Wounded quarks in p+p, p+A and A+A collisions*

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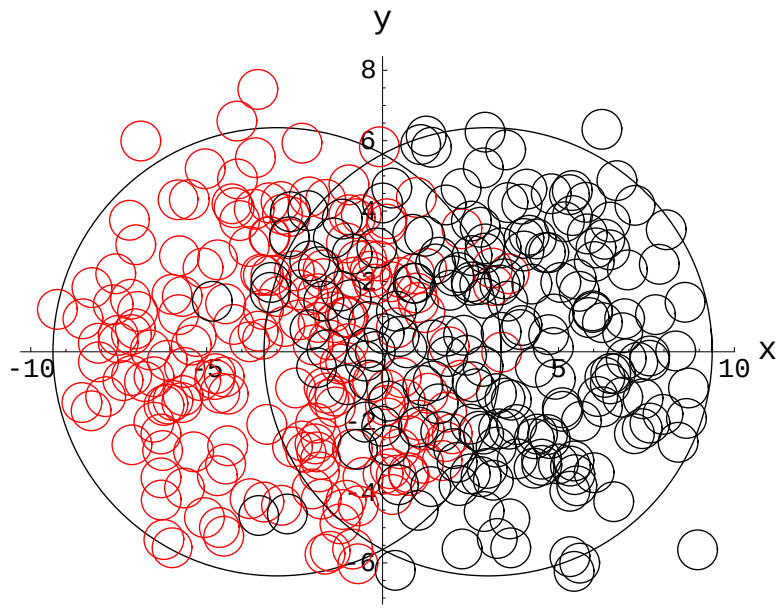
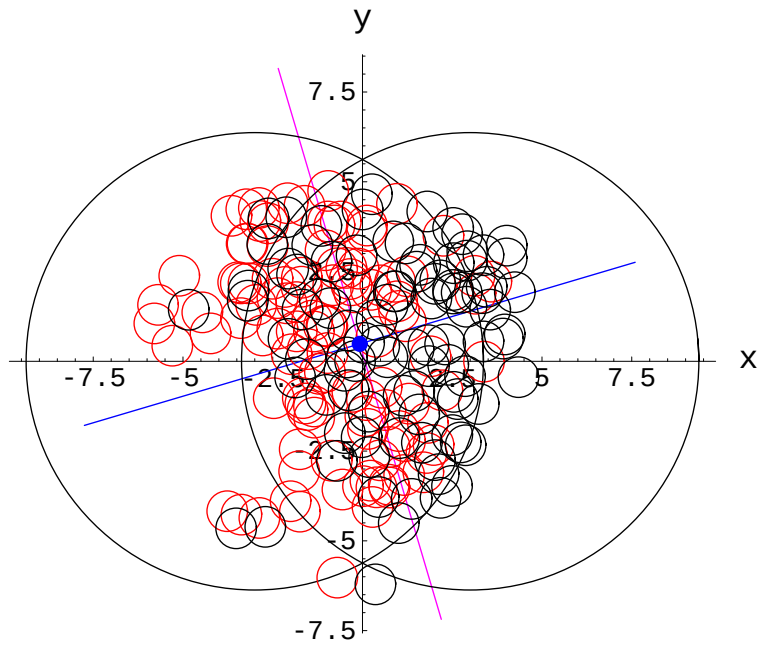
Wounded nucleons

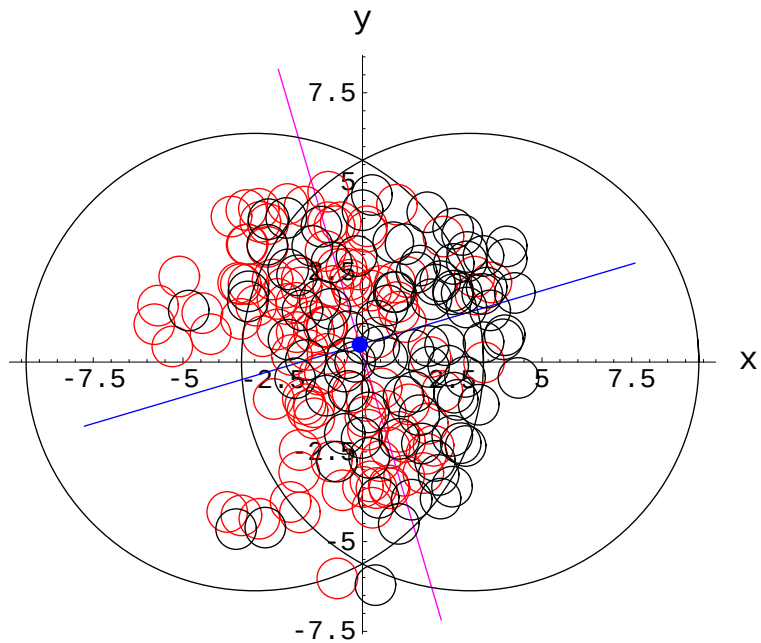


Wounded nucleons



Wounded – interacted inelastically at least once

Wounded nucleons



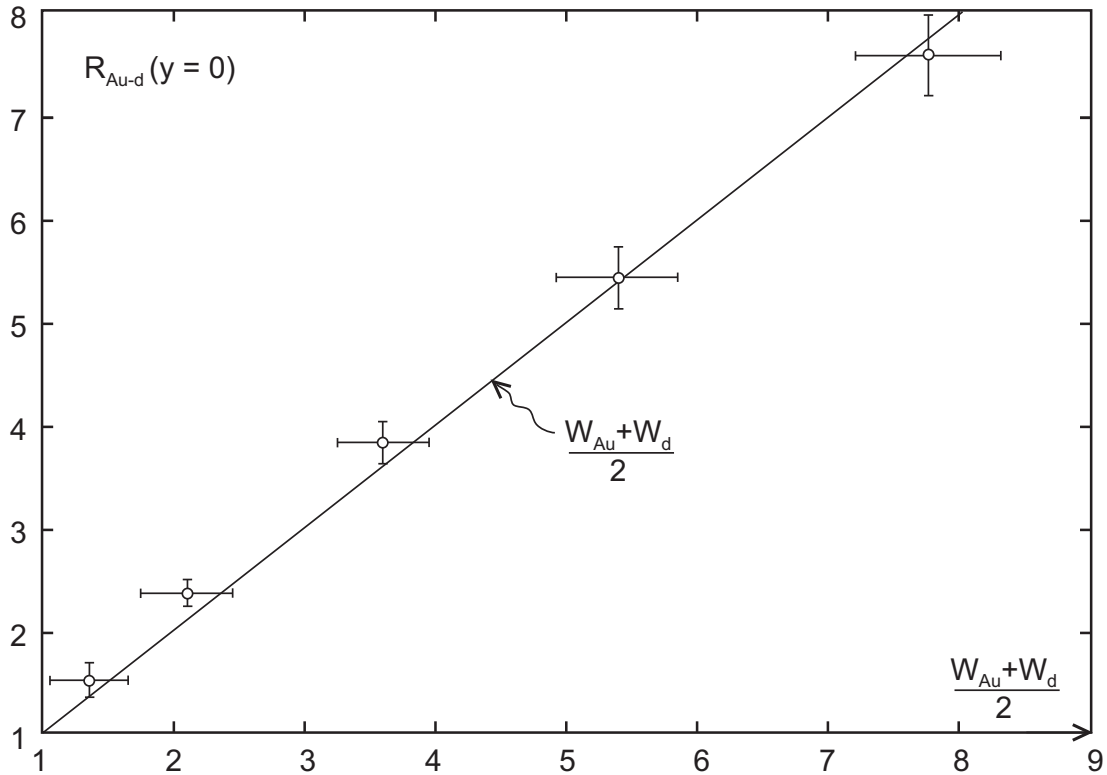
Wounded – interacted inelastically at least once

What are the degrees of freedom (sources)?

Wounded nucleon scaling

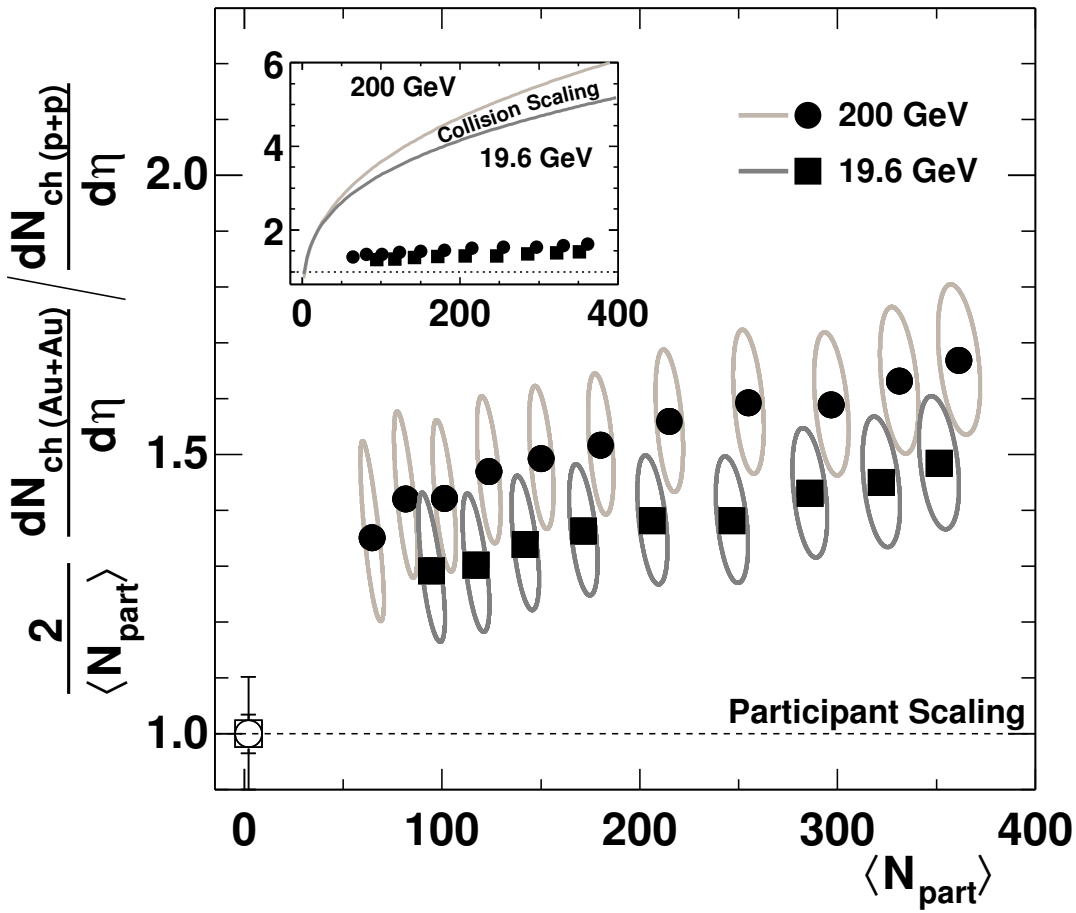
$\frac{dN_{ch}^{AB}}{d\eta} = \frac{dN_{ch}^{pp}}{d\eta} N_{\mathrm{W}}^{AB}/2$ (Białas, Błeszynski, Czyż 1976)

$\frac{dN_{ch}^{AB}}{d\eta} \propto N_{\mathrm{W}}^{AB}$ – weaker scaling (with centrality)



confirmed for d+Au at RHIC (Białas, Czyż 2004)

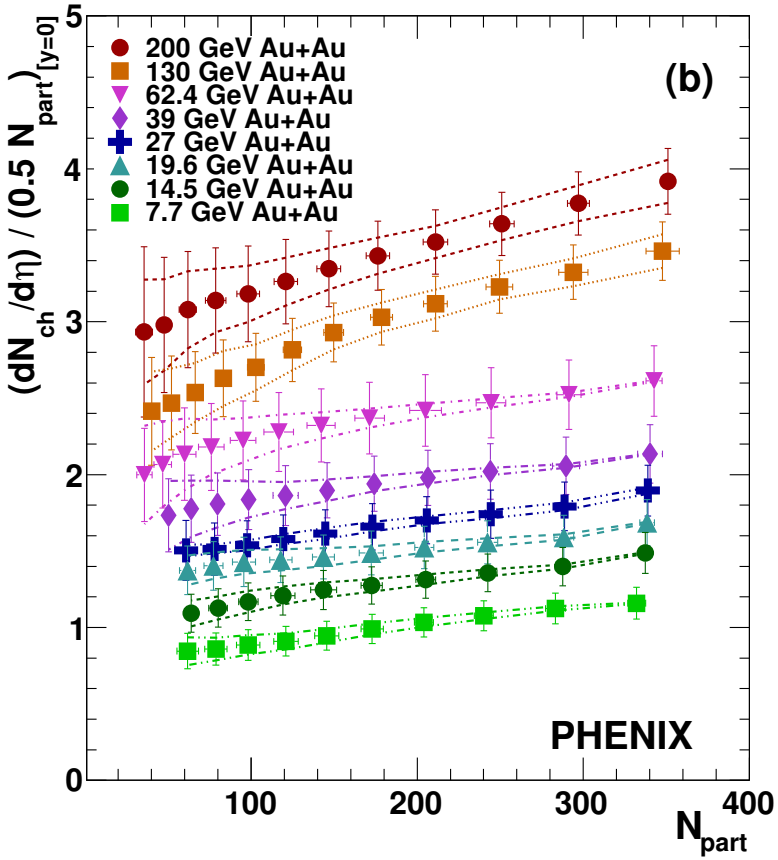
Broken scaling for A+A at RHIC

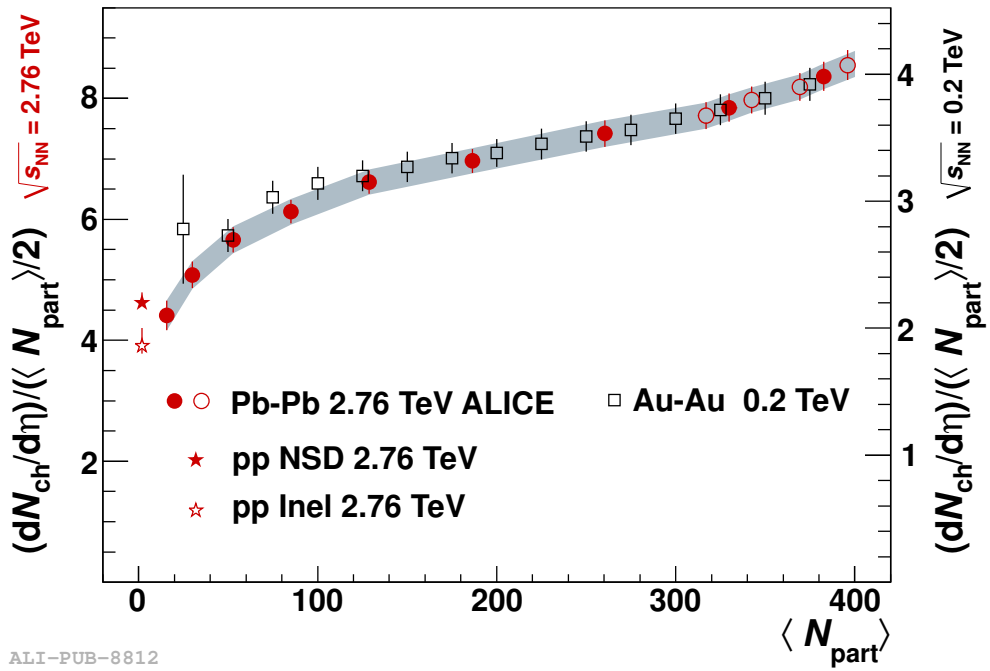


(PHOBOS 2004)

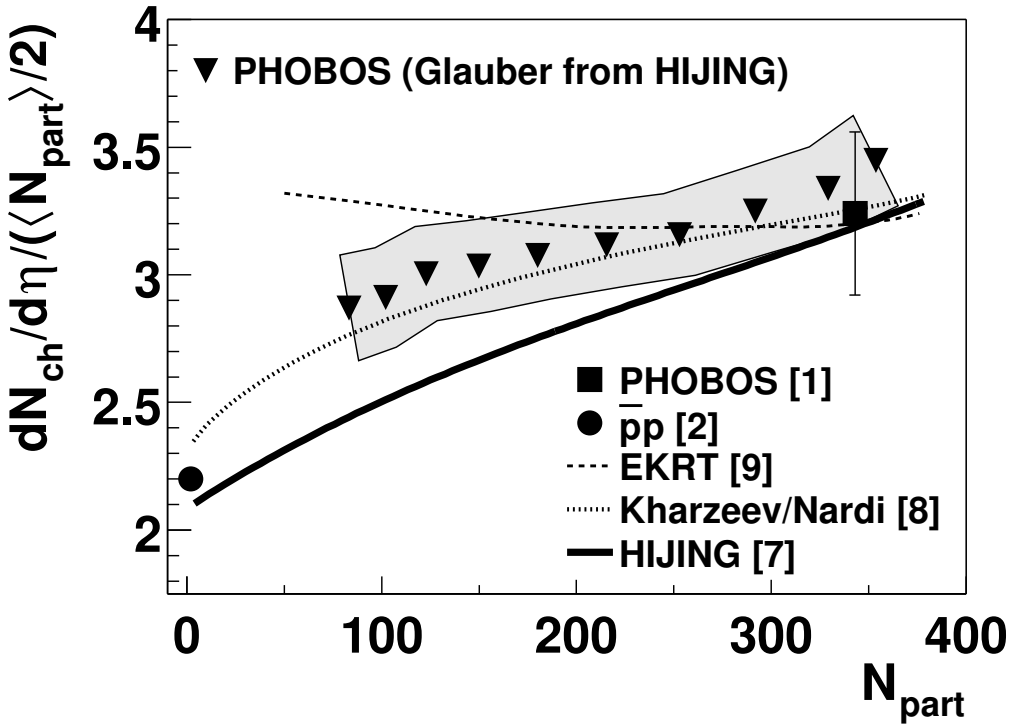
- scaling with centrality broken
- p+p point too low

RHIC → LHC


200 GeV Au+Au
130 GeV Au+Au
62.4 GeV Au+Au
39 GeV Au+Au
27 GeV Au+Au
19.6 GeV Au+Au
14.5 GeV Au+Au
7.7 GeV Au+Au
(b)
PHENIX
$(dN_{ch}/d\eta) / (0.5\ N_{part}{}_{[y=0]})$
N_{part}


$\sqrt{s_{NN}}$ = 2.76 TeV
$\sqrt{s_{NN}}$ = 0.2 TeV
Pb-Pb 2.76 TeV ALICE
Au-Au 0.2 TeV
pp NSD 2.76 TeV
pp Inel 2.76 TeV
$(dN_{ch}/d\eta)/(\langle N_{part}\rangle/2)$
$\langle N_{part}\rangle$
ALI-PUB-8812

Two component model

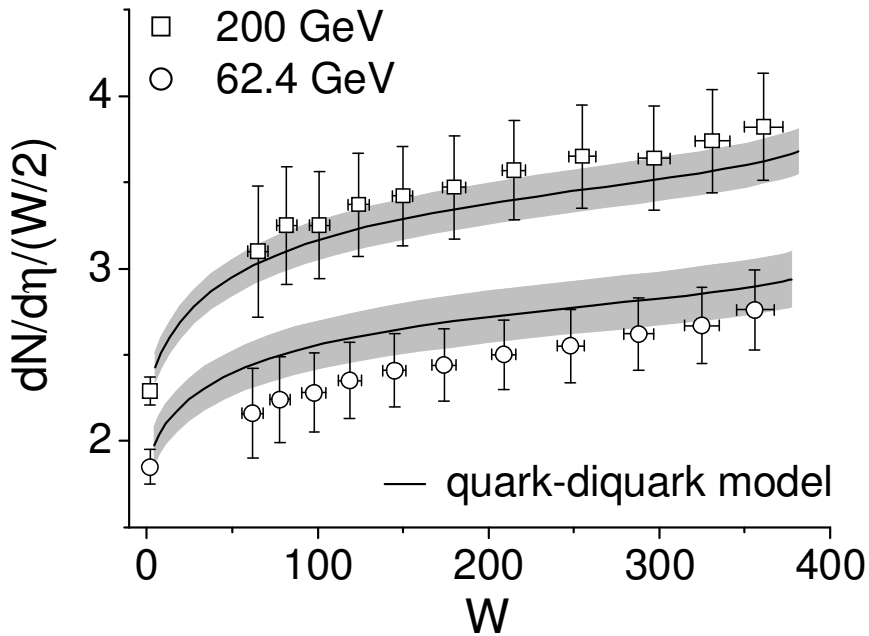


$$\frac{dN_{ch}}{d\eta} \propto \frac{1-\alpha}{2} N_{part} + \alpha N_{coll}$$

- binary (N_{coll}) contribution $\alpha = 0.1 - 0.2$ (Kharzeev, Nardi 2000)

Subnucleonic structure

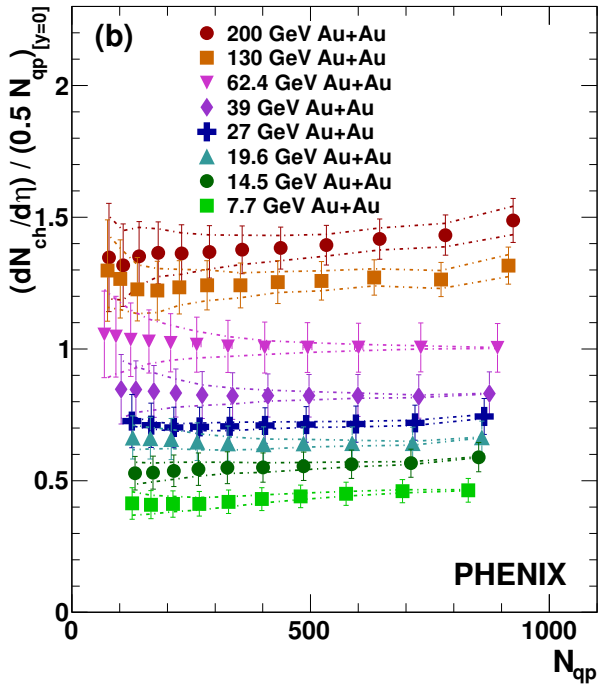
- wounded quark model (Białas, Czyż, Furmański 1976 + many others)
- quark-diquark model, fitted to p+p scattering (Białas, Bzdak 2006)



At higher collision energies lower distances are probed and nucleons are better resolved → more constituents show up (wounded partons)

Constituent quark model - PHENIX

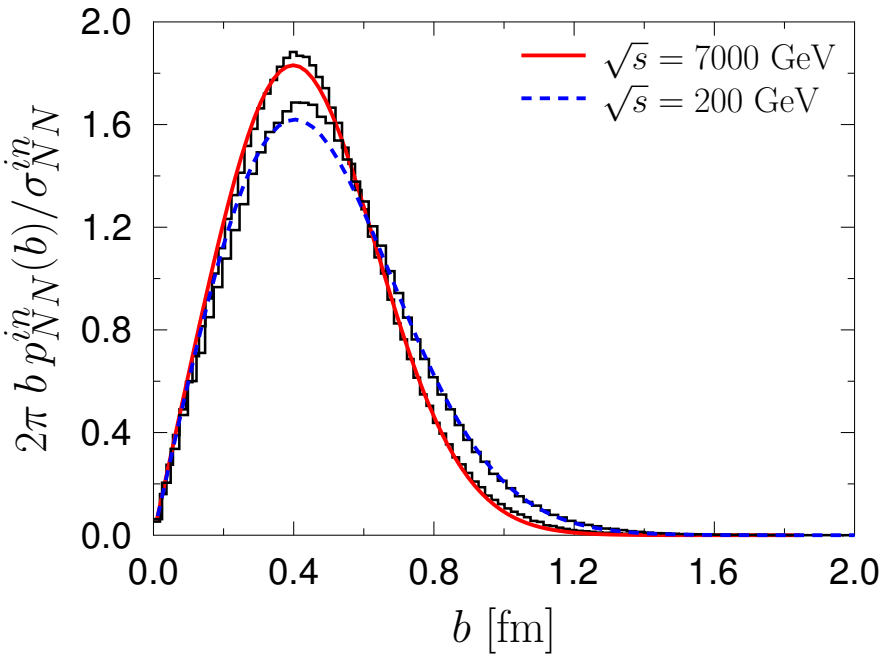
recent (2016) calculations: Lacey et al., Zheng et al., Loizides, Mitchell et al.



- three quarks per nucleon
- Q distribution in N from electron-proton
- hard-sphere Q-Q scattering (8.17 mb at 200 GeV)
- fairly good scaling with Q_{W}, some problem with p+p point

Wounded quark model matching p+p scattering

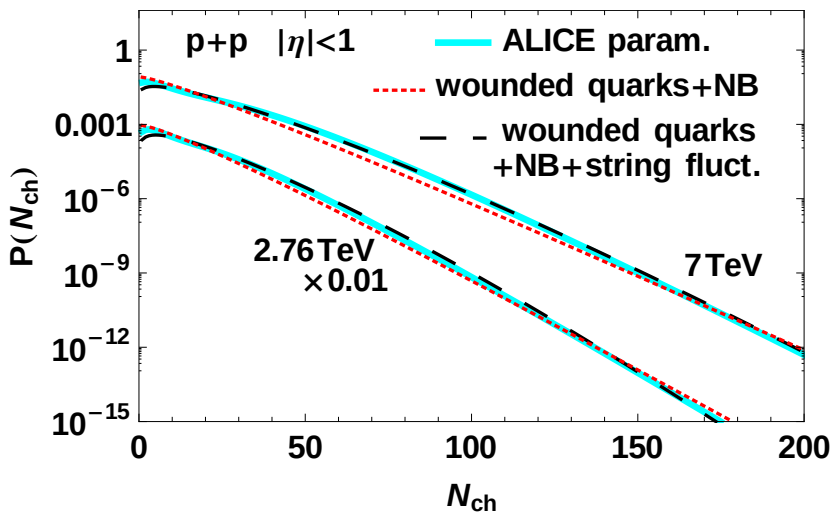
- 3 quarks distributed in each nucleon $\rho(r) \simeq e^{-r/r_{QQ}}$, recentered
- Gaussian Q-Q wounding profile
- parameters fitted to reproduce N-N scattering

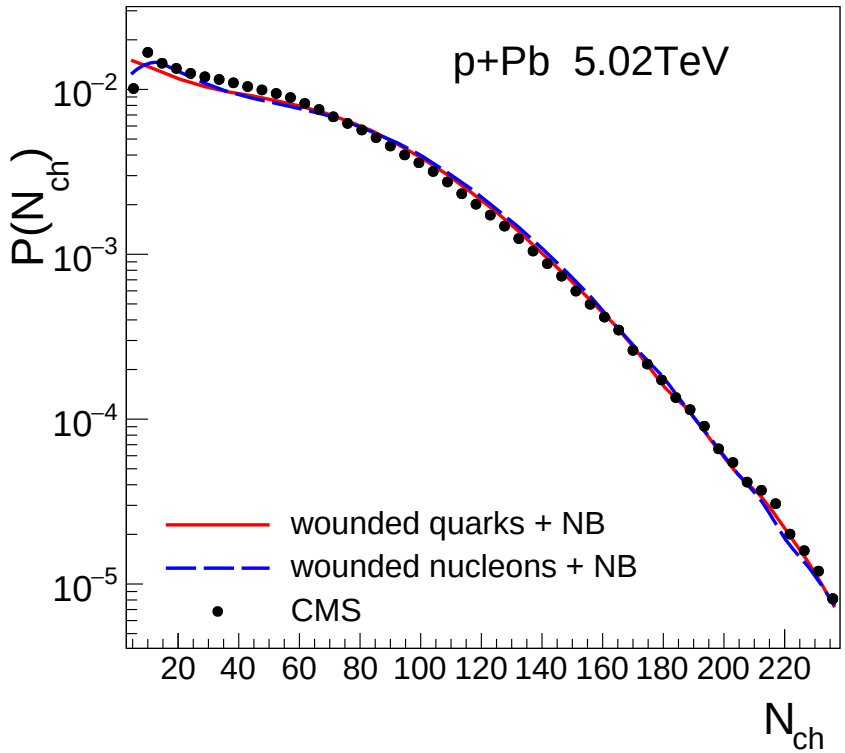


200 GeV: $\sigma_{QQ} = 7$ mb, $r_{QQ} = 0.29$ fm, 7 TeV: $\sigma_{QQ} = 14.3$ mb, $r_{QQ} = 0.30$ fm

small change of nucleon size, large increase of σ_{QQ} with $\sqrt{s}$

Multiplicity distribution p+p and p+A





Overlaid negative binomial distribution on each wounded quark (same width)

p+p scattering

Each source is smeared with the function:

$$g(x,y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{(x-x_0)^2+(y-y_0)^2}{2\sigma^2}\right)$$

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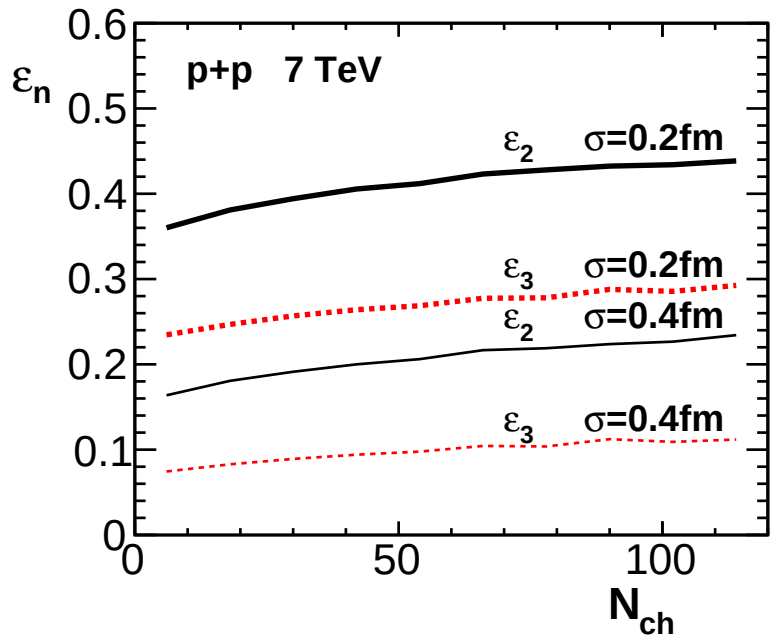

Significant eccentricities in p+p

p+p scattering

$$\langle r \rangle^2 = \frac{\int dx\, dy\, s(x,y)(x^2+y^2)}{\int dx\, dy\, s(x,y)}$$

The function $s(x, y)$ is the entropy density in the transverse coordinates (x, y). The variable: $\langle r \rangle = \sqrt{\langle r \rangle^2}$ is analyzed event by event, in particular $\langle\langle r \rangle\rangle$ is the event-by-event average of the size.

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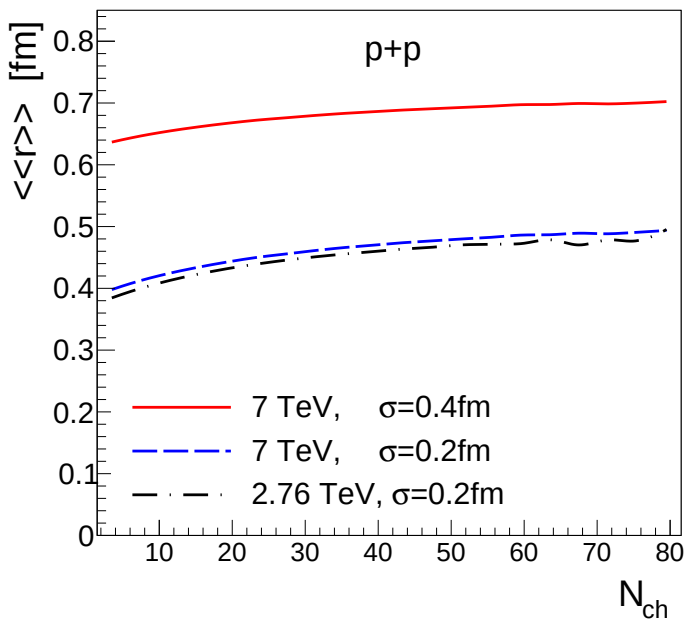
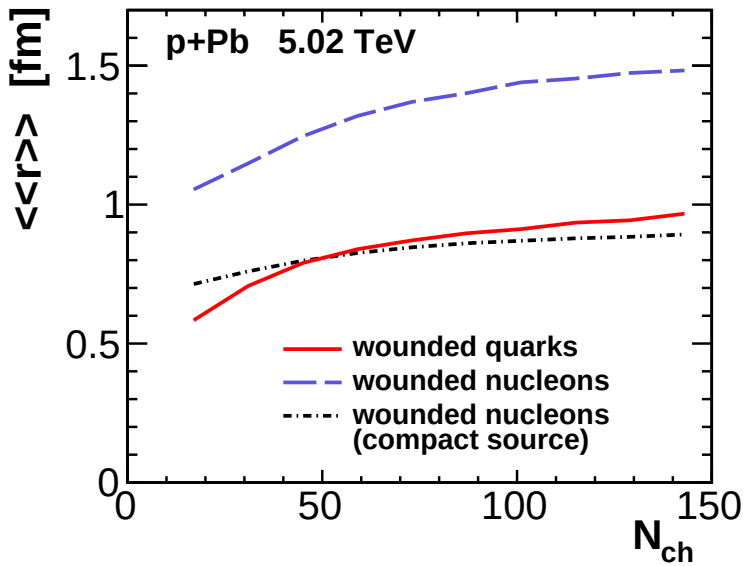


Small size of the interaction region ~ 0.4 fm

Compact initial size in p+Pb

In the hydrodynamic model the best description of the data is obtained when the entropy is deposited in the middle between the two colliding nucleons, in the so called compact source scenario



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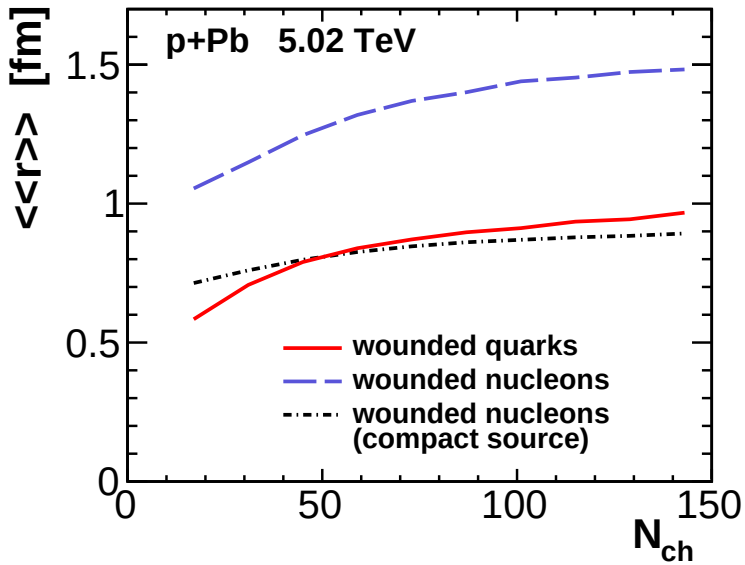
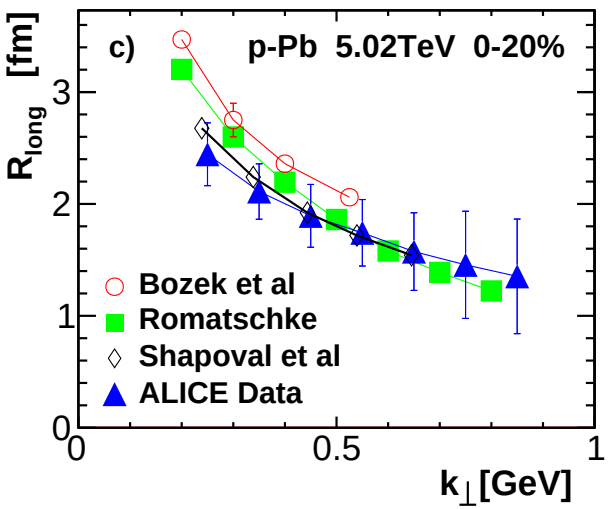
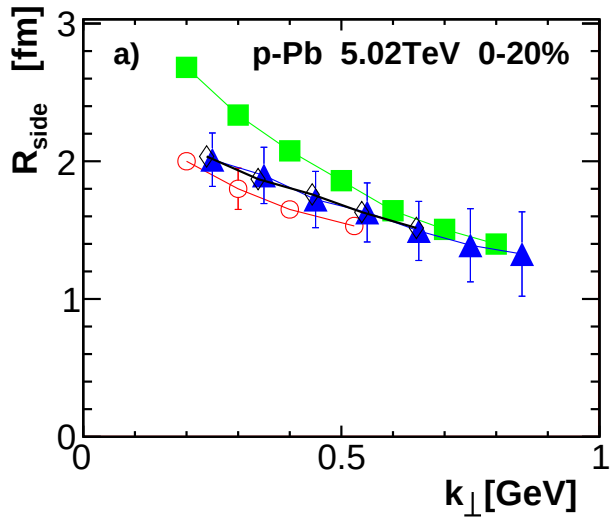
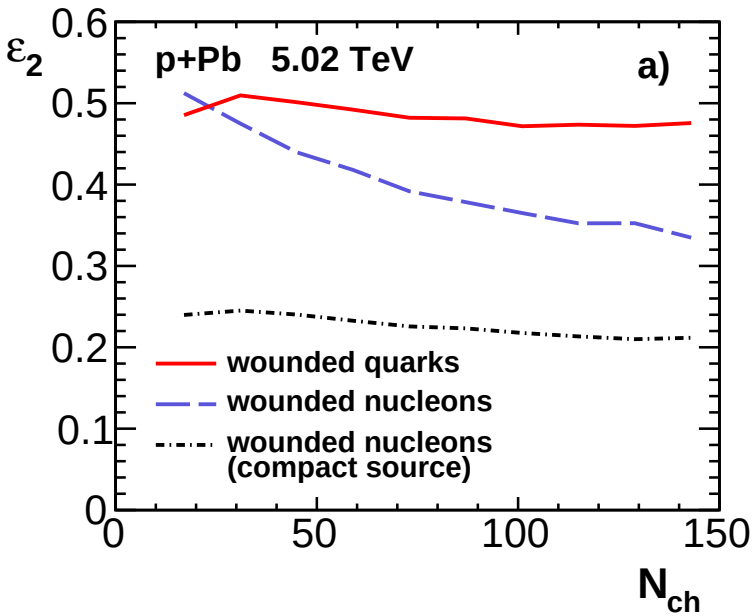


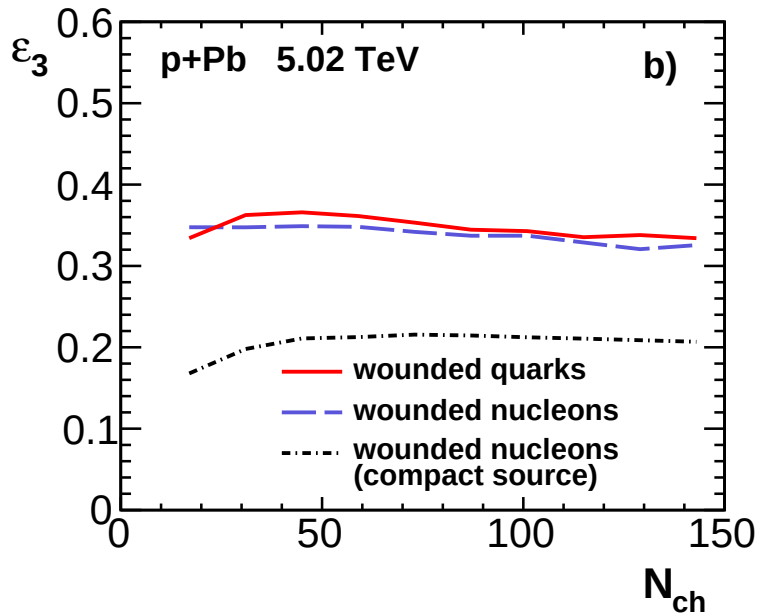




compact source consistent with p+Pb data (HBT, $\langle p_\perp \rangle$)

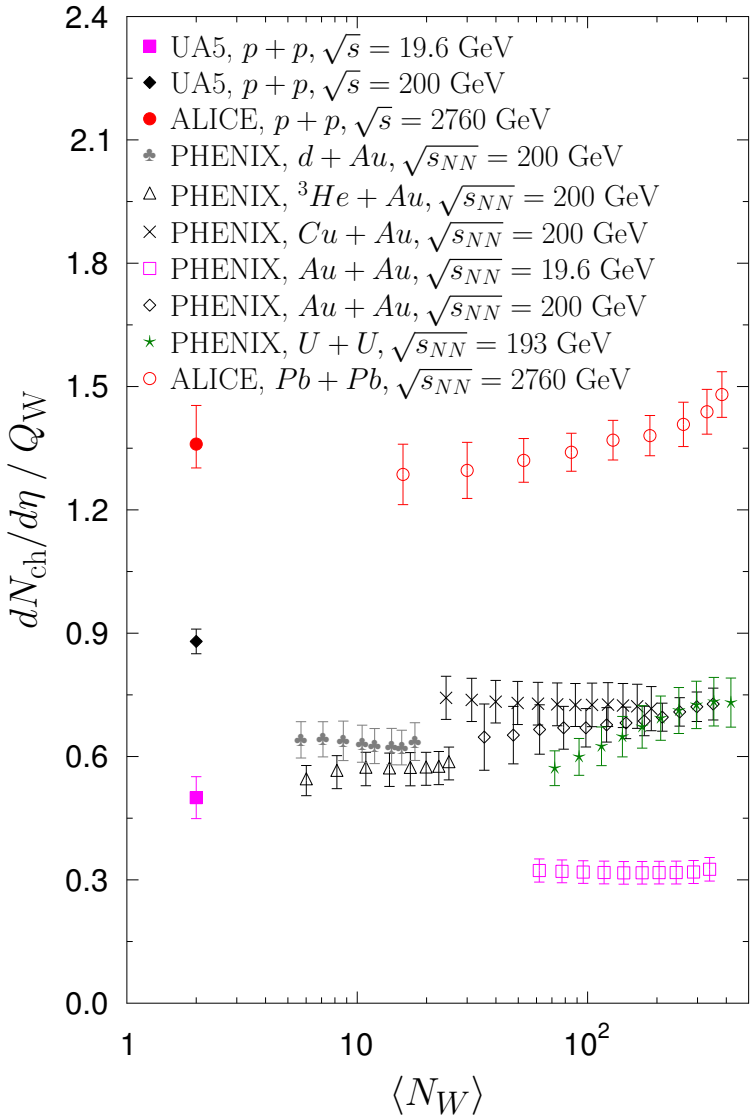
Fireball eccentricities in p+Pb





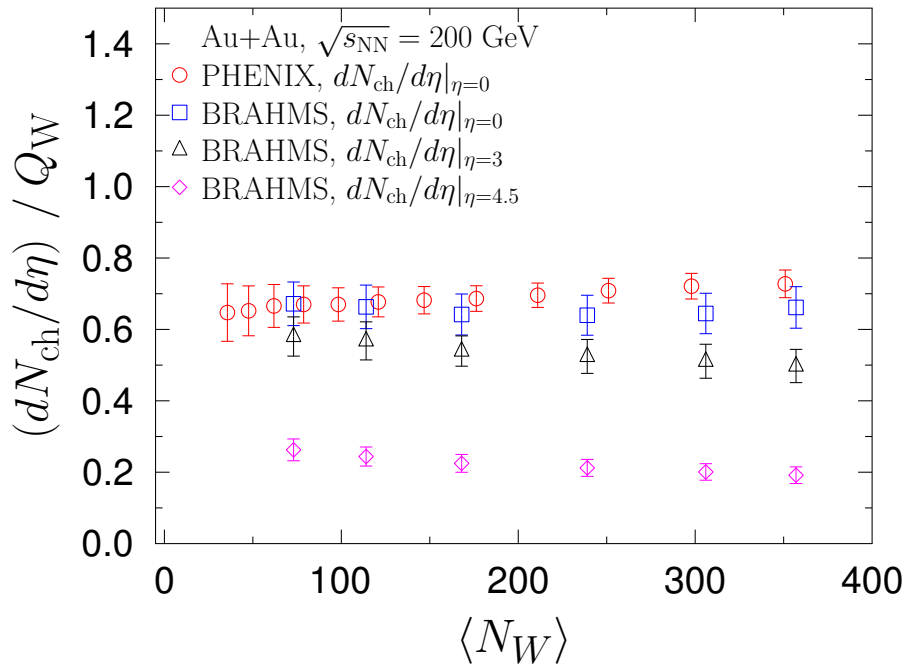
- significant eccentricities in p+Pb
- weak dependence on centrality (N_{ch})

Wounded quark scaling in A+A



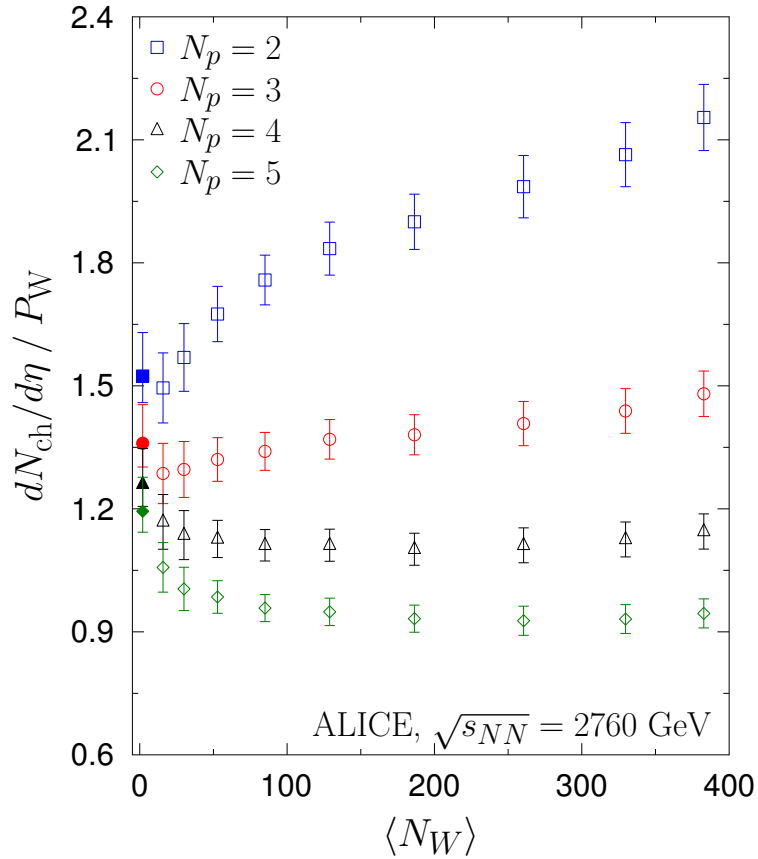
- good scaling at the LHC
- approximate scaling at RHIC
- LHC - 3 constituents, RHIC - 2?

Wounded quark scaling in A+A



Wounded quark scaling holds
for particles produced in different kinematical regions.

How many partons?



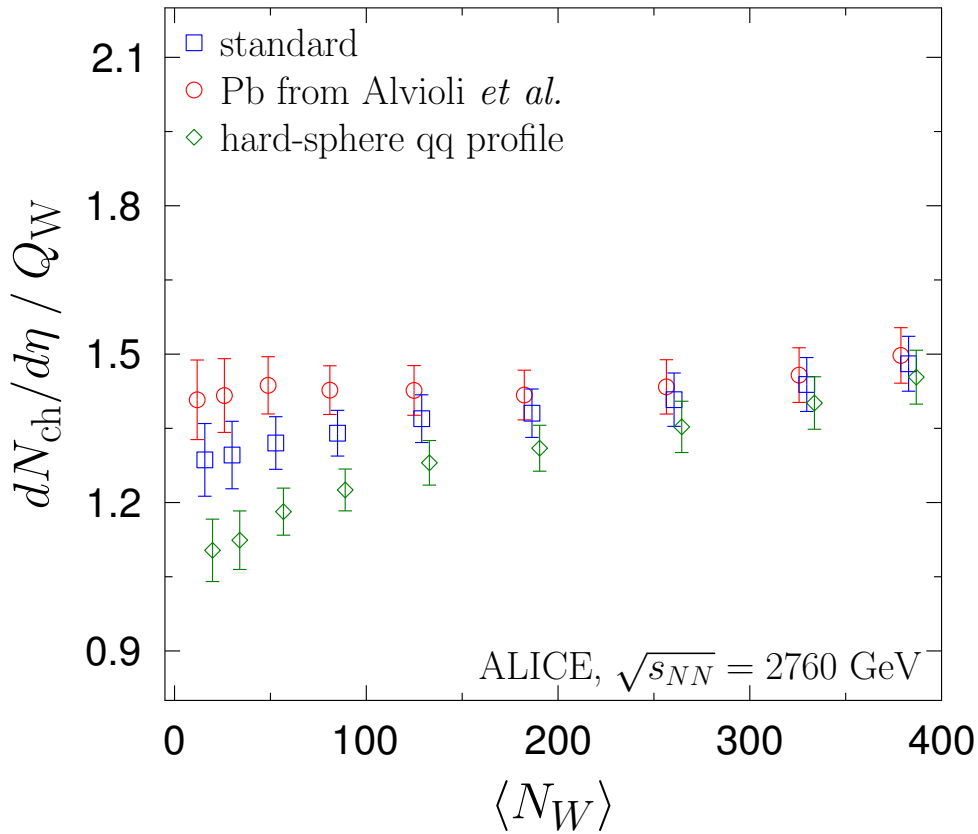
- wounded quark scaling changes with effective number of partons
- for each N_p N-N scattering profile reproduced
- number of constituents increases with energy (?)

Summary

- Wounded quark model for p+p, p+A, and A+A collisions
- Quark distribution in nucleon and Q-Q scattering adjusted to reproduce N-N scattering
- Particle production scales with number of wounded quarks at LHC
- Semi-microscopic description of subnucleonic structure in p+Pb consistent with experimental data
- Strongly deformed interaction region in p+p
- Indication of an increase of the effective number of partons with $\sqrt{s}$

Additional slides

Details matter



- sensitive to modeling of N-N scattering
- sensitivity to the nuclear density profile