Hydrodynamical description of dn/dη by CMS and TOTEM at 7 and 8 TeV

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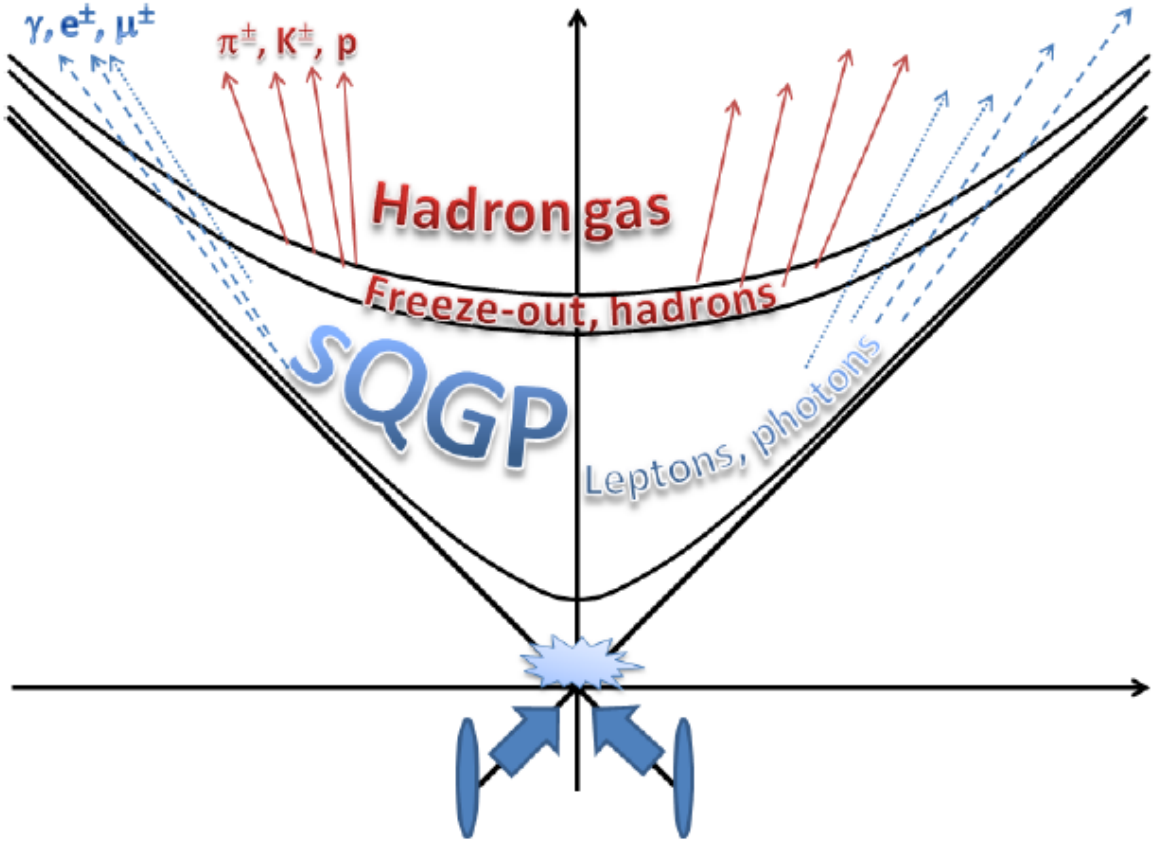
Intro to initial energy density estimate
Improving Bjorken's estimate
pp dn/dη data @ 7 and 8 TeV
from TOTEM, and CMS/TOTEM
Cu+Cu, Au+Au@RHIC
Pb+Pb@LHC
Implications
Summary
Predictions

Standard Hydro Model for A+A

- Strongly interacting QGP discovered at RHIC & created at LHC
- A hot, expanding, strongly interacting, perfect QG fluid
- Hadrons created at the freeze-out
- Leptons, photons "shine through"



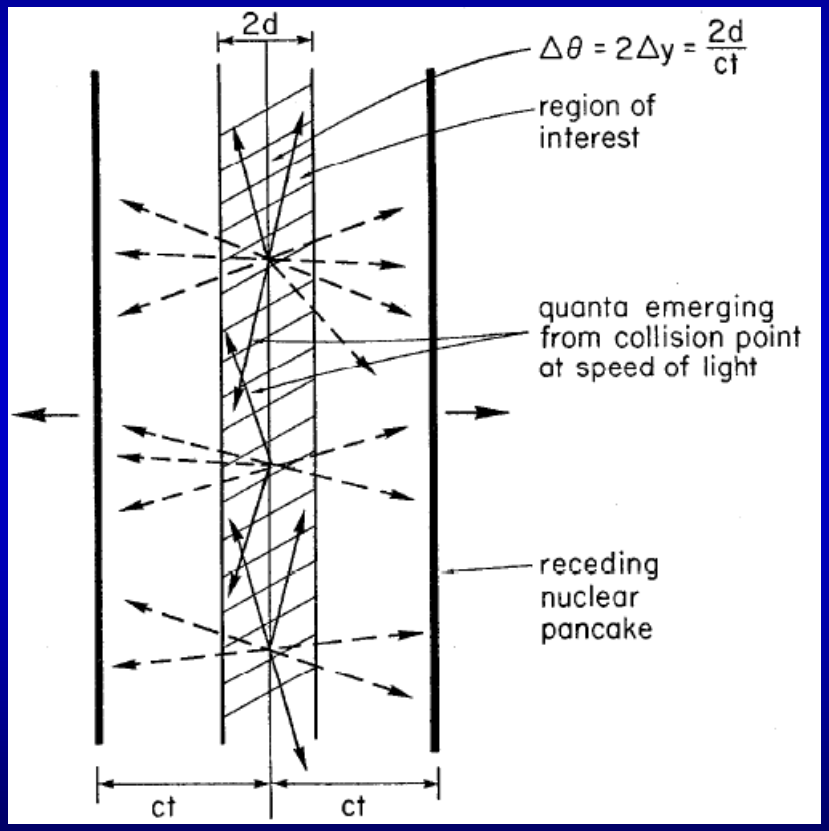
Björken-estimate – hydro for p+p

Idea:
Initial energy density measurable from dE/dy
QGP critical ε: ~1 GeV/fm^3
dE/dy = $\langle m_t \cosh(y) \rangle dn/dy$
Area from HBT

Top cited result:

J.D. Bjorken,Phys.Rev. D27 (1983)

$$\varepsilon_{Bj} = \frac{1}{R^2 \pi \tau_0} \frac{dE}{d\eta} = \frac{\langle E \rangle}{R^2 \pi \tau_0} \frac{dn}{d\eta}$$



IF dn/dη is not flat: Needs correction!

Advanced estimate

Need for correction:
dn/dy not flat, no rapidity plateax even @ LHC
Finite, accelerating!

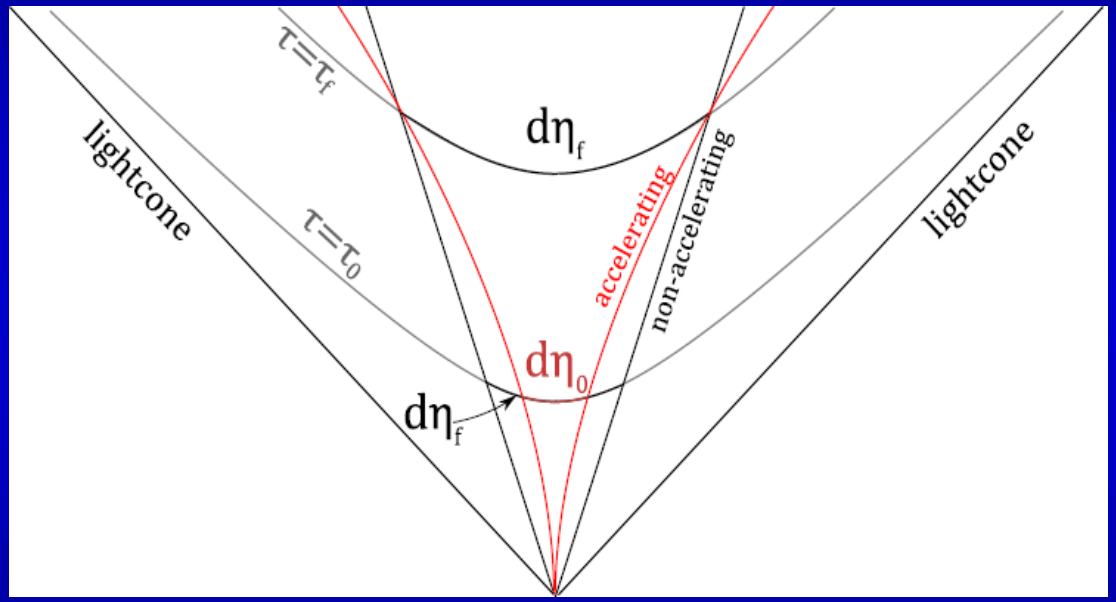
Need:
accelerating solution
of relativistic hydro

Two modifications:

$y \neq \eta$

$\eta_{final} \neq \eta_{initial}$

Advanced estimate
of initial energy density:

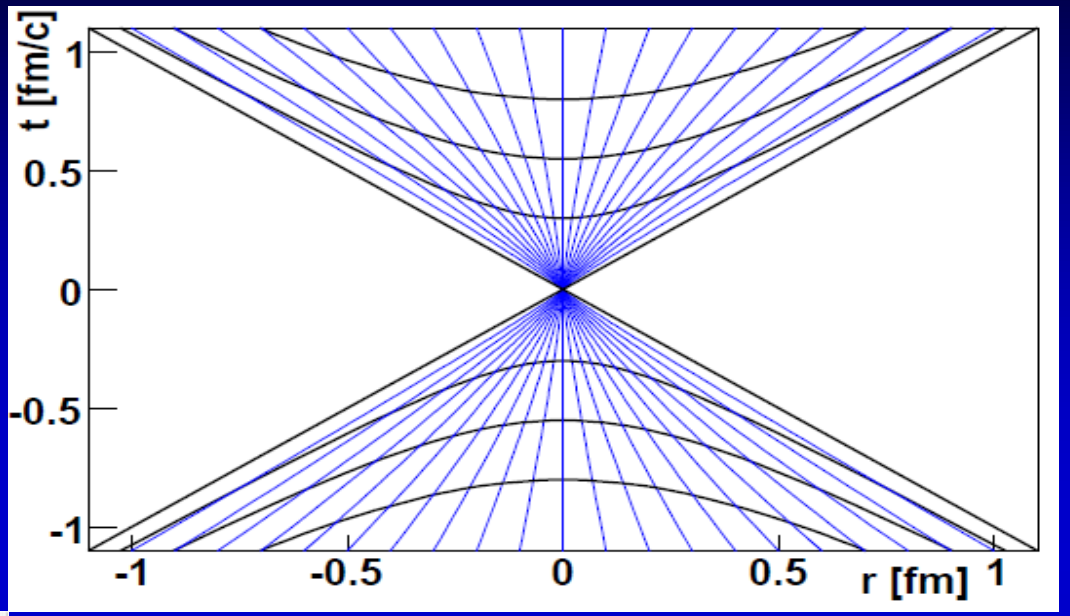


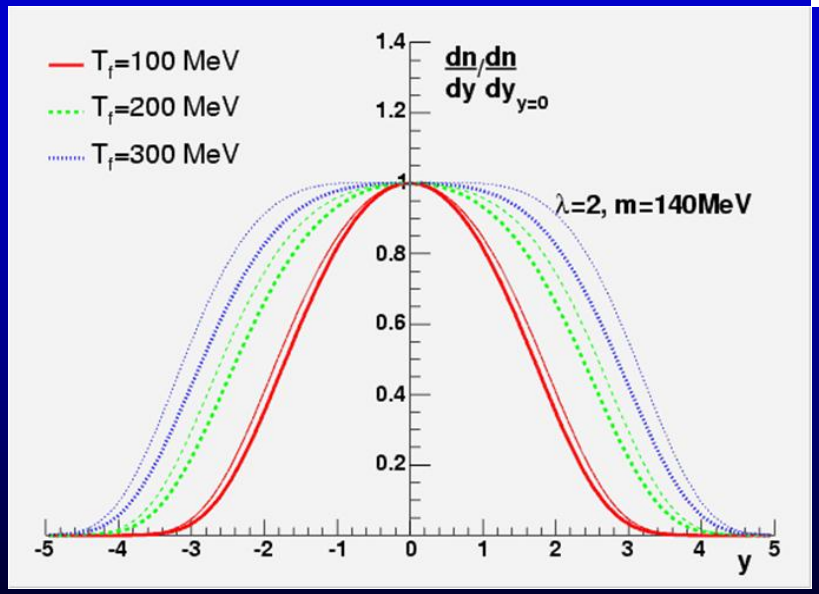
$$\varepsilon = \varepsilon_{Bj} \frac{dy}{d\eta_f} \frac{d\eta_f}{d\eta_i}$$

A new solution of relativistic hydro

Velocity: tanh($\lambda\eta$)
Acceleration: $\lambda \neq 1$
Density: $(\tau/\tau_0)^{\lambda}$
dn/dy calculated, simple
but NOT
on a back-of-the-envelope,

Full details: 15 pages, 126 eqs
arXiv:0709.3677 M.I. Nagy et al,
Phys. Rev. C.C77:024908,2008





Compare to RHIC data!
BRAHMS dn/dy measurement:
advanced initial ε estimate

Significant correction@RHIC!

Phys.Lett. B663 (2008) 306
nucl-th/0605070

Initial energy density at RHIC

Bjorken estimate from BRAHMS: 5 GeV/fm^3

Advanced estimate gives:

Correction:

2-3x, result: 15 GeV/fm^3, QCD EoS agreement!

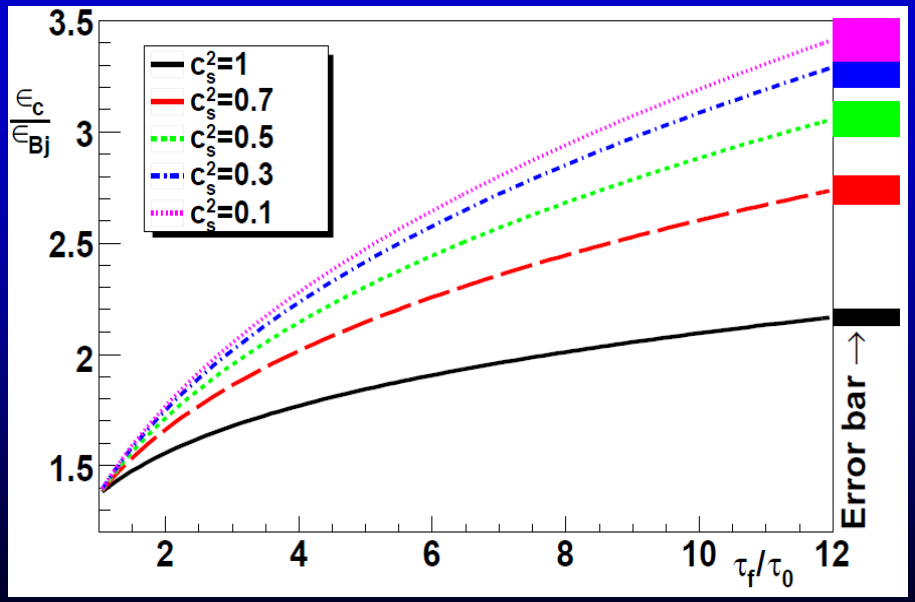
J.Phys.G35 (2008) 104128 (arXiv:0805.1562)

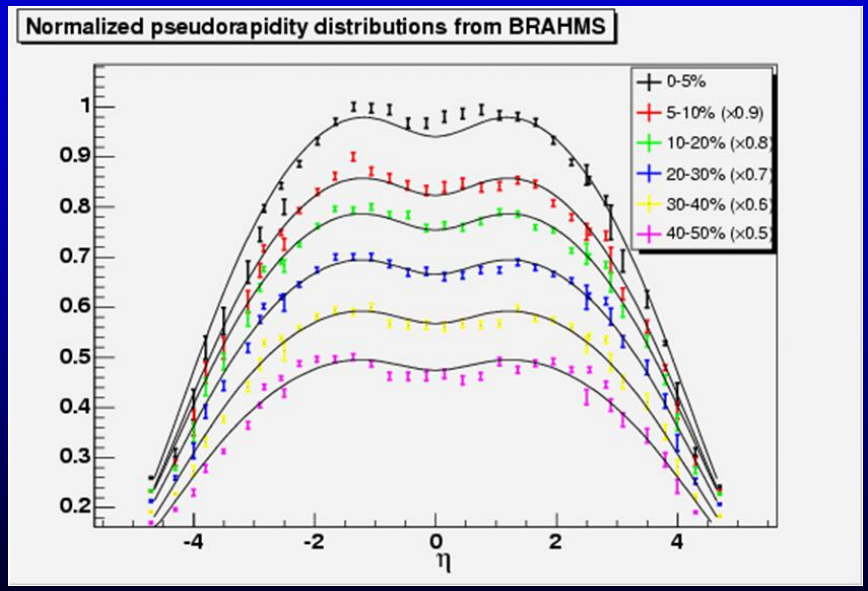
$$\varepsilon = \varepsilon_{Bj}\,(2\lambda - 1)\left(\frac{\tau_f}{\tau_i}\right)^{(\lambda-1)(2-c_{\mathrm{sound}}^2)}$$

Corresponds to $T_{ini} \cong 2T_c \cong 340$ MeV

Consistent with PHENIX direct photon spectra

http://arxiv.org/abs/arXiv:0804.4168 PRL 104:132301, 2010





Initial energy density for pp@7 TeV

Bjorken estimate:

- **Number of particles at midrapidity: ~7 (measured)**
- **Average energy: $\langle m_t \rangle$~0.5 GeV (measured)**
- **Initial radius of the system R: ~1 fm ($R^2\pi=\sigma_{inel}/2$, or HBT)**
- **Formation time τ_0: 1 fm/c**

Energy density from this:

$$\varepsilon_{Bj} = \frac{1}{R^2\pi\tau_0}\frac{dE}{d\eta} = \frac{\langle E \rangle}{R^2\pi\tau_0}\frac{dn}{d\eta} = \frac{0.5\times 7\,\mathrm{GeV}/c}{3.67\,\mathrm{fm}^3/c} \approx 0.95\,\mathrm{GeV}/\mathrm{fm}^3$$

Just below critical??

Correction may be important ...

Missed opportunity?

Energy density from TOTEM dn/dη

	TOTEM data		CMS data		Joint data	
Norm	10,51	±0,04	7,39	±0,03	7,48	±0,01
T_f	0,12	fixed	0,122	±0,002	0,117	±0,001
Λ	1,073	±0,003	1,061	±0,002	1,0535	±0,0002
χ^2/N_{DF}	2068/32		82,7/6		8502/42	

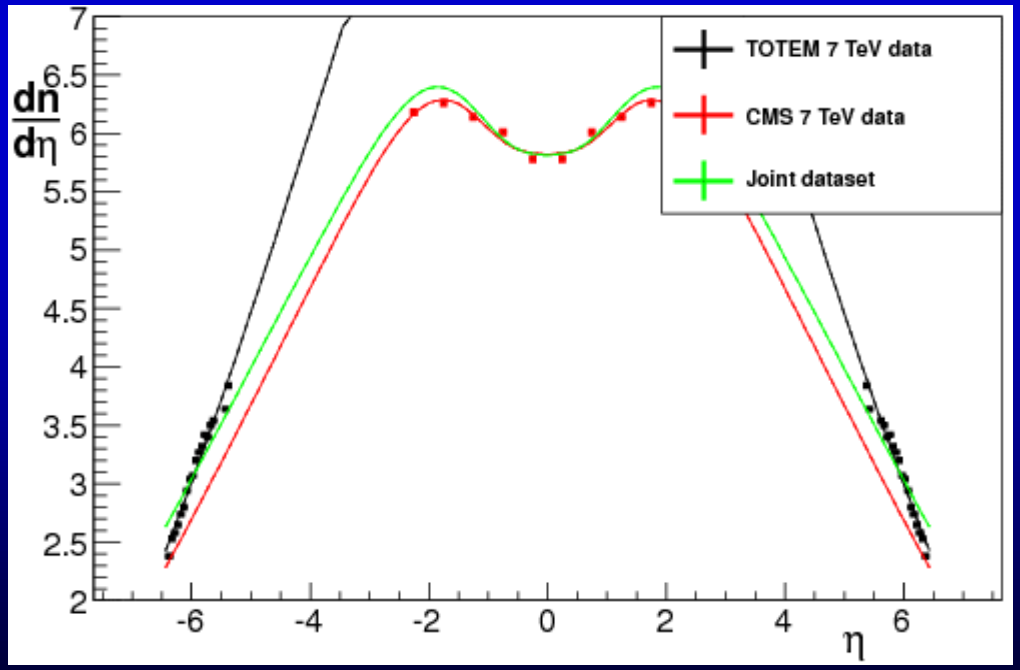
Errors of 0.1% (?)

Normalization (?)

NSD events in CMS

λ ~1.05-1.1

χ^2 too big (joint fit…)



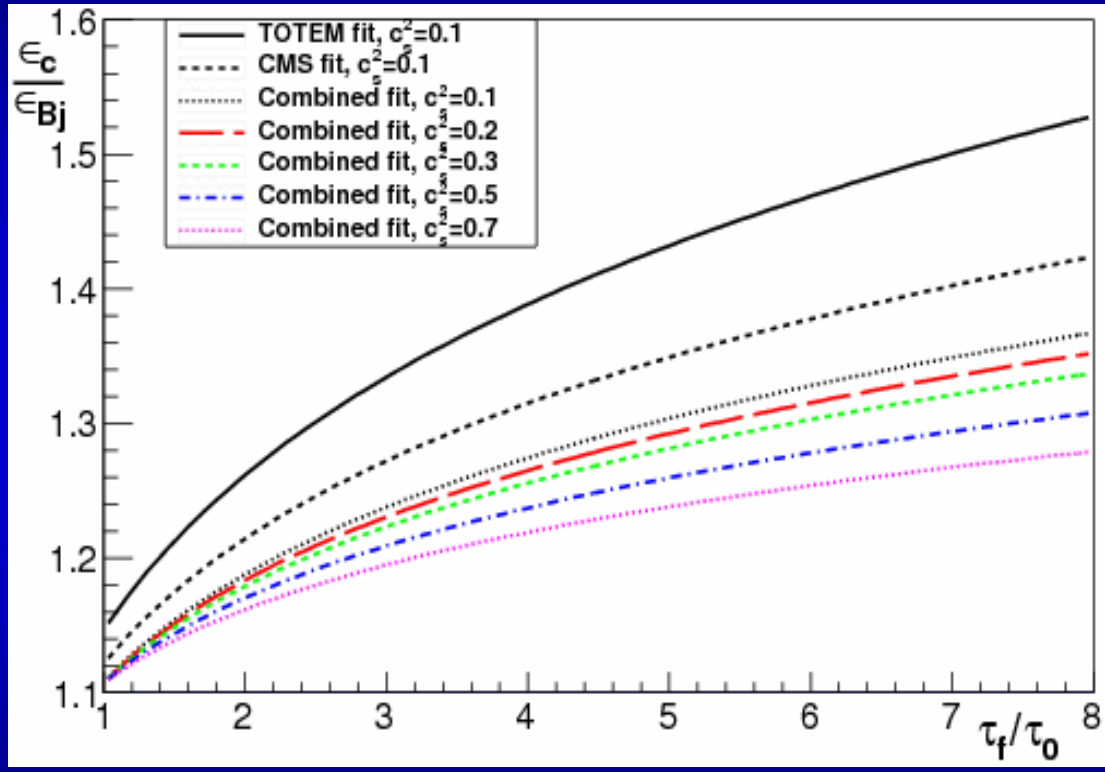
Initial energy density in 7 TeV p+p?

Rough result: $\lambda \cong 1.05\text{-}1.07$

~25% correction

Input parameters:

- **dn/dy: ~7**
- **Mean E: ~0.5 GeV**
- **Radius: ~1 fm**
- **Form. time: ~1 fm/c**



Corrected result:

~1.2 GeV/fm^3

→

Initial ε just above the critical value of 1 GeV!

Small correction, but big difference in physics ...

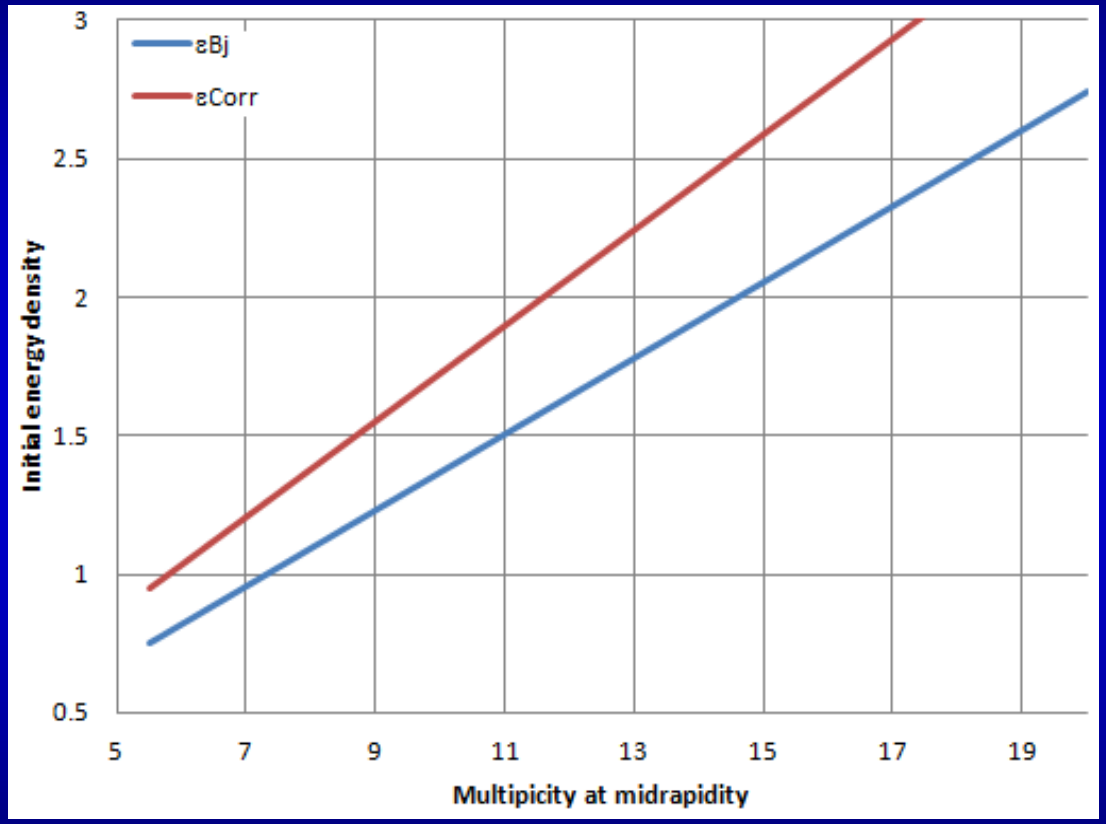
Dependence on particle number

Several multiplicity classes can be defined

CMS: ‹n› ~ 6-20

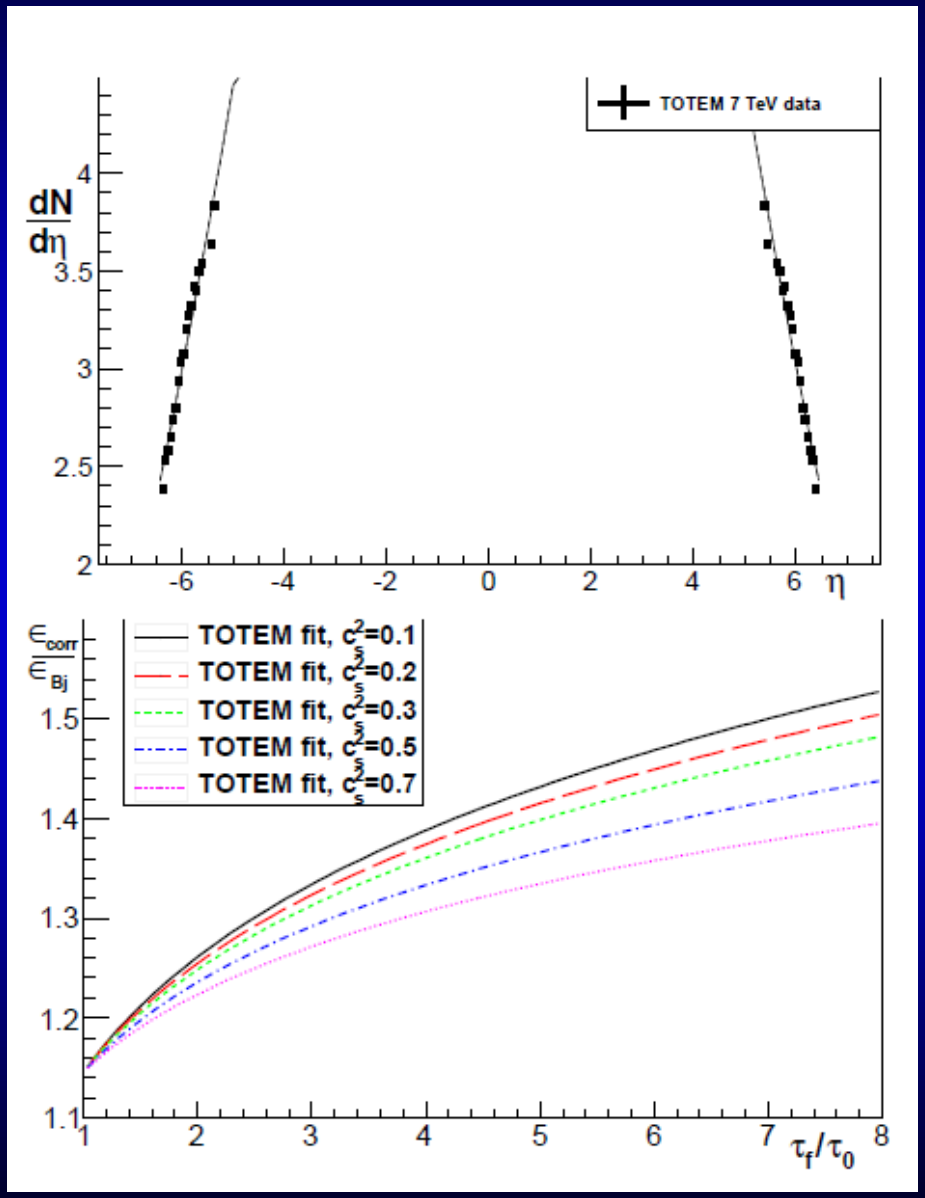
Bjorken result:
- **above critical**
- **IF ‹n› ≥ 7.5**

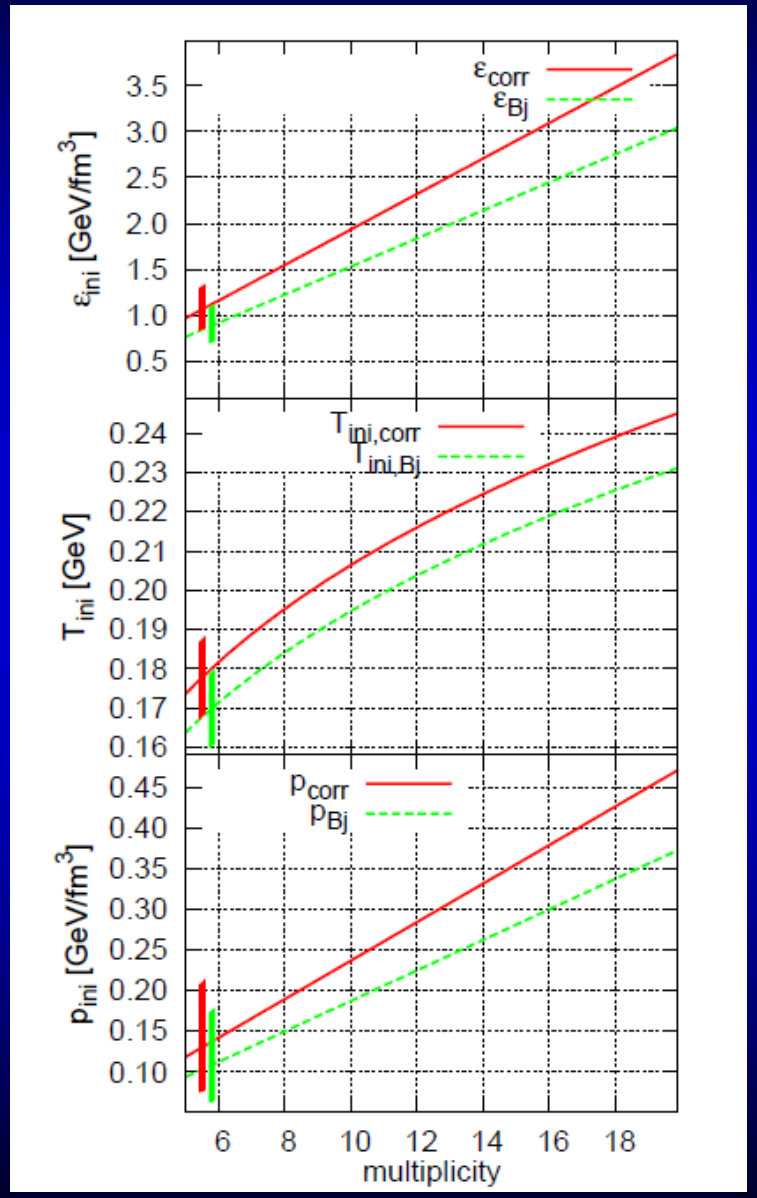
Corrected estimate:
- **above critical**
- **for ANY ‹n›**



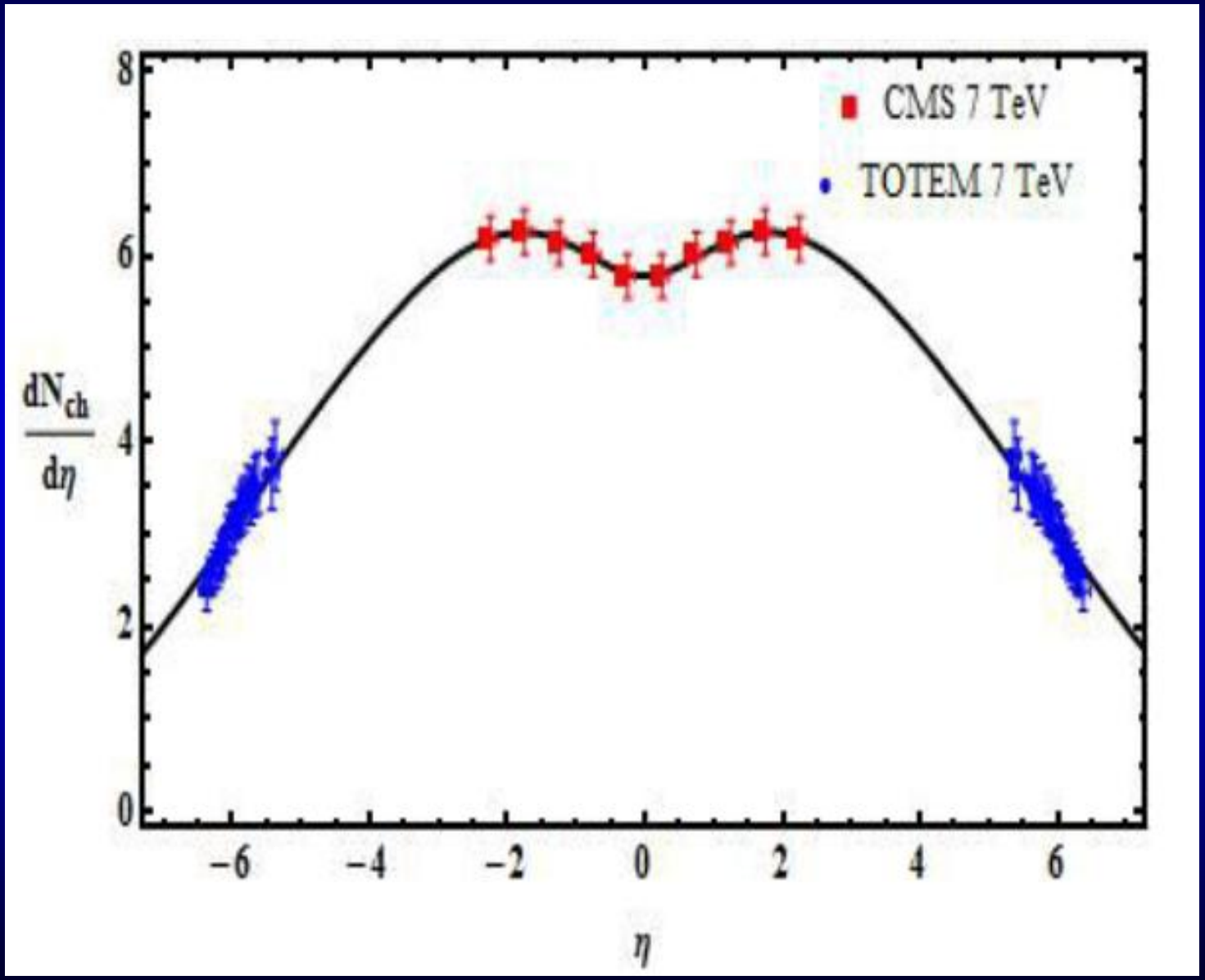
QGP is formed in ~ALL
- **p+p collisions at LHC @ 7 TeV**

Results for TOTEM dn/dη data@7 TeV

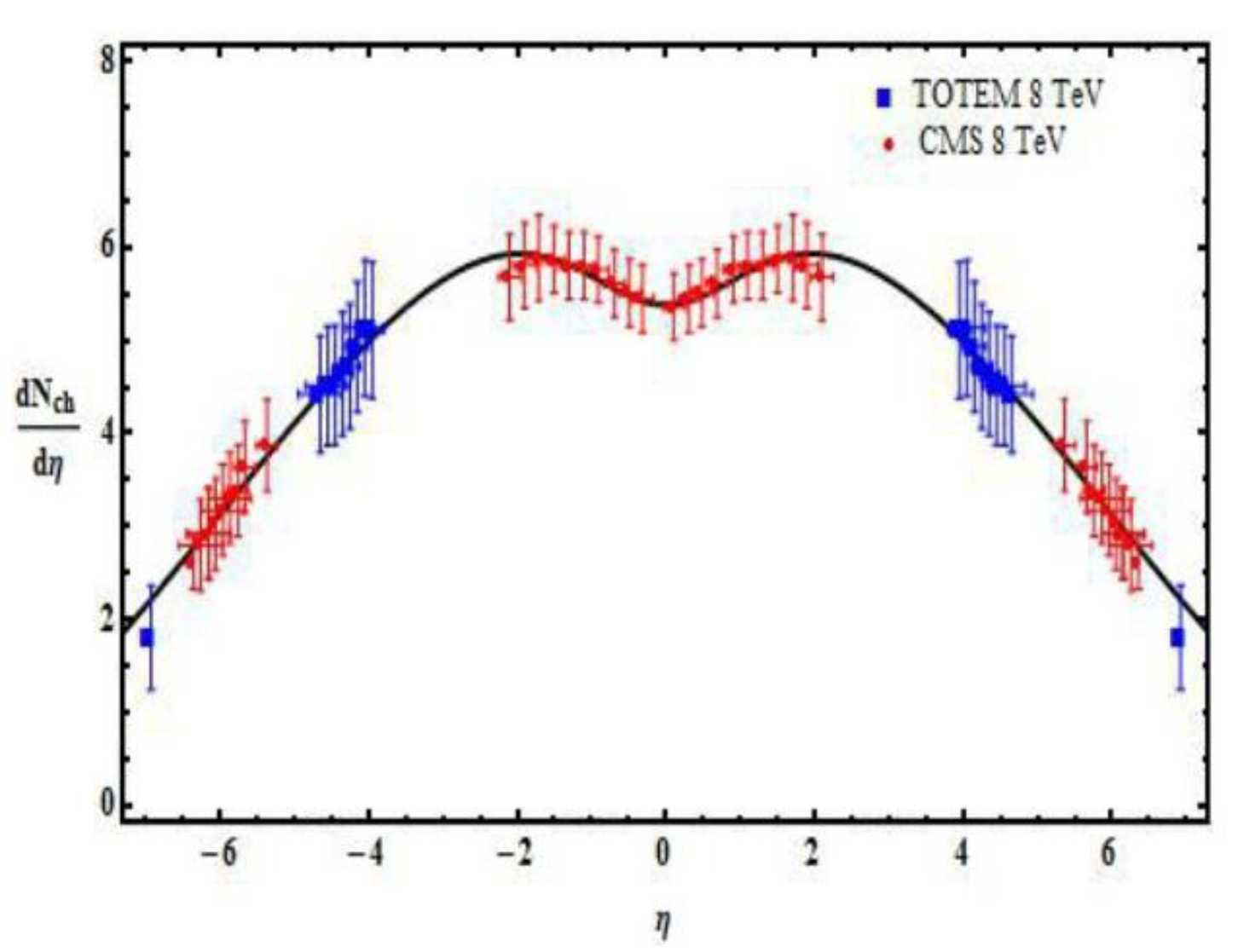




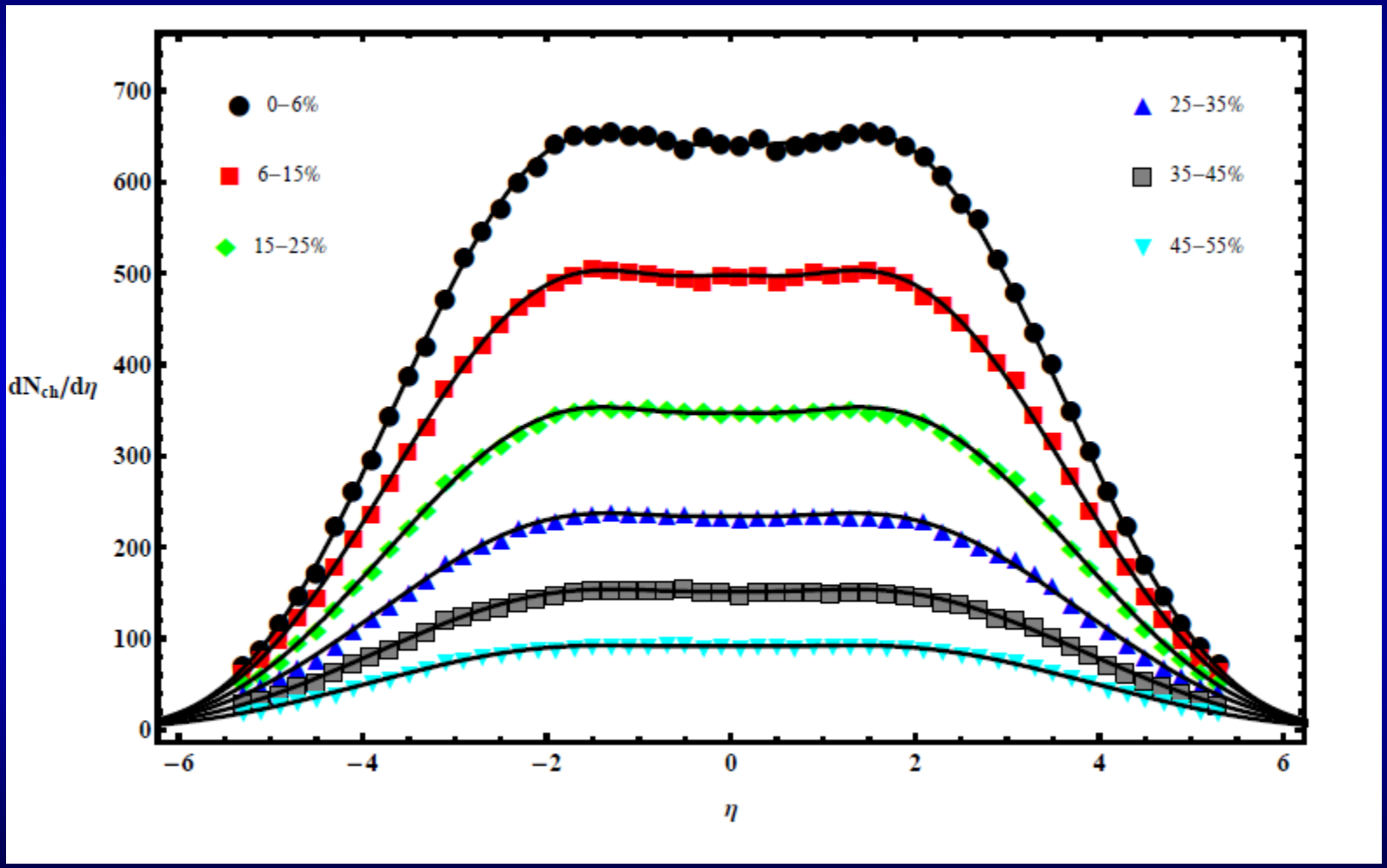
Results for CMS+TOTEM dn/dη data@7 TeV



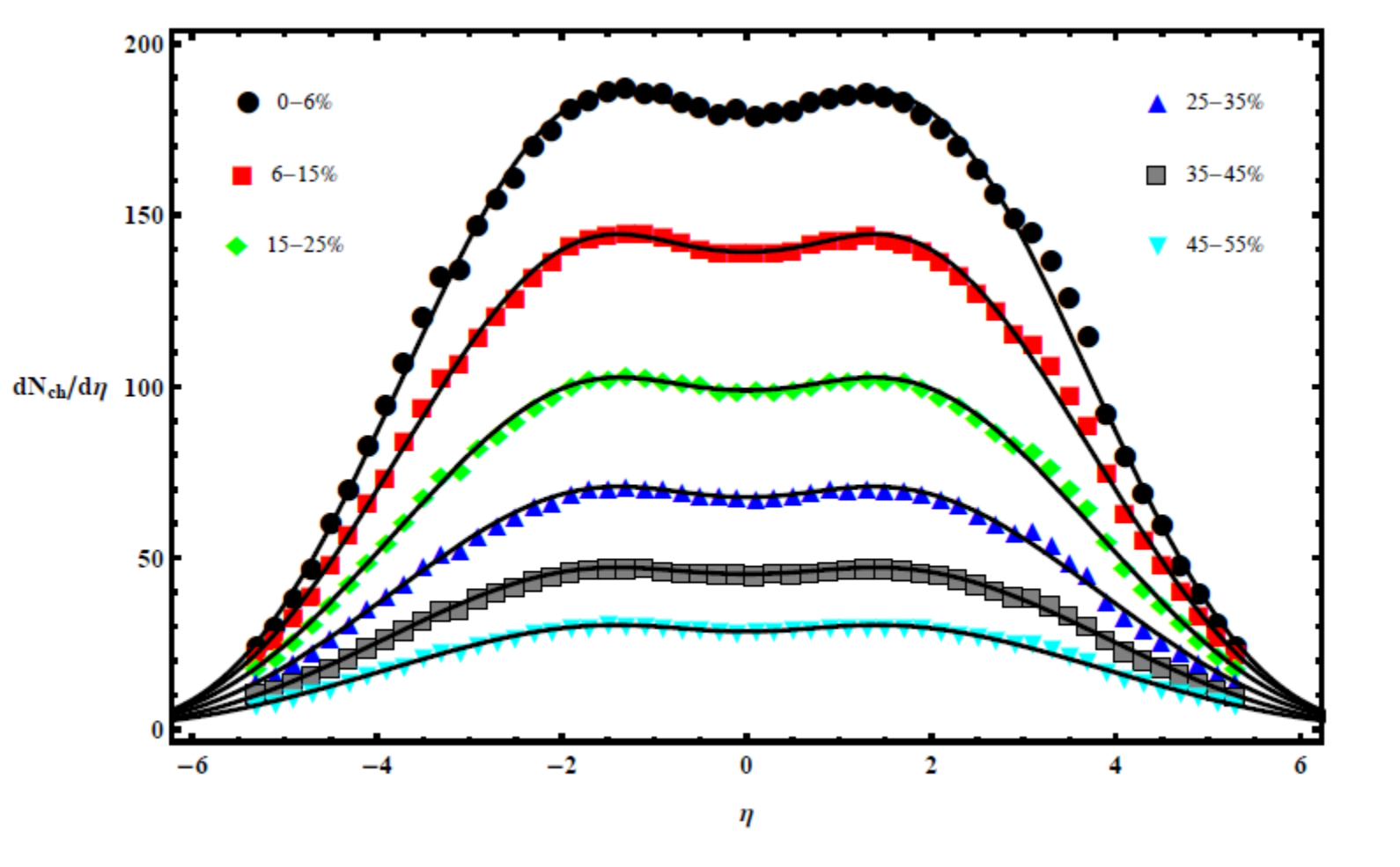
Results for CMS+TOTEM dn/dη data@8 TeV



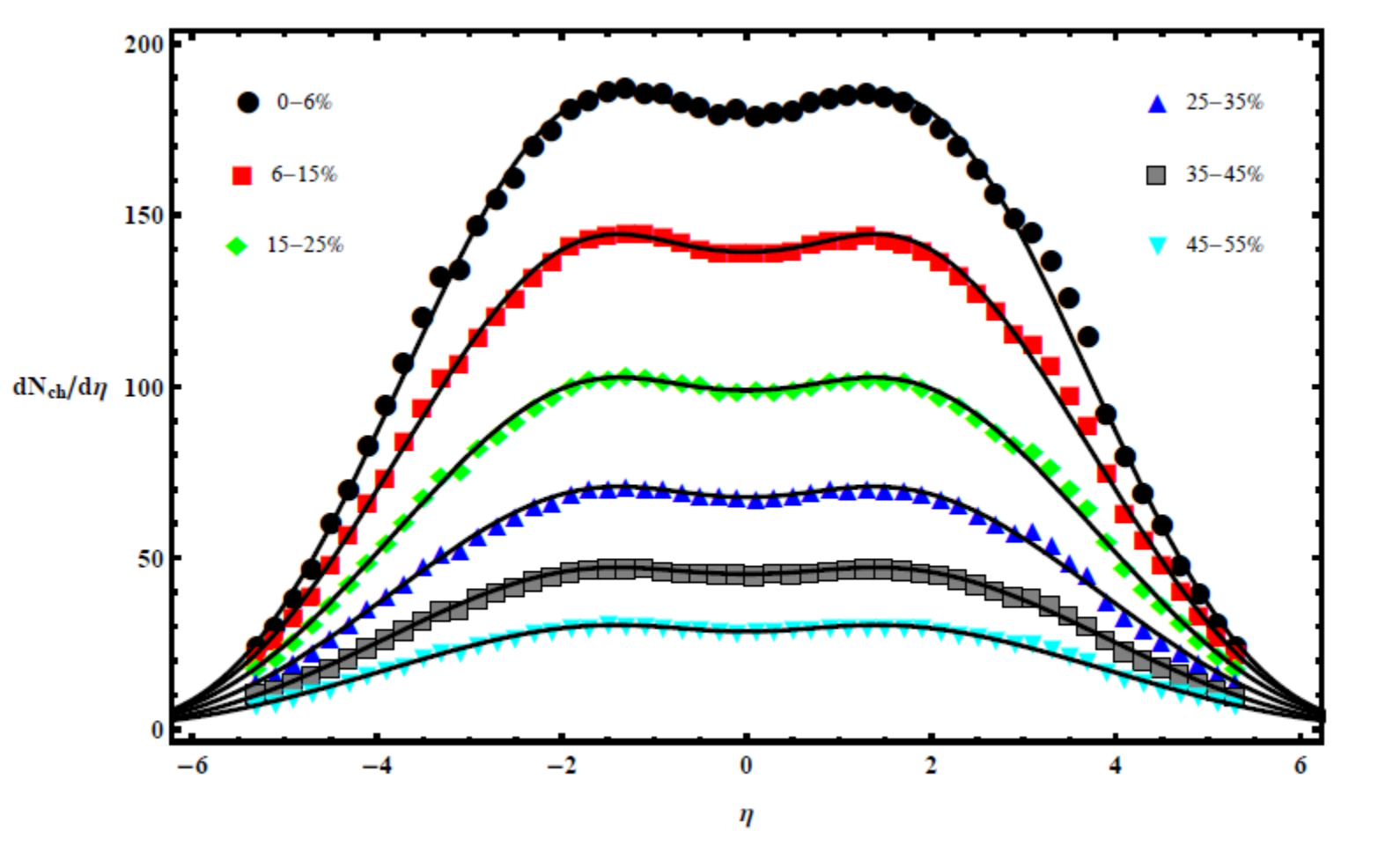
Cross-check: Au+Au at 200 GeV, PHOBOS data from RHIC



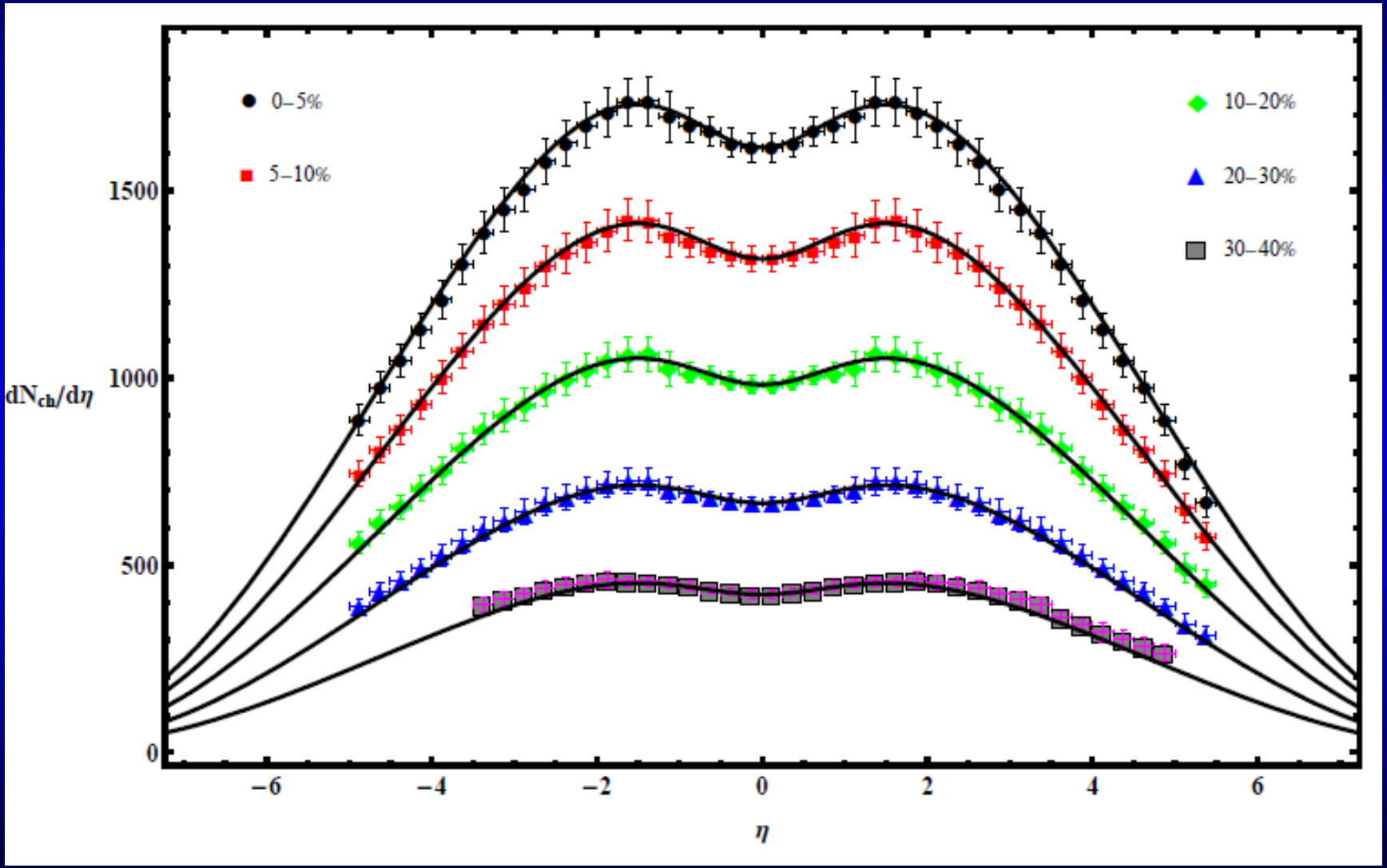
Cross-check: Cu+Cu at 200 GeV, PHOBOS data from RHIC



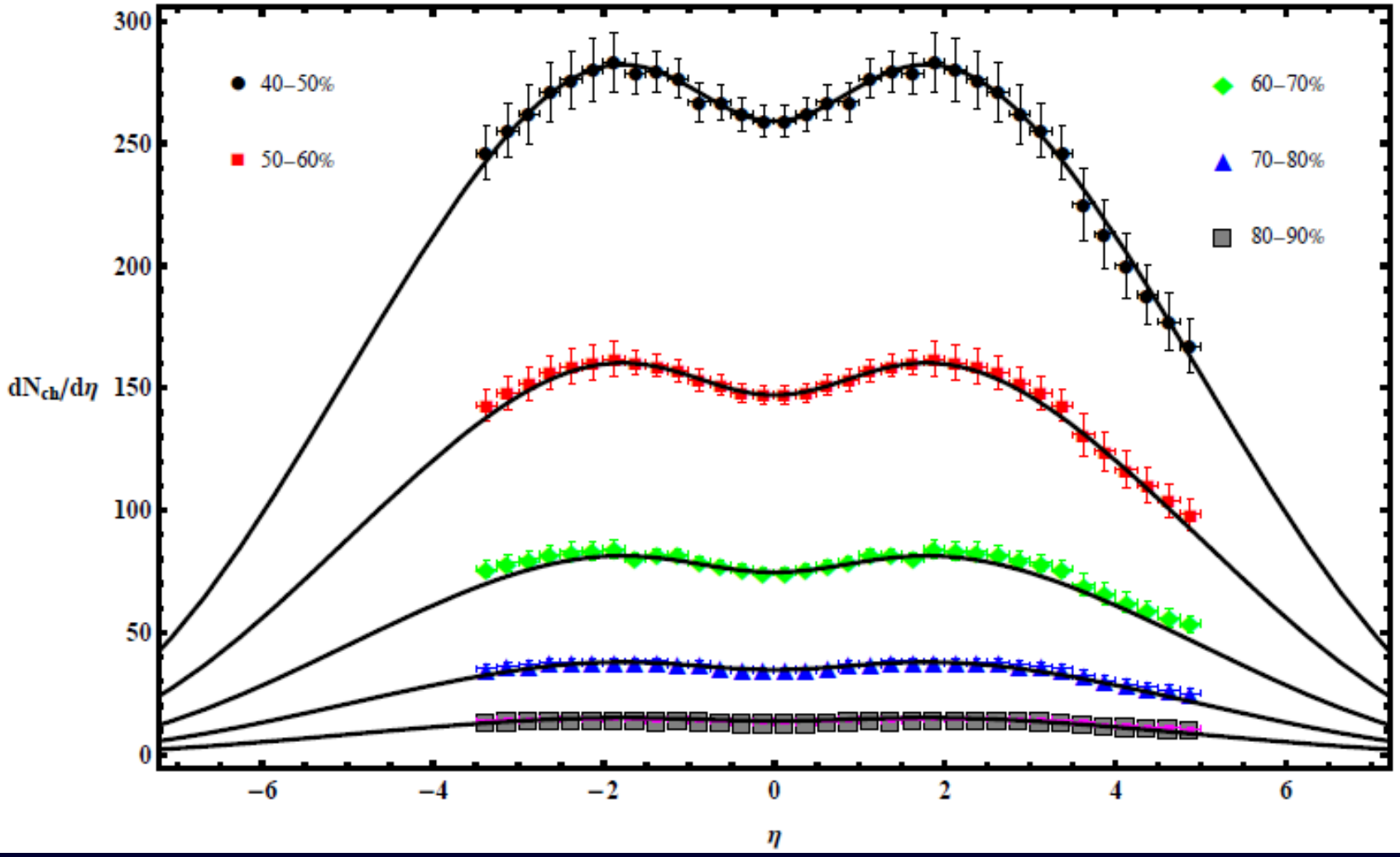
Cross-check: Cu+Cu at 200 GeV, PHOBOS data from RHIC



Heavy Ions at LHC: Pb+Pb at 2.76 TeV, ALICE data



Heavy Ions at LHC: Pb+Pb at 2.76 TeV, ALICE data, peripheral collisions



Summary

Experimentally widely used Bjorken est. (1800+)
QGP critical energy density: 1 GeV/fm^3

Advanced estimate from forward dn/dη
Results on the initial ε for c_s^2=0.1, at τ_f/τ_{ini}=2

	Bjorken	TOTEM fit	CMS fit	Combined fit
ε_{ini}	0.95 GeV/fm^3	1.20 GeV/fm^3	1.15 GeV/fm^3	1.13 GeV/fm^3

Small correction but important implications

- **pp is not a good reference**
- **R_{AA} not such a good concept, need:**
  R_{AA} per unit lenght ≡ optical opacity,

arXiv:0911.5015

Implications

pp, pA, dA, AA are similar
But differ in sizes (multiplicity)

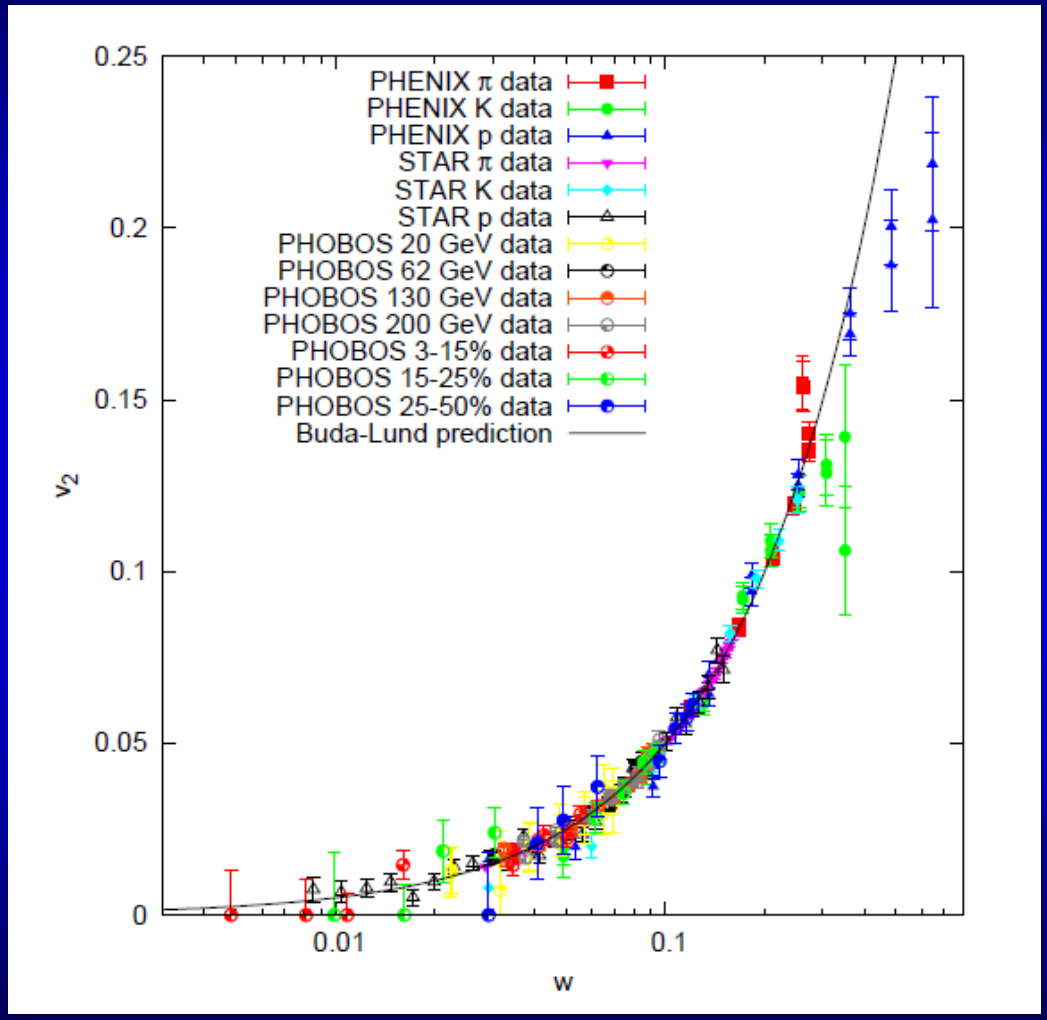
Need for an electron-proton and eA collider
to determine a clear reference

Prediction:
Scaling laws for spectra,
elliptic flows
and HBT radii in pp@ LHC

New result:
Initial energy density is
Larger than 1 GeV/fm3 in pp@LHC

Quark Matter even in pp@LHC

Prediction: UNIVERSAL
hydro scaling of v_2 will hold for pp@LHC



nucl-th/0512078 but new: v_2/n_q vs K_{ET}/n_q will be violated in p+p@LHC