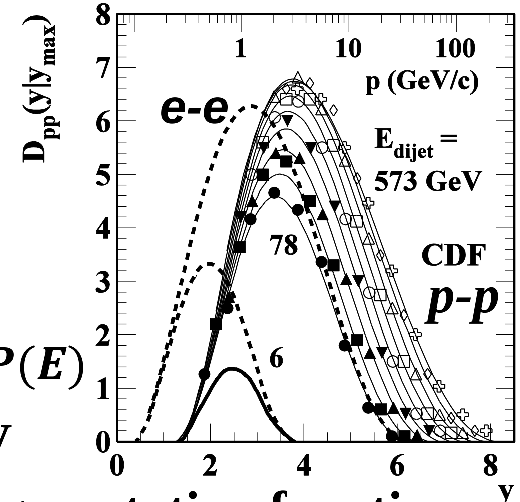


universal form

PRD 89, 094011 (2014)

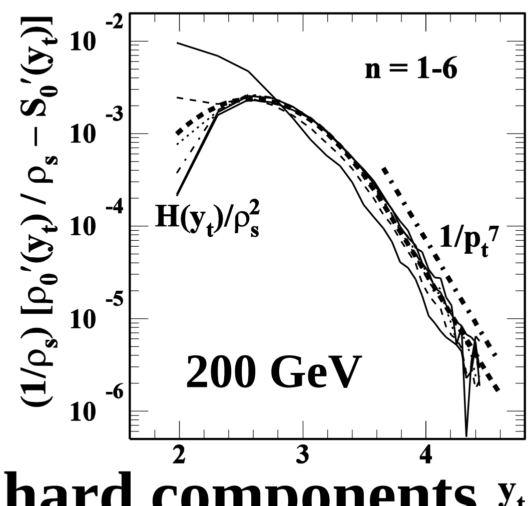
$$P(p) = \int_{E_{min}}^{\infty} dE\, P(p|E) P(E)$$

3 GeV



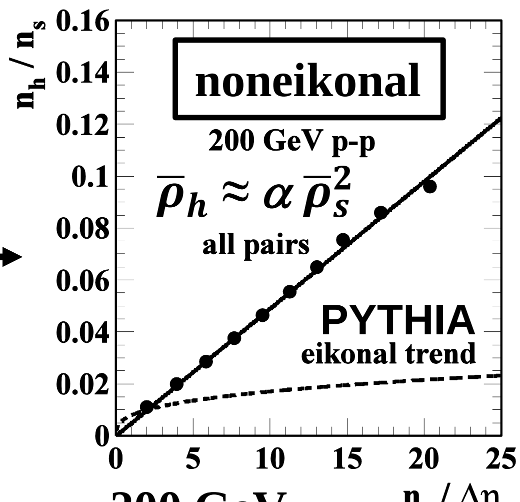
FF – fragmentation functions

PRD 74, 034012 (2006)



hard components

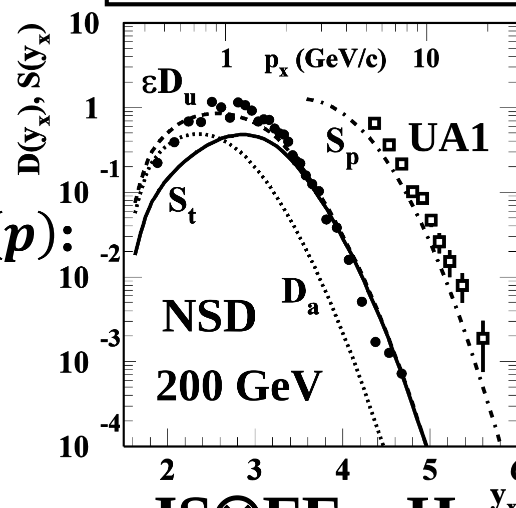
PRD 93, 014031(2016)



200 GeV

dijet production

$P(p)$:



JS⊗FF = H

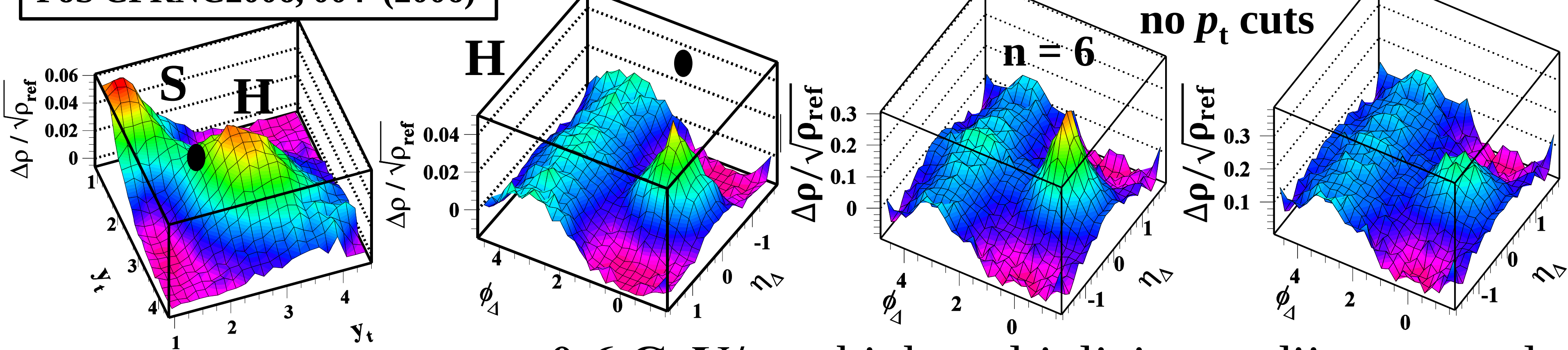
JPHYSG 42, 085105 (2015)

p-*p* Angular Correlations – 2D Model Fits

two-particle correlations

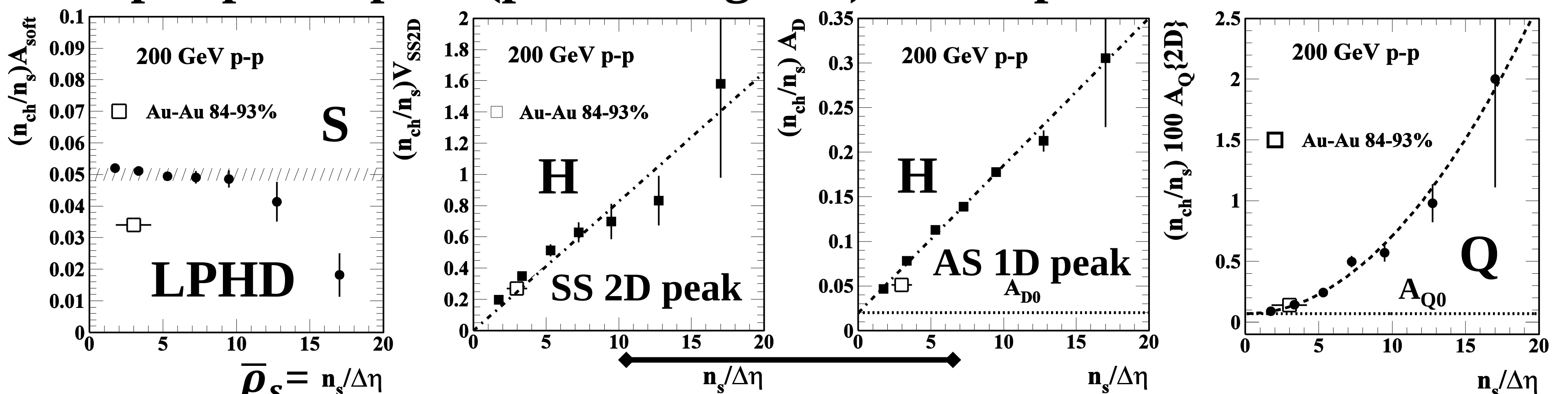
PoS CFRNC2006, 004 (2006)

PRD 93, 014031 (2016)



$y_t \times y_t$ | $p_t \approx 0.6$ GeV/c | high multiplicity | dijets + quad

per-participant (per low-*x* gluon) model-parameter trends



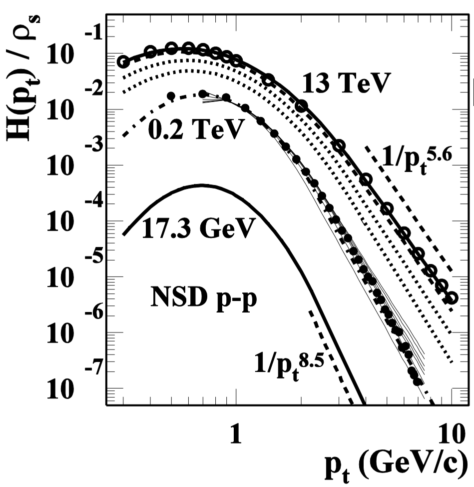
soft $\propto \bar{\rho}_s$ | hard (dijets) $\propto \bar{\rho}_s^2$ | quadrupole $\propto \bar{\rho}_s^3$

p-p p_t Spectrum Hard Component

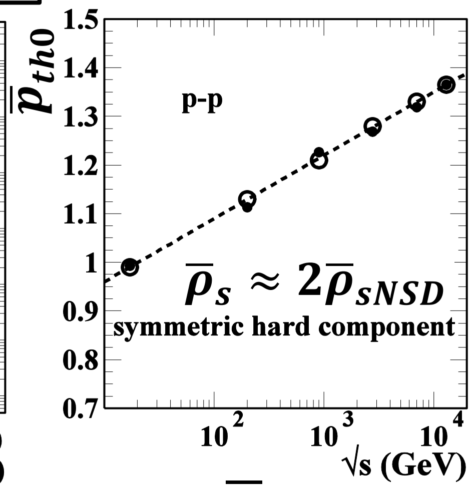
JPHYSG 44, 075008 (2017)

HC energy dependence

lower p_t cut

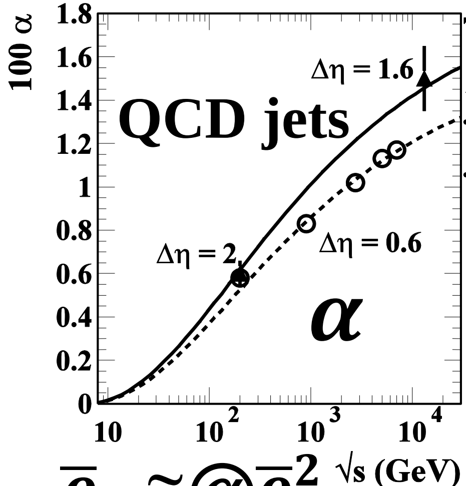


spectrum HCs

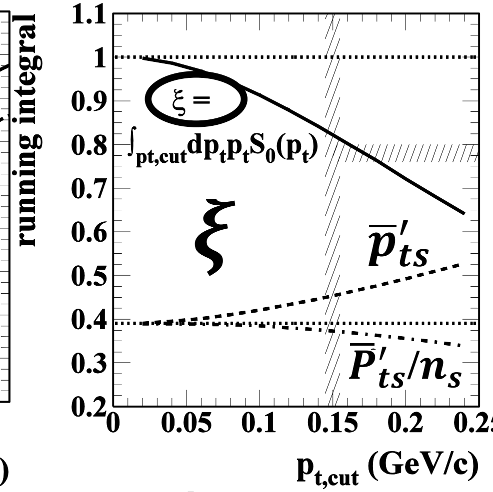


$\bar{\rho}_s \approx 2\bar{\rho}_{sNSD}$

$\bar{p}_{th0}$



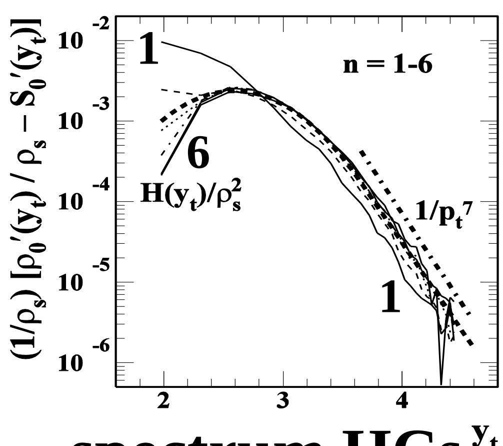
$\bar{\rho}_h \approx @\bar{\rho}_s^2$



$\bar{p}'_{ts} = \bar{p}_{ts}/\xi$

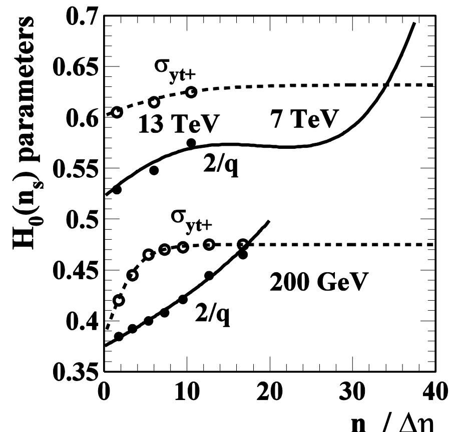
HC n_{ch} dependence

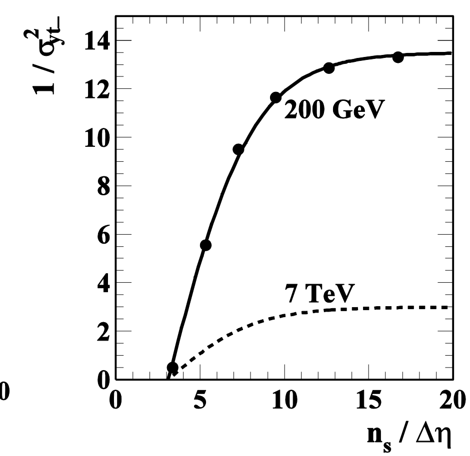
SC density:
$\bar{\rho}_s = n_s/\Delta\eta$



spectrum HCs

PRD 93, 014031(2016)

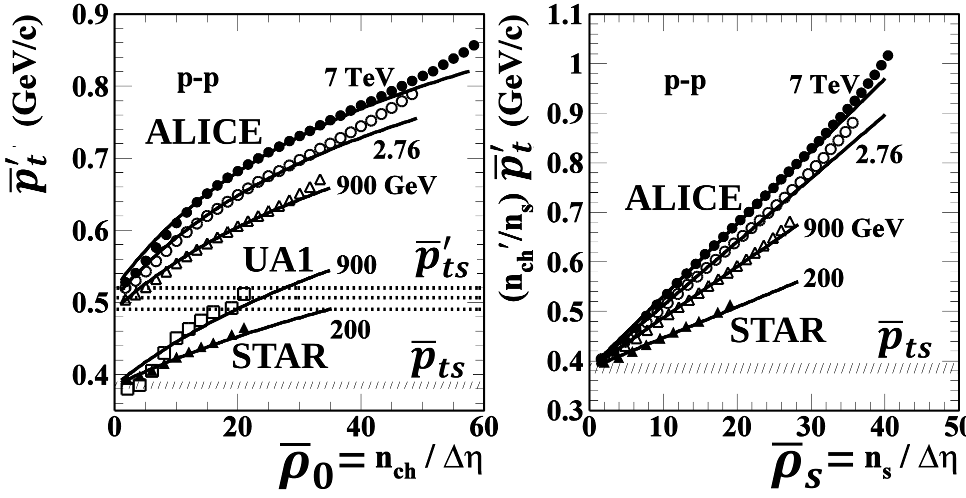




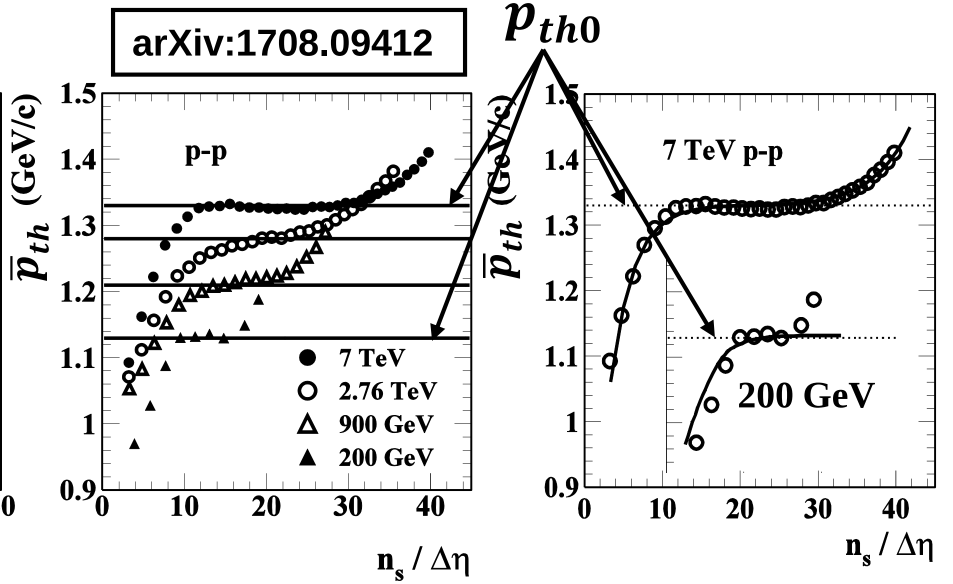
HC model parameters vs n_{ch}
(biased jet spectra)

p-p $\bar{p}_t$ TCM

ALICE: PLB 727, 371(2013)



arXiv:1708.09412



$n'_{ch}/n_s = \xi + x(n_s)$ $\xi \approx$ 0.76-0.80

$x(n_s, \sqrt{s}) \equiv n_h/n_s \approx \alpha(\sqrt{s})\bar{\rho}_s$

$\bar{P}'_t/n'_{ch} = \bar{p}'_t \approx \frac{\bar{p}_{ts} + x(n_s)\bar{p}_{th}(n_s)}{\xi + x(n_s)}$

$\frac{n'_{ch}}{n_s}\bar{p}'_t \approx \bar{p}_{ts} + x(n_s, \sqrt{s})\,\bar{p}_{th}(n_s, \sqrt{s})$

$\bar{p}_{th}(n_s, \sqrt{s})$

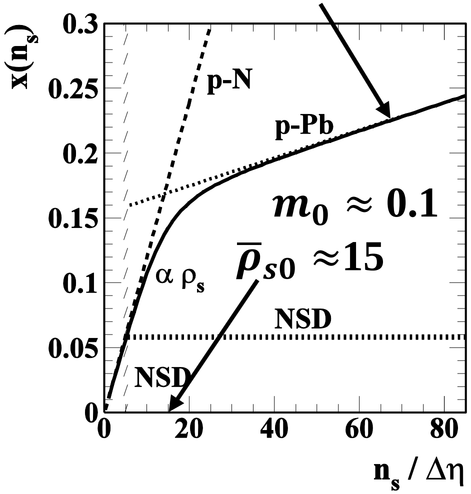
(takeaway from *p-p*)

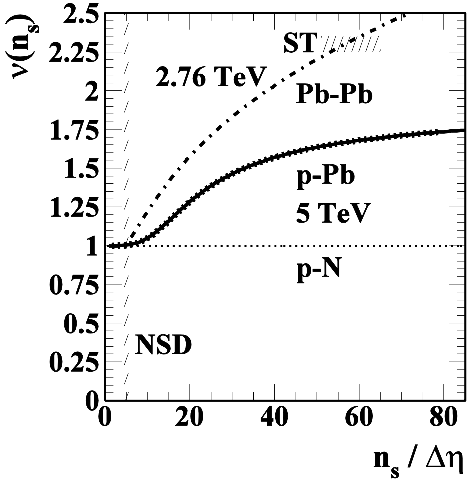
$\bar{p}_{th}(n_s)$: n_{ch} **dependence, spectrum HC**

direct correspondence: $\bar{p}_{th}$ *vs* spectrum HC *vs* isolated QCD jets

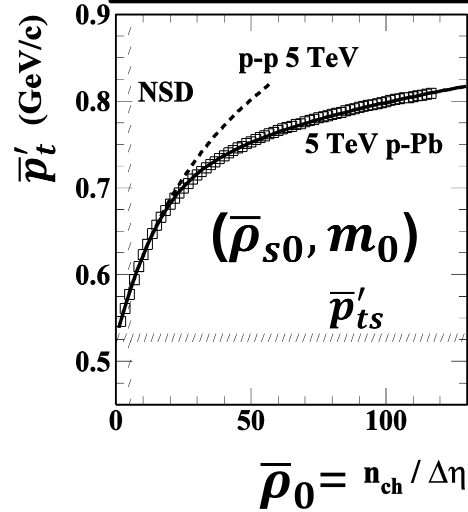
p-Pb $\bar{p}_t$ TCM

$\alpha\,[\bar{\rho}_{s0}+m_0(\bar{\rho}_s-\bar{\rho}_{s0})]$

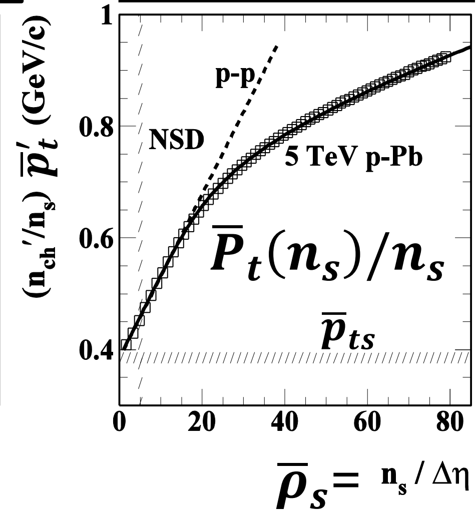




PLB 727, 371(2013)



arXiv:1708.09412



$$n'_{ch}/n_s = \xi + x(n_s)\nu(n_s)$$

$$\bar{P}'_t/n'_{ch} = \bar{p}'_t = \frac{\bar{p}_{ts} + x(n_s)\nu(n_s)\,\bar{p}_{thNN}(n_s)}{\xi + x(n_s)\nu(n_s)}$$

* $\boxed{\bar{\rho}_s = (N_{part}/2)\bar{\rho}_{sNN}\ (n_s)}$

$$\bar{P}_t(n_s)/n_s =$$

$$x(n_s) \equiv \bar{\rho}_{hNN}(n_s)/\bar{\rho}_{sNN}(n_s) \approx \alpha\,\bar{\rho}_{sNN}(n_s)$$

$$\frac{n'_{ch}}{n_s}\bar{p}'_t = \bar{p}_{ts} + x(n_s)\nu(n_s)\,\bar{p}_{thNN}(n_s)$$

assume:

$$N_{part}/2 = \alpha\,\bar{\rho}_s\,/\,x(n_s)$$

$\bar{p}_{thNN}(n_s) \approx \bar{p}_{th0}$ ***p-p* value**

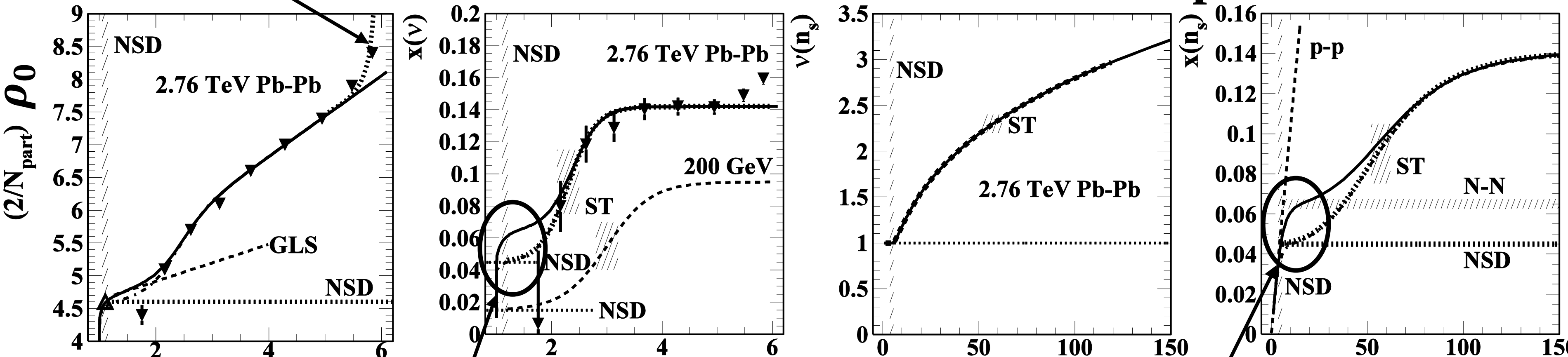
$$N_{part} = N_{bin} + 1 \quad \nu \equiv 2N_{bin}/N_{part}$$

no jet modification

Pb-Pb $\bar{p}_t$ TCM – I

fluctuations PRC 91, 044905(2015)

ST: sharp transition



PRL 106, 032301(2011)

x_{pp}?

ST: PRC 86, 064902(2012)

$\bar{\rho}_s =$ n_s / Δη

x_{pp}?

$\bar{\rho}_s =$ n_s / Δη

Glauber:

$$\nu(n_s) \approx (\bar{\rho}_s/\bar{\rho}_{sNN})^{1/3}$$

$$x(n_s) = x[\nu(n_s)]$$

TCM for A-A yield *vs* centrality:

$$(N_{part}/2)\,\bar{\rho}_0 = \bar{\rho}_{sNN}[1 + x(\nu)\nu]$$

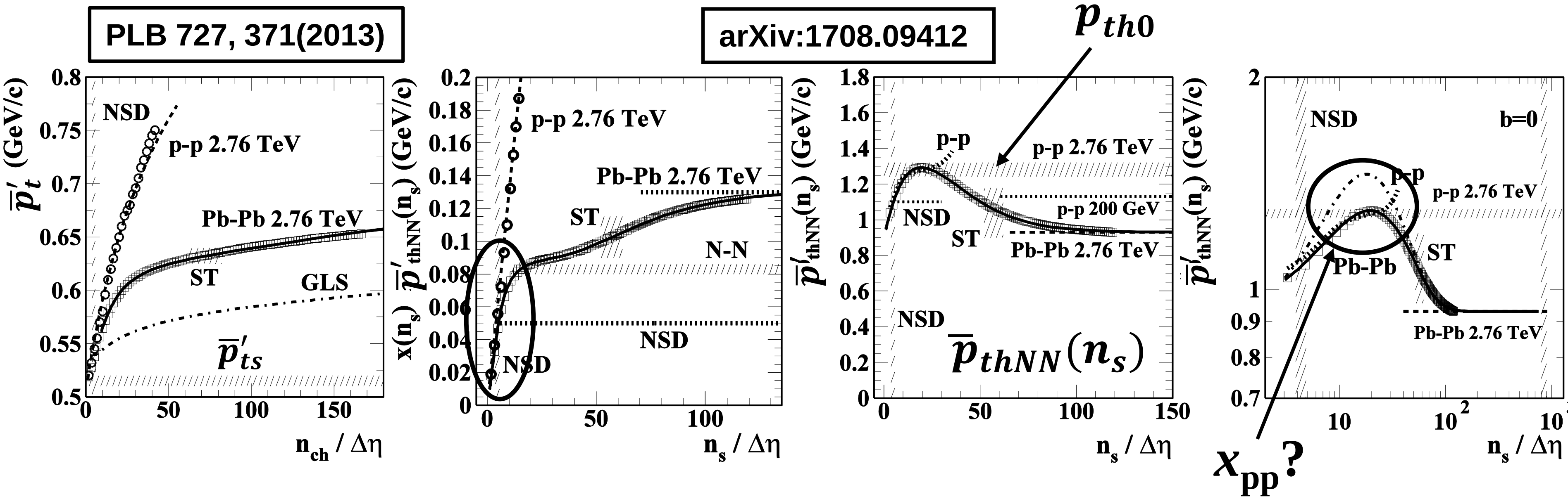
obtain from data above:

$$x(\nu) = x_{pp} + (0.142 - x_{pp}) \times \{1 + \tanh[(\nu - 2.3)/0.5]\}/2$$

peripheral Pb-Pb follows *p-p*

more-central Pb-Pb shows ST: jet modification PRC 86, 064902(2012)

Pb-Pb $\bar{p}_t$ TCM – II



$$\bar{P}'_t/n'_{ch} = \bar{p}'_t = \frac{\bar{p}_{ts} + x(n_s)\nu(n_s)\,\bar{p}_{thNN}(n_s)}{\xi + x(n_s)\nu(n_s)}$$

given Glauber $\nu(n_s)$ solve for:

$$x(n_s)\,\bar{p}_{thNN}(n_s) \approx \bar{P}_{thNN}/n_{sNN}$$

given $x(n_s)$ solve for:

$$\bar{p}_{thNN}(n_s)$$

new information from Pb-Pb:

$\bar{p}_{thNN}(n_s)$ **follows *p-p* trend for peripheral, falls to saturation value for central**

minimum is 73% of maximum

Lessons from $\bar{p}_t$ Data

three successive collision systems

- ***p-p*** $\bar{p}_{th}(n_s, \sqrt{s})$ **trends agree with spectrum HC and MB dijets**
- ***p-p*** **dijet production is noneikonal, centrality not relevant**

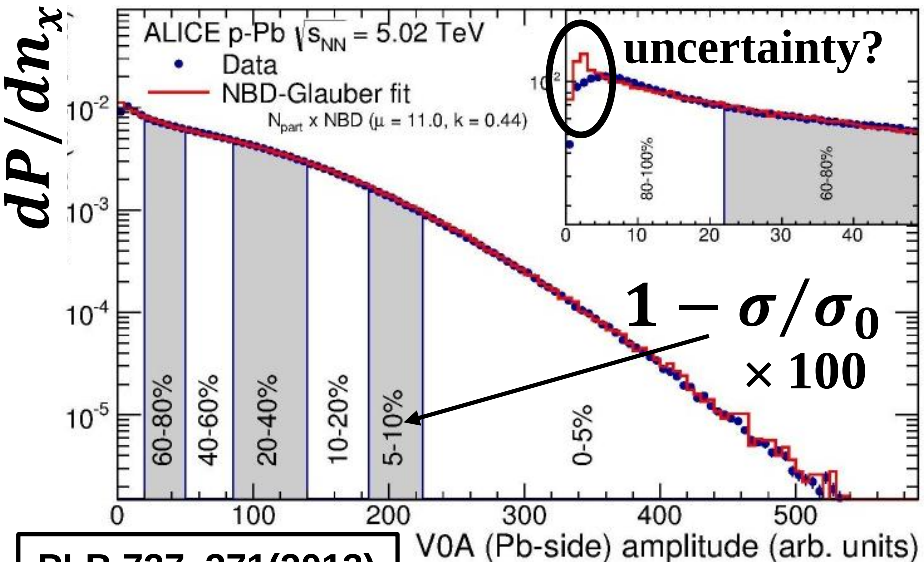
- ***p*-Pb** $\bar{p}_t(n_s)$ **establishes factorization of A-B Glauber and N-N noneikonal**
- ***p*-Pb** $\bar{p}_t$ **data confirm MB dijets dominate** $\bar{p}_t(n_s)$ **trends**

- **Pb-Pb** $\bar{p}_t$ **data confirm that naïve Glauber dominates A-A collisions, but peripheral A-A collisions follow p-p trends**
- **Pb-Pb** $\bar{p}_{thNN}(n_s)$ **trend confirms jets are modified above ST**

- **Jets still dominate structure in more-central Pb-Pb collisions**

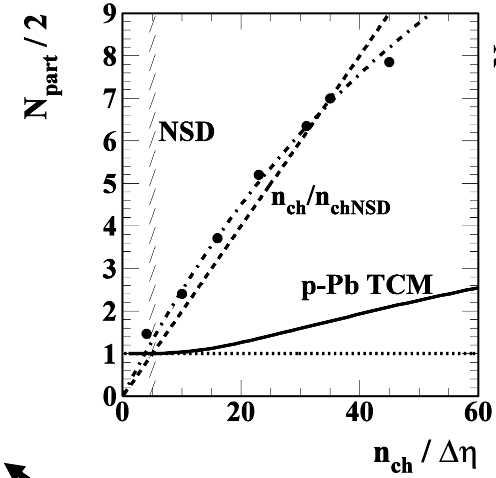
arXiv:1708.09412

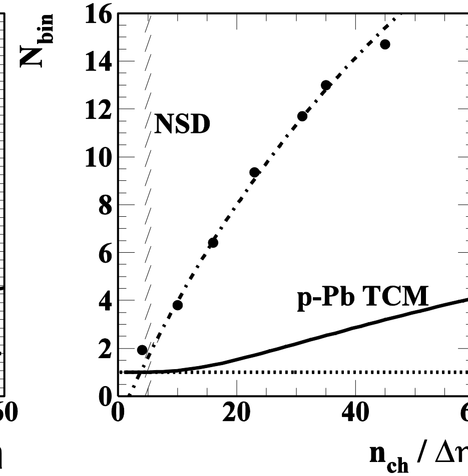
Naïve Glauber Model for *p*-Pb



PLB 727, 371(2013)

n_x



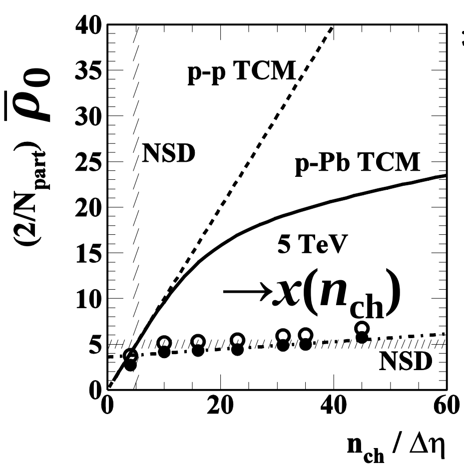


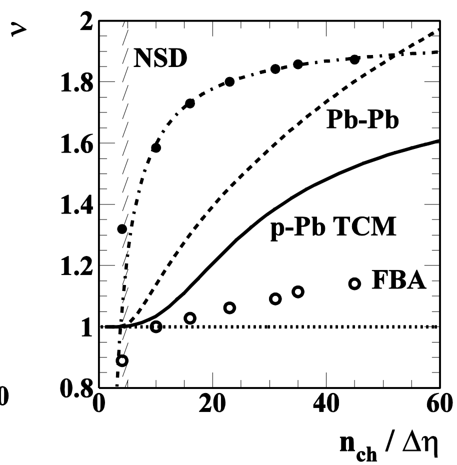
$N_{part} = N_{bin} + 1$ in p−A

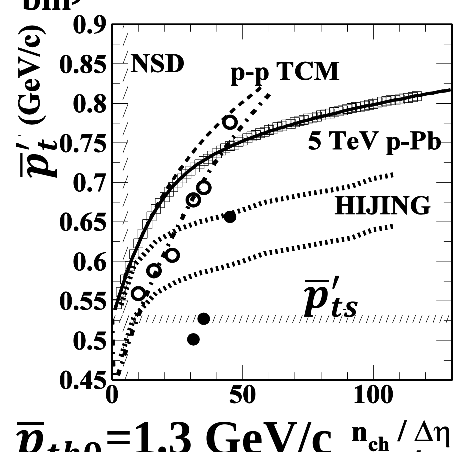
“[n_{ch}] at mid-rapidity scales linearly with [N_{part}]”

assumes: $dP/dn_x \rightarrow (1/\sigma_0)\, d\sigma/dn_x$

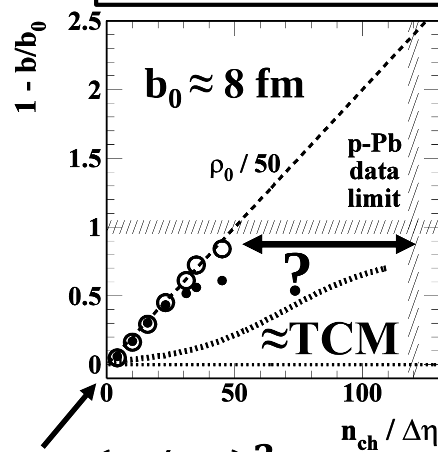
black points derived from n_{ch}, N_{part}, N_{bin}, b Glauber values in PLB 727, 371(2013)





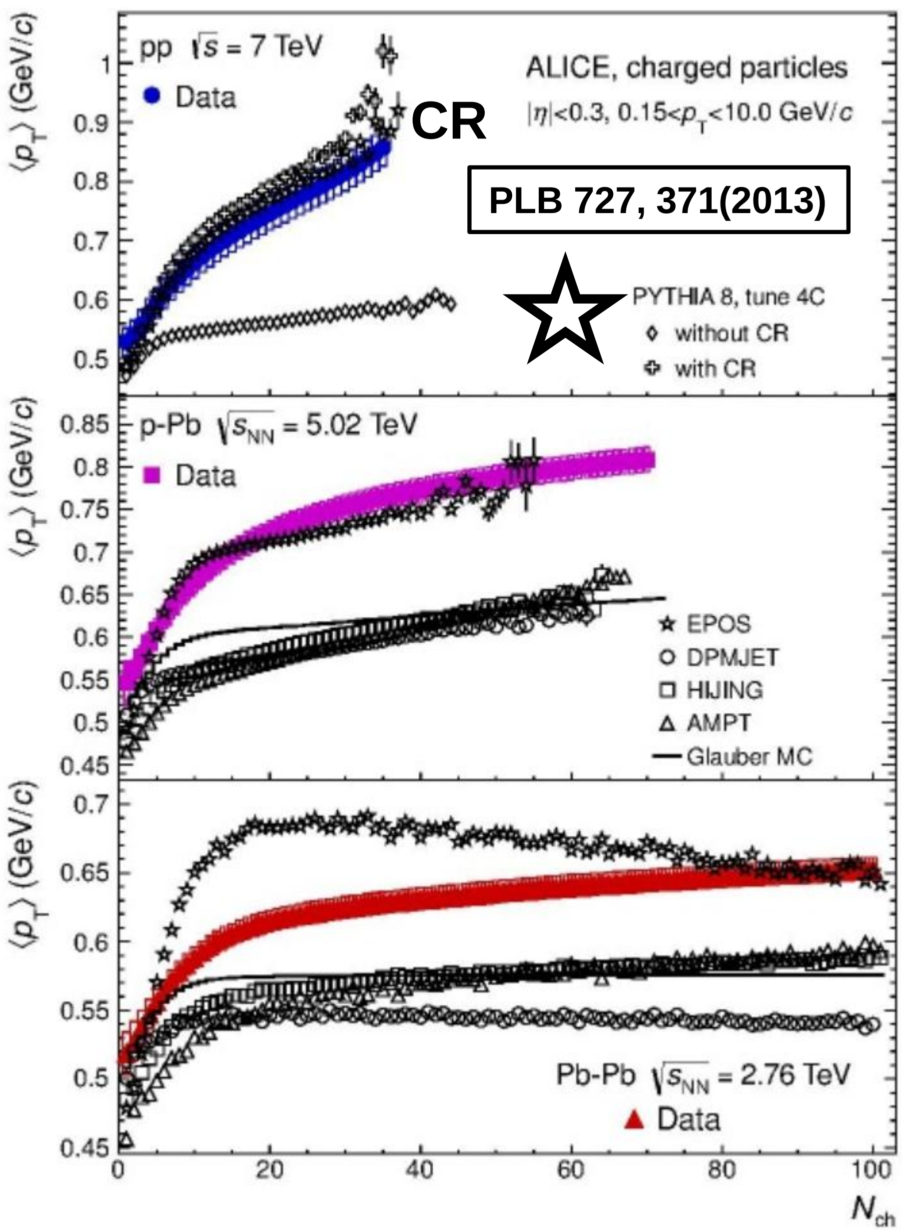


$\bar{p}_{th0}$=1.3 GeV/c



$\sigma/\sigma_0 = (b/b_0)^2$

PYTHIA (and Other Monte Carlos)



arXiv: 1706.02166

MPI = multiple parton interactions

$$n_{ch} \propto n_{MPI}$$

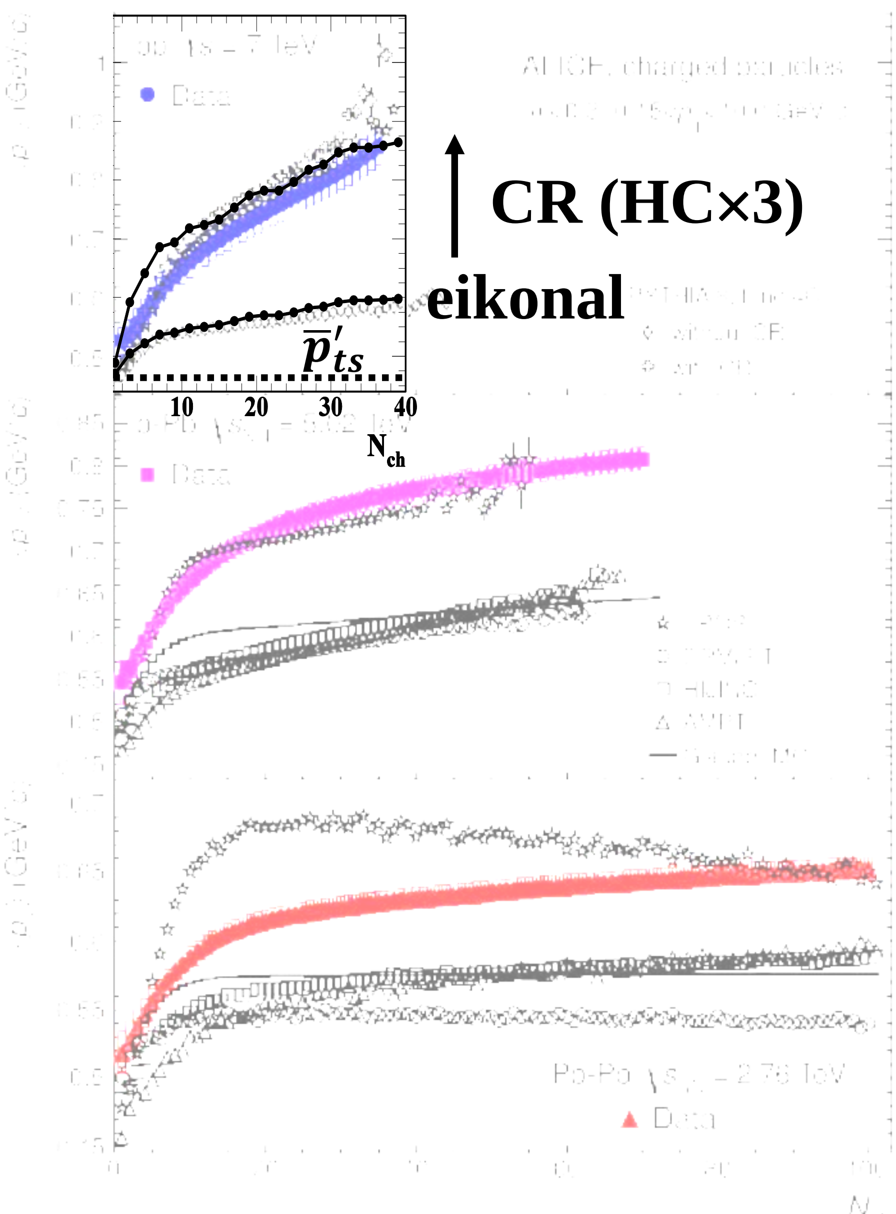
no jet spectrum cutoff

$$p_0 \to 2 \text{ GeV}$$

$n_{MPI}(b)$ **depends on centrality**
eikonal model

$\bar{p}_t(n_{ch})$ **trend requires**
color reconnection (CR)

PYTHIA (and Other Monte Carlos)



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eikonal model

$\bar{p}_t(n_{ch})$ **trend requires**
color reconnection (CR)

those assumptions conflict with MB dijets and the *p-p* TCM

see also HIJING, AMPT

Conclusions

- **TCM provides accurate, comprehensive description**
- **Soft component S(y_t) is universal: $\bar{\rho}_s$ ~ low-*x* gluons**
- **Jets dominate $\bar{p}_{th}(n_s, \sqrt{s})$ structure in all systems**
- **Centrality <u>not relevant</u> for *p-p* collisions (noneikonal)**
- **A-B systems evolve from isolated N-N to Glauber**
- **Naïve Glauber model applied to *p*-A system fails**
- ***p-p* TCM is opposite to PYTHIA basic assumptions**
- **A-B "collectivity" is jet manifestations, not flows**