Universal curves in Pseudo-Rapidity Spectra

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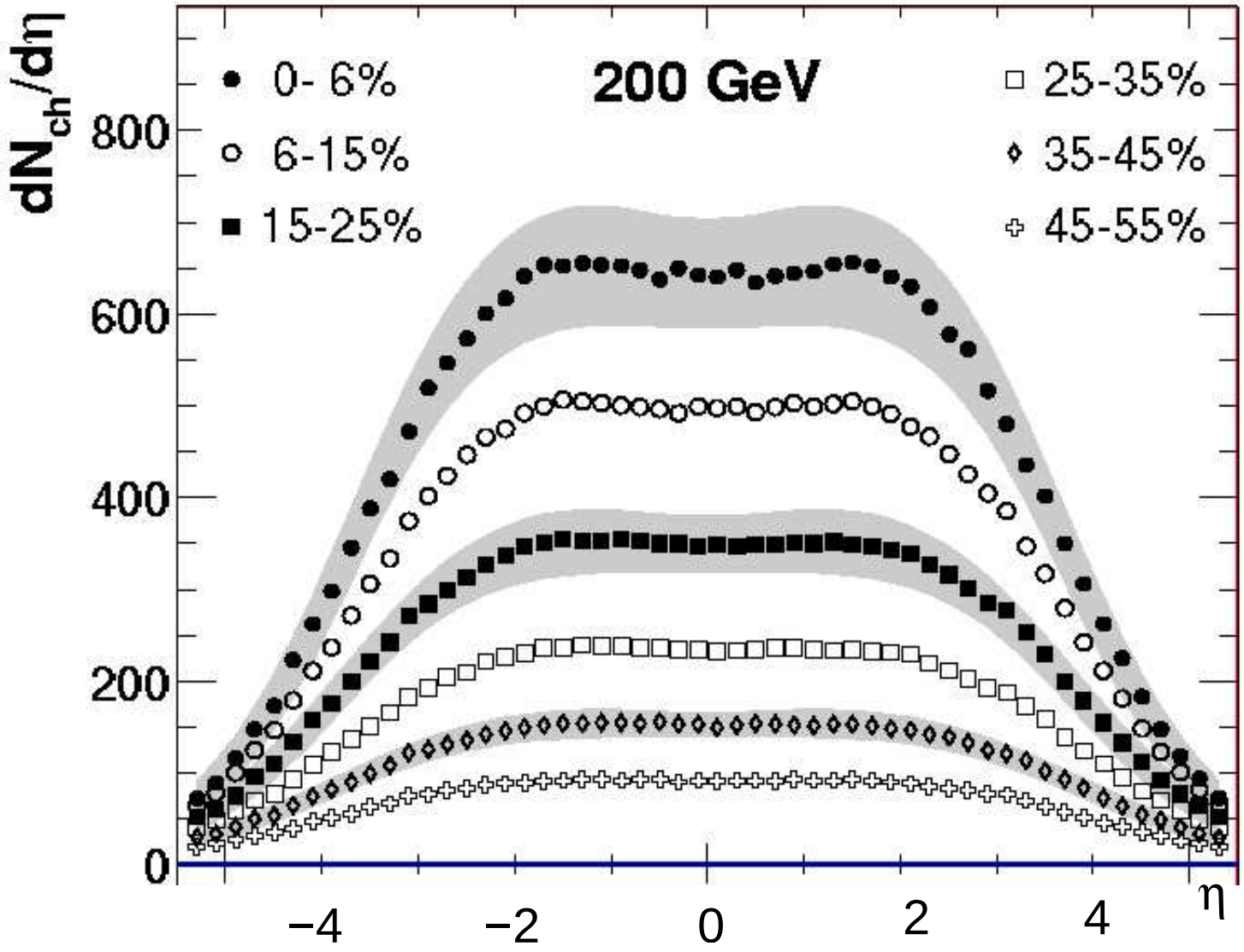
What is Central Plateau?

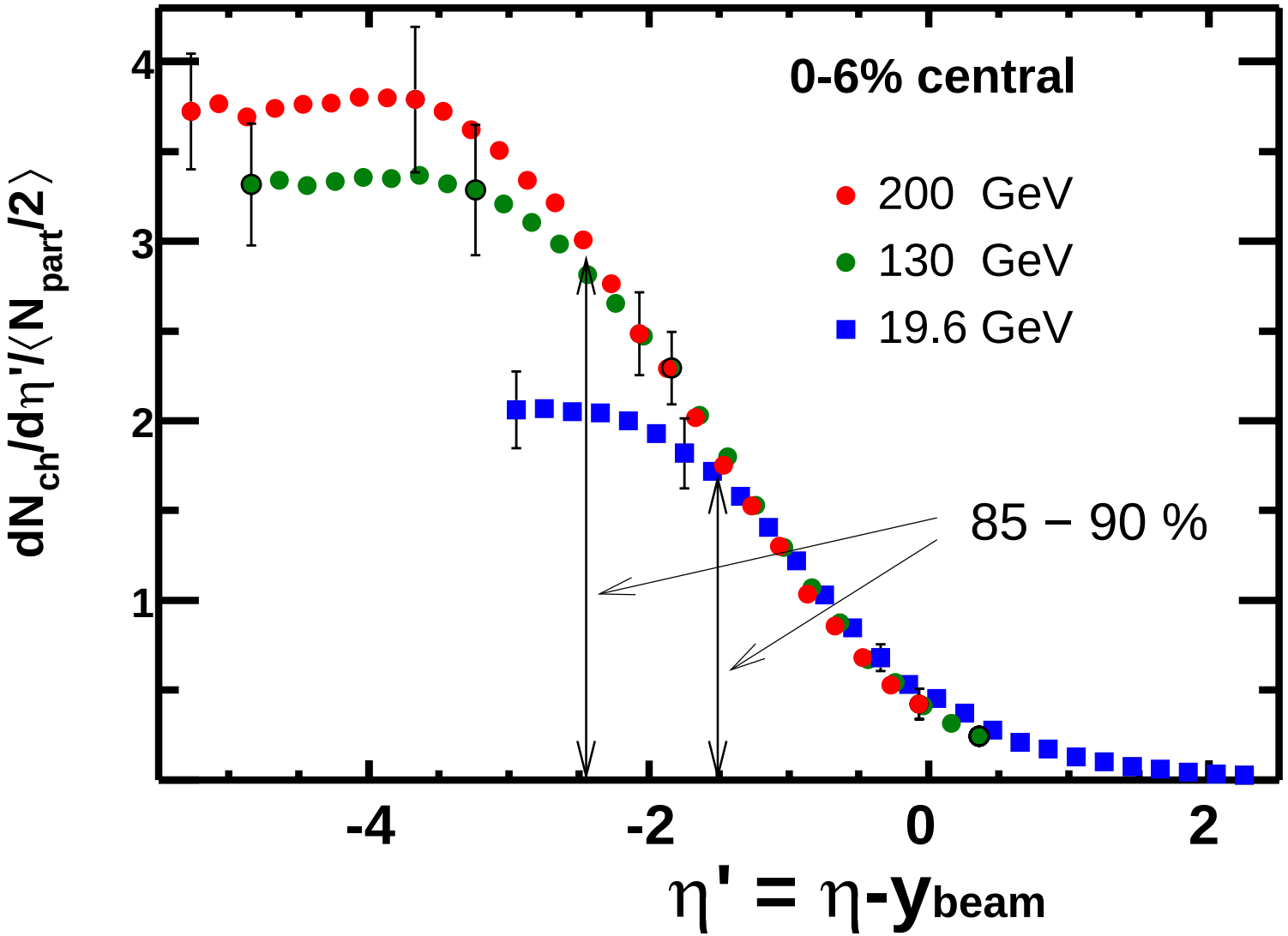


PHOBOS:

nucl-ex/0210015

- Dynamics near $y = 0$: Independent of η

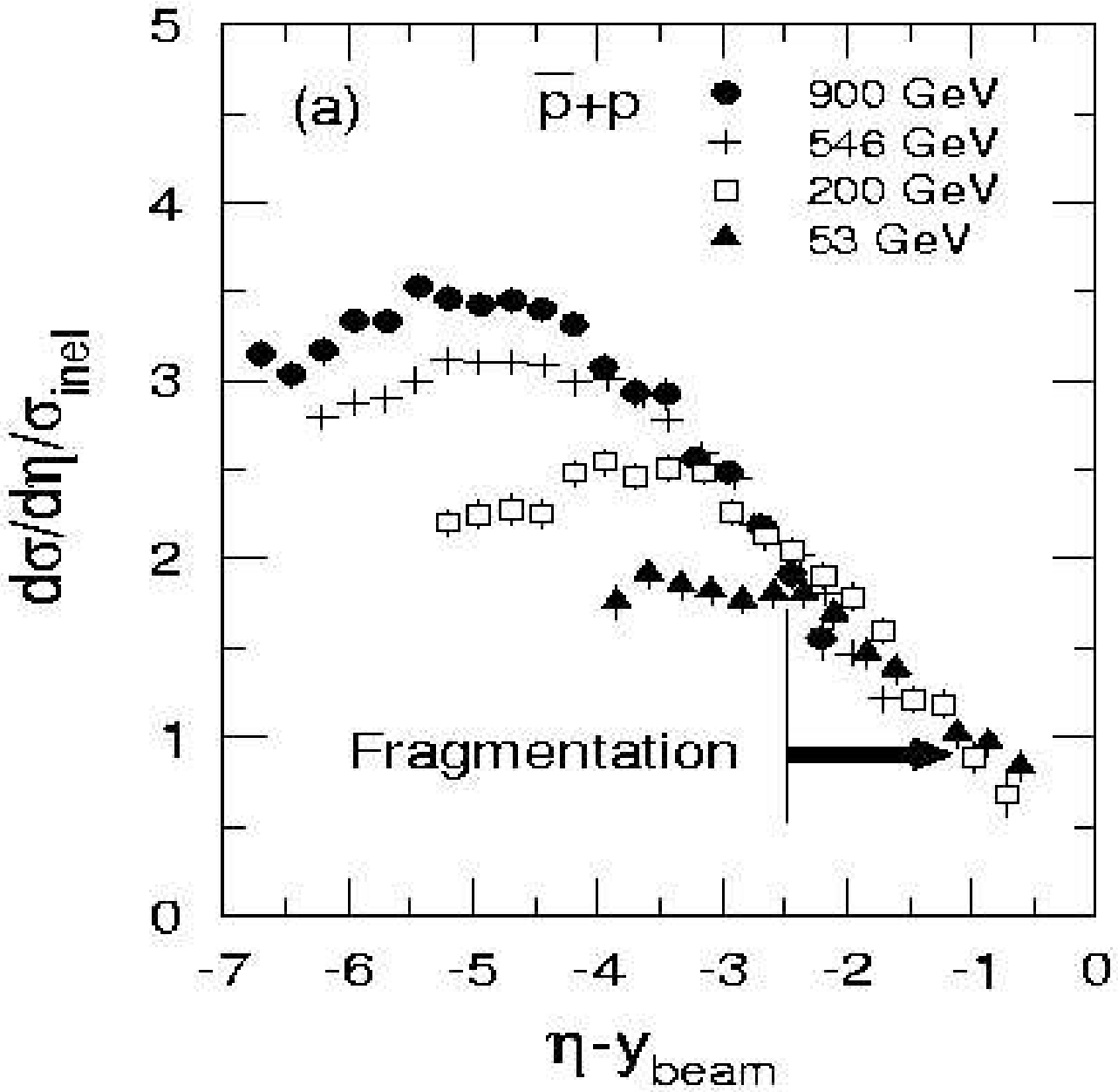
What is Limiting Fragmentation?



PHOBOS:

nucl-ex/0210015

- Dynamics near $y_{\rm beam}$: Independent of $\sqrt{s}$



Rachid Nouicer:

Heavy Ion Physics 16

1- 4 153 (2002)

Connection?

- Tail and Center: Far apart in $\eta \Longrightarrow$ Expect independence
- However ... PHOBOS : "Both the 19.6 and 130 GeV data reach $85 - 90\,\%$ of their maximum value before deviating significantly (more than 5 %) from the common limiting curve." [nucl-ex/0210015]
- If this is indeed the case

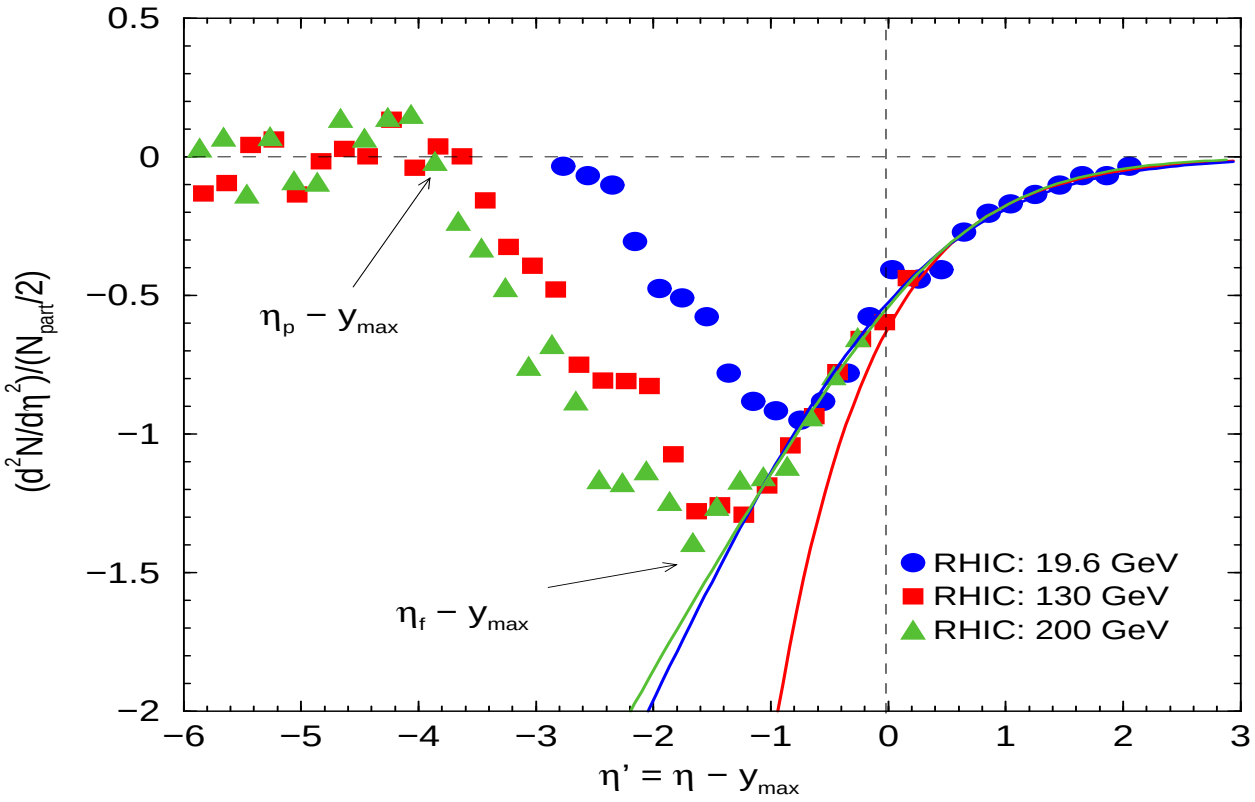
$\Longrightarrow$ Plateau height is determined by the limiting curve.

$\Longrightarrow$ The whole $dn/d\eta$ is determined by the limiting curve.

$\Longrightarrow$ The total multiplicity is determined by the limiting curve.

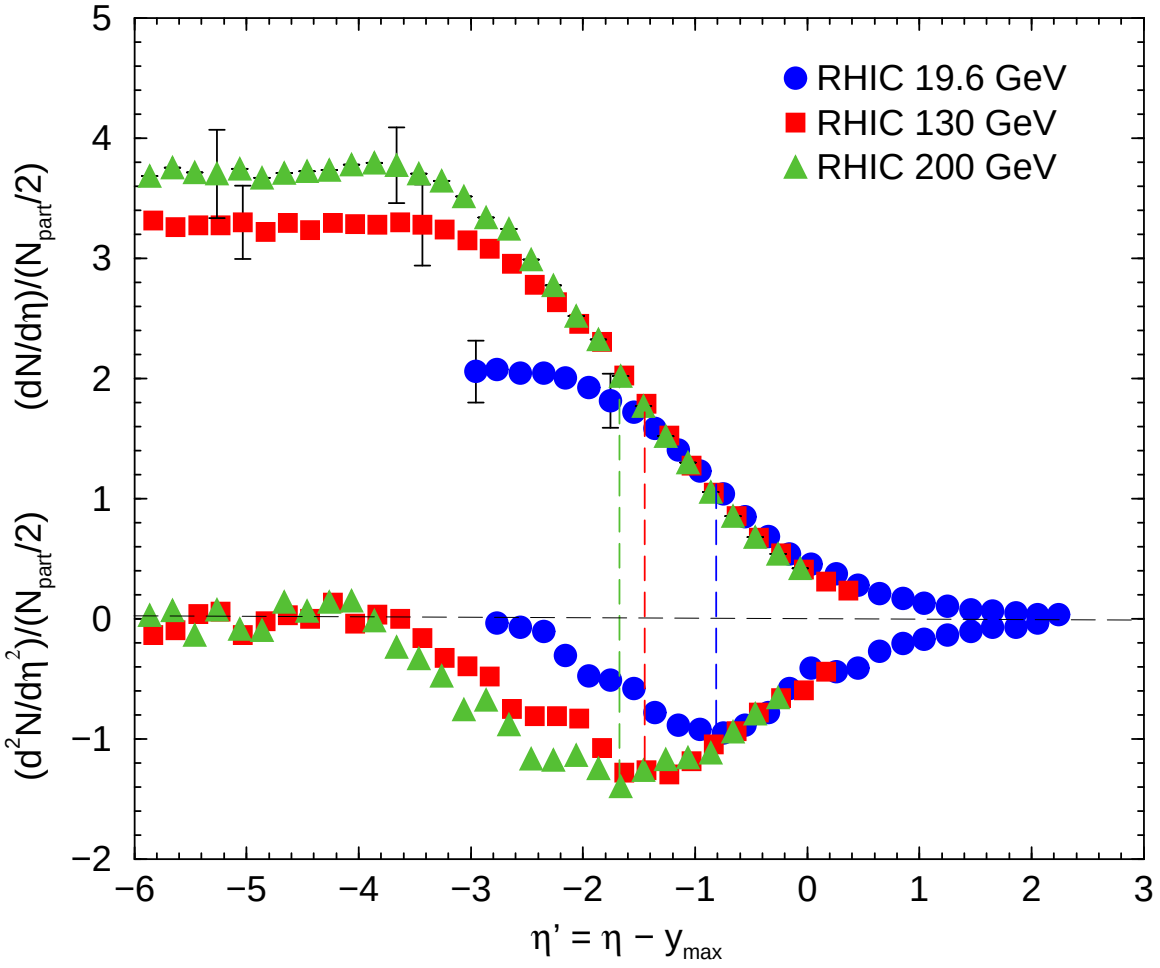
- How much of this is really true? – That's the question.

What does the data actually say?



- 3 Distinct regions in $d^2n/d\eta^2$
  - ∗ Limiting fragmentation region – $\eta_f < \eta$
  - ∗ Transition region – $\eta_p < \eta < \eta_f$
  - ∗ Plateau region – $0 < \eta < \eta_p$

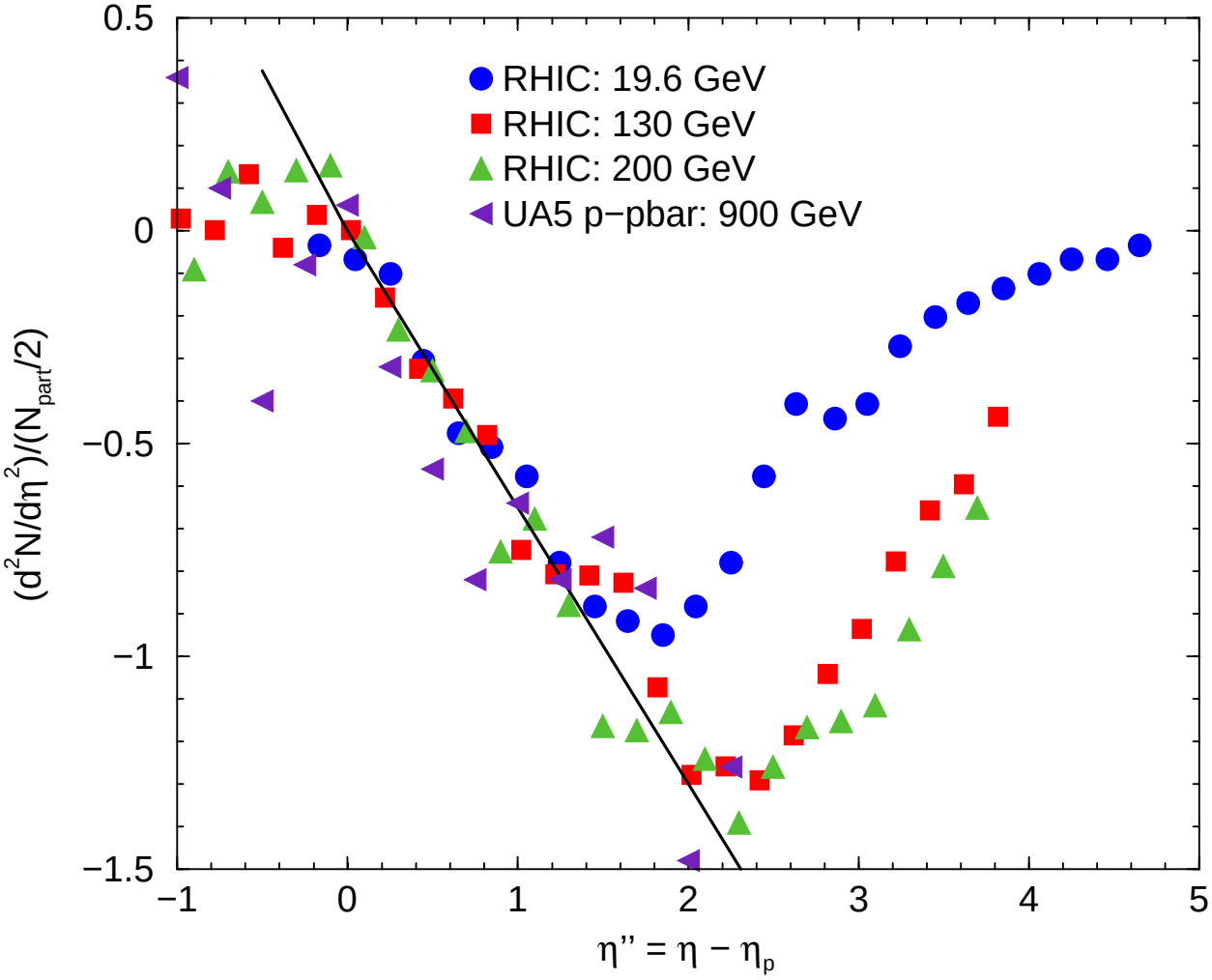
What does the data actually say?



- Limiting fragmentation region extends only up to $50\,\%$.
- $85 - 90\,\%$ seen in $dn/d\eta$: Optical Illusion

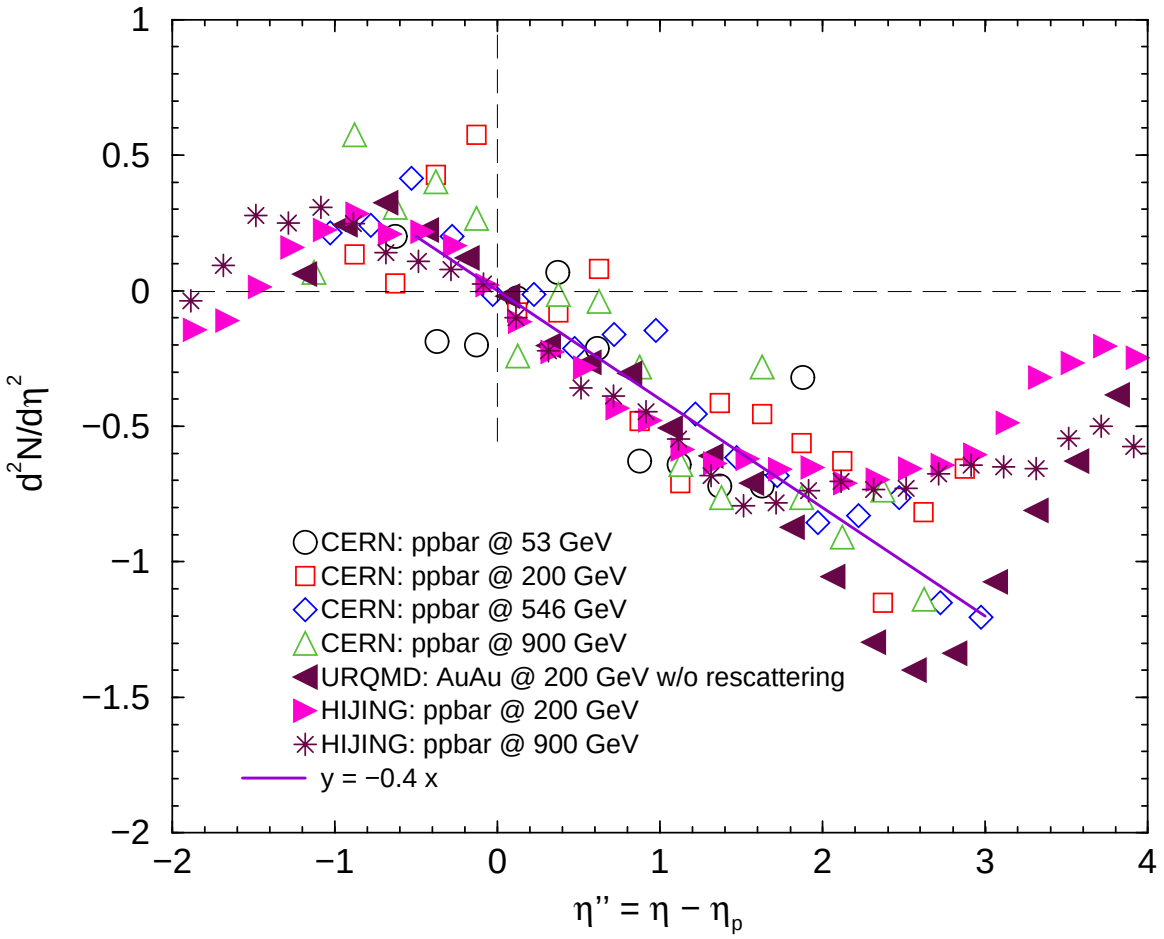
This talk is not really about limiting fragmentation!

What does the data actually say?



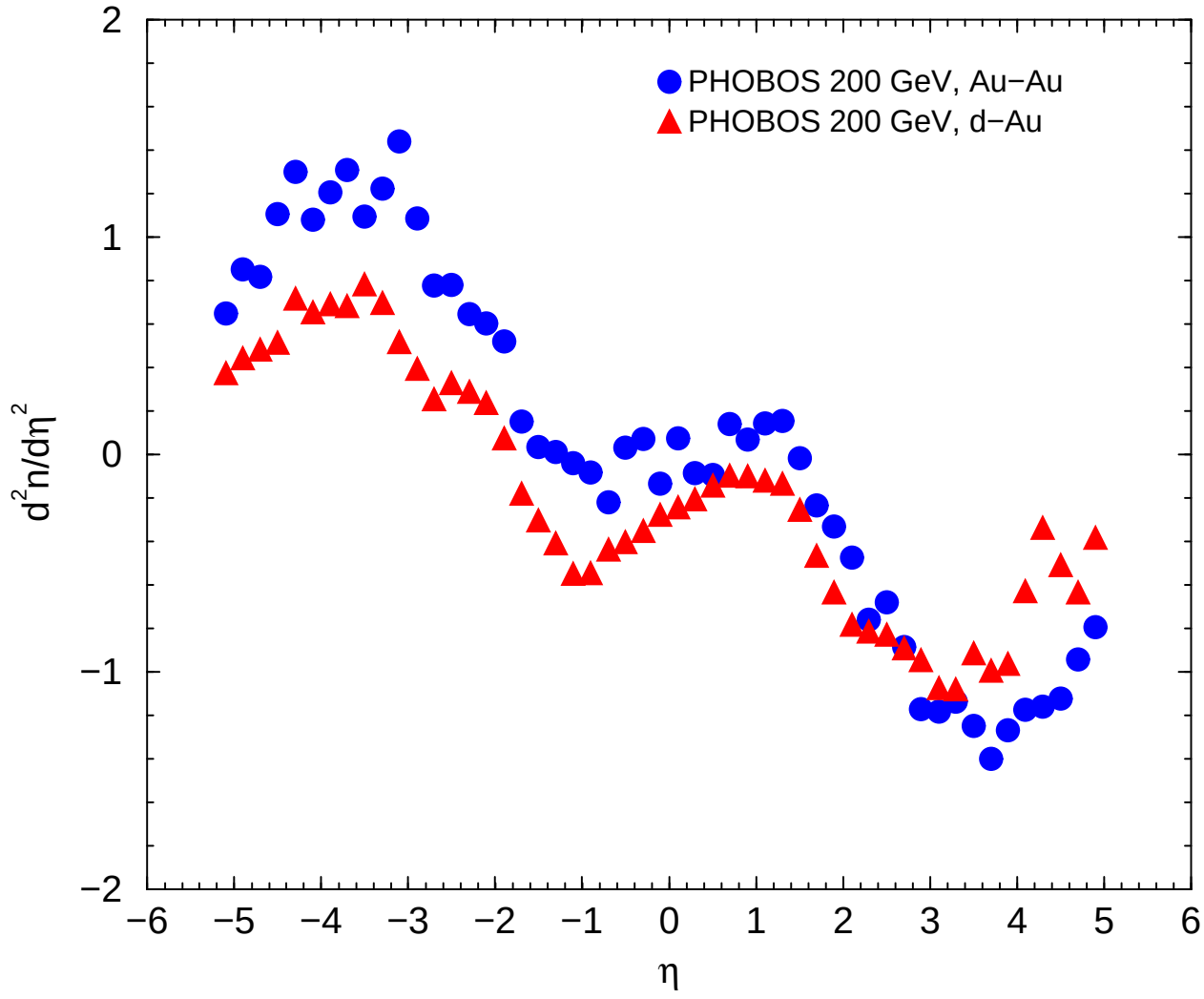
- Transition region also shows 'universal behavior'

What does the data actually say?



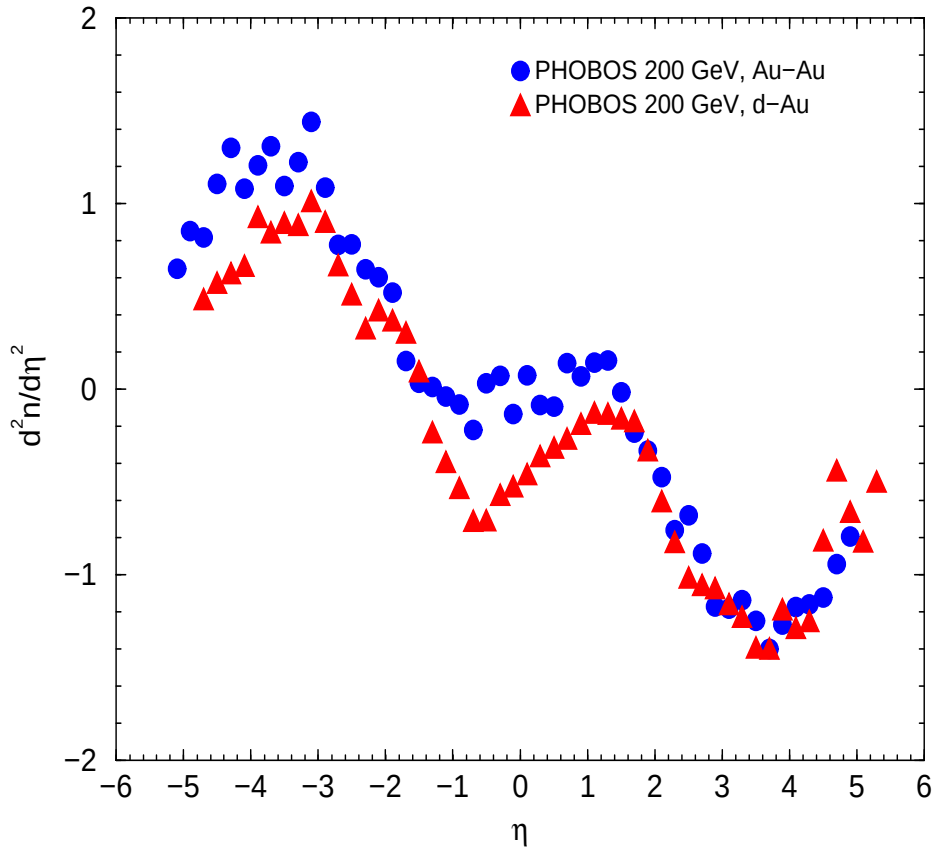
- Same trend even in $p\bar{p}$
- Slope is a bit shallower

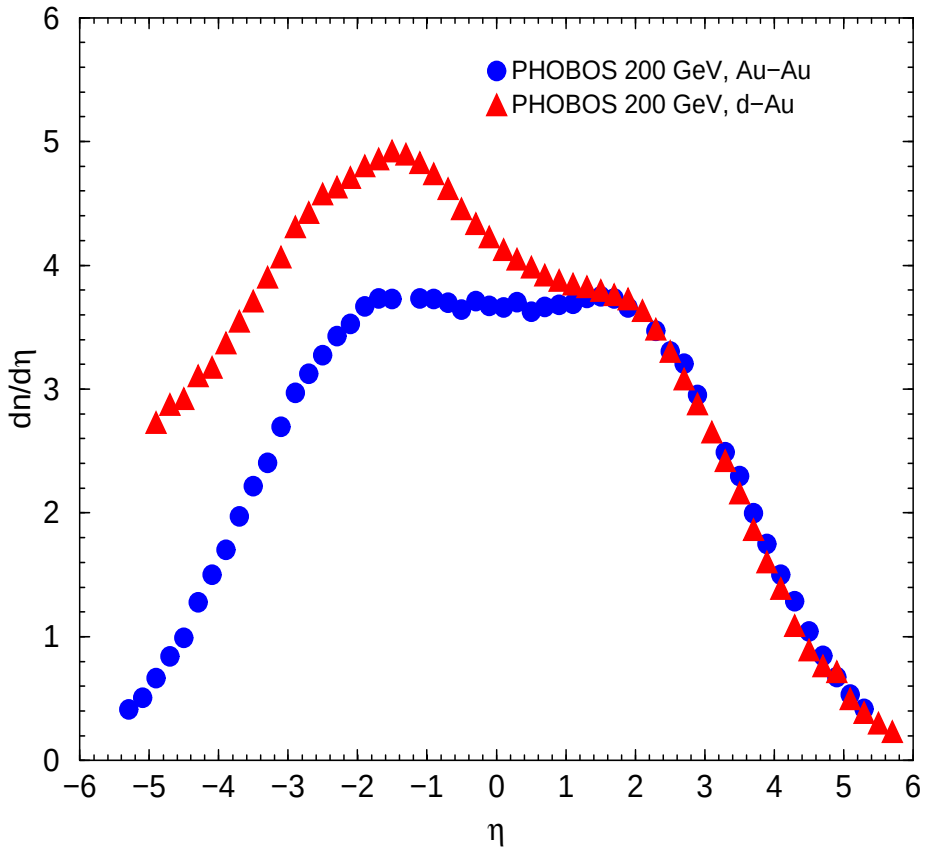
What does the data actually say? – dAu



- Almost matches up?

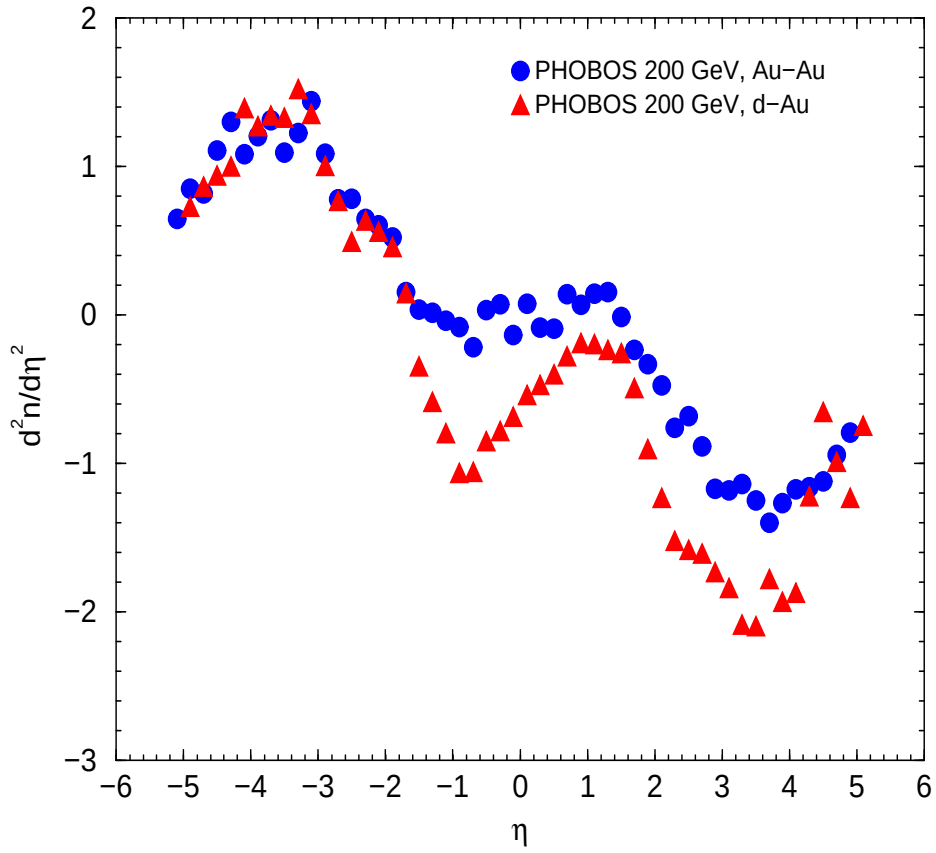
What does the data actually say? – d side

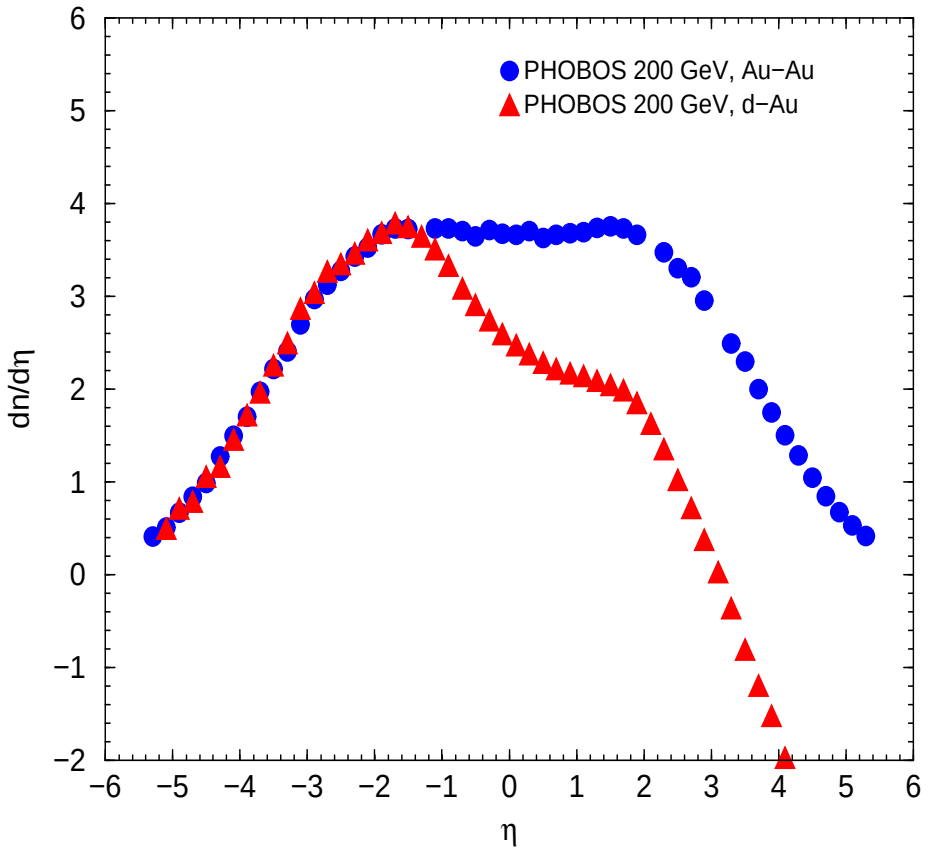




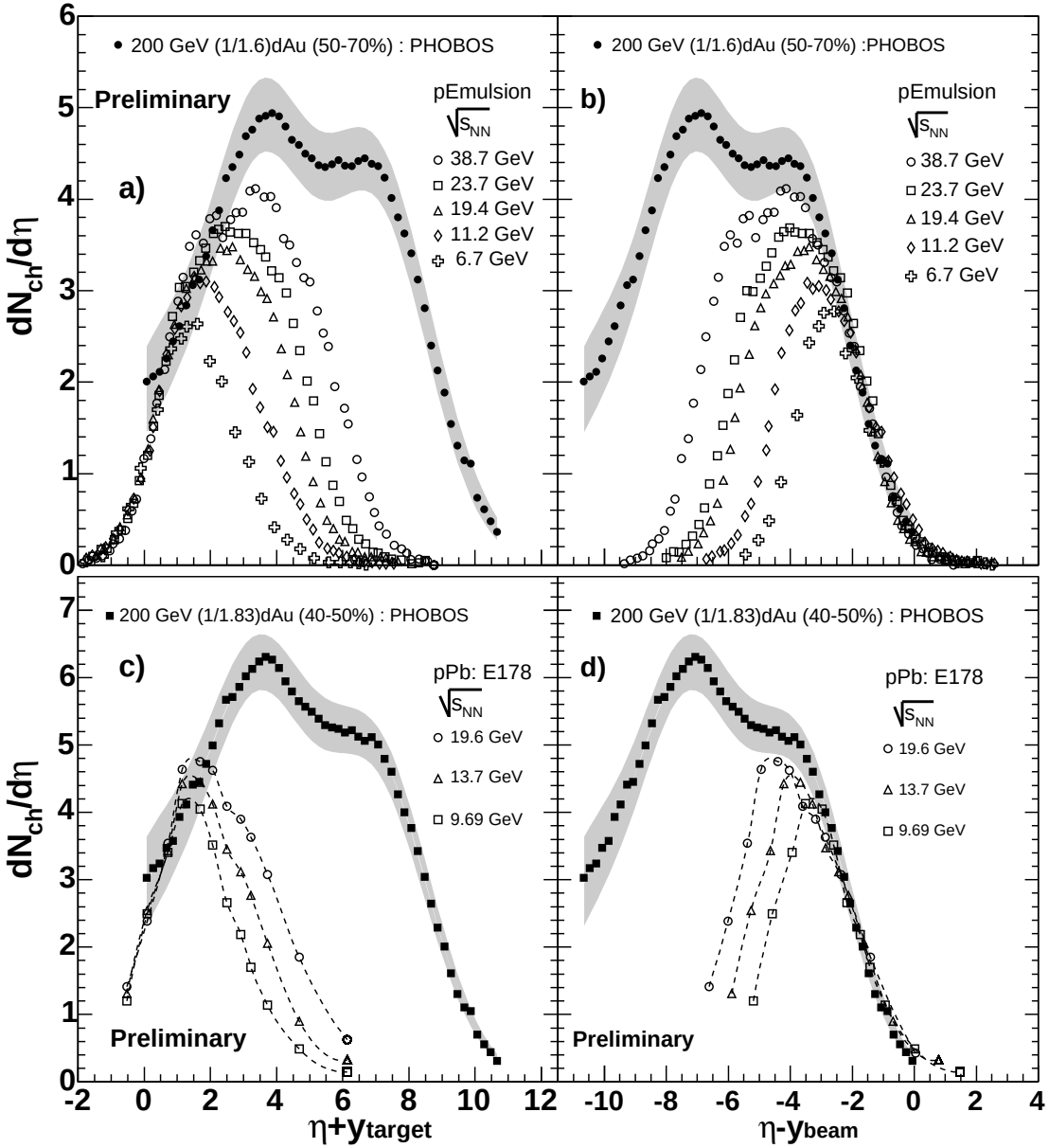
- Vertical scaling: $\times 1.3$
- Horizontal shifting: $+\,0.4$ (2 experimental bins)

What does the data actually say? – Au side





- Vertical scaling: $\times 1.3 \times 1.5$
- Horizontal shifting: $+\,0.2$ (1 experimental bin)



Rachid Nouicer
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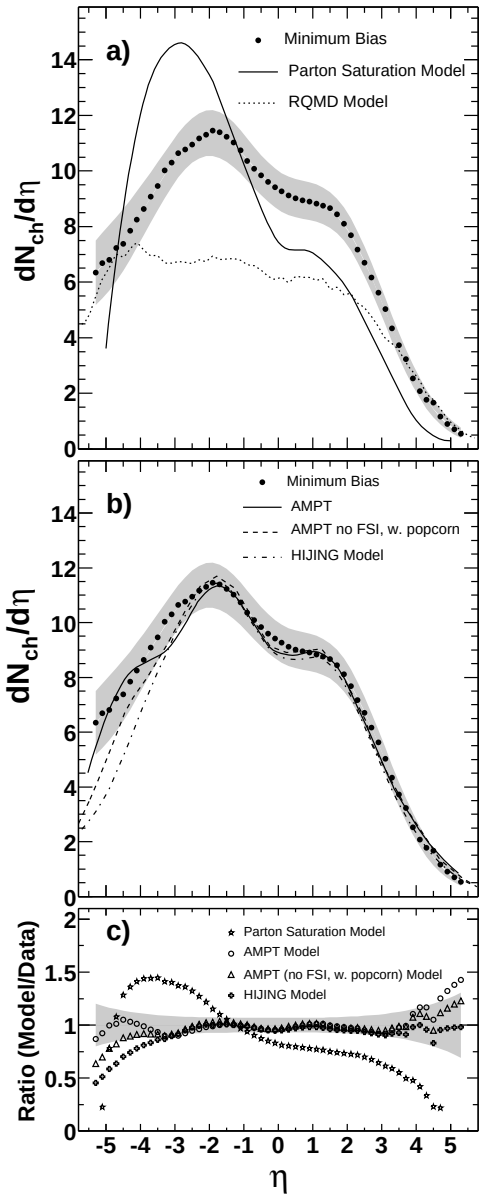
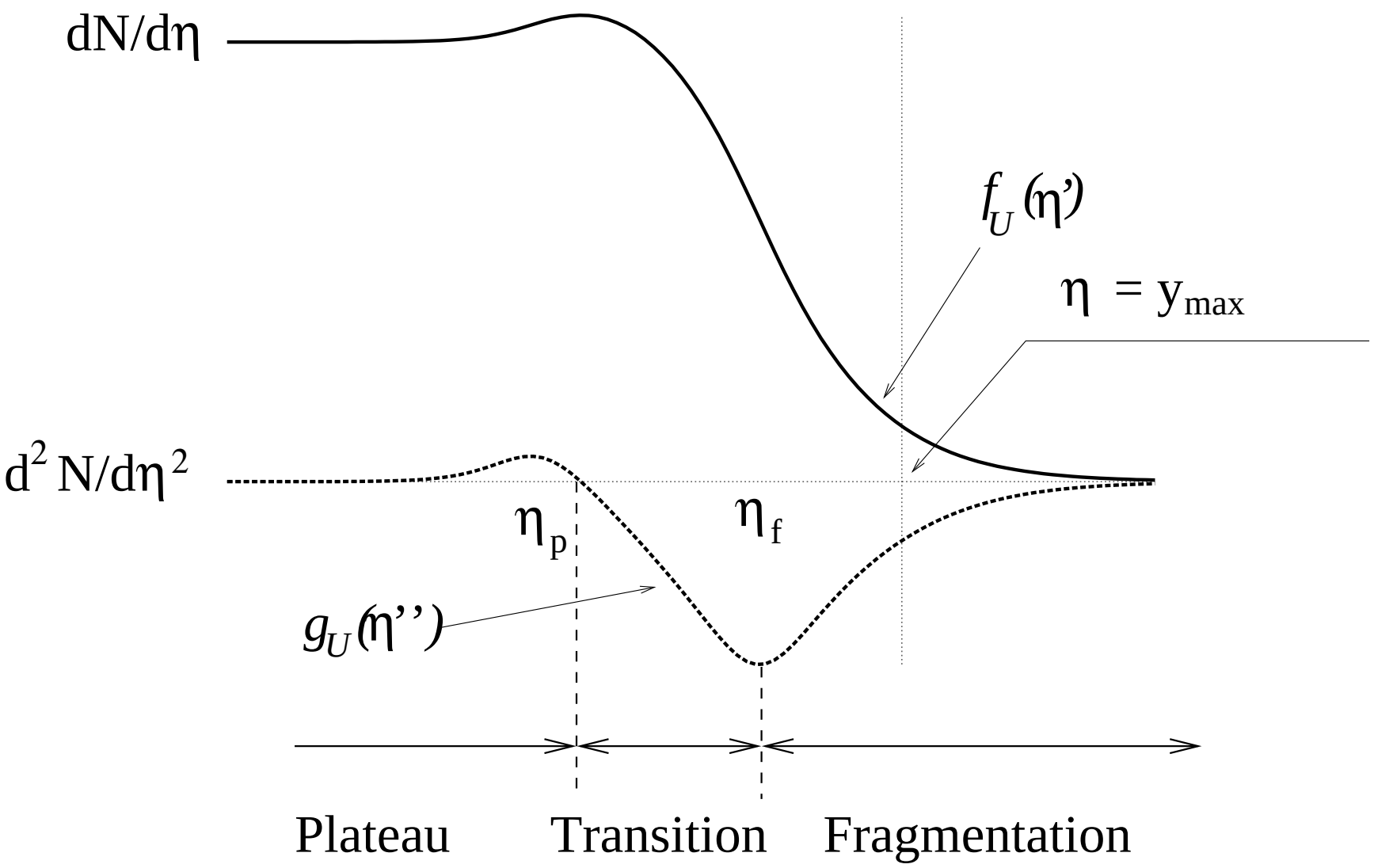
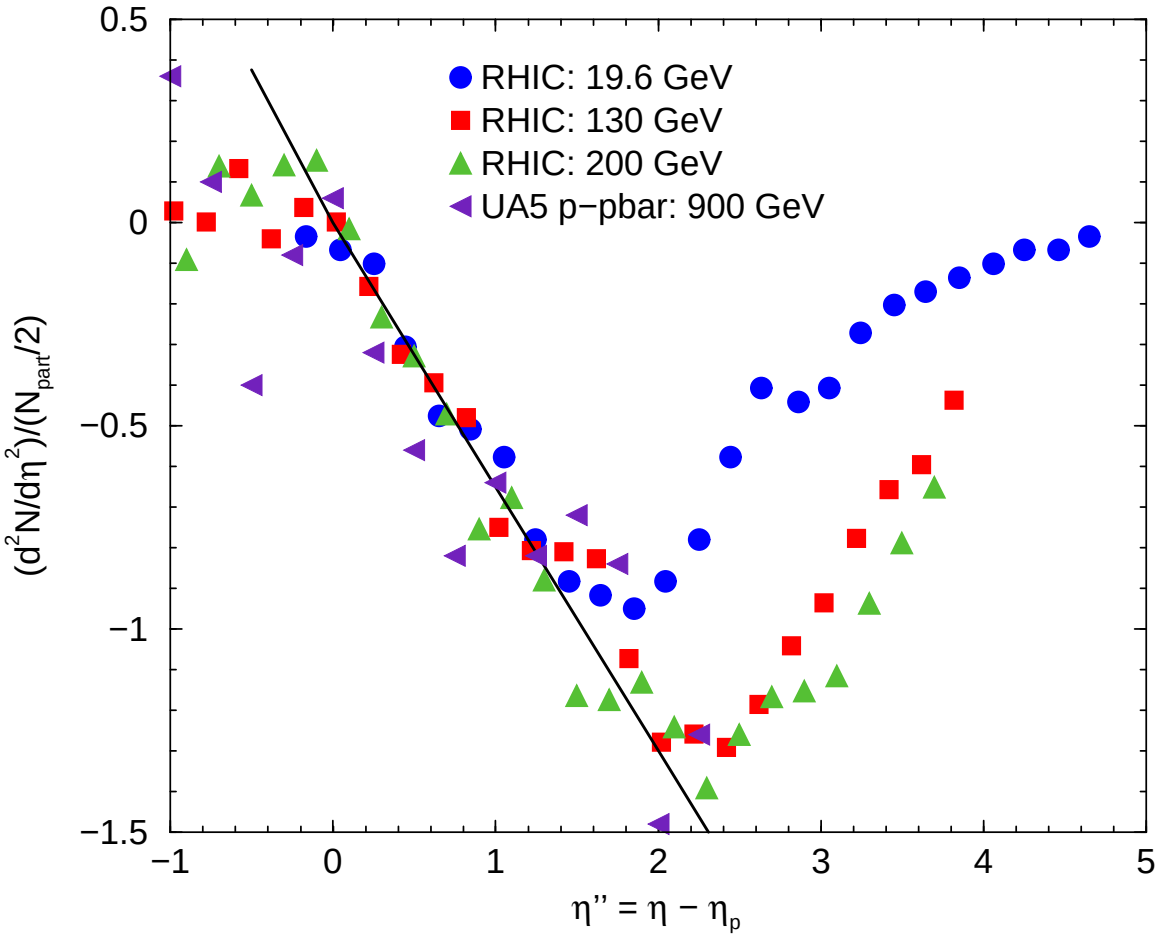

a)
Minimum Bias
Parton Saturation Model
RQMD Model
$dN_{ch}/d\eta$
b)
Minimum Bias
AMPT
AMPT no FSI, w. popcorn
HIJING Model
$dN_{ch}/d\eta$
c)
Parton Saturation Model
AMPT Model
AMPT (no FSI, w. popcorn) Model
HIJING Model
Ratio (Model/Data)
η

What determines $dn/d\eta$?



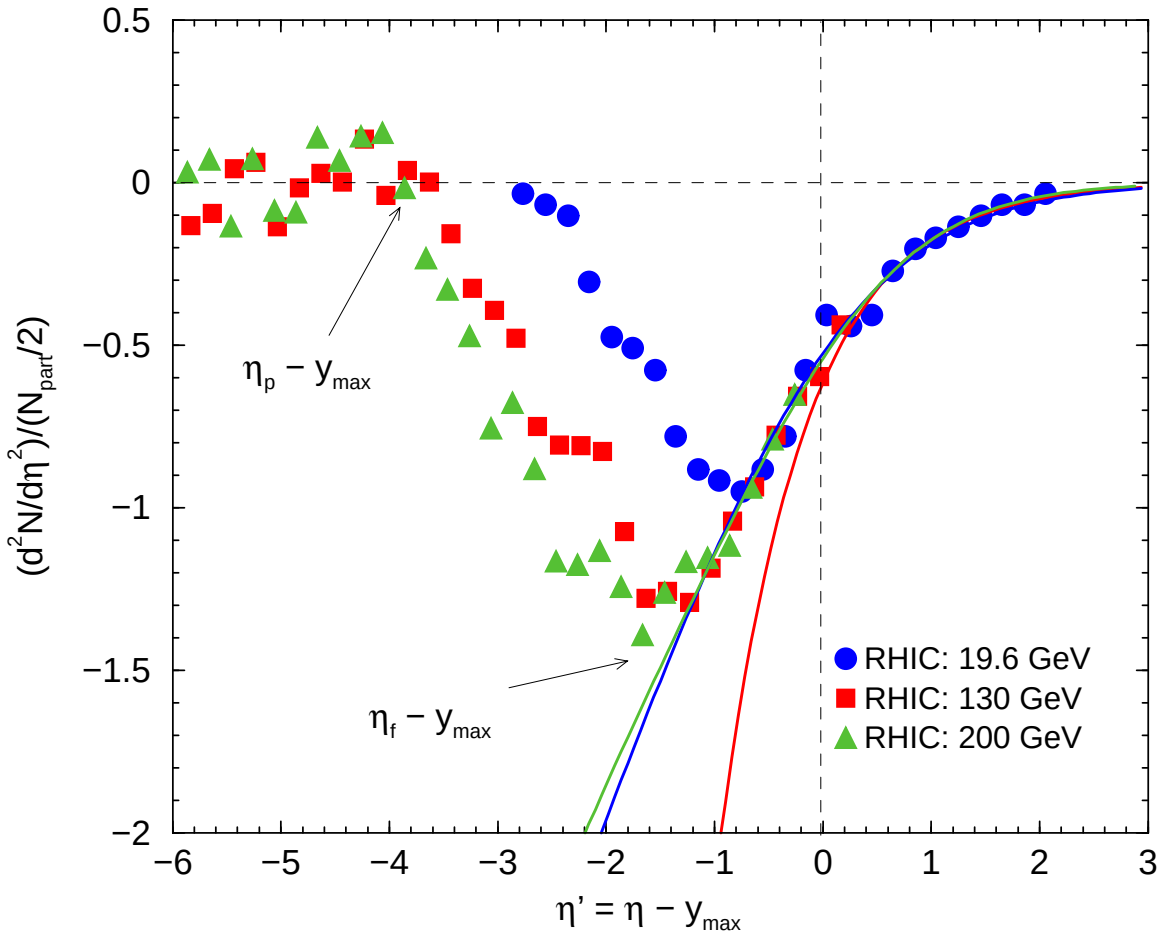
The universal transition curve



$$g_U(\eta'') = -K\eta''$$

$$K \approx 0.65$$

The universal fragmentation curve

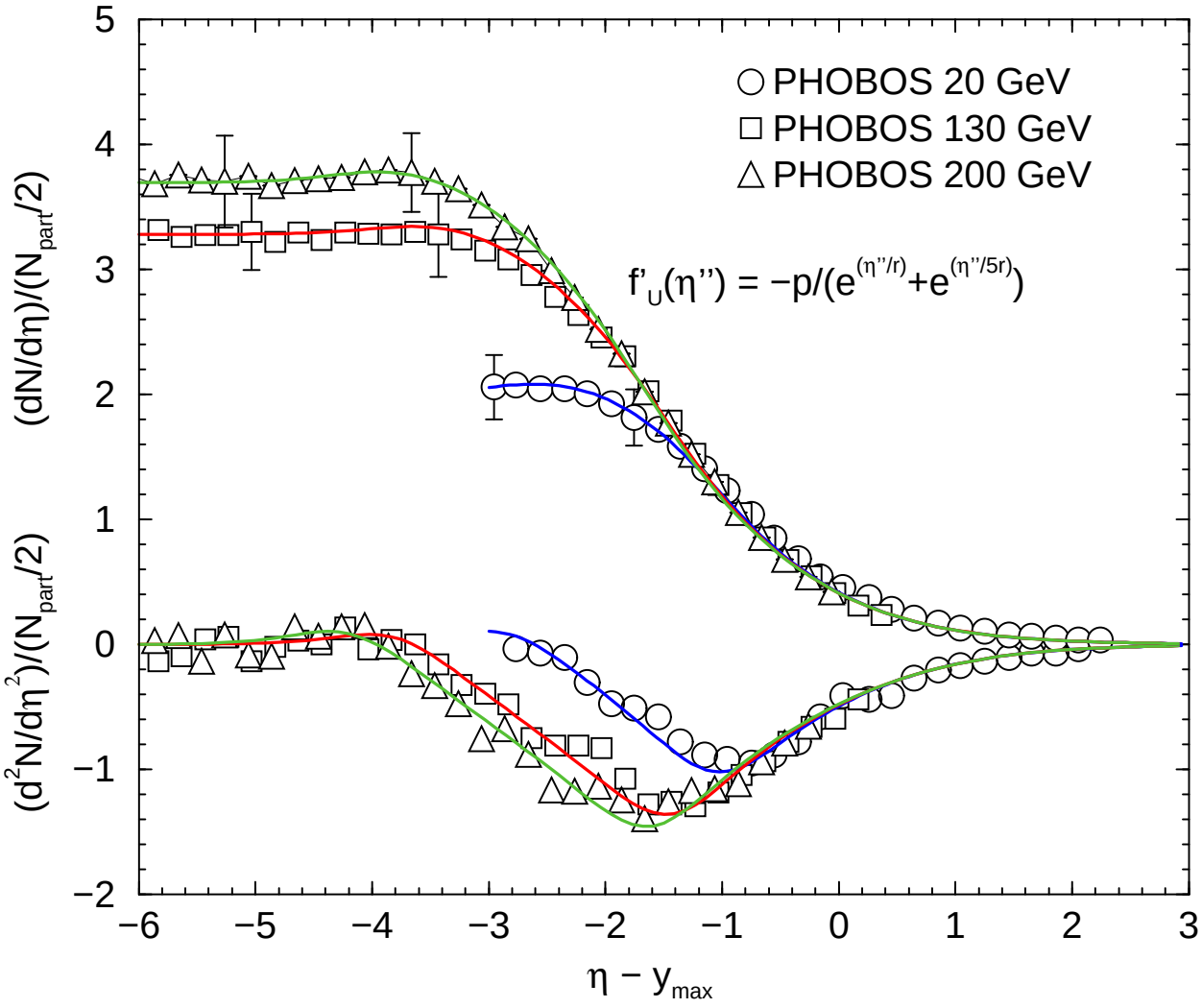


$$\frac{df_U}{d\eta'} = -\frac{p}{e^{\eta'/r} + e^{5\eta'/r}}$$

$$1/r \approx 0.3 \quad p \approx 1$$

$dn/d\eta$

Combining $g(\eta'')$ and $f_U(\eta')$ with smeared θ functions



- η_p: Fit to the Data

$$\eta_p \approx y_{\max} - 0.60 \ln y_{\max} - 0.73 {y_{\max}}^{0.91}$$

$$\eta_p \approx y_{\max} - 0.33 \ln y_{\max} - 0.96 {y_{\max}}^{0.75}$$

- η_f: Solve $g_U(\eta_f - \eta_p) = f'_U(-y_{\max} + \eta_f)$

$$\eta_f = y_{\max} + O(\ln y_{\max})$$

Upper bounds in the large $y_{\max}$ limit

$$\left(\frac{dn}{d\eta}\right)_0 \approx \frac{1}{2}(\eta_f - \eta_p)^2 \quad < \ln^2(\sqrt{s}/m_N)$$

$$n_{\text{total}} \approx \frac{K}{3}(\eta_f - \eta_p)^2(2\eta_f + \eta_p) < \ln^3(\sqrt{s}/m_N)$$

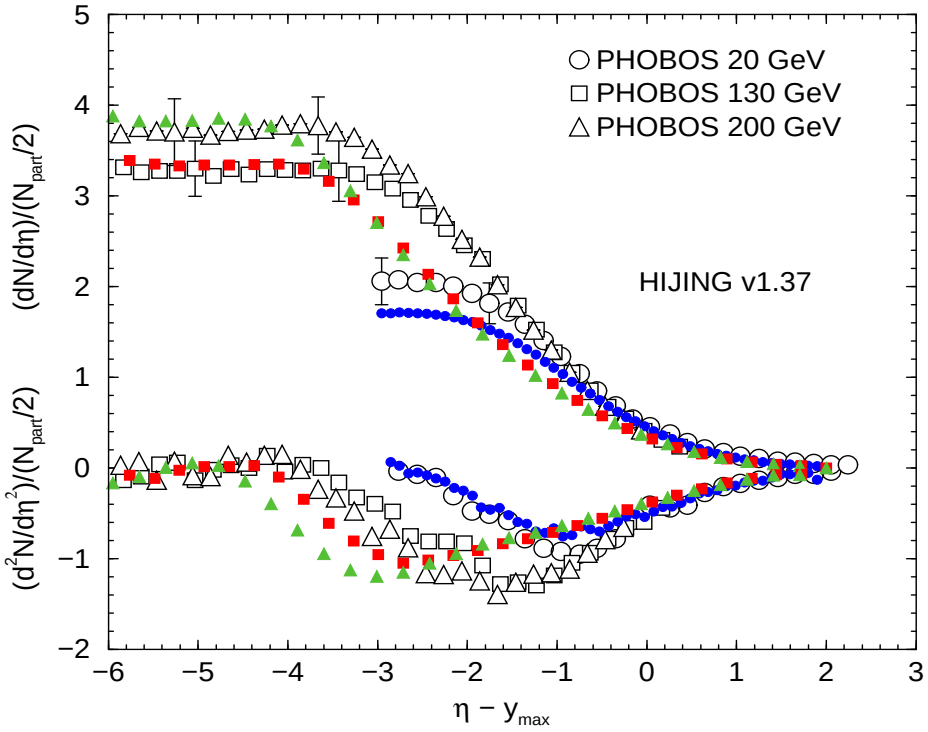
- As $y_{\max} \longrightarrow \infty$, it is the transition curve that determines the plateau height and total multiplicity.

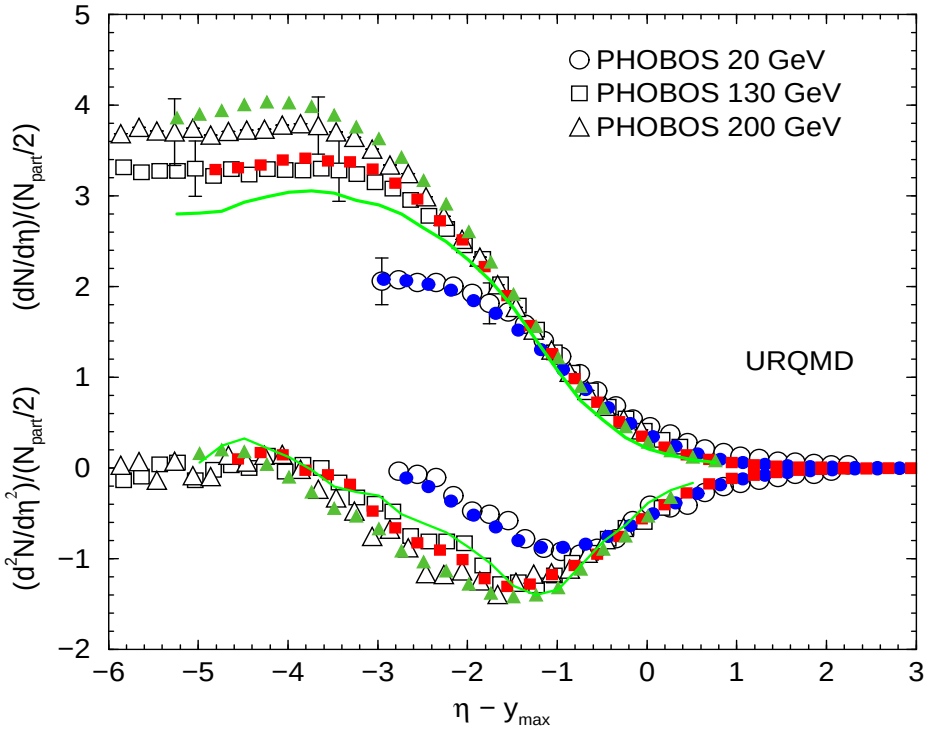
Physics - Fragmentation Region

- Limiting fragmentation: Feynman scaling

$$\lim_{\sqrt{s}\to\infty} E_p \frac{dn_{hh}}{d^3p} = \lim_{\sqrt{s}\to\infty} \frac{dn_{hh}}{dy\, d^2p_T} = f(x_L, p_T)$$

- Models based on PDF + Fragmentation should work

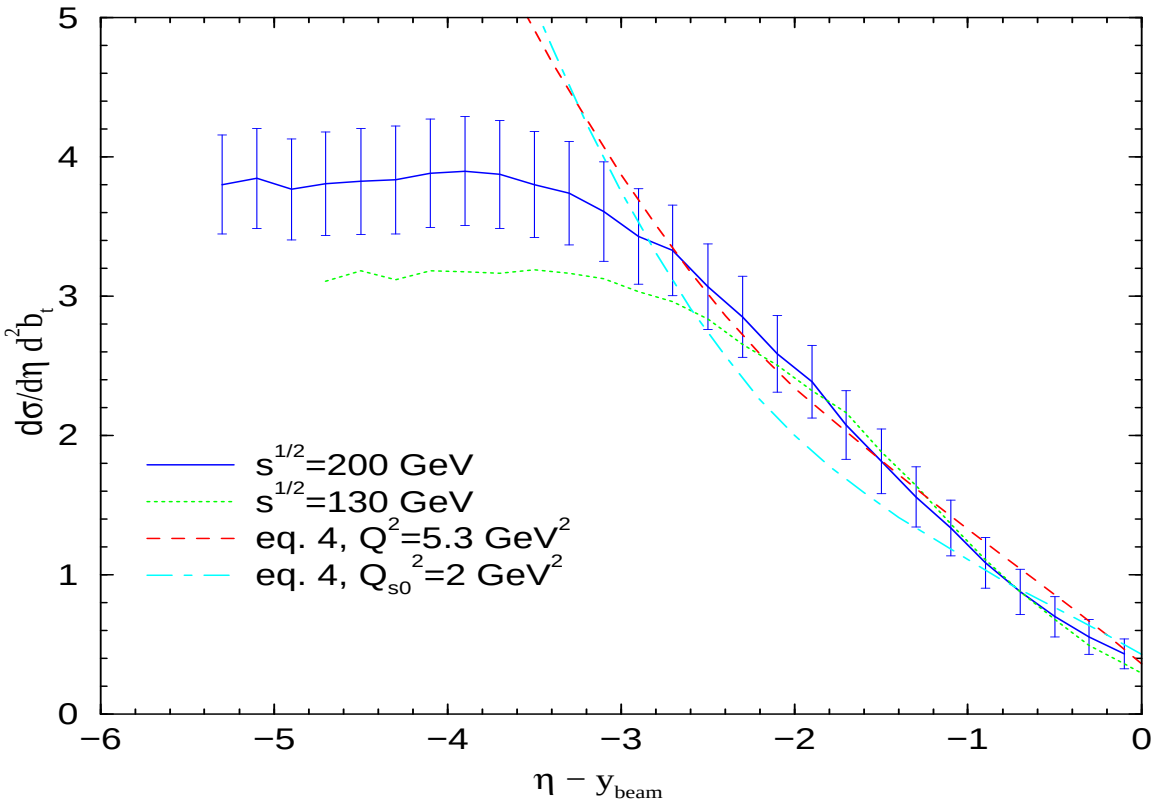




Physics - Frag. Region

- A model based on CGC also works reasonably well (Jamal Jalilian-Marian)

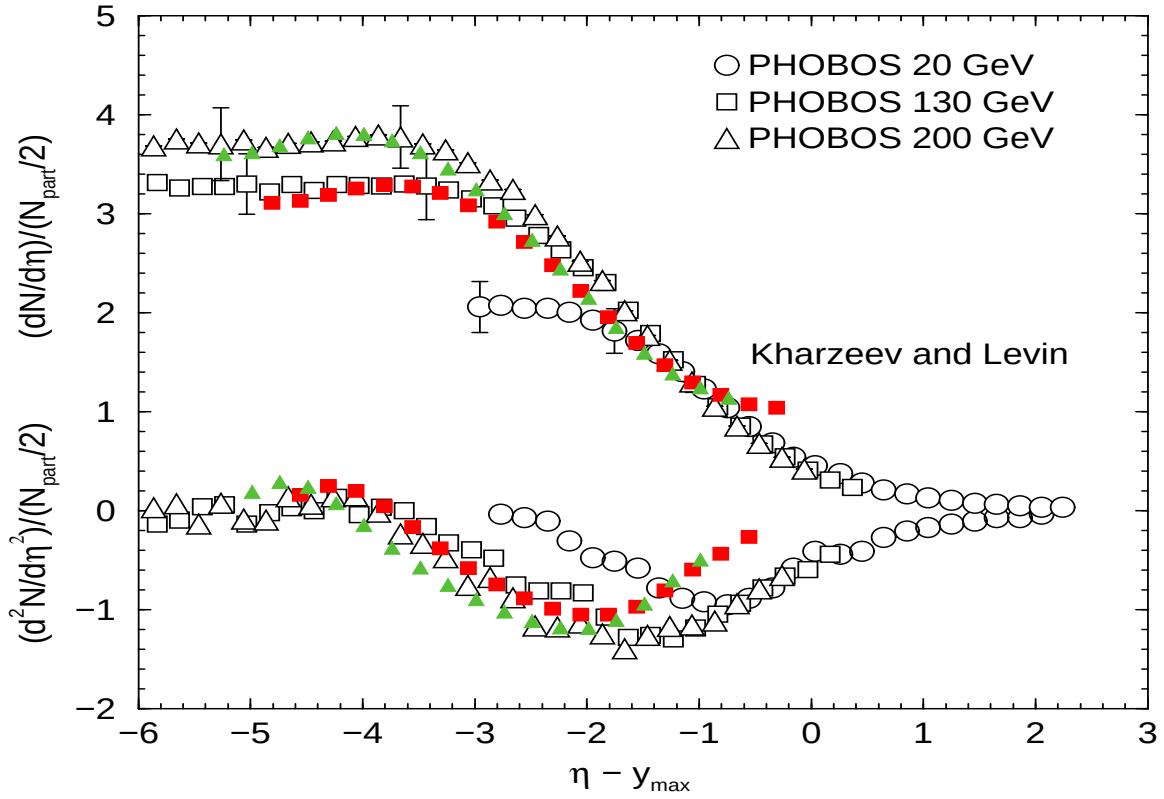
$$\frac{d\sigma^A}{d\eta d^2b} \sim \left[x_q f_{q/A}(x_q) + x_g G_A(x_g)\right]$$



Physics - Frag. Region

- Kharzeev-Levin-McLerran-Nardi (KLMN) doesn't work so well in this region, but neither it is supposed to.

$$\frac{dN}{dy} \propto N_{\rm part} \left(\frac{s}{s_0}\right)^{\lambda/2} e^{-\lambda|y|} \left[\ln\left(\frac{Q_s^2}{\Lambda^2}\right) - \lambda|y|\right] \left[1 + \lambda|y| \left(1 - \frac{Q_s}{\sqrt{s}} e^{(1+\lambda/2)|y|}\right)^4\right]$$

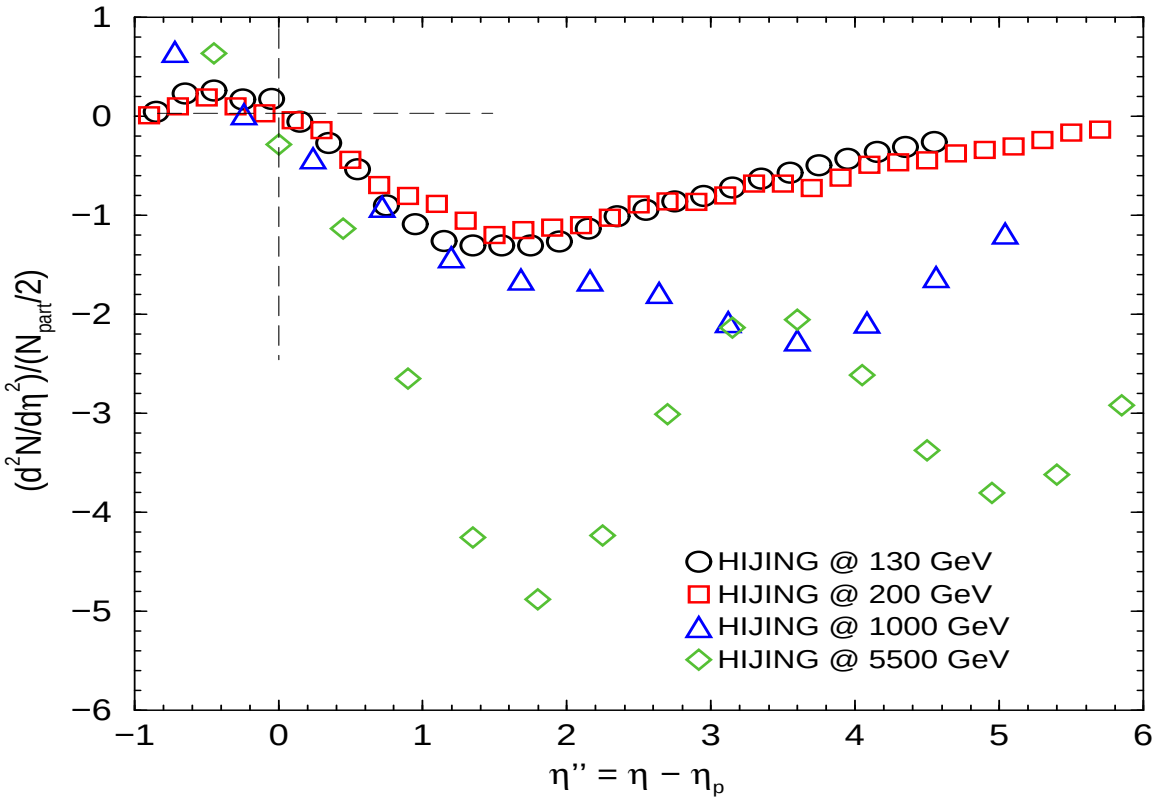


Physics - Transition Region

The story so far ...

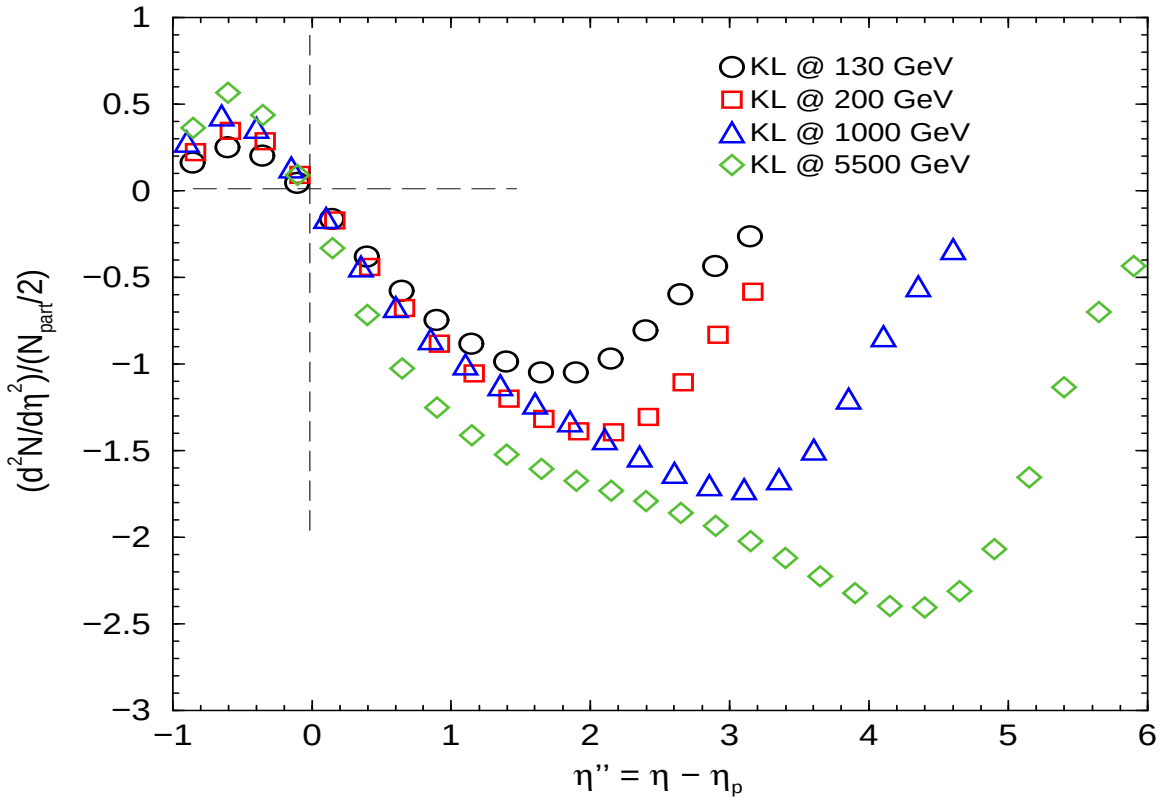
- Must be an initial state effect.
  - Independent of the colliding energy $(20\text{GeV} - 200\text{GeV})$
  - Not a collective phenomenon – d+Au, Au+Au has the same feature
  - Ideal place to check initial state models (CGC, PYTHIA based, etc)
- Not a place to look for QGP signal – Longitudinal dynamics of the central region (QGP) decouples from the rest (p_T is another story)

HIJING up to LHC



- PYTHIA + Nuclear Effects + Fragmentation + Minijets
- Fragmentation region dominates
- Minijet production introduces humps

Kharzeev and Levin up to LHC



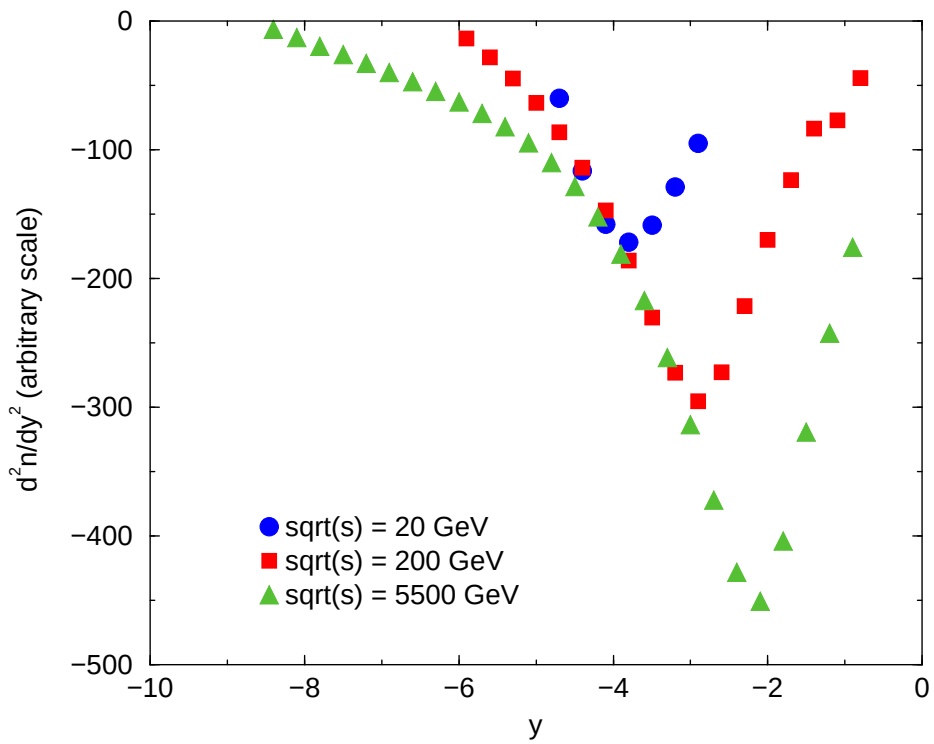
- CGC initial states + gluon production
- Not supposed to work for high η – no valence quarks
- No plateau!

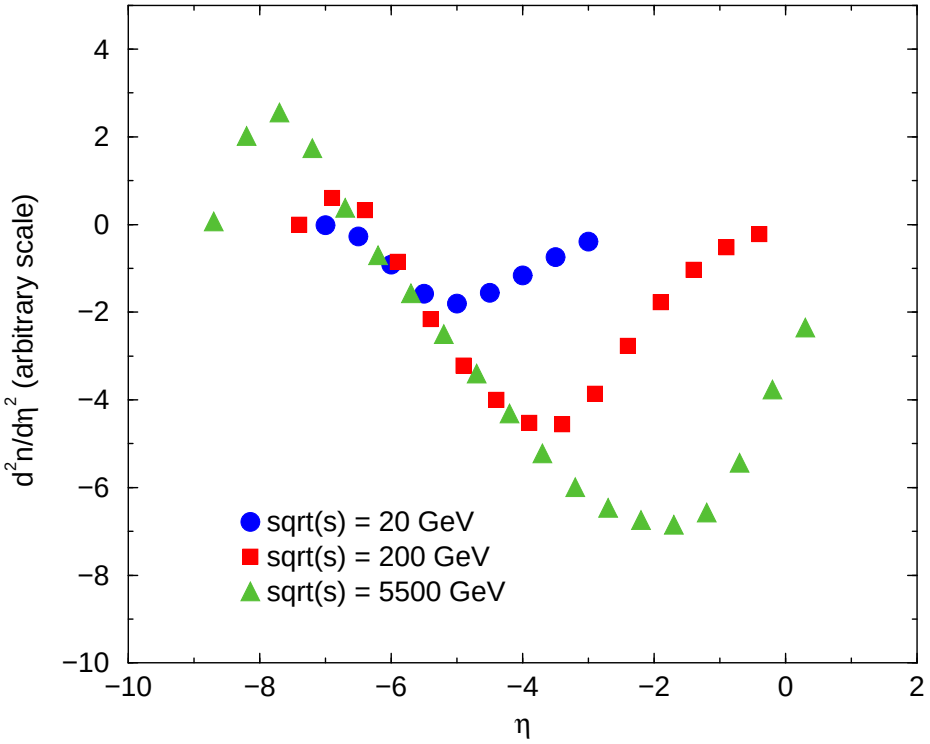
Hirano and Nara up to LHC

- CGC: Initial condition for Hydro
- Numerical solution of the gluon distribution functions

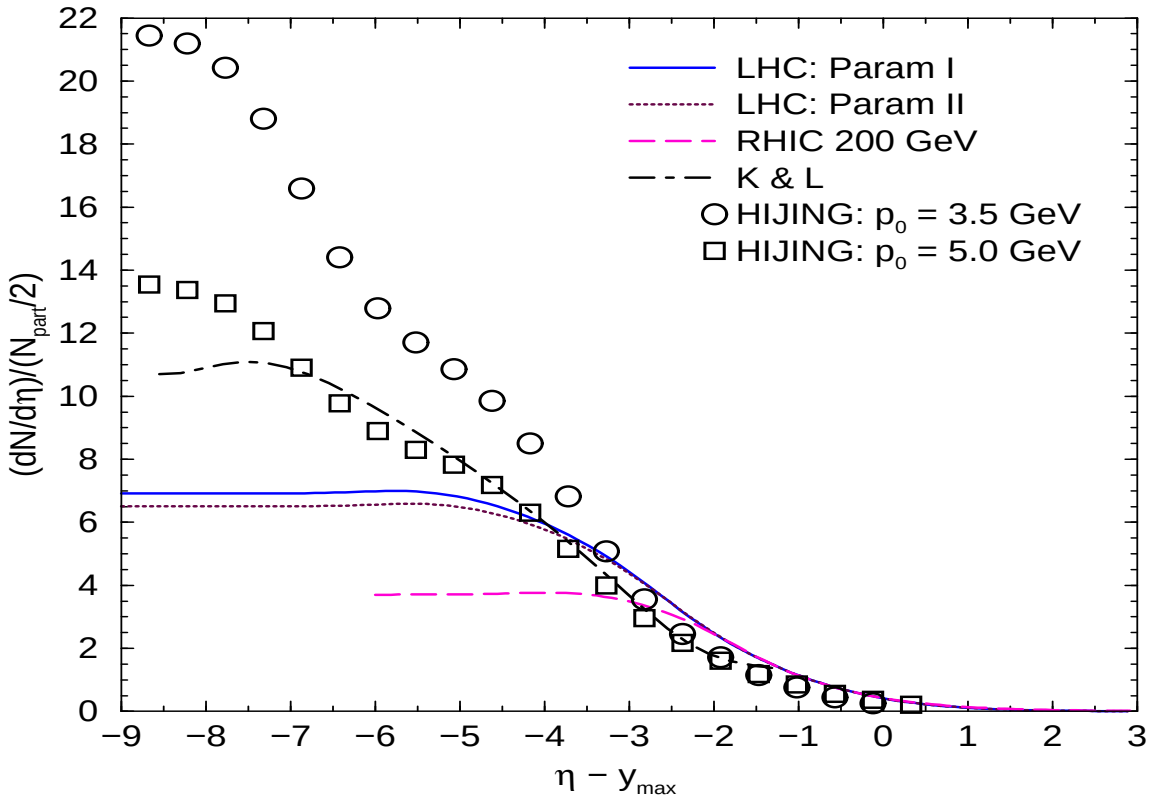
  Left: dn/dy for initial gluons before hydro

  Right: $dn/d\eta$ for final particles after hydro





LHC predictions



	$y_{\max} - \eta_p$	$(dn/d\eta)_0$	n_{total}
Model I	5.8	6.9	87
Model II	5.6	6.5	83
K & L	–	10.7	110
HIJING w/ $p_0 = 3.5$ GeV/c	–	21.4	160
HIJING w/ $p_0 = 7.0$ GeV/c	–	11.6	100

What have we learned?

- Important to look at $\frac{d^2n}{d\eta^2}$
  - Limiting fragmentation region up to about 50 % of the height not $85 - 90\,\%$
  - Existence of 2 universal curves in pseudo-rapidity spectrum
- Universal curves common to $Au + Au$ and $d + Au \Longrightarrow$Initial state effect
  - Limiting frag: Needs valence quarks
  - Transition region: Pointing to CGC? (What about $p\bar{p}$?)

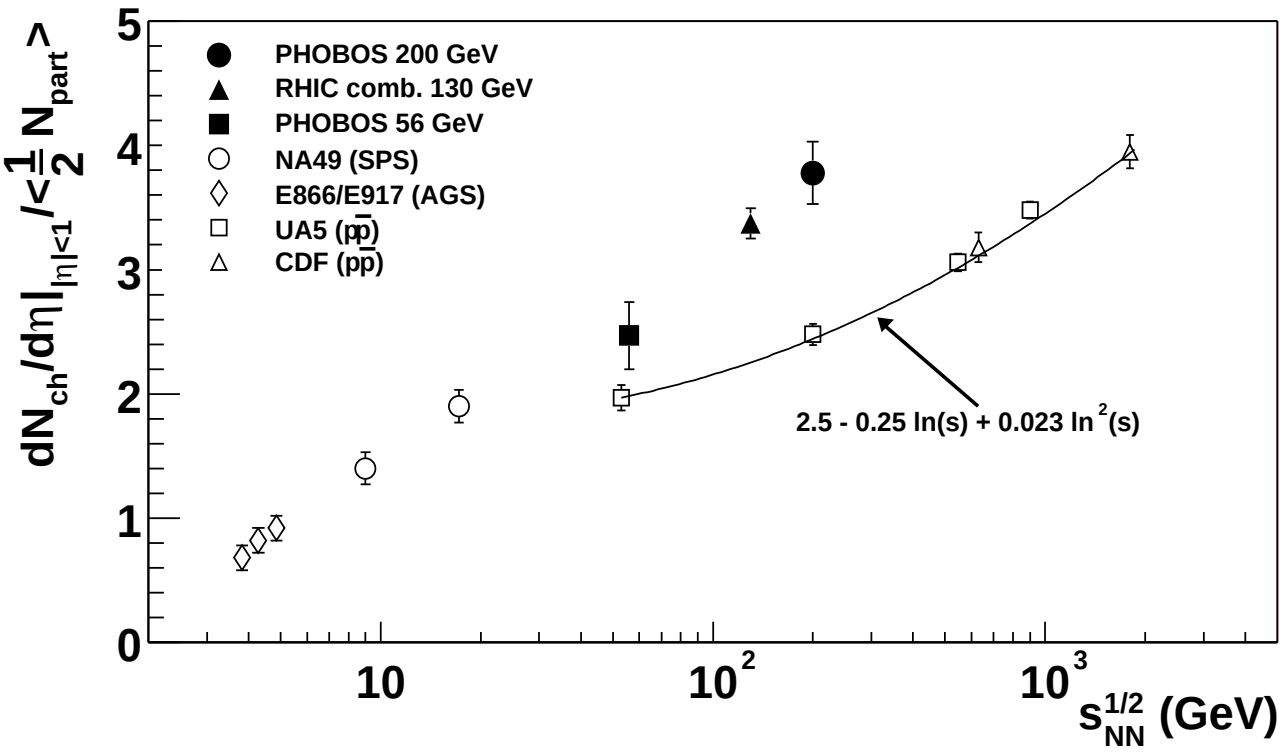
- $\left(\frac{dn}{d\eta}\right)_0$ and $n_{\rm tot}$ determined by the transition region universal curve. Current data suggests

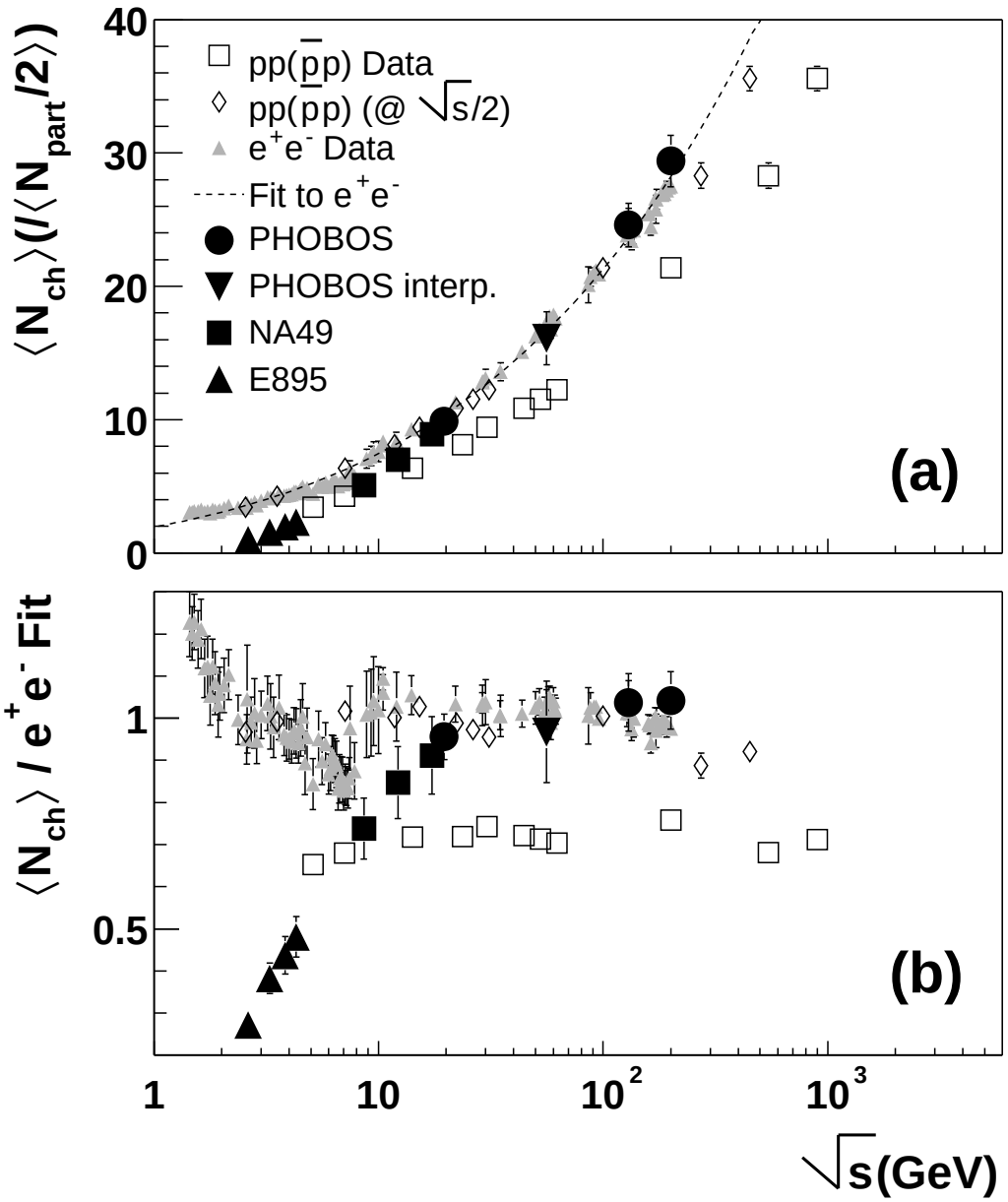
$$\left(\frac{dn}{d\eta}\right)_0 < \ln^2 \sqrt{s}$$

$$n_{\rm tot} < \ln^3 \sqrt{s}$$

Need to understand

- What determines g_U? Analytic understanding possible?
- $d + Au$ puzzling
  - Both sides? Is that understandable within KLMN?
  - What's that constant component in the Au side?
- Plateau?
  - What determines the plateau size?
  - Why should having a plateau reduce $n_{\rm tot}$?
  - Is there even a plateau or is it just an artifact of $y \longrightarrow \eta$ conversion?
  - Where is the boost-invariant QGP?


PHOBOS 200 GeV
RHIC comb. 130 GeV
PHOBOS 56 GeV
NA49 (SPS)
E866/E917 (AGS)
UA5 (pp̄)
CDF (pp̄)
2.5 - 0.25 ln(s) + 0.023 ln²(s)
dN_ch/dη|_|η|<1 / <½ N_part>
s^1/2_NN (GeV)
0
1
2
3
4
5
10
10²
10³


$\langle N_{ch}\rangle/(l/\langle N_{part}/2\rangle)$
40
30
20
10
0
pp($\bar{p}$p) Data
pp(pp) (@ $\sqrt{s}/2$)
e^+e^- Data
Fit to e^+e^-
PHOBOS
PHOBOS interp.
NA49
E895
(a)
$\langle N_{ch}\rangle$ / e^+e^- Fit
1
0.5
(b)
1
10
10^2
10^3
$\sqrt{s}$(GeV)