Wounded quarks at the LHC

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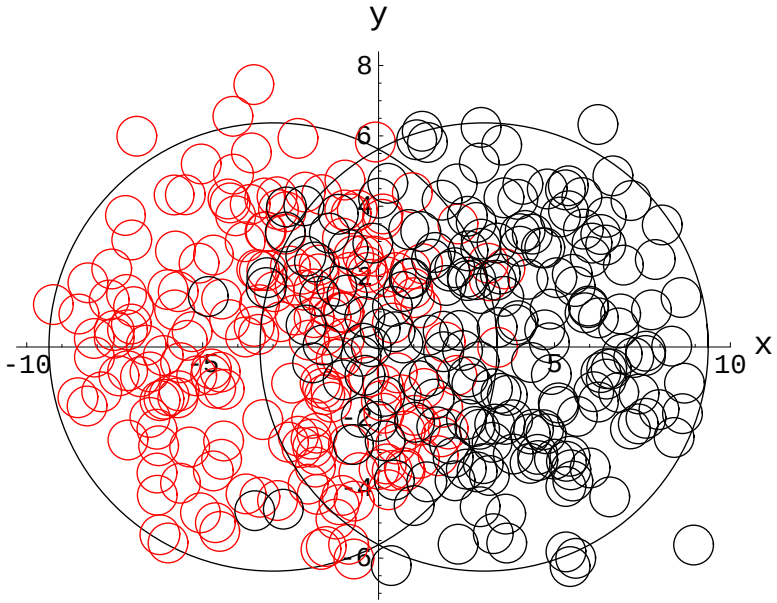
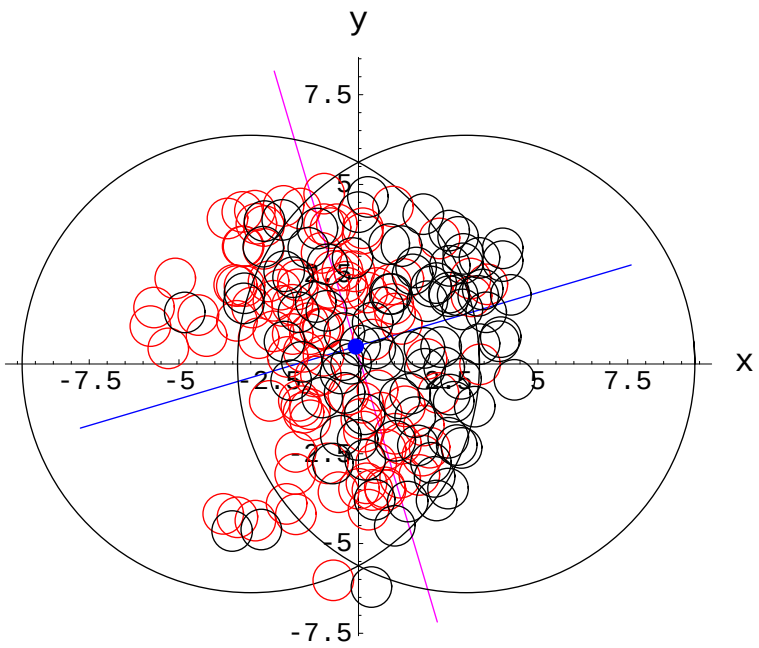
Critical Point and the Onset of Deconfinement
(CPOD 2016)
Wrocław, 30 May - 4 June 2016

Wounded nucleons

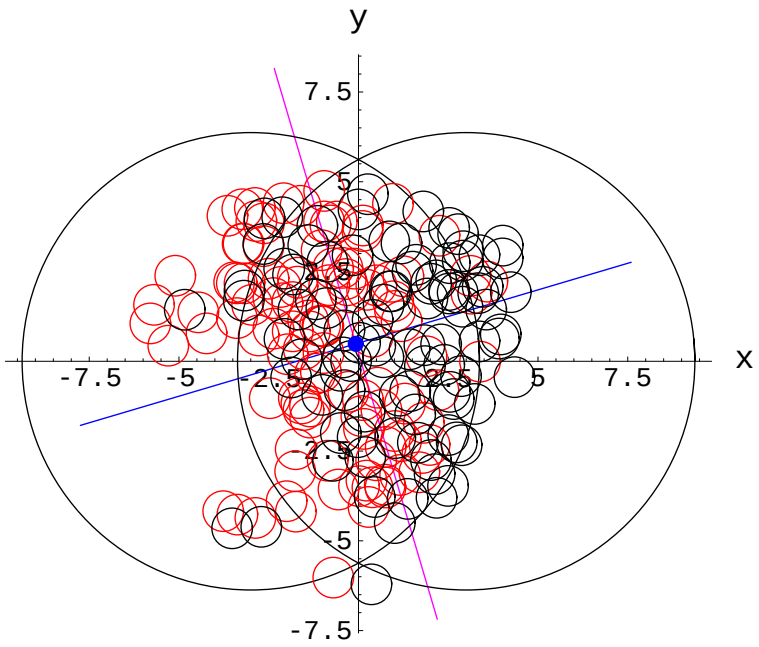


Wounded nucleons



Wounded – interacted inelastically at least once

Wounded nucleons

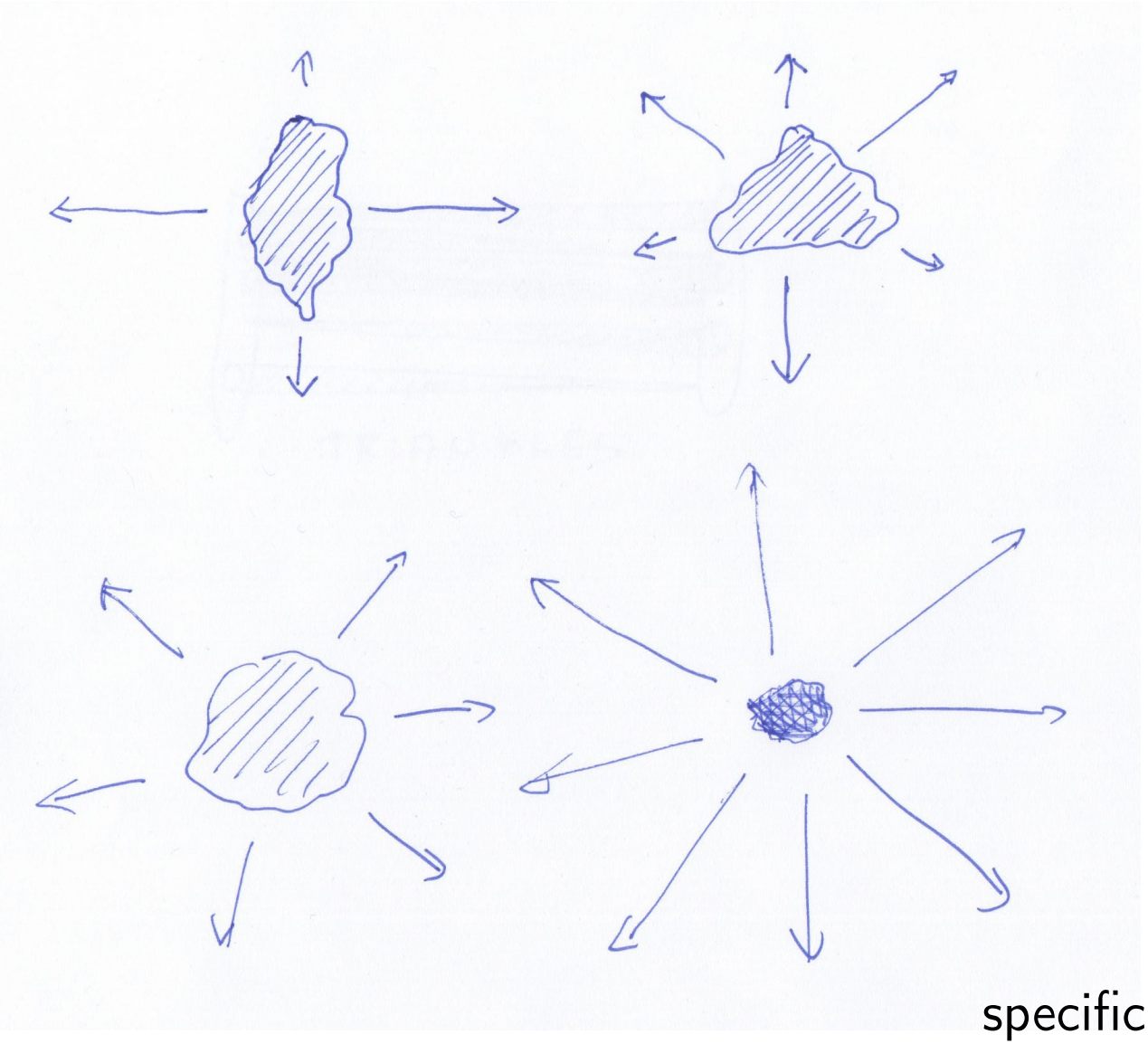


Wounded – interacted inelastically at least once

What are the degrees of freedom (sources)?

Nucleons, partons, random fields?

Shape–flow transmutation (collectivity)

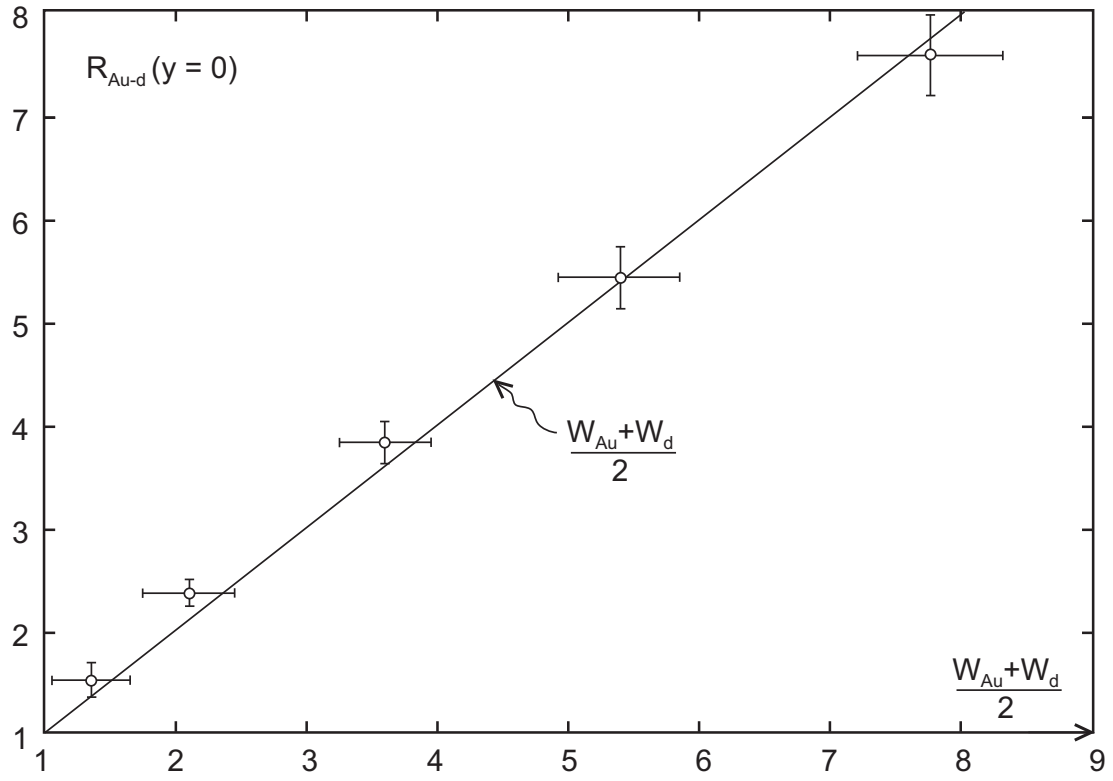


specific correlations

Wounded nucleon scaling

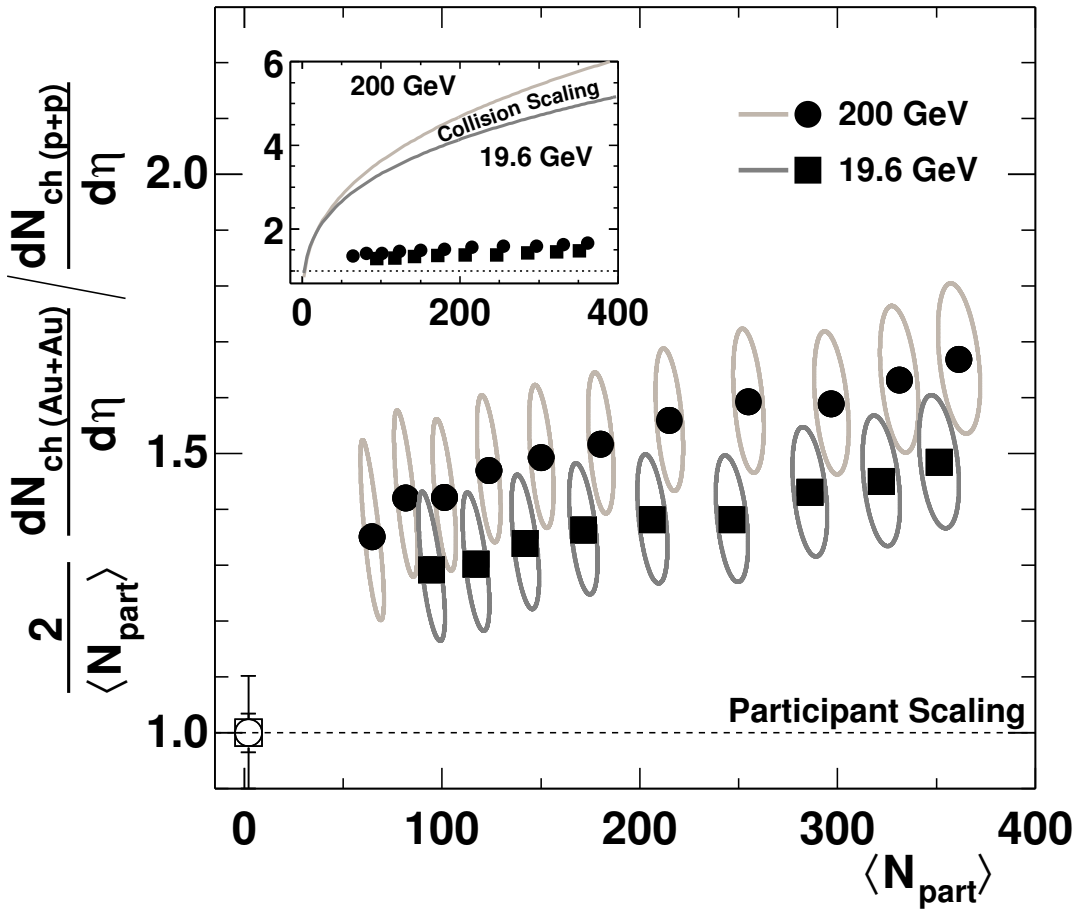
$$\frac{dN_{ch}^{AB}}{d\eta} = \frac{dN_{ch}^{pp}}{d\eta} N_{\mathrm{W}}^{AB}/2$$ [Białas, Błeszynski, Czyż 1976]

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



confirmed for d-Au at RHIC [Białas, Czyż 2004]

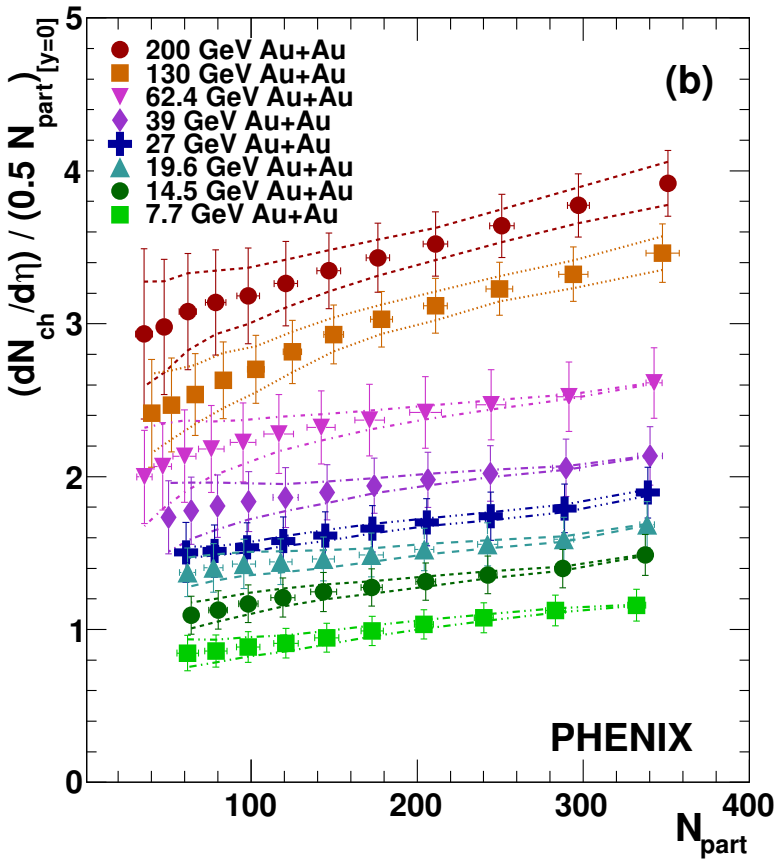
Broken scaling for A-A at RHIC

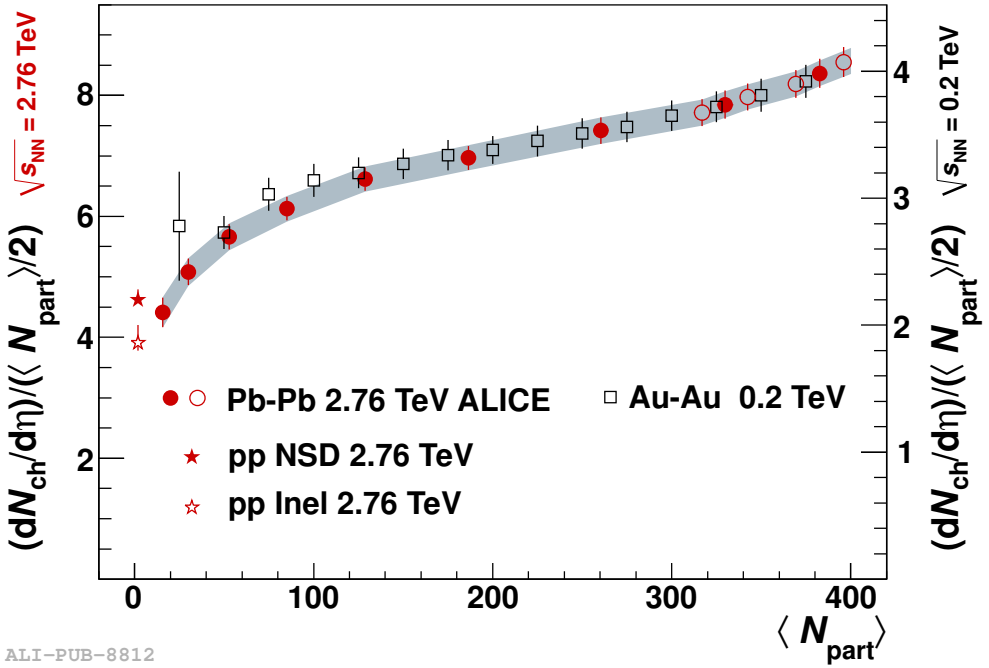


[PHOBOS 2004]

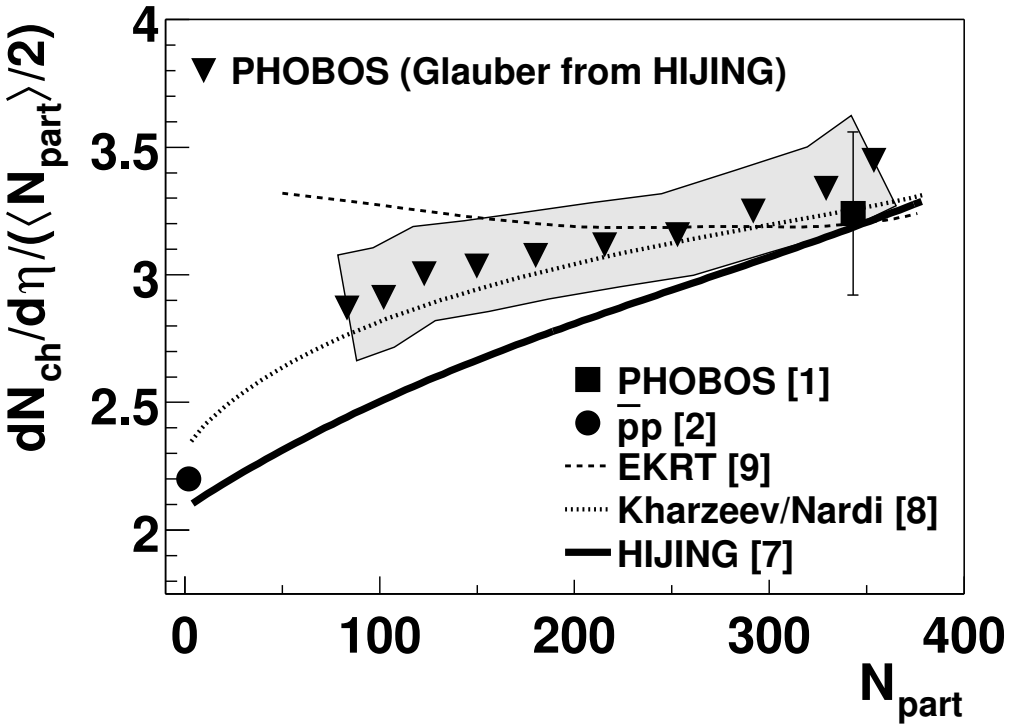
- scaling with centrality broken
- p-p point too low

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/dη) / (0.5 N_part[y=0])
N_part


Pb-Pb 2.76 TeV ALICE
Au-Au 0.2 TeV
pp NSD 2.76 TeV
pp Inel 2.76 TeV
√s_NN = 2.76 TeV
√s_NN = 0.2 TeV
(dN_ch/dη)/(⟨N_part⟩/2)
⟨N_part⟩
ALI-PUB-8812

Two component model

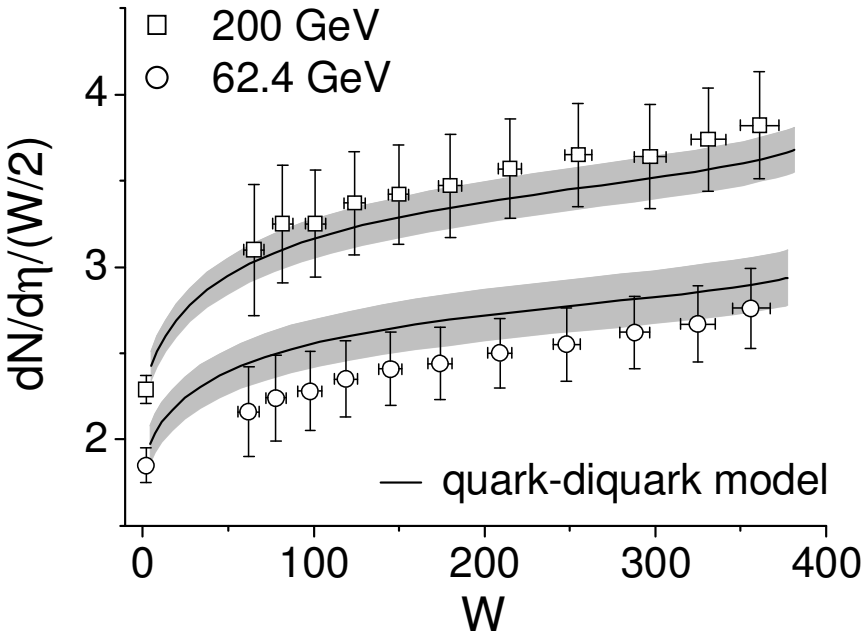


$$\frac{dN_{ch}}{d\eta} \propto \frac{1-\alpha}{2} N_{part} + \alpha N_{coll}$$

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

Subnucleonic structure

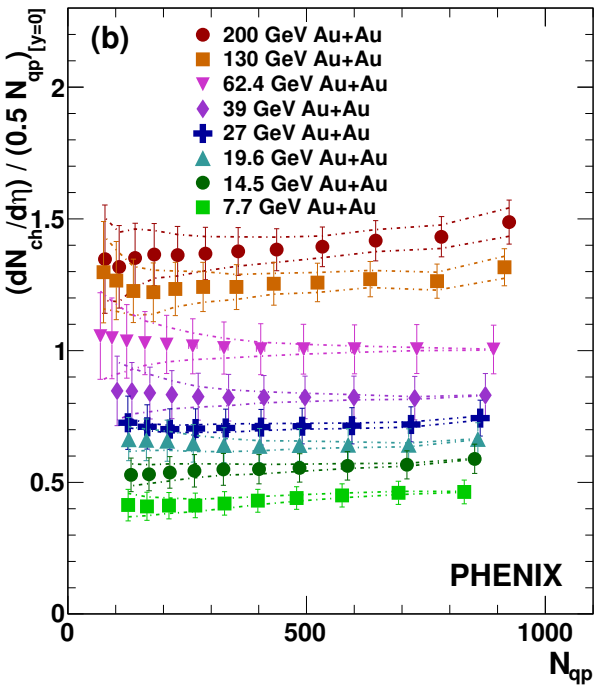
- wounded quark model [Białas, Czyż, Furmański 1976 + many others]
- quark-diquark model, fitted to p-p scattering [Białas, Bzdak 2006]



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

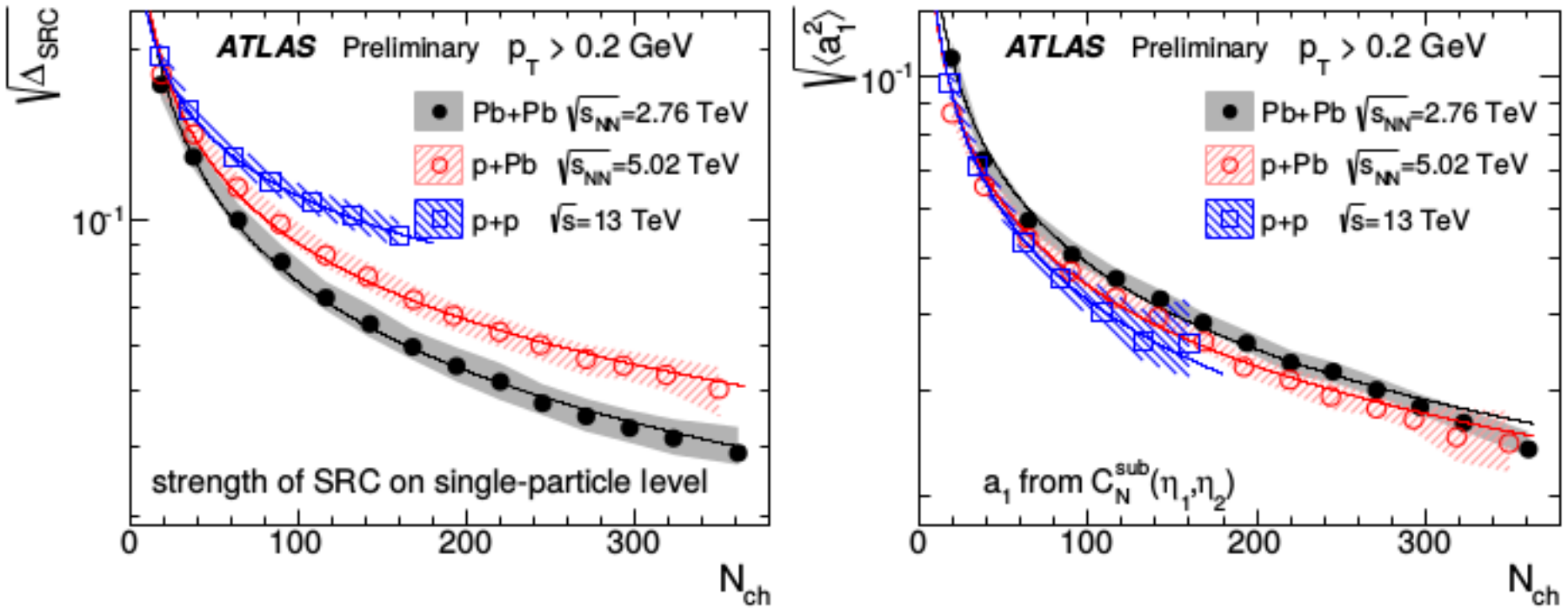
Constituent quark model - PHENIX

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



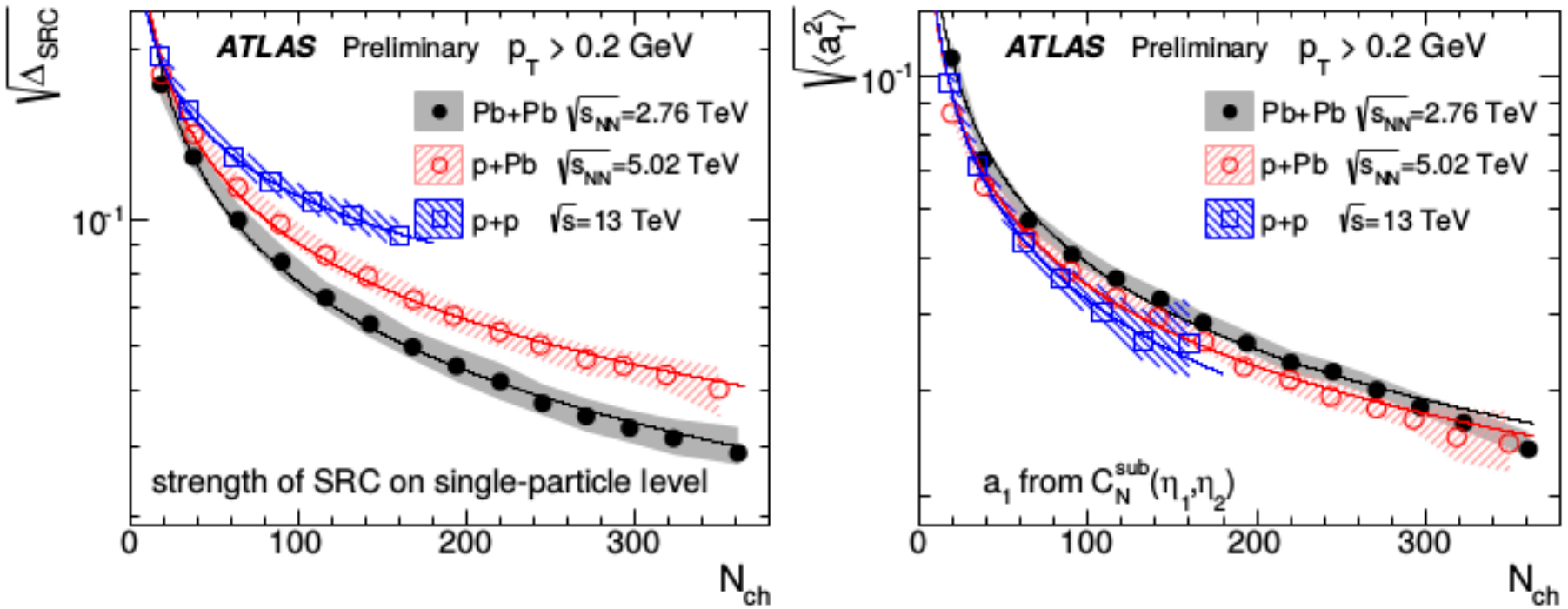
- three quarks per nucleon
- Q distribution in N from electron-proton
- hard-sphere Q-Q scattering (8.17mb at 200GeV)
- fairly good scaling with Q_{W}, some problem with p-p point

Scaling from longitudinal fluctuations



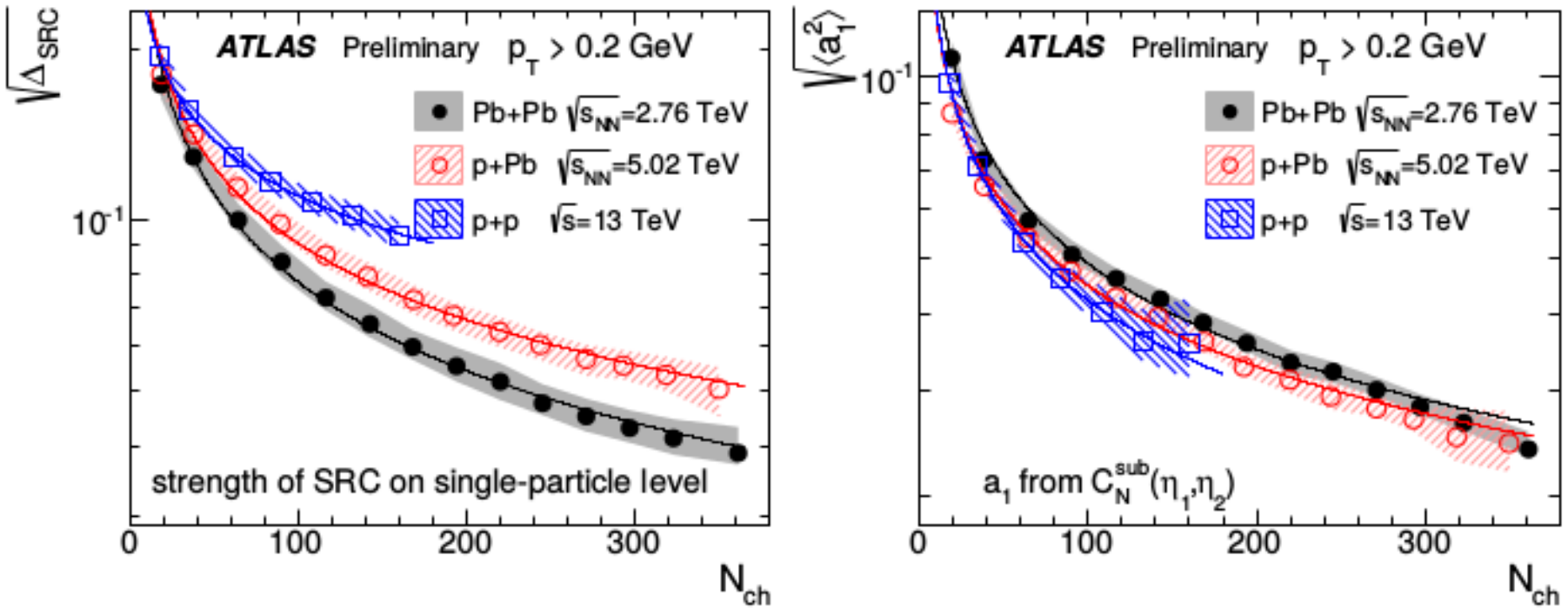
$a_{11}^{\rm exp} = c^{\rm exp}/N_{\rm ch}$, longitudinally-extended sources: $a_{11}^{\rm mod} = c^{\rm mod}/N_+$

Scaling from longitudinal fluctuations



$a_{11}^{\rm exp} = c^{\rm exp}/N_{\rm ch}$, longitudinally-extended sources: $a_{11}^{\rm mod} = c^{\rm mod}/N_+$
Matching $\rightarrow N_{\rm ch} = 4.7 N_+$, acceptance $\Delta\eta = 4.8 \longrightarrow dN_{\rm ch}/d\eta \simeq 1 \times N_+$

Scaling from longitudinal fluctuations



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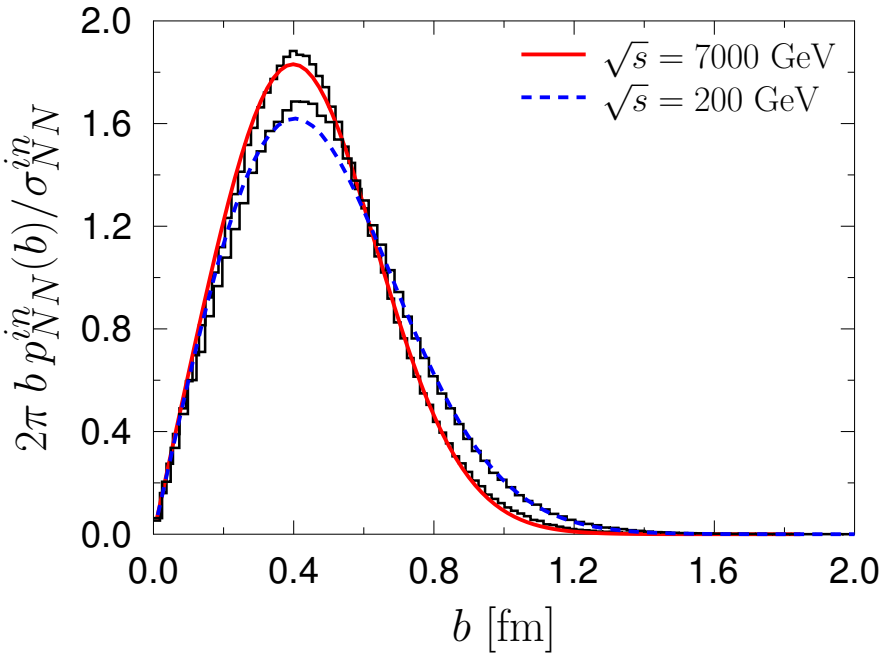
From multiplicity data $dN_{\rm ch}/d\eta \simeq (3-4) \times N_W$ and $dN_{\rm ch}/d\eta \simeq 1.3 \times Q_W$
$\rightarrow$ wounded quarks/partons)

Wounded quark model matching pp scattering

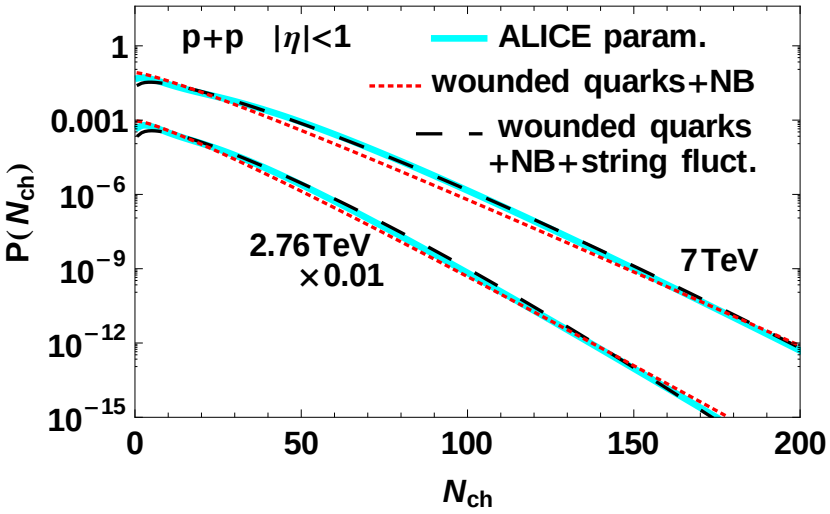
- 3 quarks distributed in each nucleon $\rho(r) \simeq e^{-r/b}$, recentered
- Gaussian Q-Q wounding profile
- parameters fitted to reproduce N-N scattering

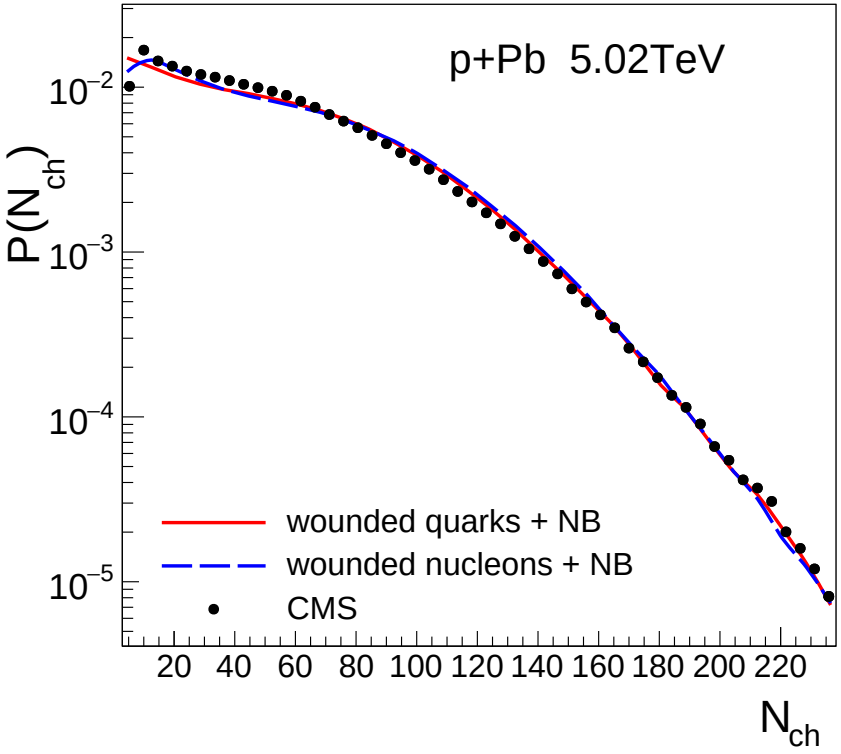


200GeV: $\sigma_{QQ} = 7$mb, $r_{QQ} = 0.29$fm), 7TeV: $\sigma_{QQ} = 14.3$mb, $r_{QQ} = 0.30$fm

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

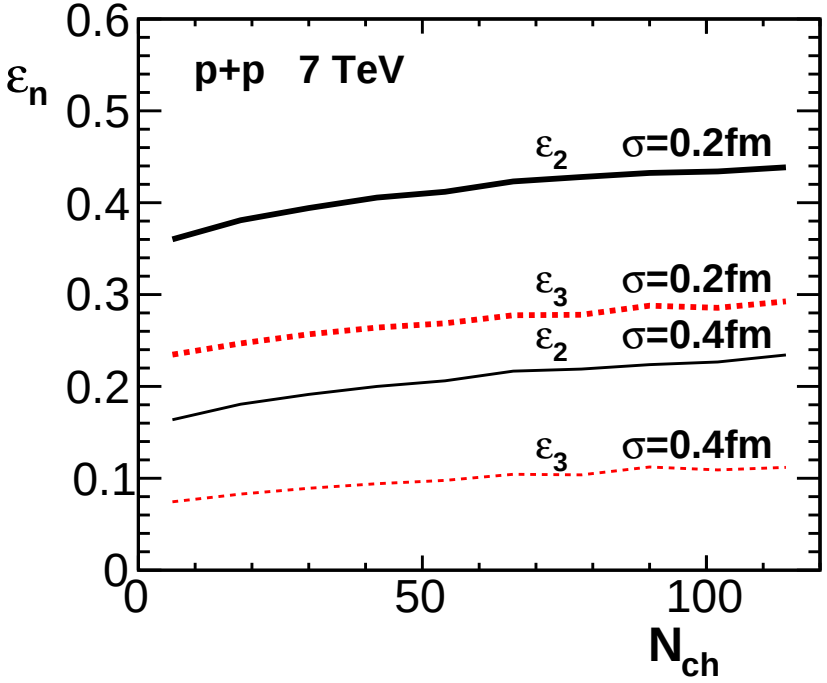
Multiplicity distribution p-p and p-A

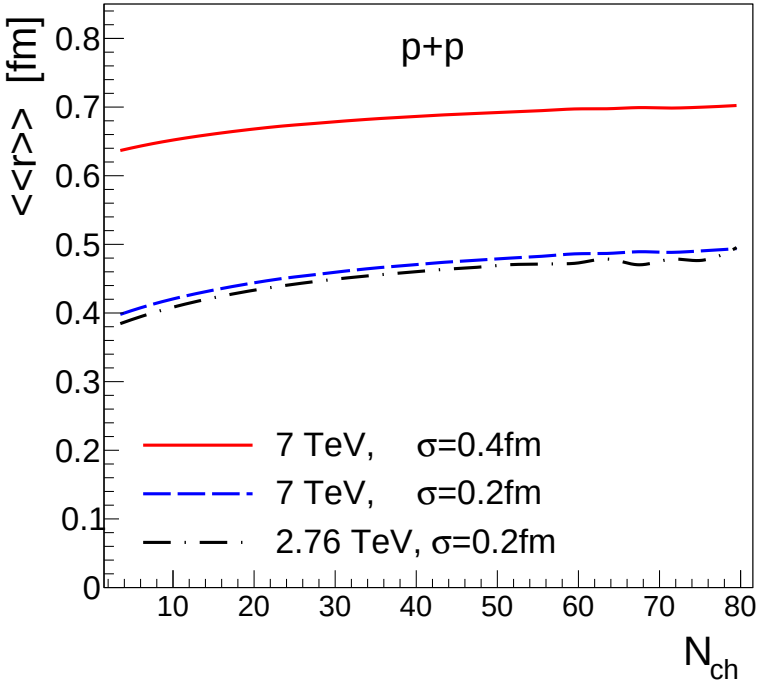




- overlaid negative binomial distribution on each wounded quark (same width)

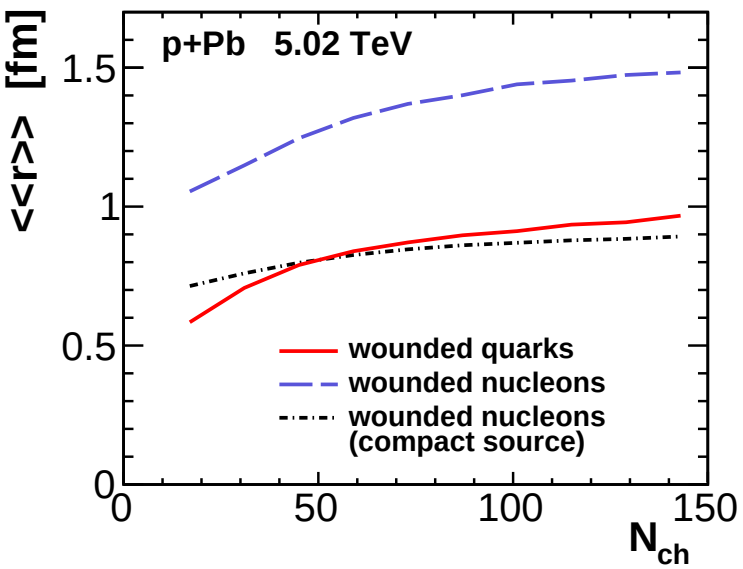
pp scattering



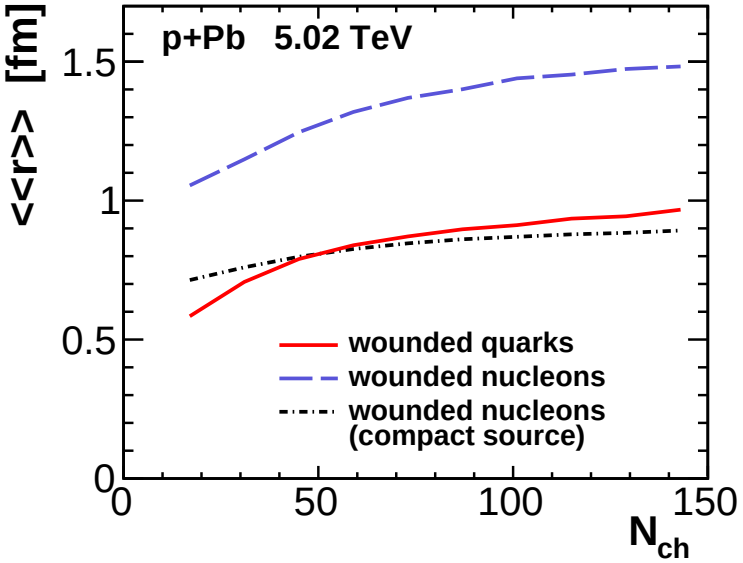


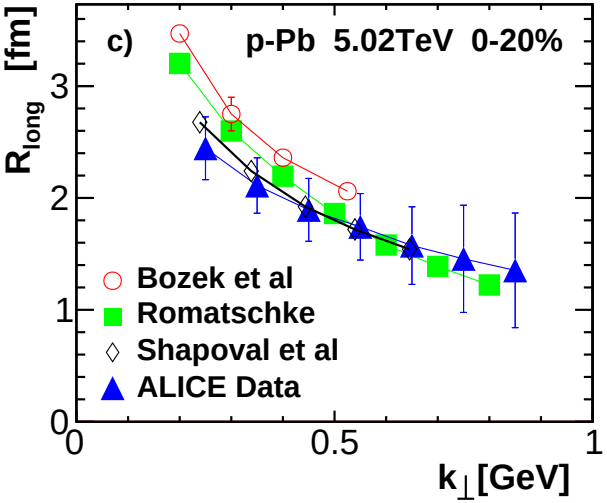
- significant eccentricities in p-p
- small size of the interaction region ~ 0.4fm

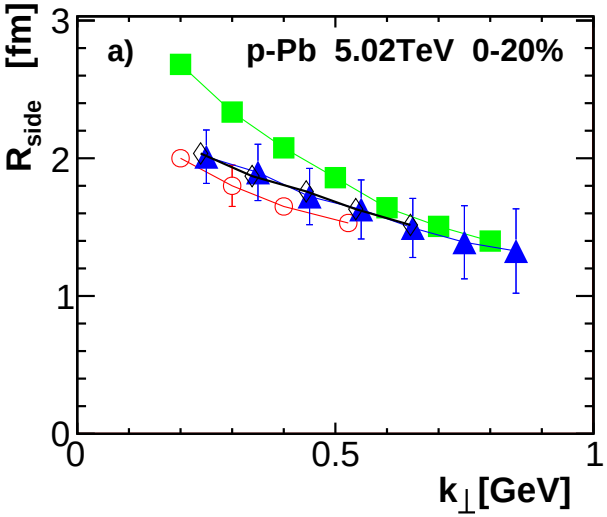
Compact initial size in p-Pb



Compact initial size in p-Pb

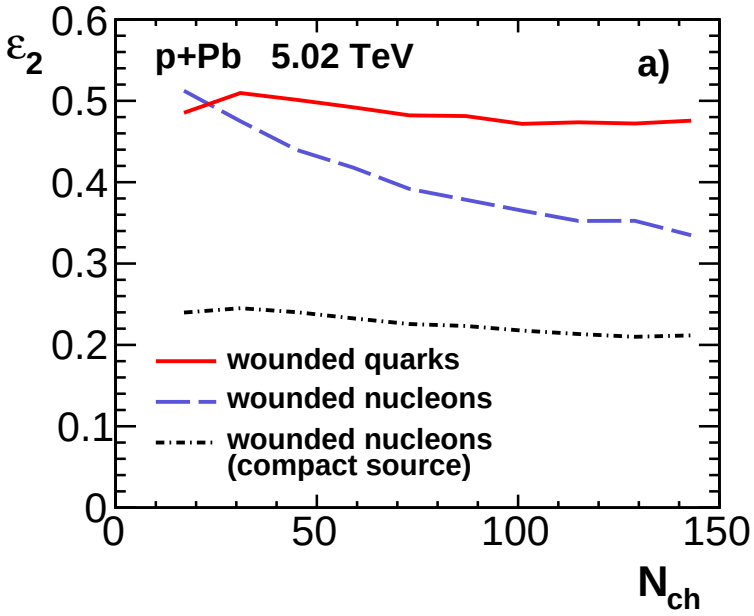


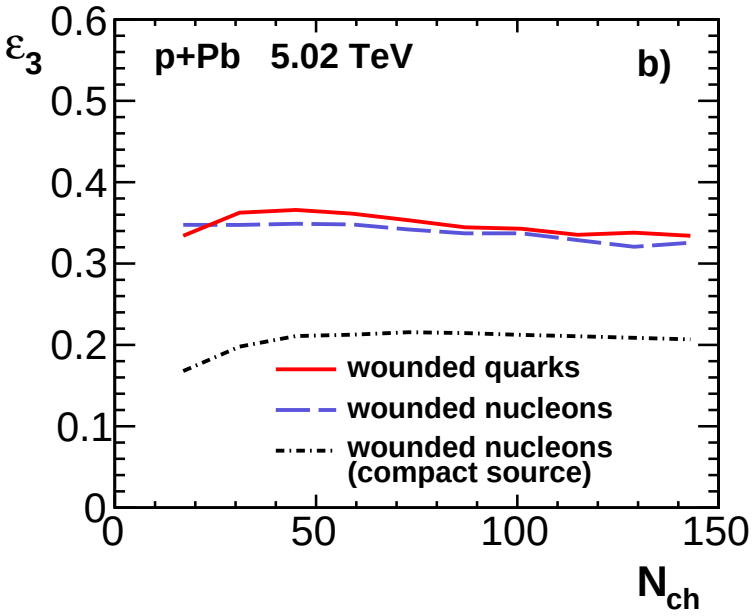




compact source consistent with p-Pb data (HBT, $< p_\perp >$)

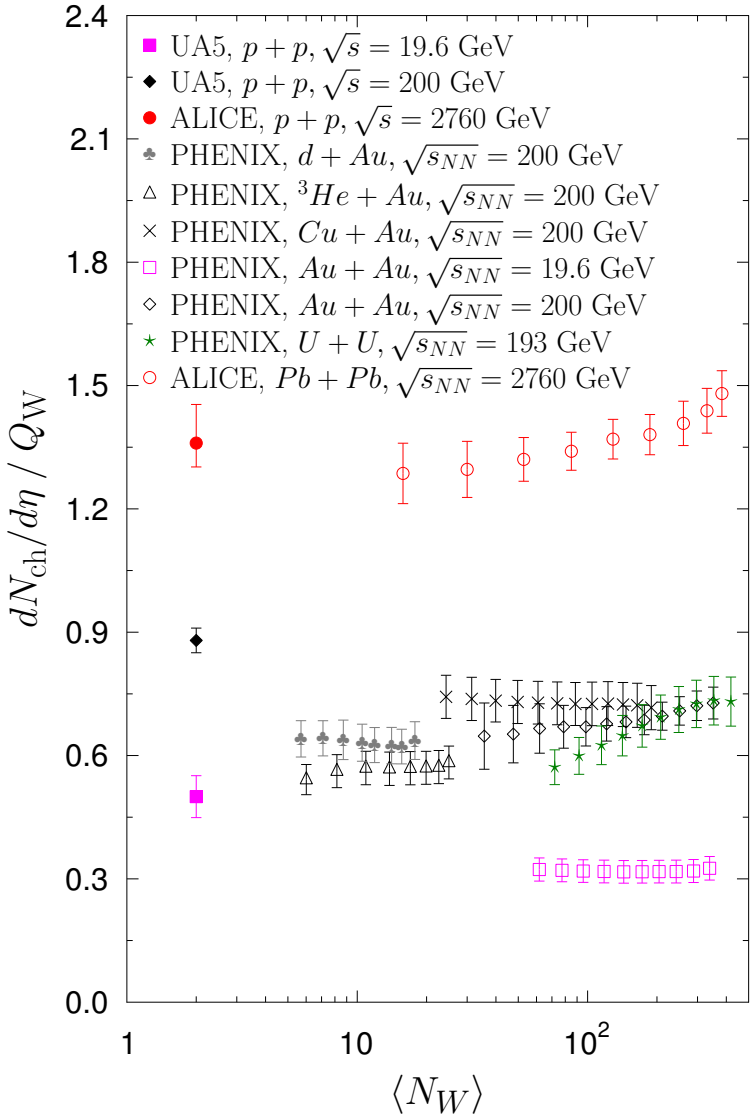
Fireball eccentricities in p-Pb





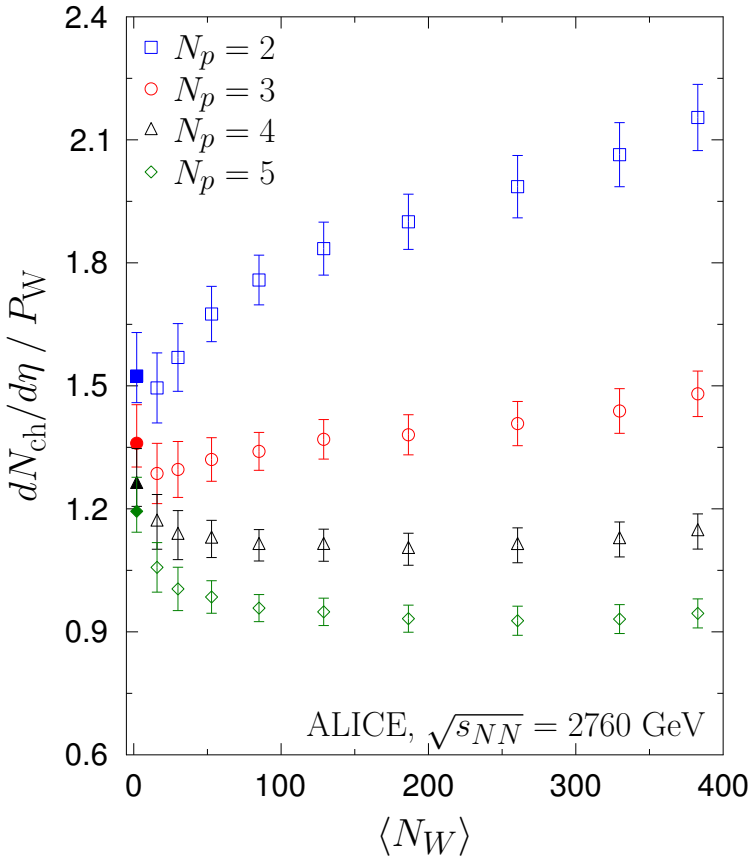
- significant eccentricities in p-Pb
- weak dependence on centrality ($N_{\rm ch}$)
- consistent experimental observation of v_2 and v_3 in p-Pb

Wounded quark scaling in AA



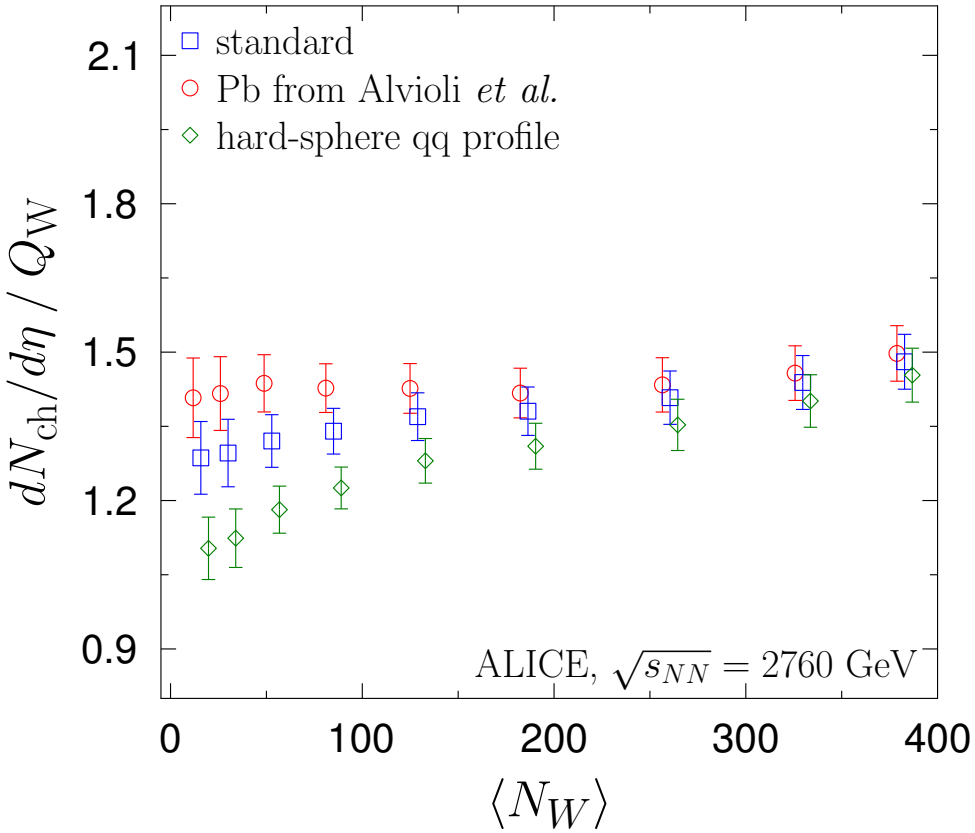
- good scaling at the LHC
- approximate scaling at RHIC
- LHC - 3 constituents, RHIC - 2?

How many partons?



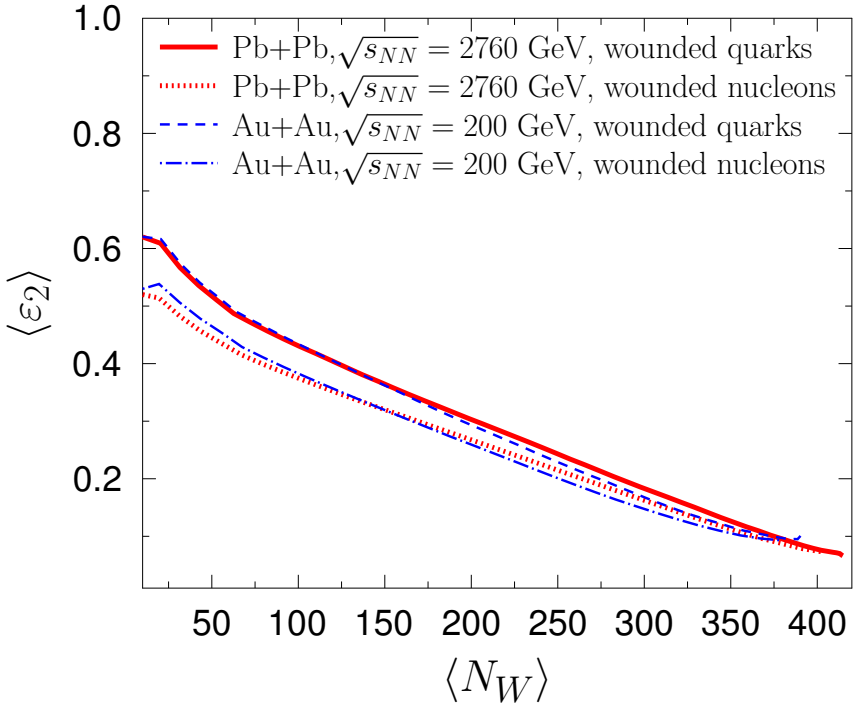
- wounded quark scaling changes with effective number of partons
- for each N_p N-N scattering profile reproduced
- number of constituents increases with energy (?)

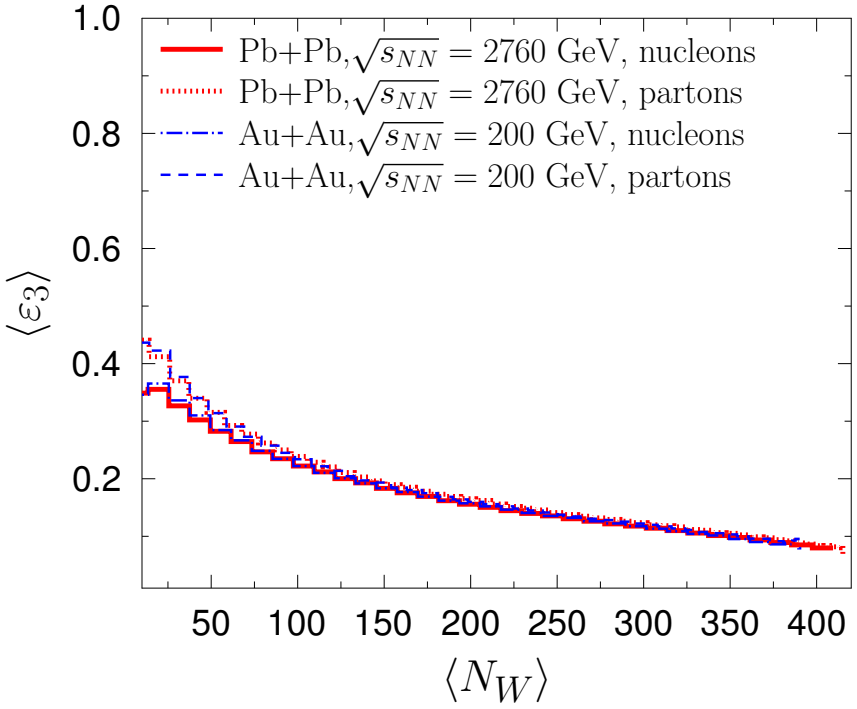
Details matter



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

Eccentricities in AA



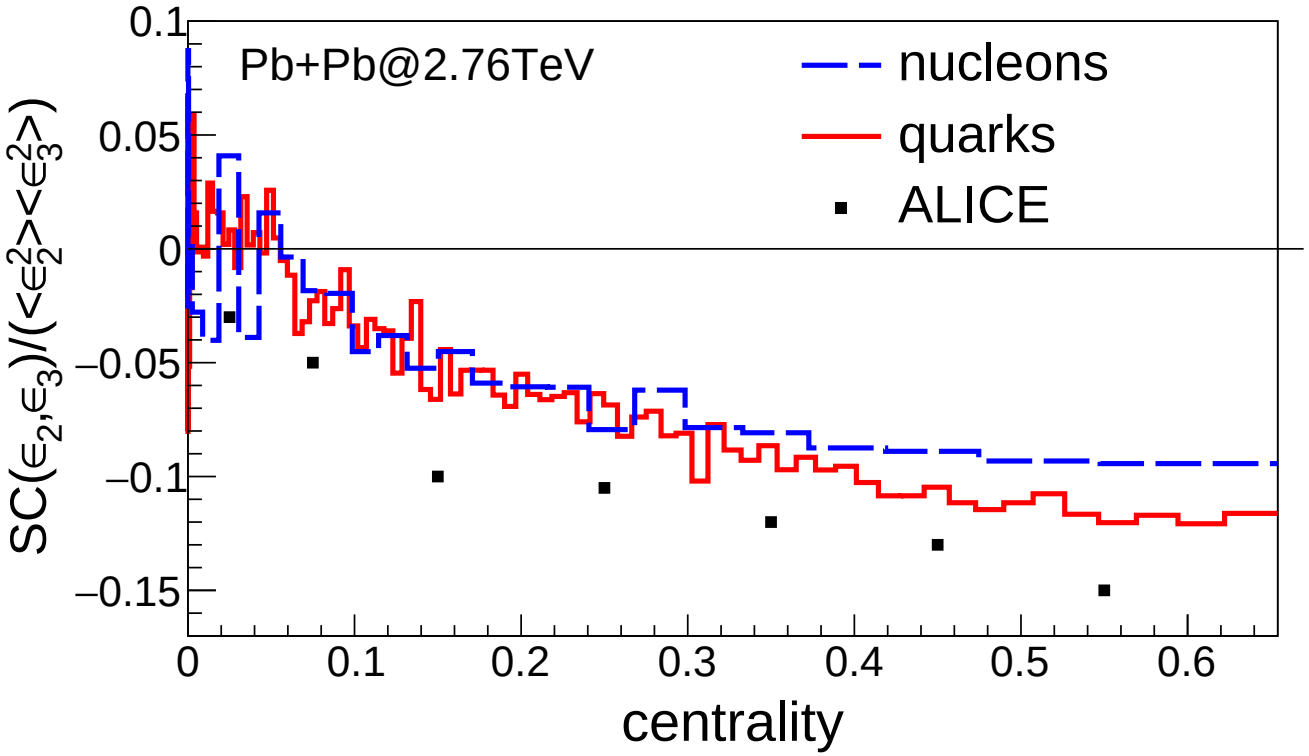


- very small effect of subnucleonic structure on eccentricities
  – similar to the wounded nucleon model with binary contribution
- similarity for other observables

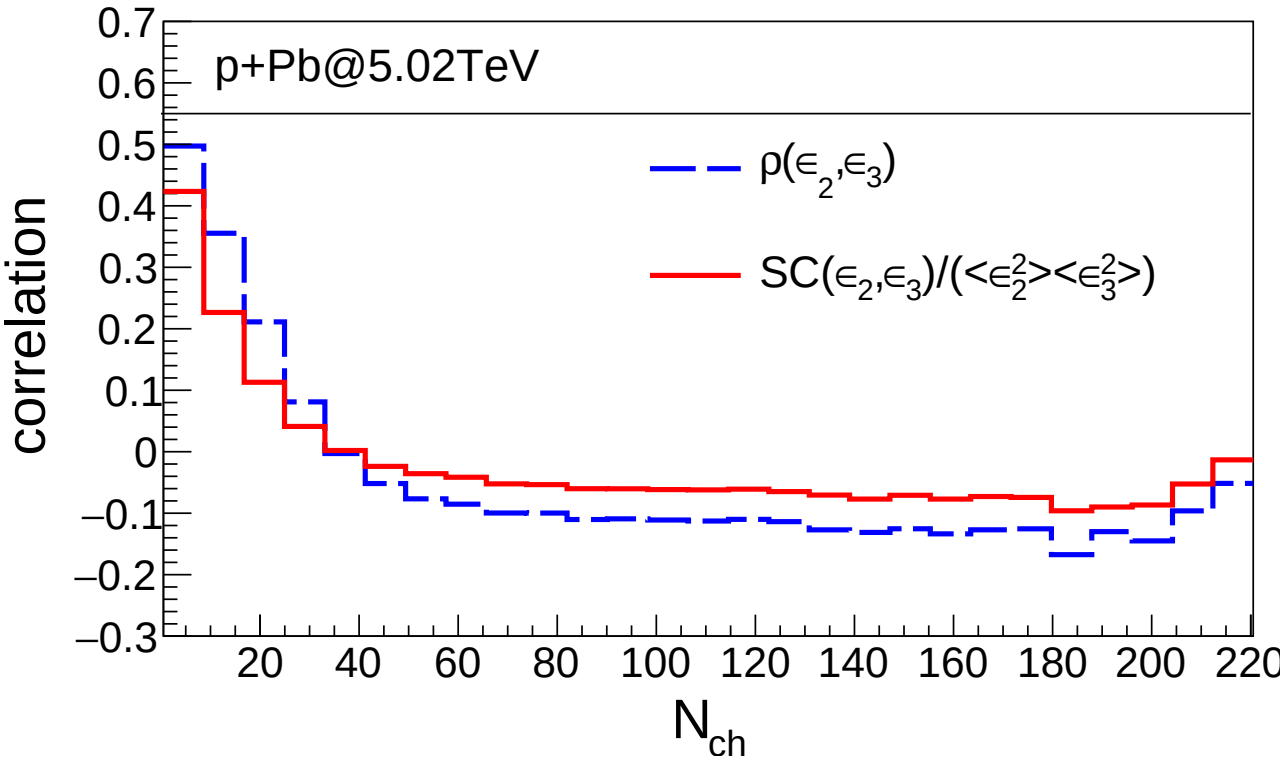
Eccentricity correlations

ALICE: $\frac{SC(a,b)}{<a^2><b^2>} = \frac{<a^2b^2>-<a^2><b^2>}{<a^2><b^2>}$

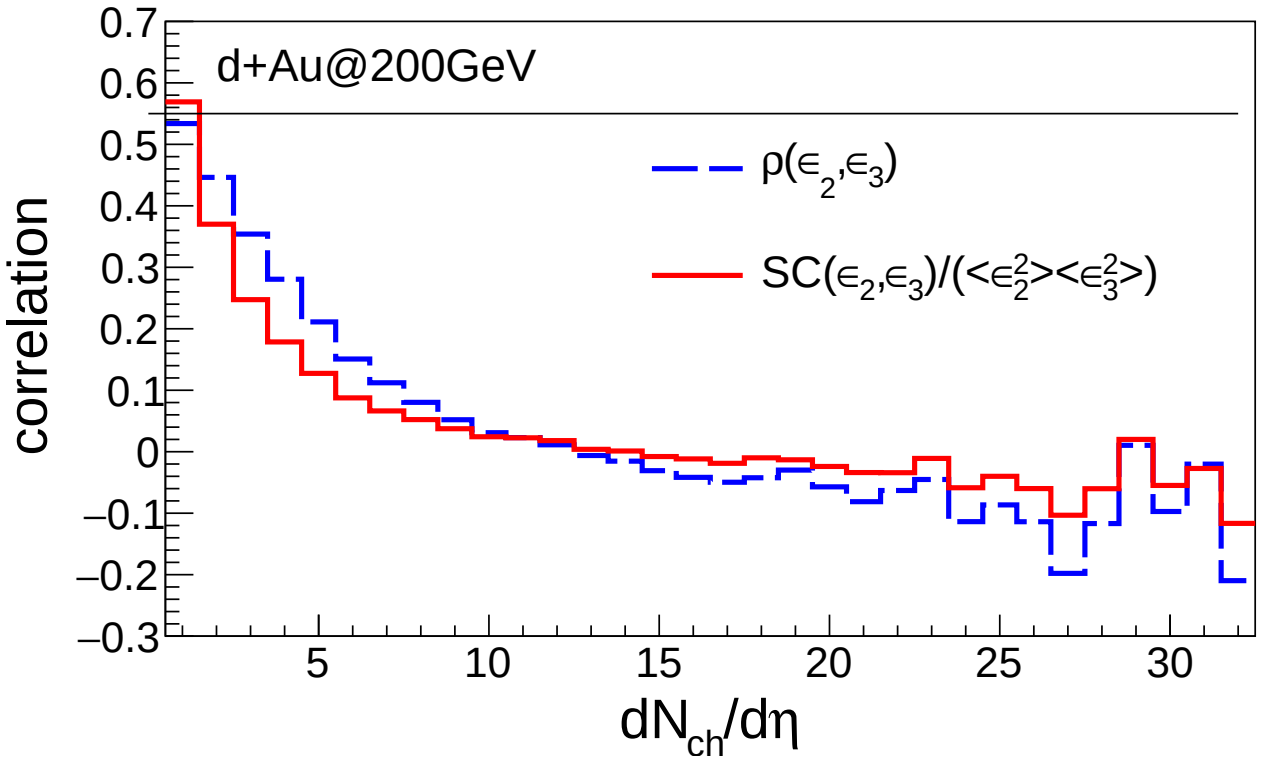
$v_n \simeq \kappa(n,c)\epsilon_n,\ n=2,3 \ \rightarrow \ \frac{SC(v_2,v_3)}{<v_2^2><v_3^2>} = \frac{SC(\epsilon_2,\epsilon_3)}{<\epsilon_2^2><\epsilon_3^2>}$



Eccentricity correlations



Eccentricity correlations



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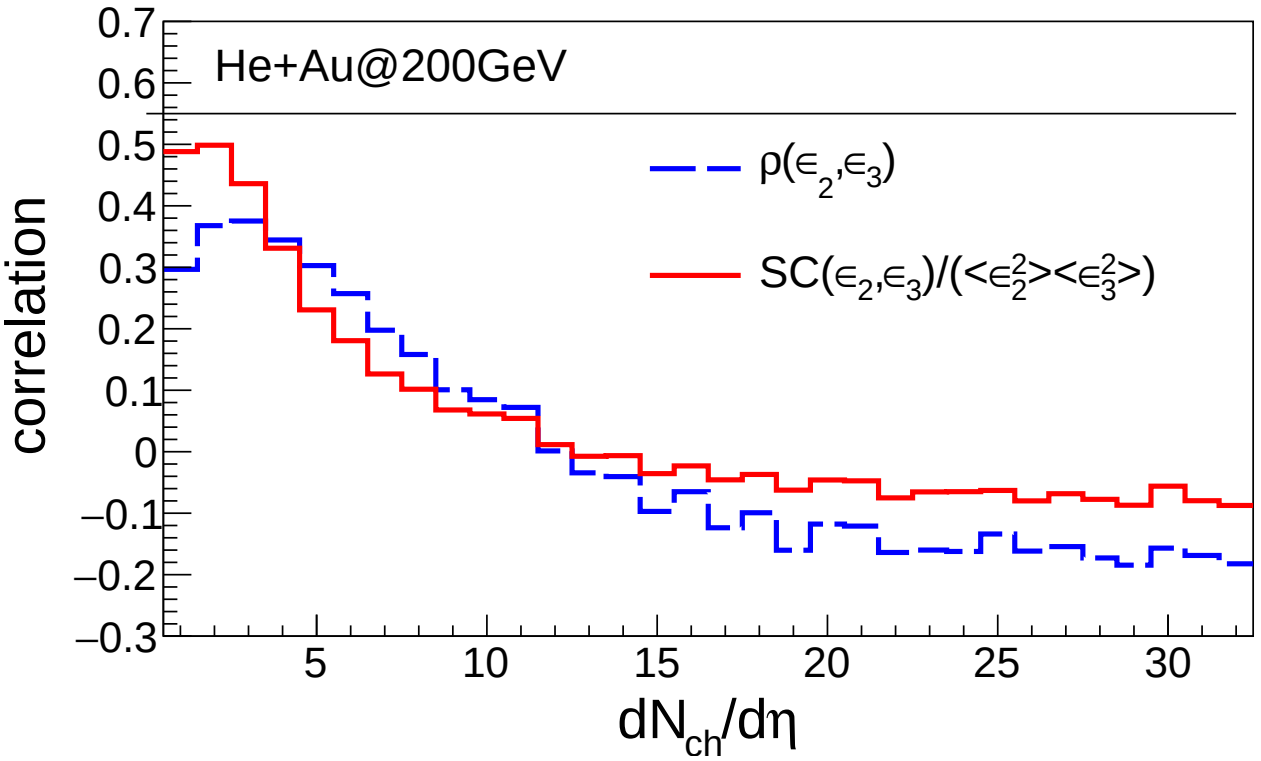

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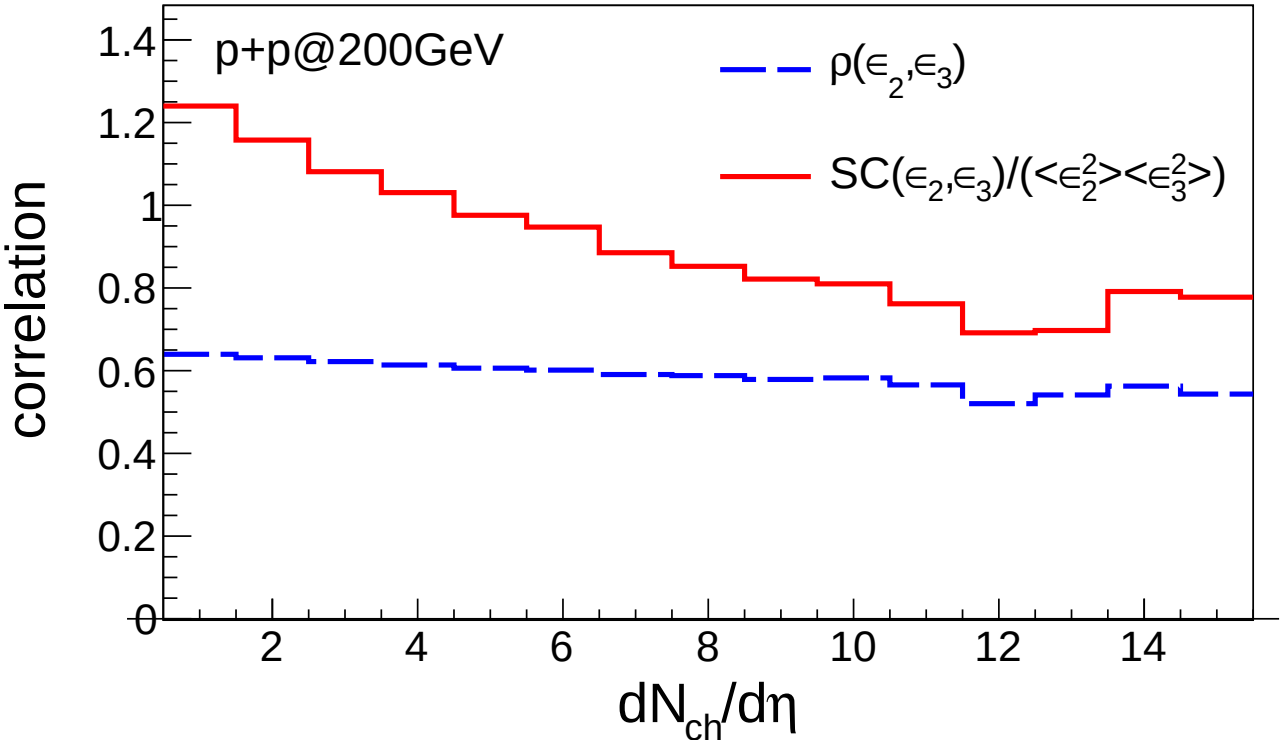
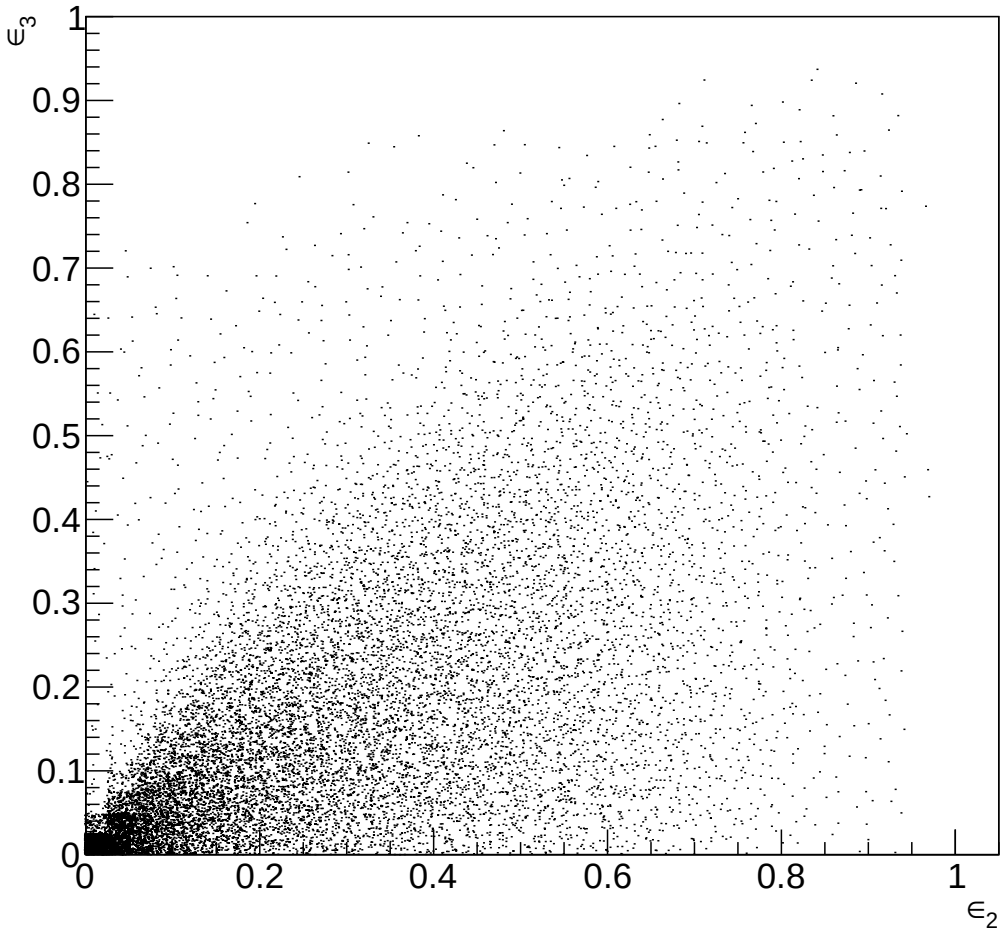


Eccentricity correlations

p-p@200GeV – collision of two trianges



Summary

- Wounded quark model for pp, pA, and AA
- Quark distribution in nucleon and Q-Q scattering adjusted to reproduce NN 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 pp
- Indication of an increase of the effective number of partons with $\sqrt{s}$
- Possibility of studying eccentricity/flow correlations