Multihadron production in nuclear and particle interactions

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E.K.G. Sarkisyan, A.S. Sakharov, arXiv:1004.4390

Motivation

- Bulk observables - mean multiplicity and rapidity densities - control parameters of the formation and evolution of the collision initial state
- extensively studied in heavy-ion collisions at RHIC
- similarities with e^+e^- and pp data: universality in multihadron production

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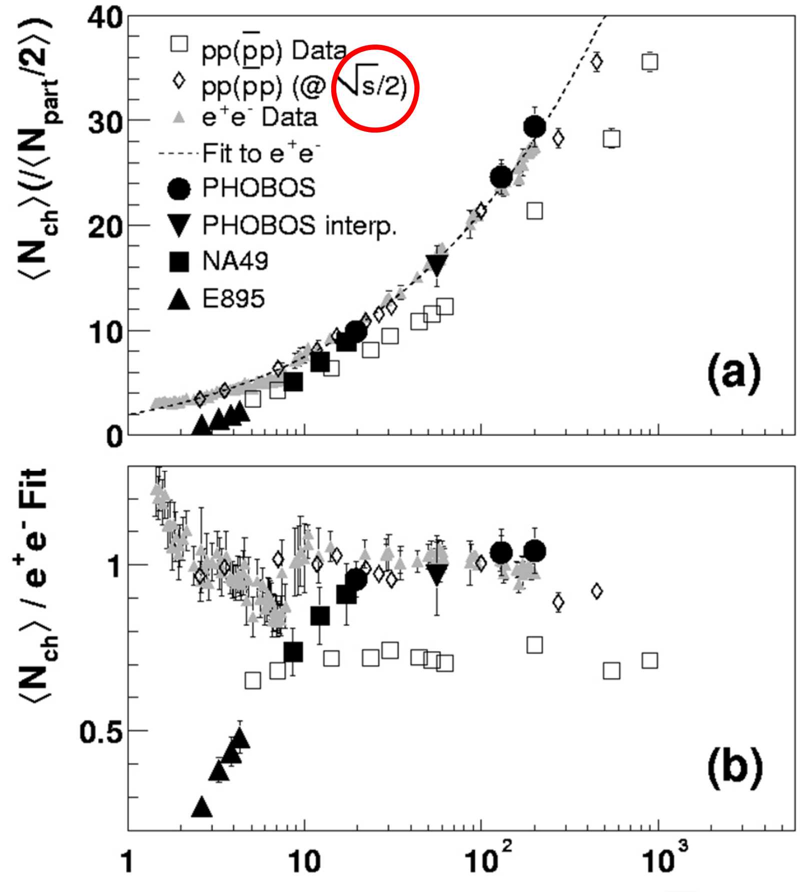

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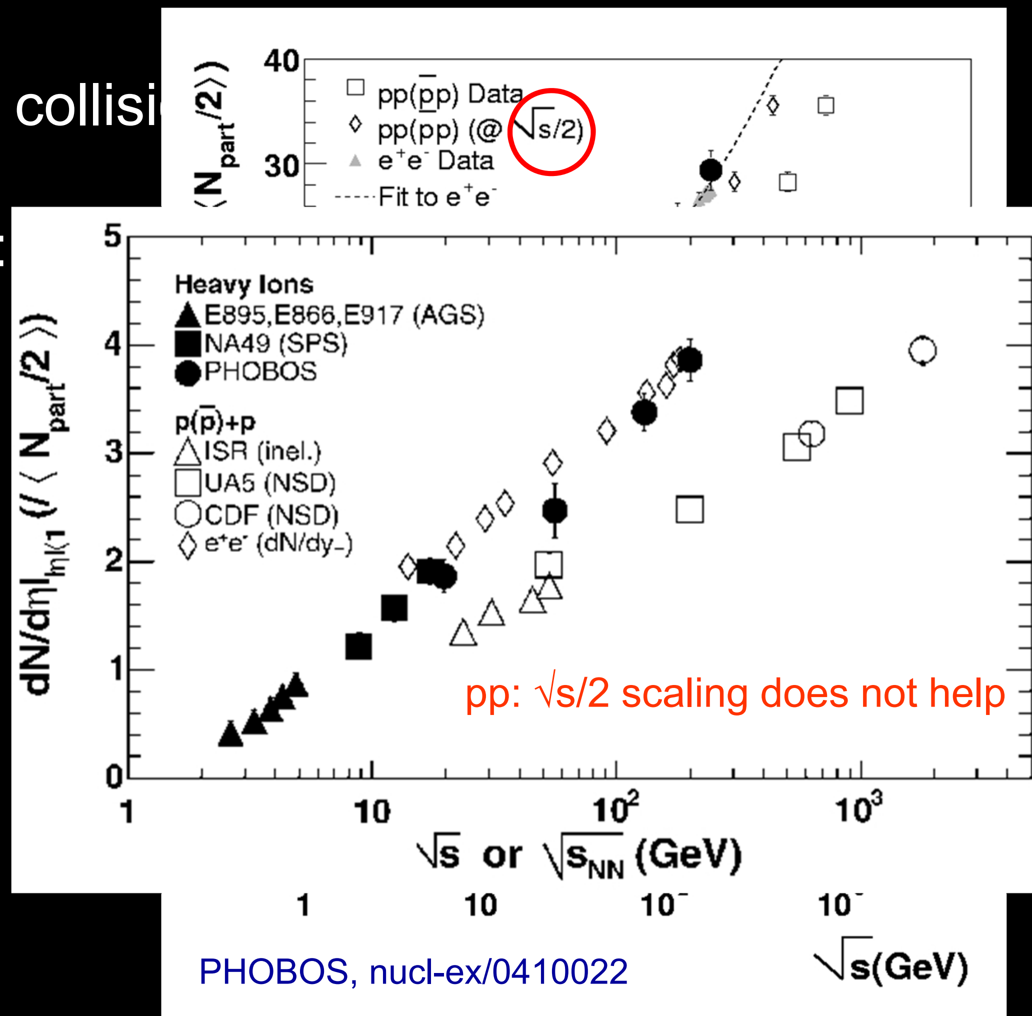

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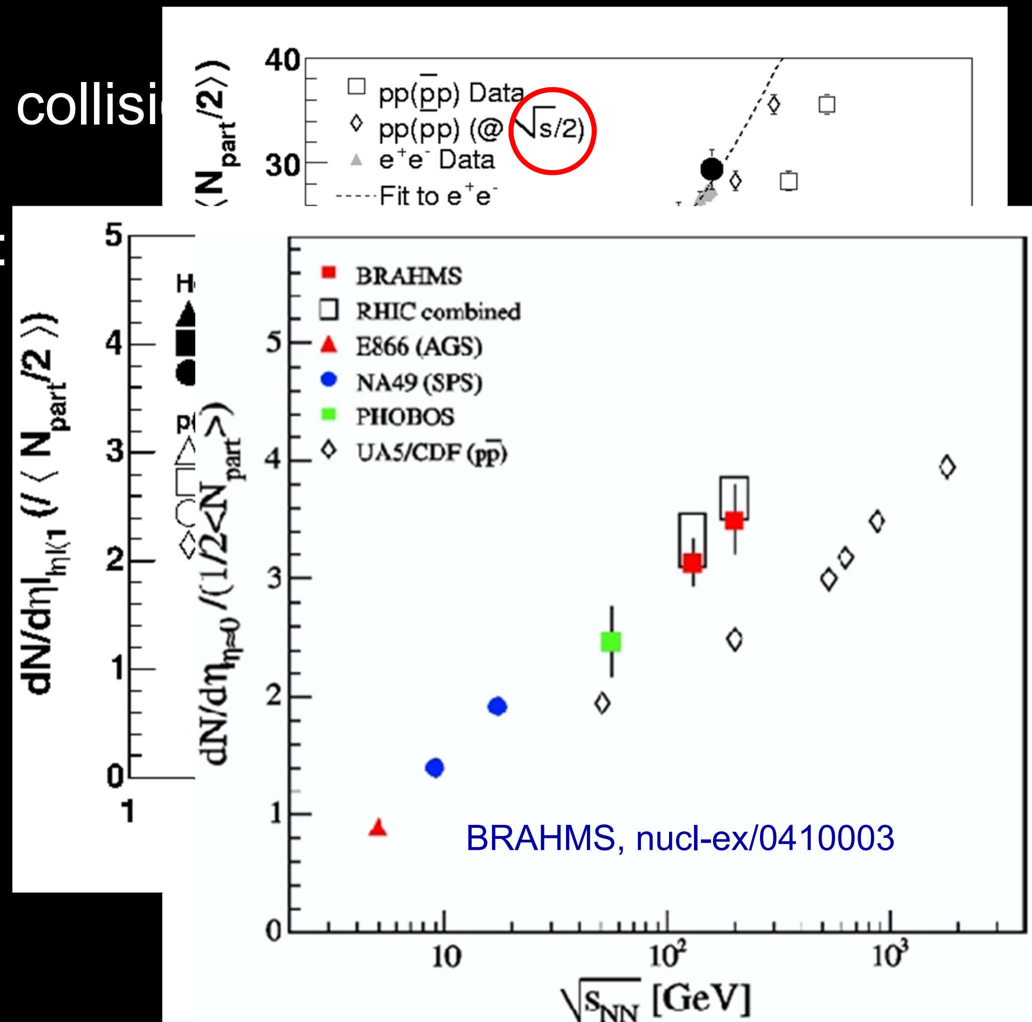
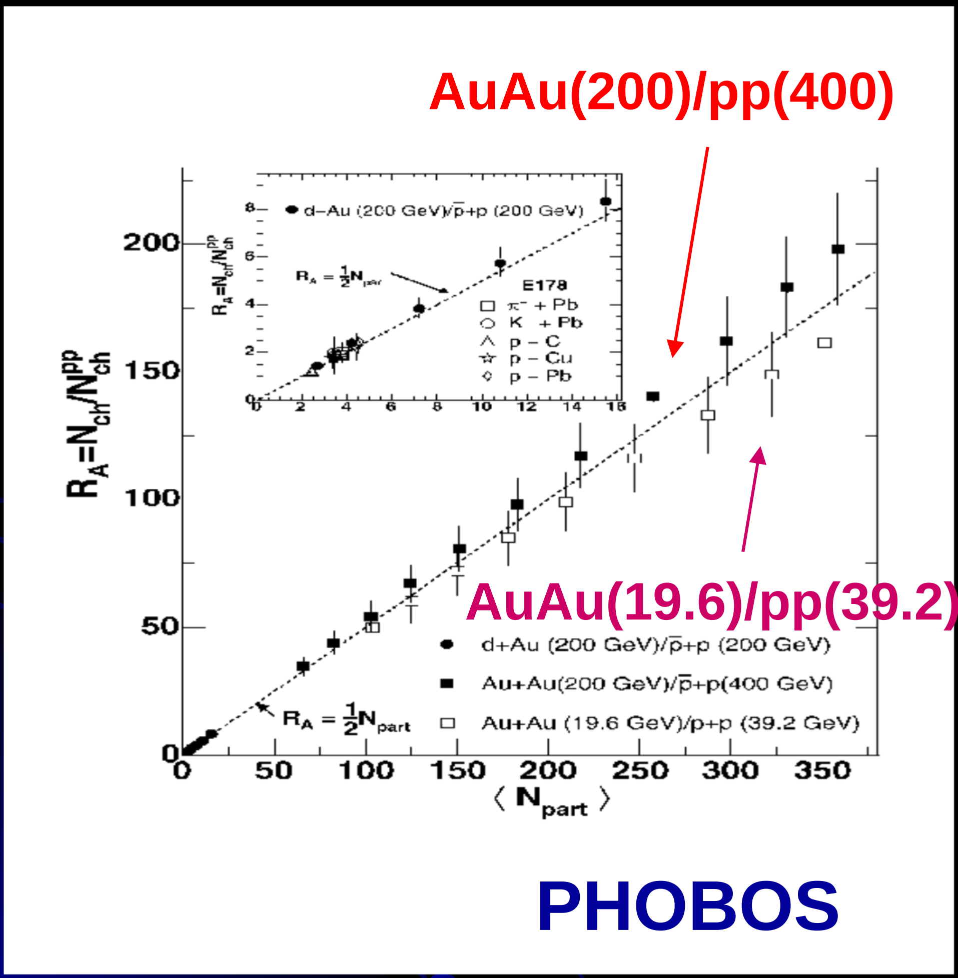
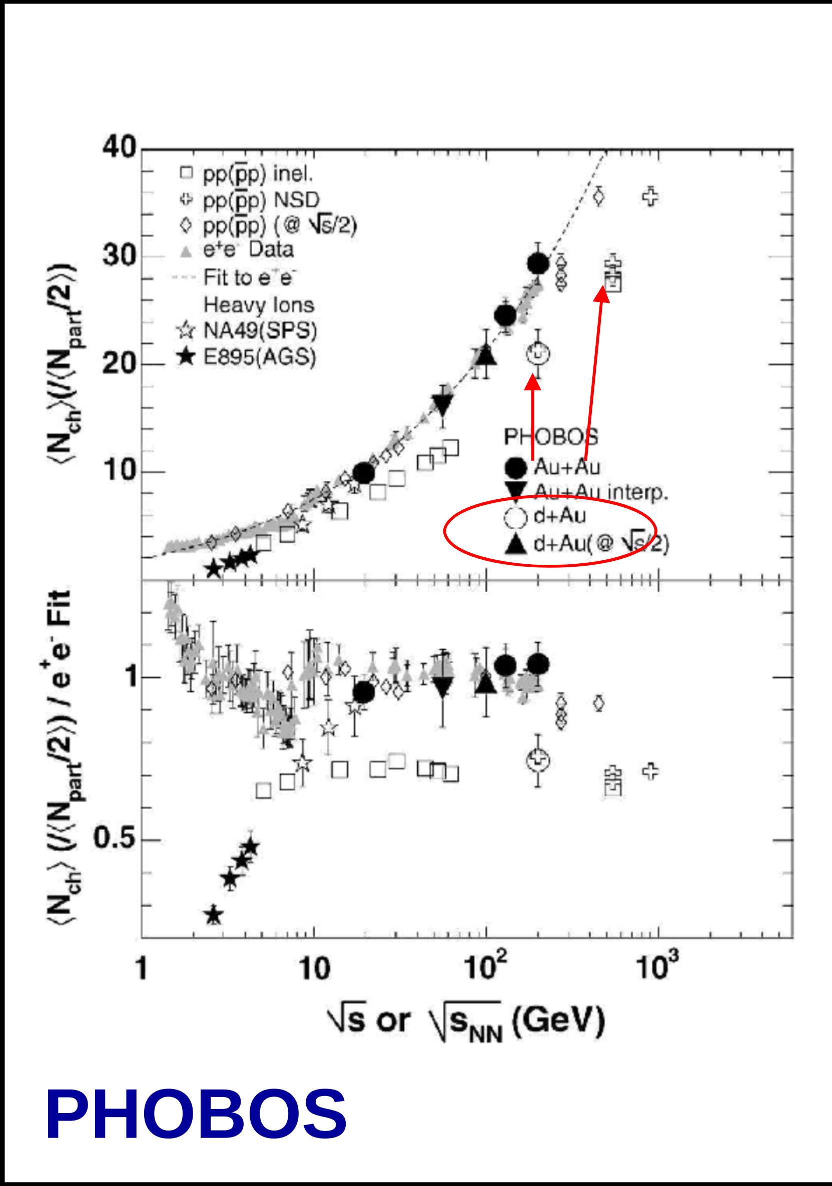
- *no scaling* needed for dAu vs pp



Multiplicity: dA vs pp, AA

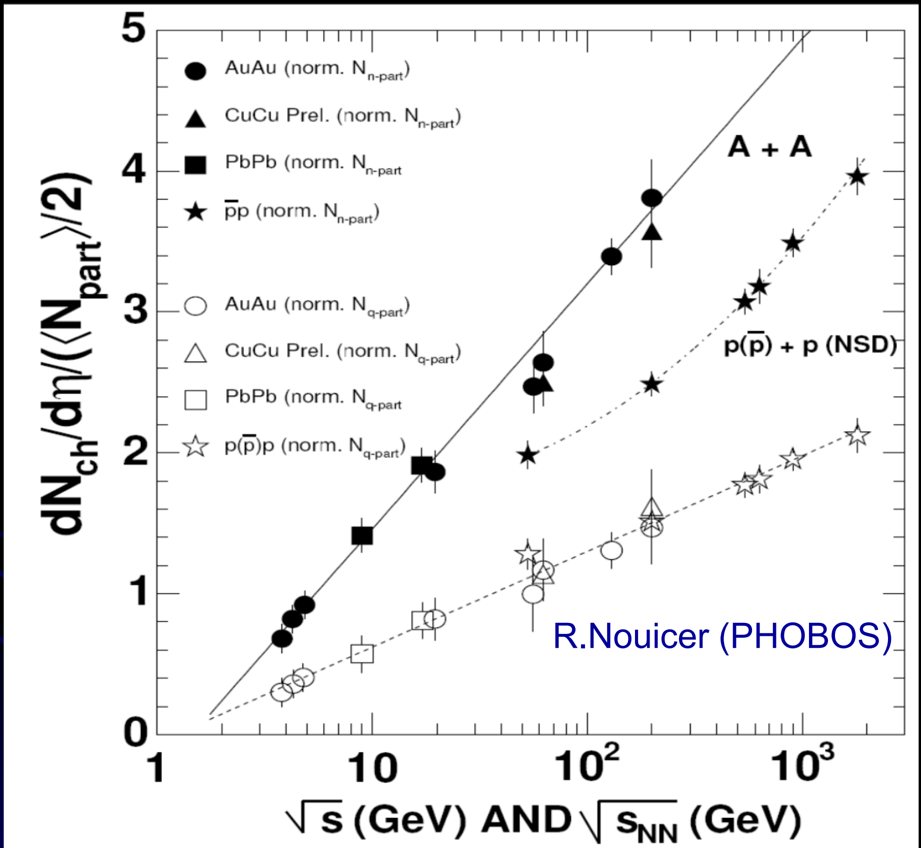
- No scaling needed for (central) **dAu vs. pp**
- Correct for **non-central AA** too as scaled with √s/2, but deviates for **most central AA**

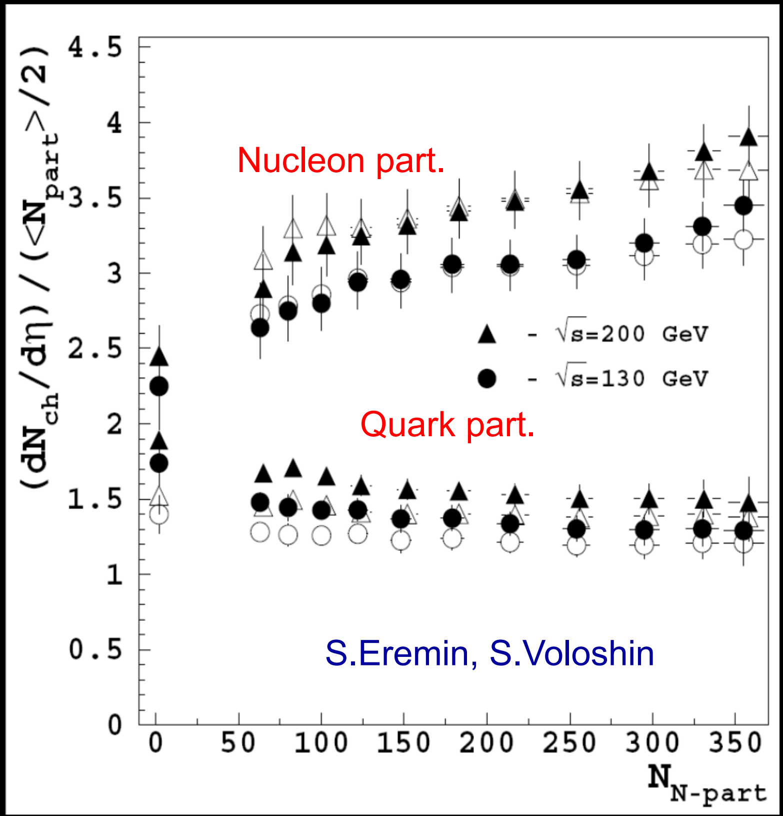




Quark participants

- Quark degrees of freedom seem to play a role, not the nucleon ones
- Works for models of constituent quark nature

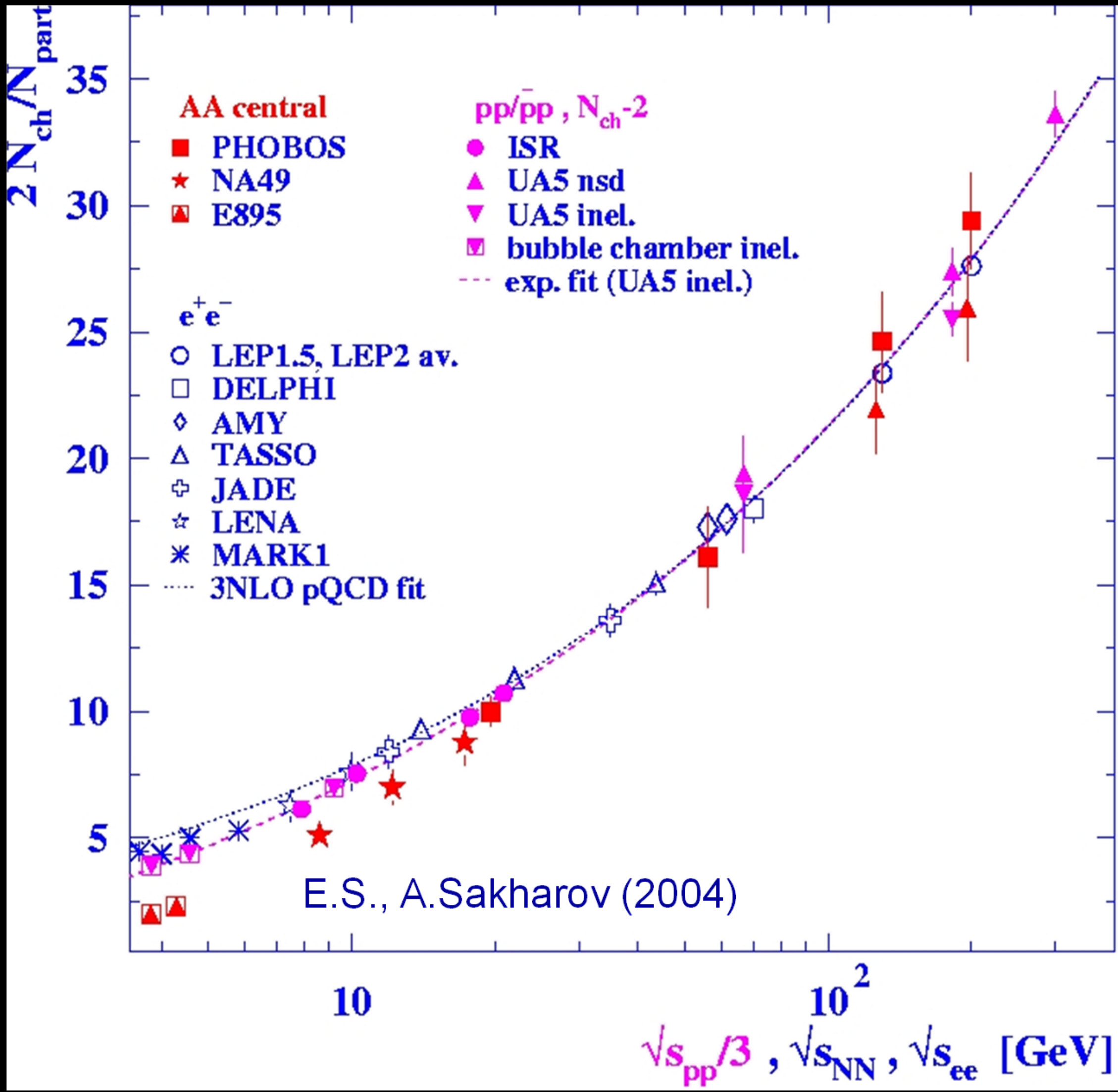




- Mid-rapidity densities show same energy behaviour as recalculated to constituent quark participant frame

Multiplicity in e^+e^-, pp and AA

- e^+e^- similar to AA data
- well **reproduced** by 3NLO pQCD
  - pp data similar to e^+e^- and AA as $\sqrt{s_{pp}} = 3\sqrt{s_{NN}}$
    - *leading particle effect:* N_{ch}-2



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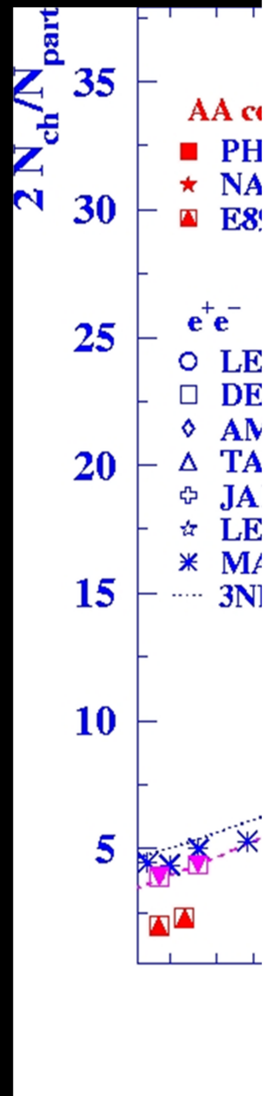
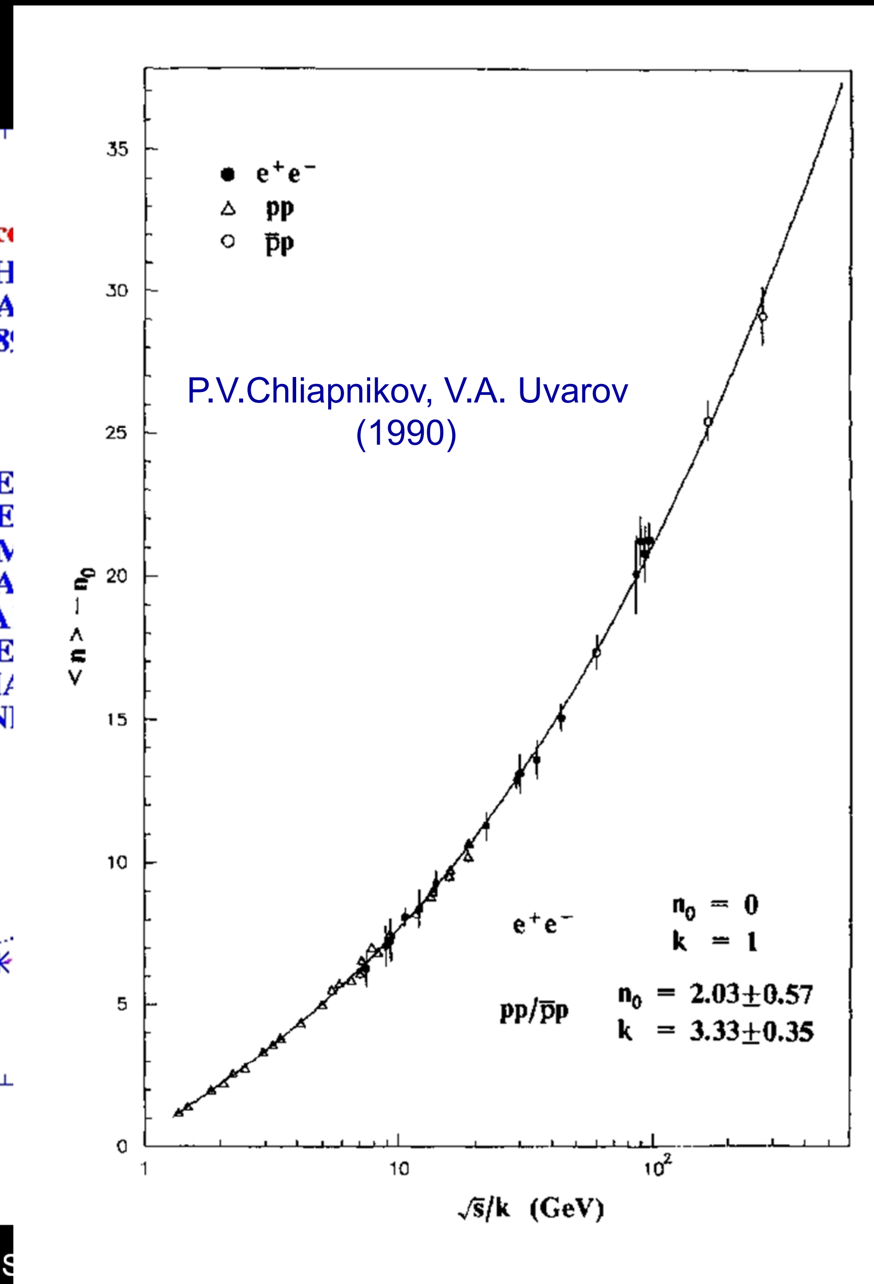
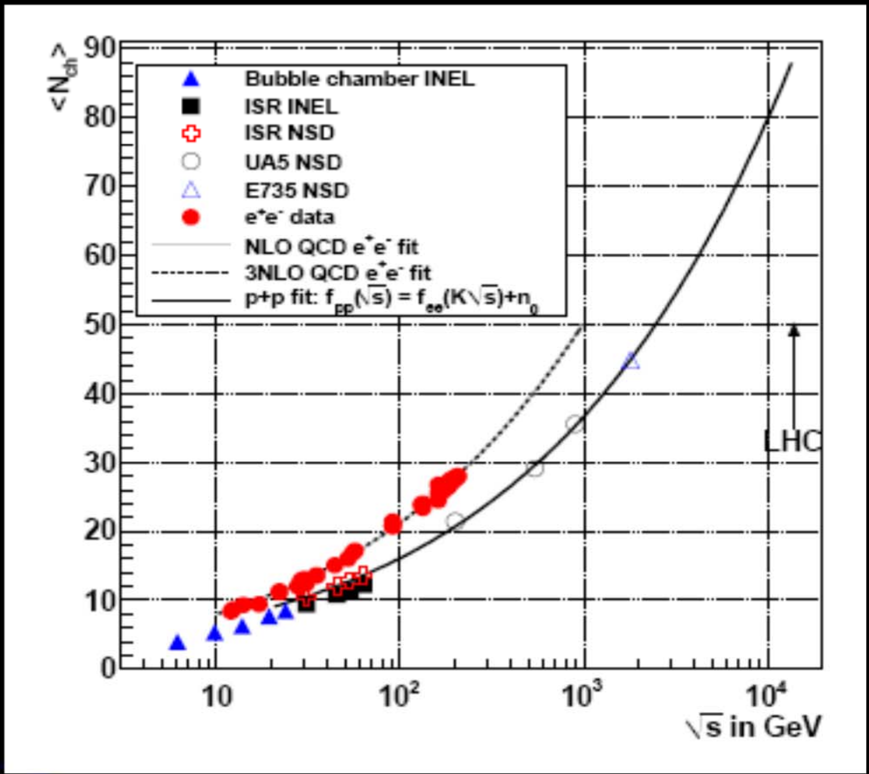
  - indicated al LEP starting years

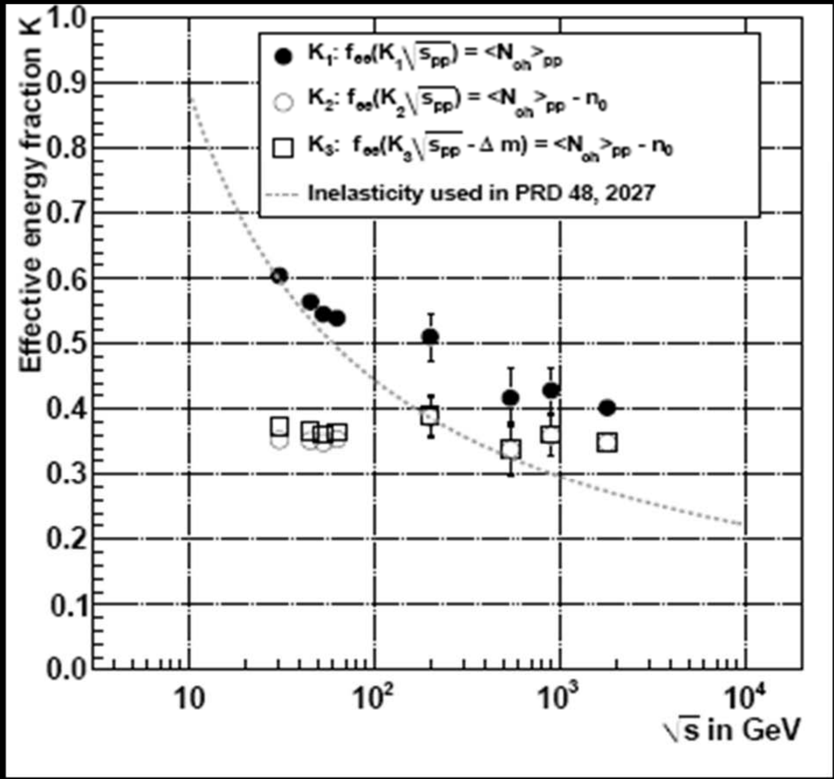




- E.S., A.Sakharov, hep-ph/0410324 & AIP 828, 35 (2005)

Multiplicity in e^+e^- and pp





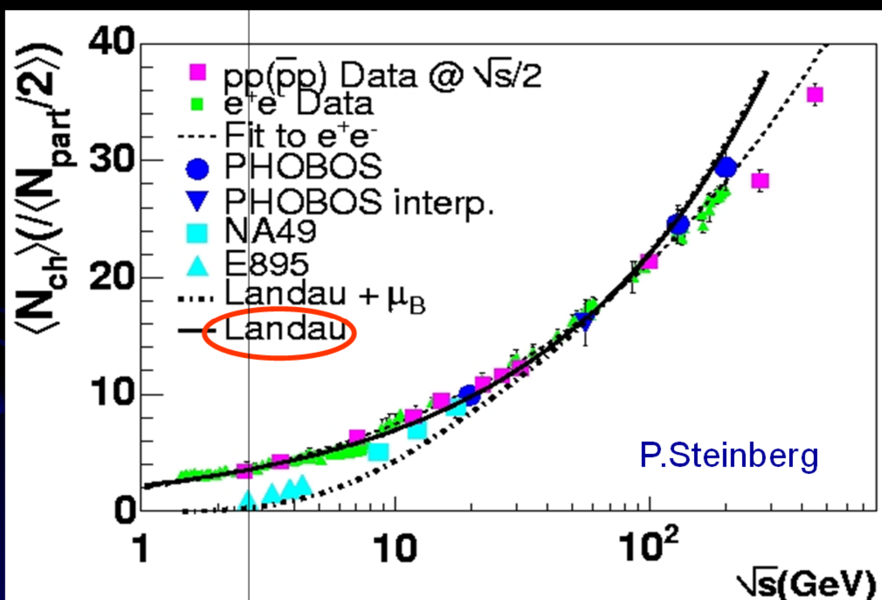
J.F. Grosse-Oetringhaus, K Reygers (2010)

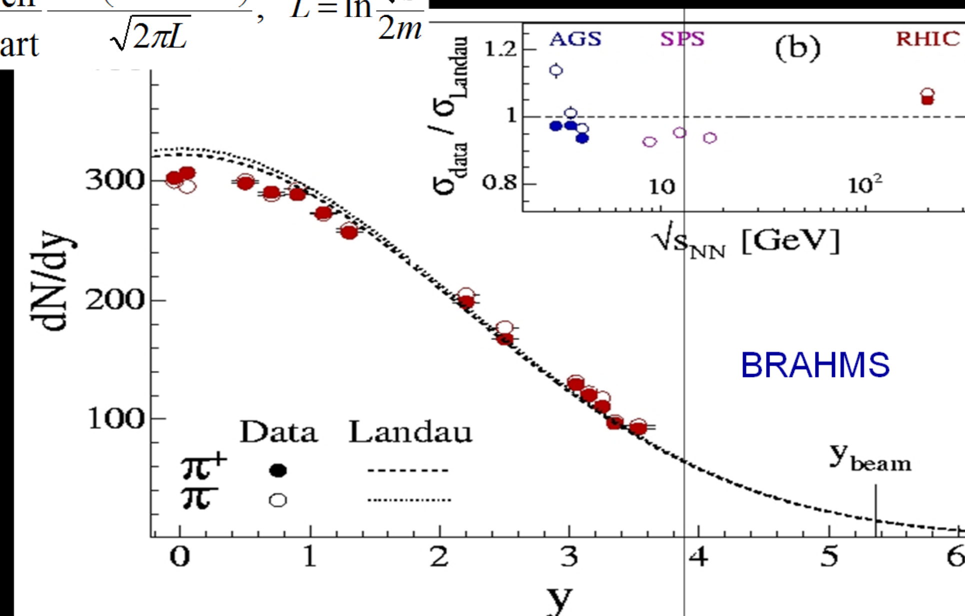
- pp data **well reproduced** from e^+e^- 3NLO fit assumimg $f_{pp} = f_{ee}(K\sqrt{s}) + n_0$: $n_0 = 2.2$ characterizies the number of leading protons and $K \approx 0.35$ is the inelasticity characterizing the fraction of effective energy (for produced particles), i.e. $\sqrt{s_{pp}} \approx 3 \sqrt{s_{ee}}$
- The inelasticity prefers the 0.35 value being *energy independent*

Hydrodynamics of collisions

- two head-on colliding Lorentz-contracted particles stop within overlapped zone
  - formation of fully thermalised initial state at the collision moment
  - the decay (expansion) of the initial state is governed by relativistic hydrodynamics - Landau model

$$\frac{2N_{ch}}{N_{part}}\frac{\exp\left(-y^2/2L\right)}{\sqrt{2\pi L}}, \quad L=\ln\frac{\sqrt{s}}{2m}$$





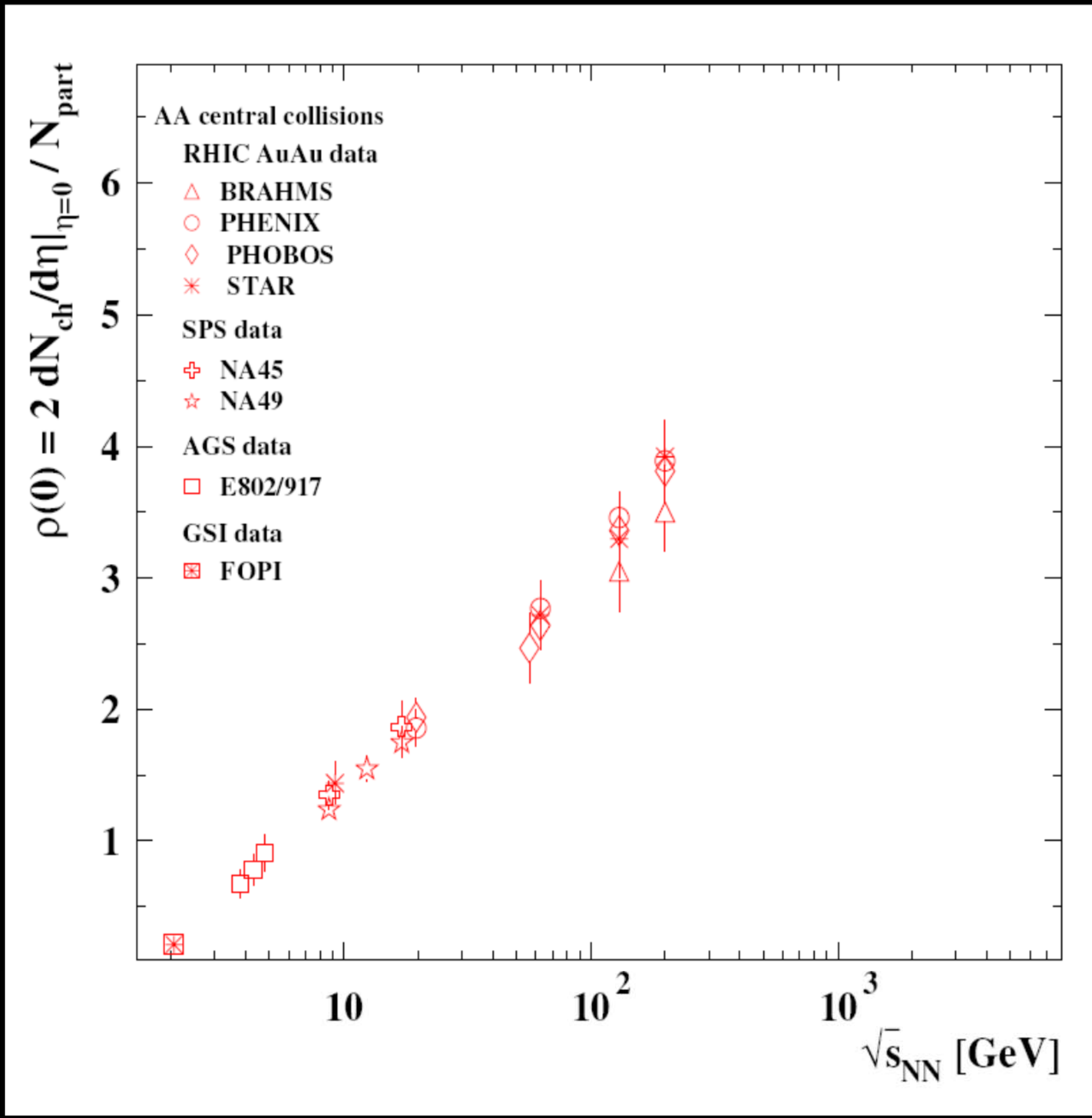
- the production of secondaries is defined by the energy deposited in the initial state

Hydrodynamics and energy scaling

- e^+e^- (structureless particles) annihilation - the total interaction energy is deposited in the initial state
- pp (superposition of three pairs of constituents) collision - only the energy of the interacting single quark pair is deposited in the initial state
- multiplicity and mid-rapidity density should be similar in pp at c.m. energy $\sqrt{s_{pp}}$ and e^+e^- at c.m. energy $\sqrt{s_{ee}} \approx \sqrt{s_{pp}}/3$
- central heavy ion collisions: more than one quark per nucleon participates
- head-on heavy ion collisions: all three quarks participate nearly simultaneously and deposit their energy coherently into initial state
- multiplicity and mid-rapidity density should be similar in pp at c.m. energy $\sqrt{s_{pp}}$ and head-on AA at c.m. energy $\sqrt{s_{NN}} \approx \sqrt{s_{pp}}/3$

Mid-rapidity density in pp and AA

- *linear logarithmic* increase with c.m. energy

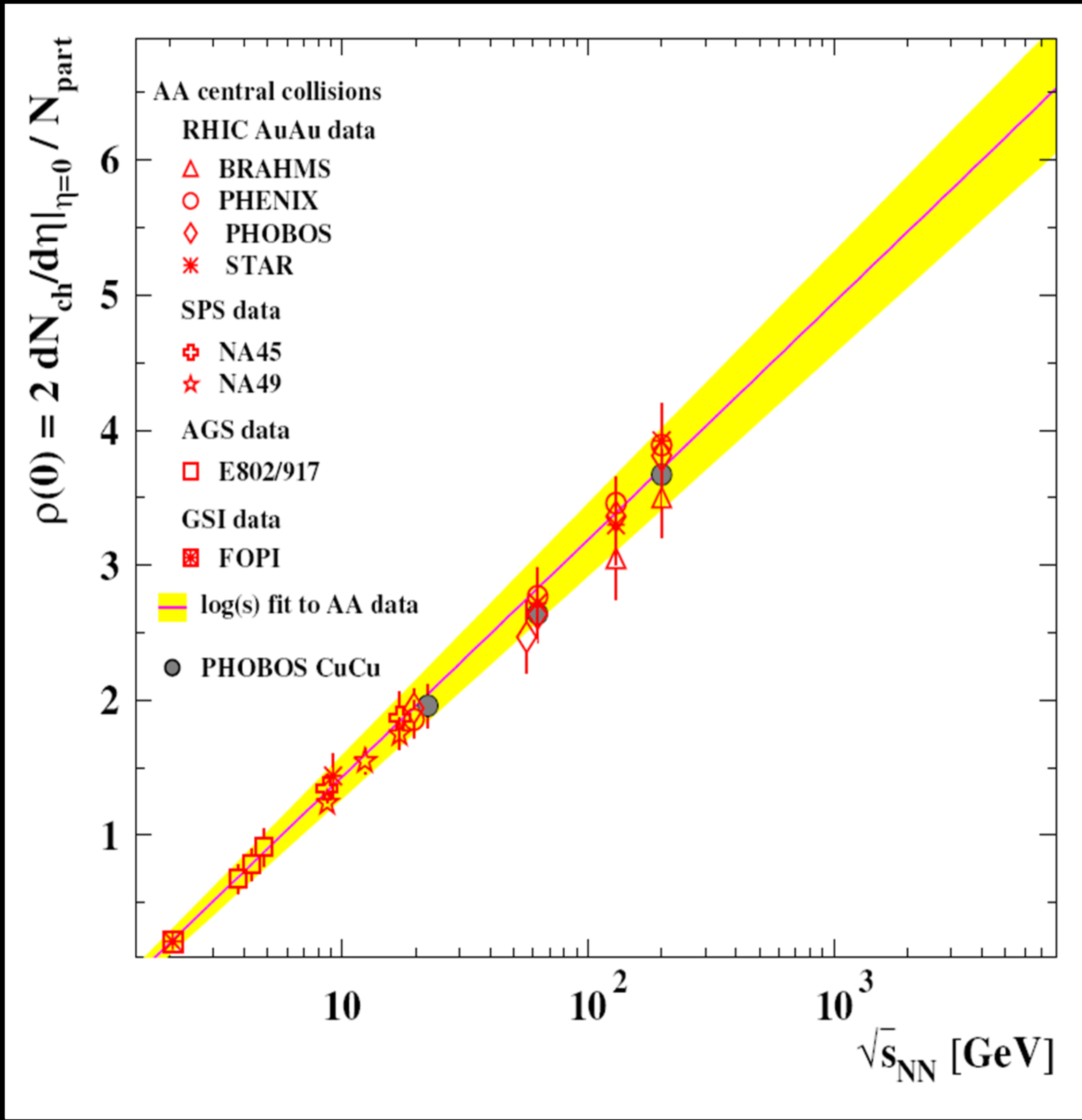


Mid-rapidity density in pp and AA

- *linear logarithmic* increase with c.m. energy
- linear logarithmic *fit* to AA data

$$\rho(0) = (-0.327 \pm 0.026) + (0.381 \pm 0.021)\ln(s_{NN})$$

- *same* for different nuclei



Mid-rapidity density in pp and AA

- *linear logarithmic* increase with c.m. energy in 2-200 GeV range
- *linear logarithmic* fit to the data

$$\rho(0) = (-0.327 \pm 0.026) + (0.381 \pm 0.021)\ln(s_{NN})$$

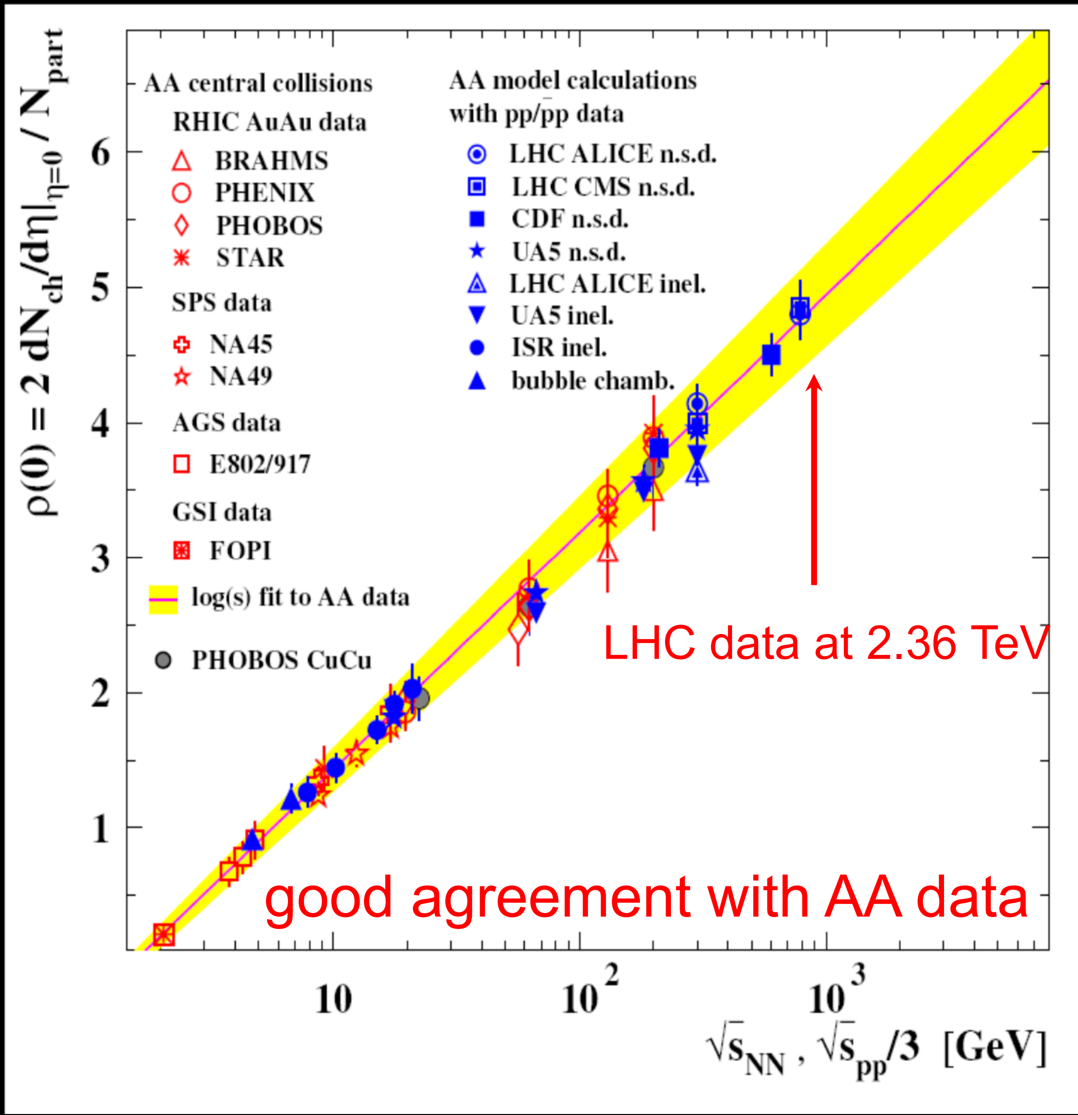
- from Landau hydrodynamics:

$$\frac{\rho_{NN}(0)}{\rho_{pp}(0)} = \frac{2N_{ch}}{N_{part}N_{ch}^{pp}}\sqrt{\frac{L_{pp}}{L_{NN}}}, \quad L = \ln\frac{\sqrt{s}}{2m}$$

- for AA $m = m_p$, for pp $m = m_p/3$

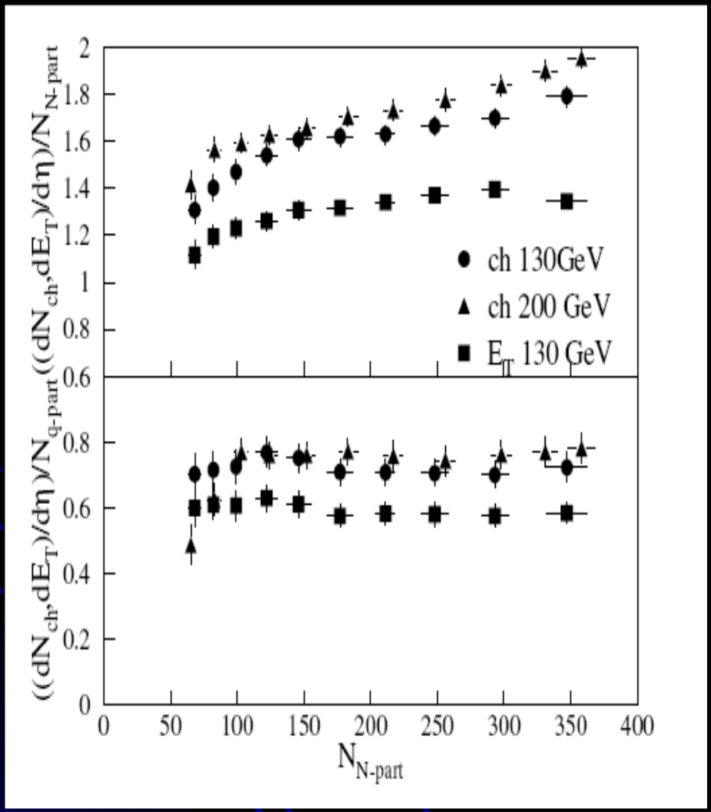
$\sqrt{s_{NN}} = \sqrt{s_{pp}}/3$

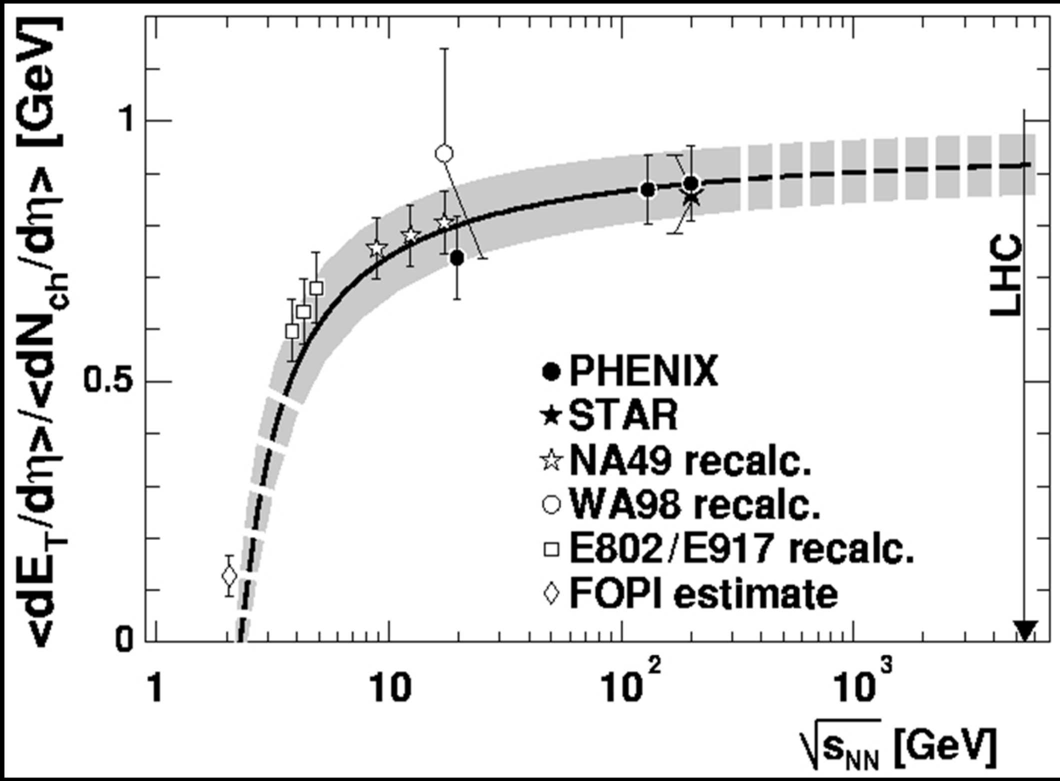
$$\rho(0) = \rho_{pp}(0)\,\frac{2\,N_{ch}}{N_{part}\,N_{ch}^{pp}}\sqrt{1 - \frac{4\ln 3}{\ln\left(4m_p^2/s_{NN}\right)}}$$



Mid-rapidity density: from pp to AA

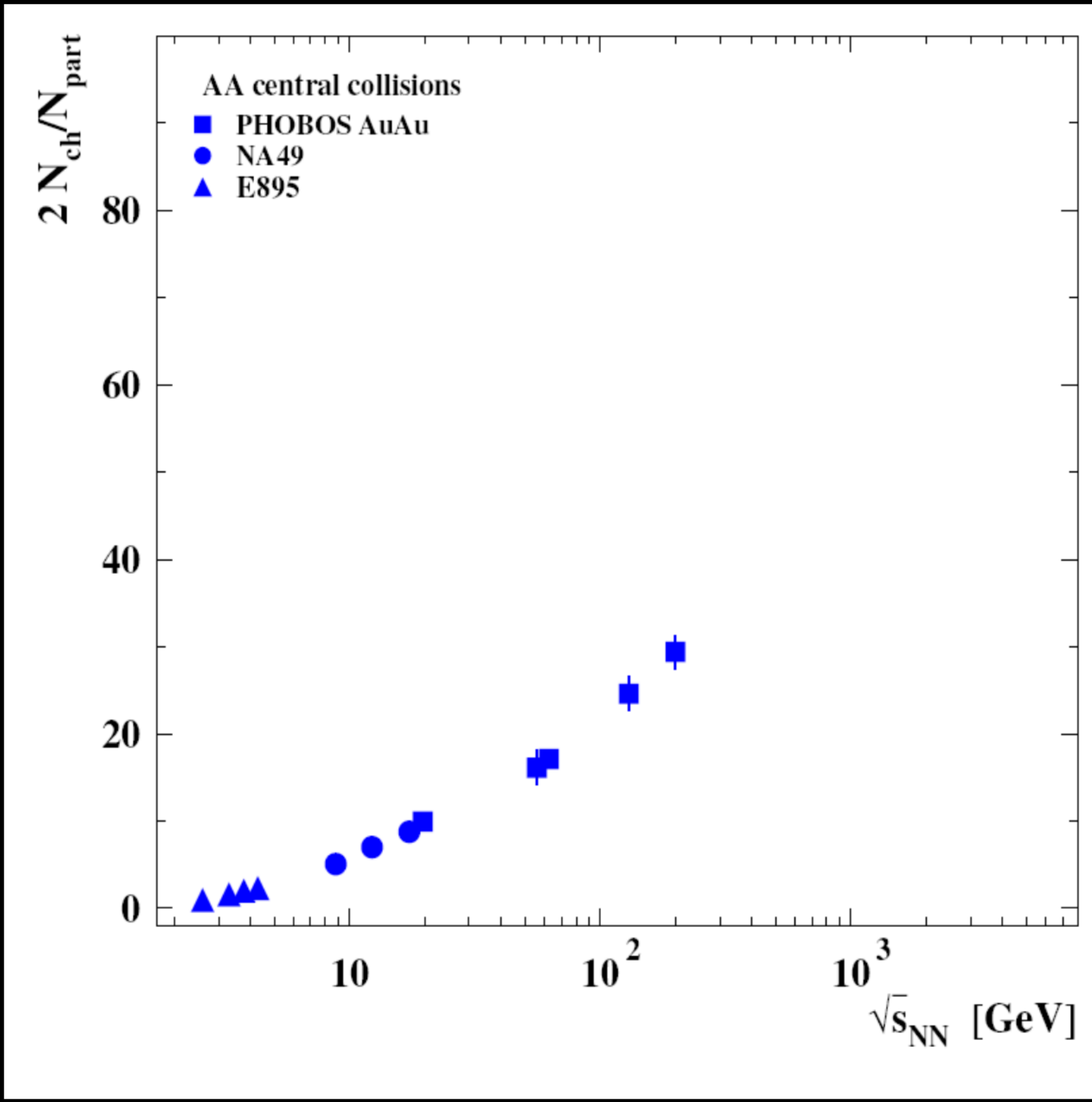
- the same effect in E_T: *similar*
- *description*





From mid-rapidity density to multiplicity

- demonstrates *non-linear log* behaviour with c.m. energy



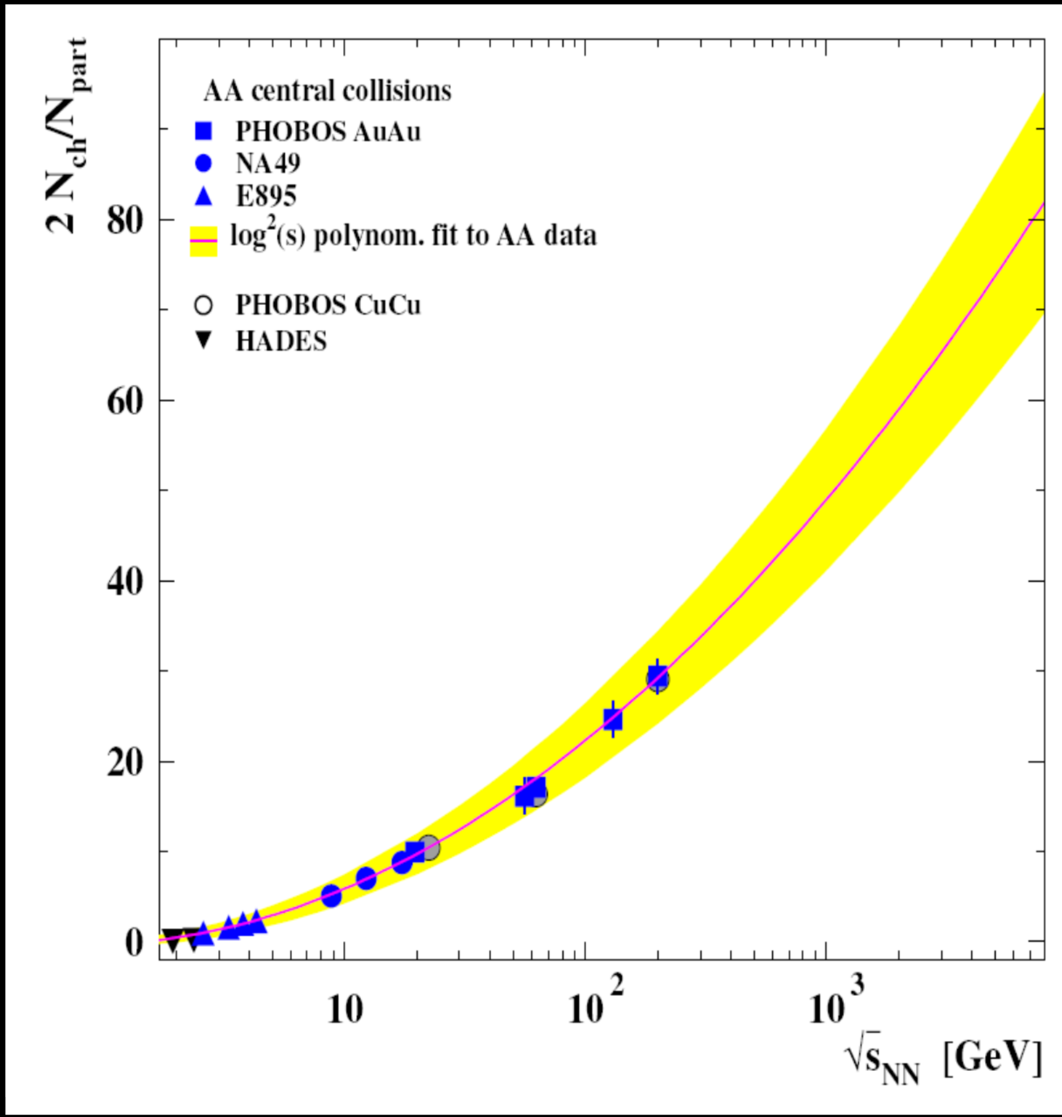
From mid-rapidity density to multiplicity

- demonstrates *non-linear log* behaviour with c.m. energy

- $\log^2(s)$ fit observed in agreement with the Landau model Gussian shape of η-spectrum, log-increase of mid-rapidity density and "limiting fragmentation"

$$N_{\rm ch}/(0.5\,N_{\rm part}) = (-0.35 \pm 0.28) + (0.24 \pm 0.16)\ln(s_{\rm NN}) + (0.24 \pm 0.03)\ln^2(s_{\rm NN})$$

- *same* for different nuclei



From mid-rapidity density to multiplicity

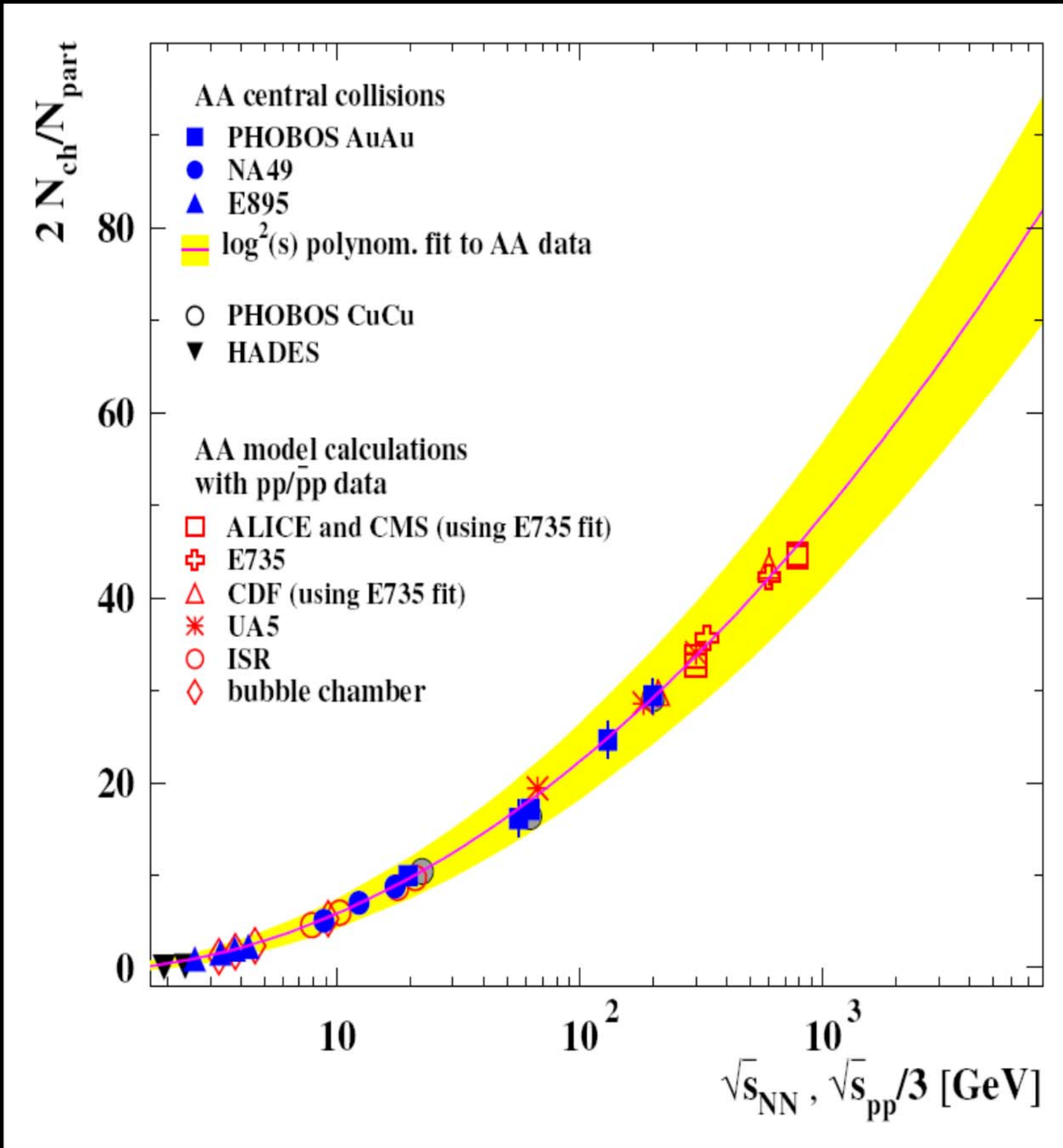
- demonstrates *non-linear log* behaviour with c.m. energy

- from Landau hydrodynamics:

$$\frac{\rho_{NN}(0)}{\rho_{pp}(0)},\quad N_{ch}^{pp} \Rightarrow \frac{2N_{ch}}{N_{part}}$$

- and constituent quark picture:
  for AA m = m_p, for pp m = $m_p/3$
  $\sqrt{s_{NN}} = \sqrt{s_{pp}}/3$

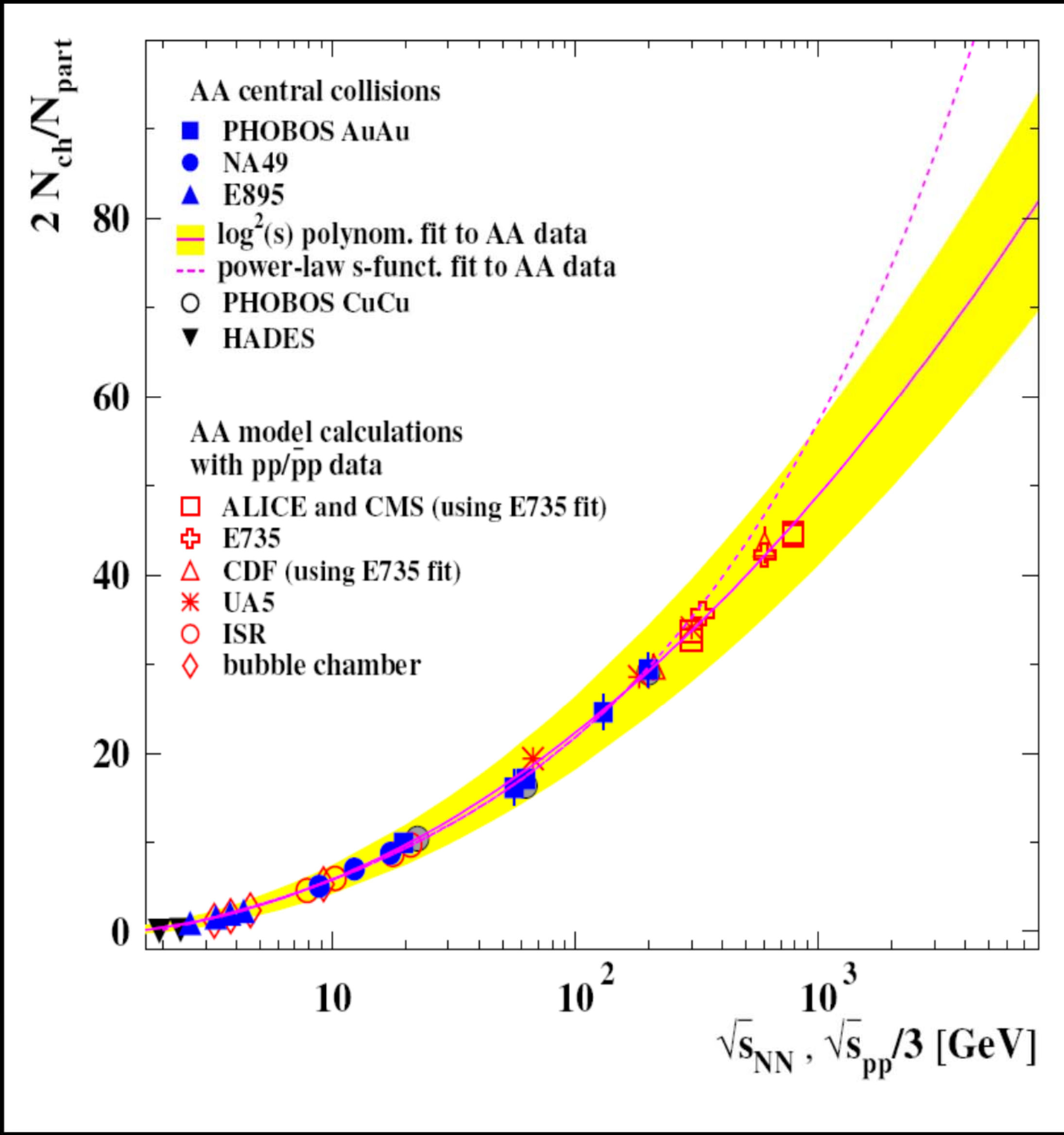
$$\frac{2\,N_{ch}}{N_{part}} = N_{ch}^{pp}\,\frac{\rho(0)}{\rho_{pp}(0)}\sqrt{1-\frac{2\ln 3}{\ln\left(4.5\sqrt{s_{NN}}/m_p\right)}}$$



- calculations agree with AA data

From mid-rapidity density to multiplicity

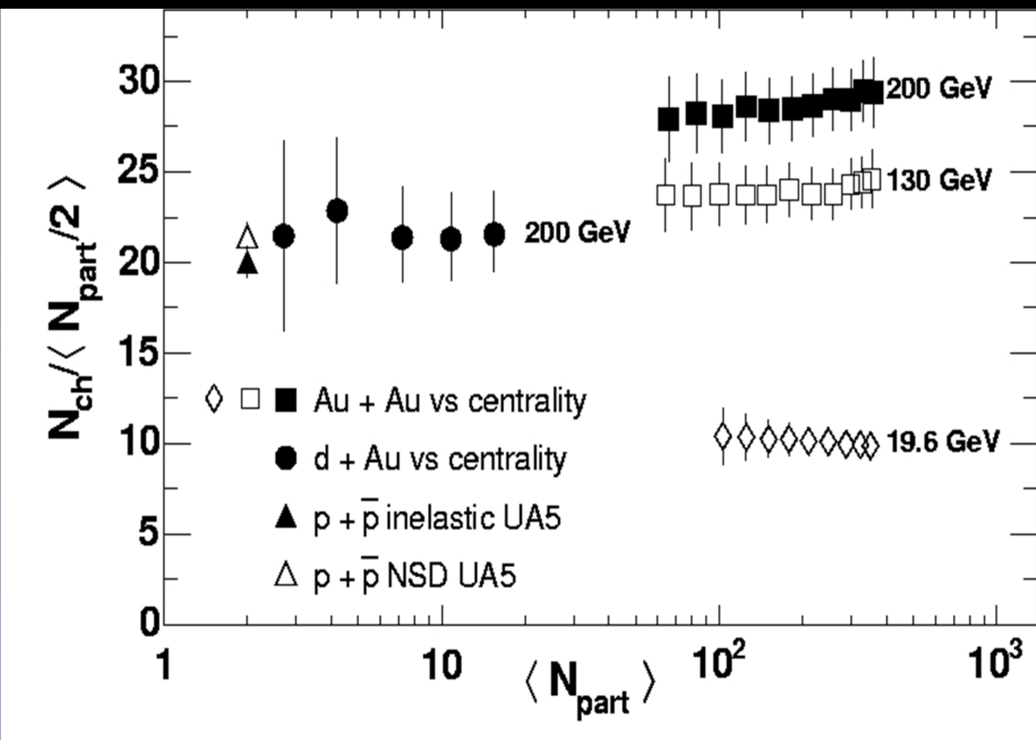
- AA data demonstrates *non-linear log* behaviour with c.m. energy
- *No power-law* fit can be used as high energy data clarifies

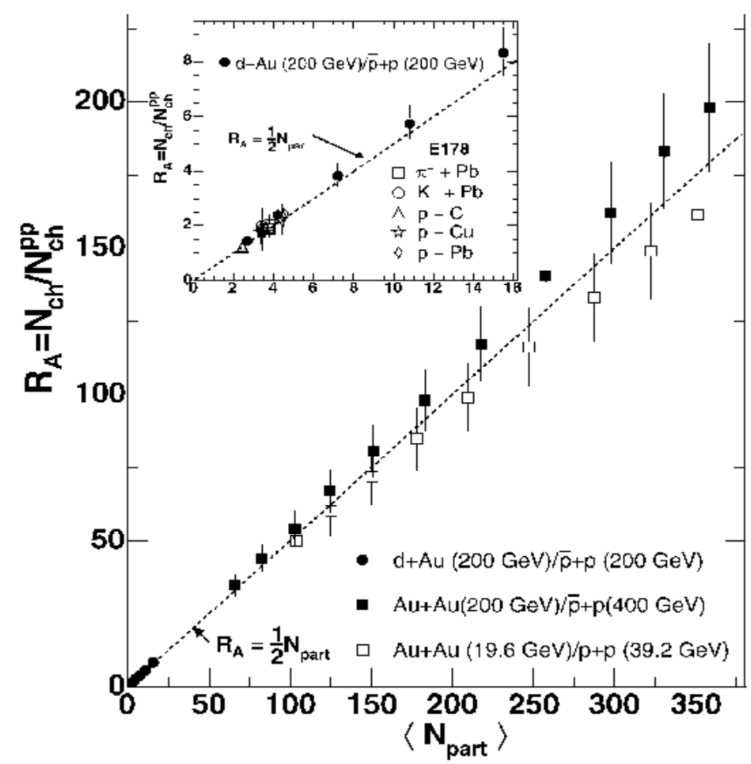


From mid-rapidity density to multiplicity

- pA *similar* to pp data as $\sqrt{s_{NN}} = \sqrt{s_{pp}}$ (Feinberg, 1983)

- No centrality dependence in *pA*





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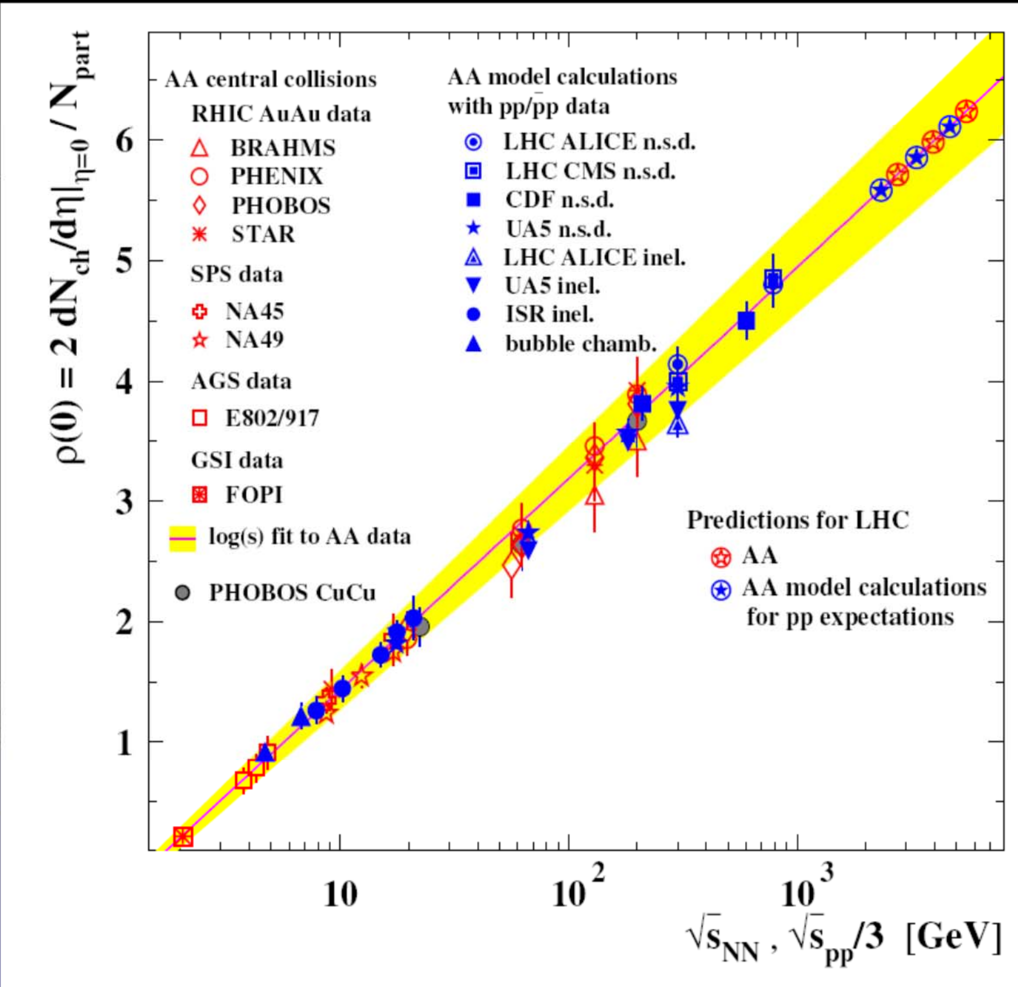
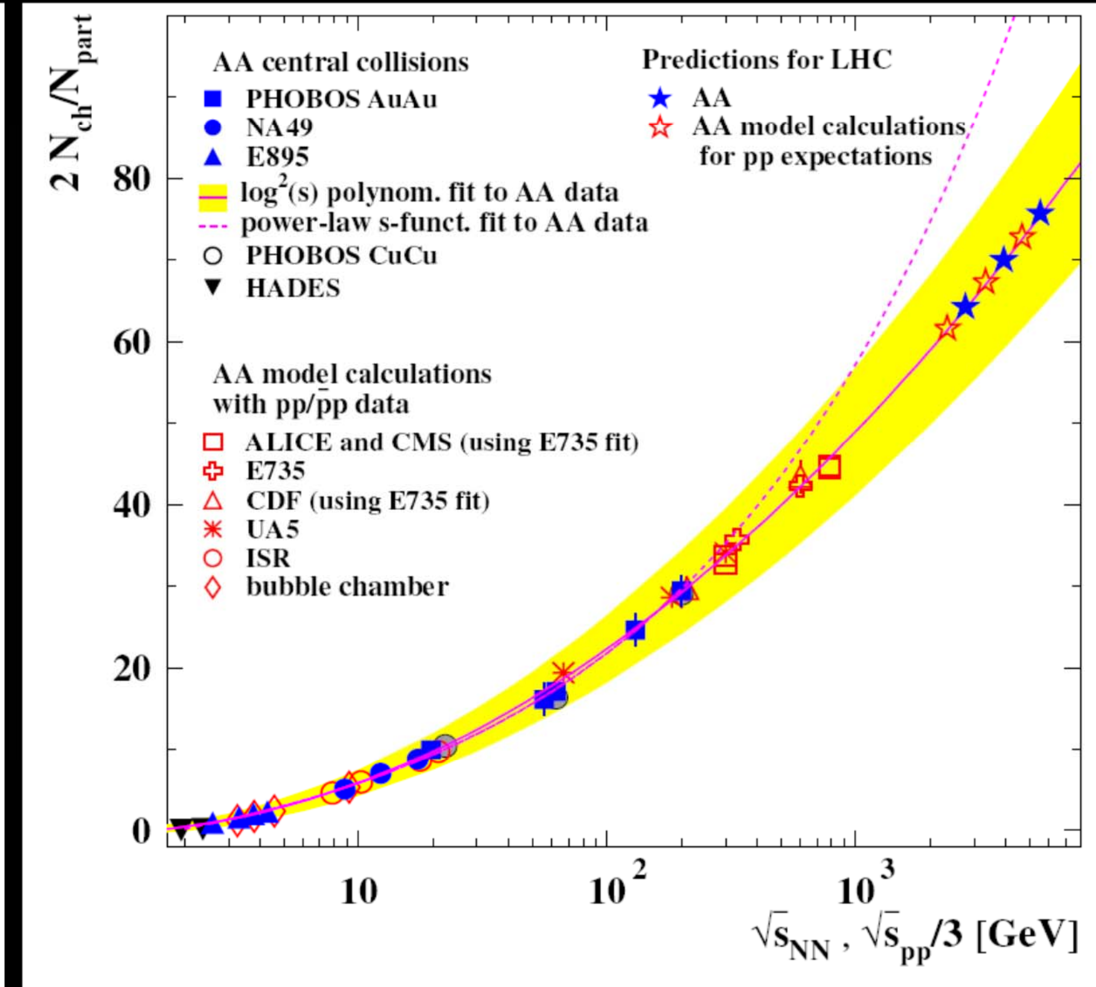
Higher-energy predictions





- our prediction for dN/dη at η≈0 in 7 TeV pp collisions: 5.8 within 10% uncert.
- CMS measurement: 5.78 ± 0.01(stat) ± 0.23(syst)
- AA predictions to be compared soon to the data from LHC (fall 2010)

Conclusions

- Bulk observables (average multiplicity and mid-rapidity density) in pp collisions vs heavy-ion collisions analysed at c.m. energies from a few GeV to hundred GeV per nucleon
- The universality of the hadroproduction process is obtained based on the model considering dissipating energy available at the early stage of collision from interacting participants depending on their types
- In head-on nuclear collisions protons behave as effectively structureless patterns in sense of the energy deposited into hadrons (similar to e^+e^- interactions)
- The bulk observables in heavy-ion collisions are reproduced from those in pp interactions, treated within the constituent quark model and Landau hydrodynamics
- The consequences of the description for pA collisions agree with resent RHIC data
- Available measurements up to the LHC energies agree with the model expectations
- Predictions for the foreseen higher energy AA data from LHC made