System Size Dependence of Particle Production at the SPS

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on Critical Point and
Onset of Deconfinement
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Outline

System size dependence of particle production (at the SPS)

Yields of strange particles and (anti-)protons

Transverse mass and rapidity spectra

Multiplicity fluctuations

What are the general features?

To what extend dominated by geometrical effects?

How to model this and subtract trivial effects?

Core-Corona approach

Where does it work and where not?

Relevance for studies of the QCP phase diagram

How do T and μ_B depend on system size?

Do these parameter really reflect a change of the fireball properties?

Experimental Access to Phase Diagram

High energies (RHIC/LHC)

μ_B small

System reaches QGP phase

Low energies (AGS)

μ_B large

System stays in hadronic phase

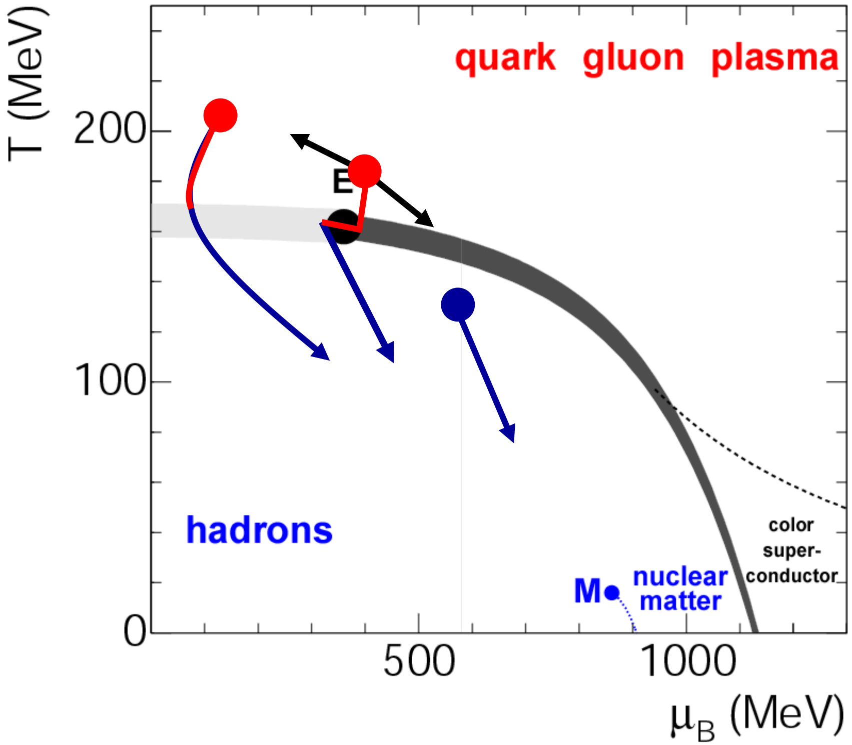
In between (SPS/FAIR/NICA)

Variation of μ_B by changing $\sqrt{s_{NN}}$

Possible to localize critical point?

Other control parameters?

How about system size?

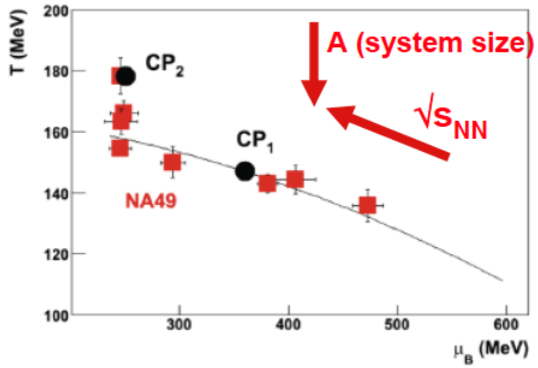


System Size Dependence of T, μ_B

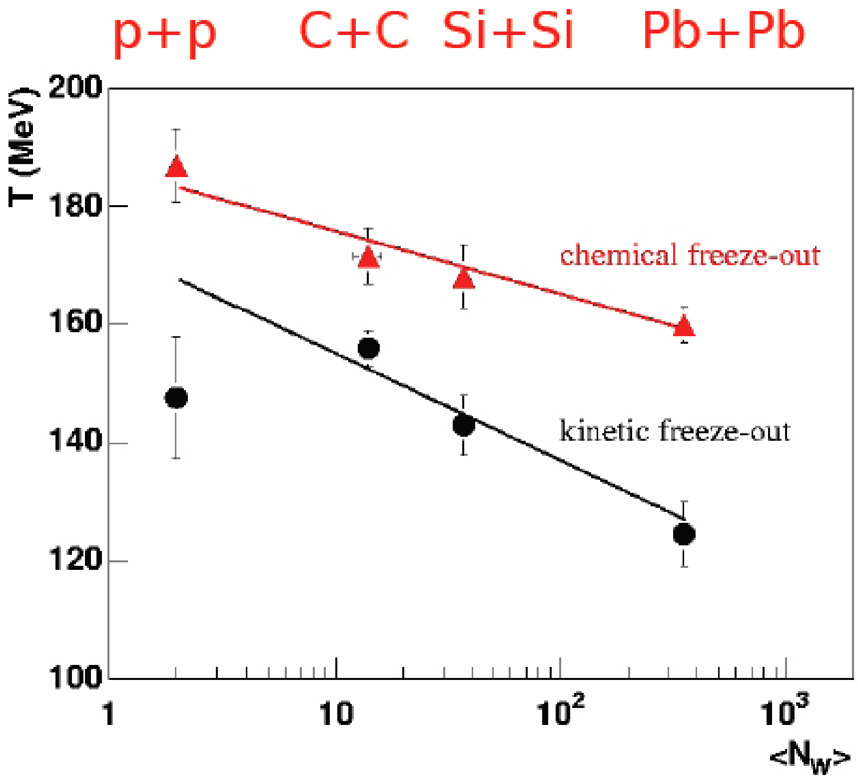
How do freeze-out parameters depend on system size ?

Statistical model fits result in different *T*

Central reactions



Good understanding of underlying effects mandatory



F. Becattini et al.,
Phys. Rev. **C73**, 044905 (2005)

Strangeness Enhancement of Λ, Ξ, and Ω

Enhancement factor

$$E = \frac{2}{\langle N_w \rangle} \frac{dn(Pb+Pb)/dy}{dn(p+p)/dy}$$

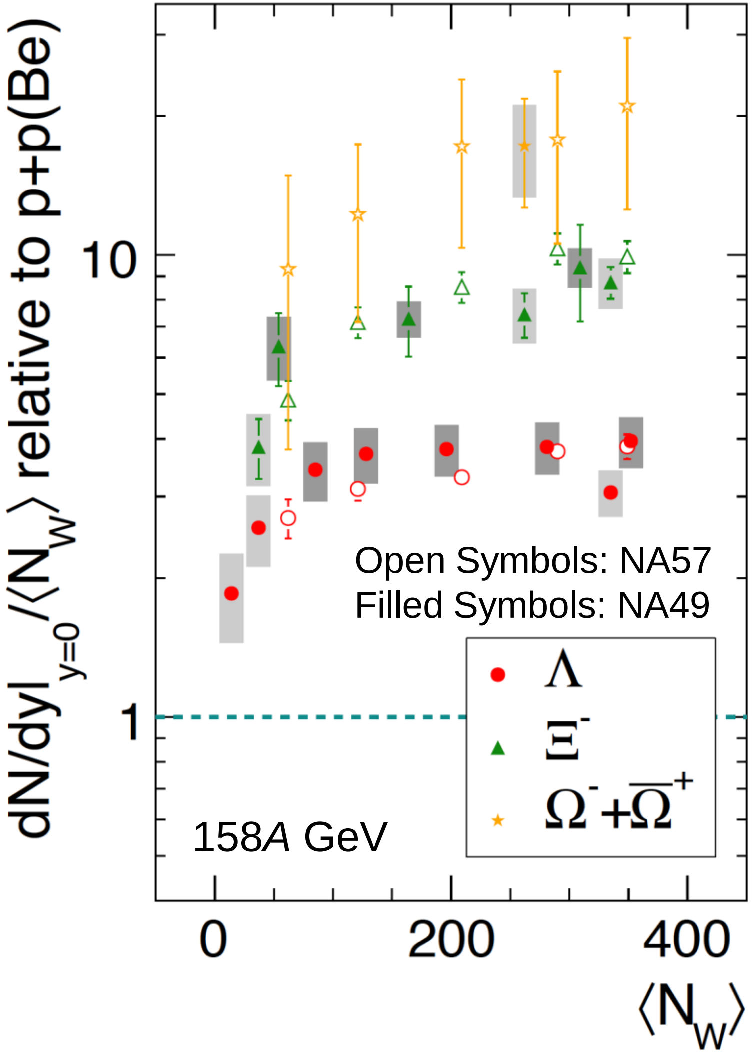
NA49 and NA57 data

Pb+Pb (C+C, Si+Si) at 158*A* GeV

General features

Rapid rise for small systems $\langle N_w \rangle < 60$

Saturation or slow increase for larger systems



Statistical Model: Canonical Suppression

Statistical model

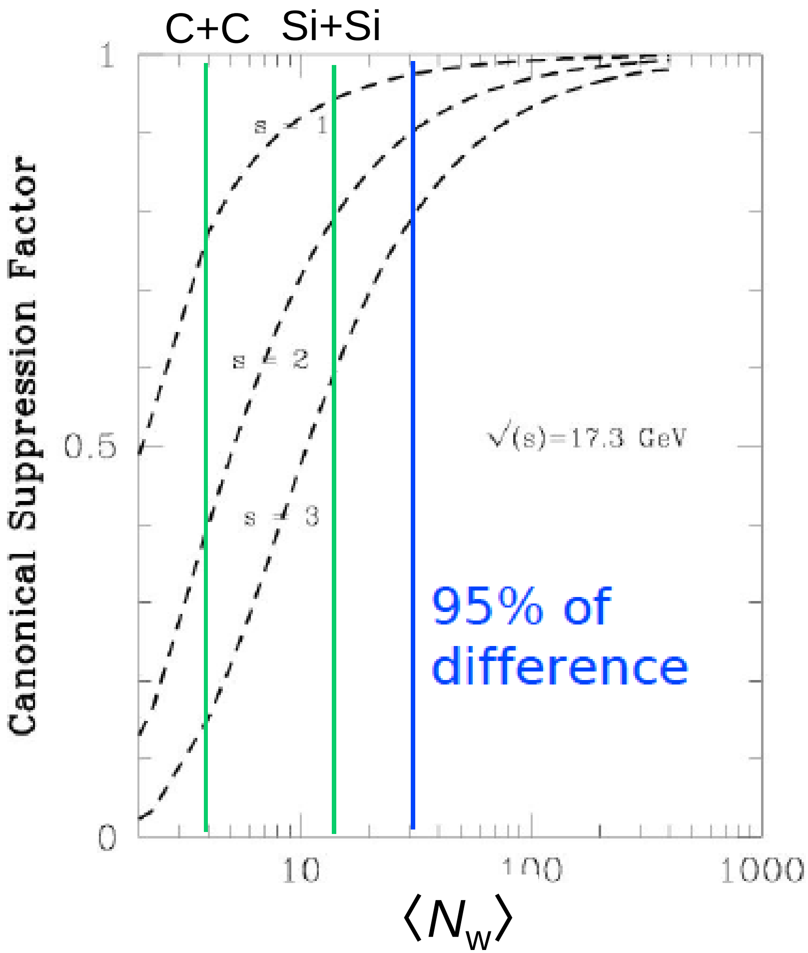
Transition from canonical to grand-canonical description

Hierarchy of suppression depending on strangeness content

Ensemble volume
$V = (V_0/2)\ \langle N_w \rangle$ with $V_0 = 7\ \text{fm}^3$

Onset of suppression does not match data

Model: $\langle N_w \rangle \approx 30$
Data: $\langle N_w \rangle > 60$



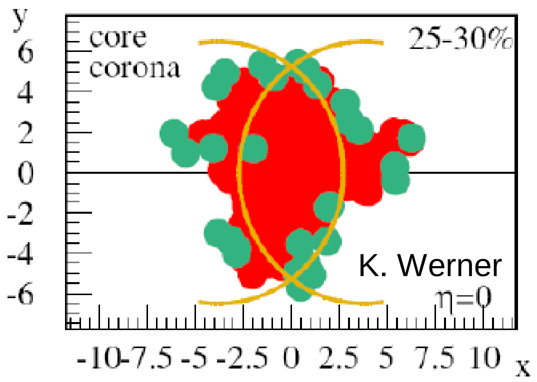
S. Hamieh, K. Redlich and A. Tounsi, Phys. Lett. B **486**, 61 (2000)

Core Corona Model

Two components in A+A collisions: core and corona

Corona:
Elementary nucleon-nucleon collisions → p+p

Core:
Hot and dense fireball → central A+A



System size dependencies determined by ratio core/corona

$f\,(N_W)$ = fraction of nucleons that scatter more than once

$$M(N_w) = N_w\,[f(N_w)M_{core} + (1 - f(N_w))M_{corona}]$$

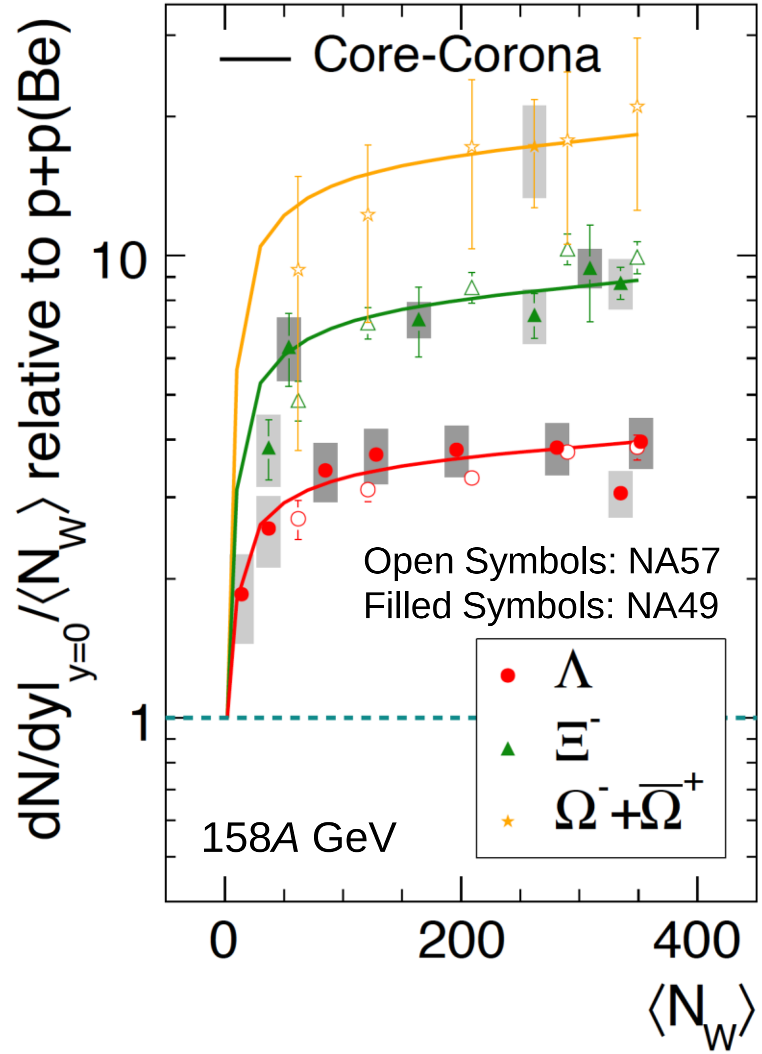
e.g.: EPOS (K. Werner)
Here: Glauber model

P. Bozek, Acta Phys. Polon. **B36**, 3071 (2005).
F. Becattini and J. Manninen, J. Phys. **G35**, 104013 (2008)
J. Aichelin and K. Werner, Phys. Rev. **C79**, 064907 (2009)

Enhancement in Core-Corona Approach

Enhancement factor

$$E = \frac{2}{\langle N_w \rangle} \frac{dn(Pb+Pb)/dy}{dn(p+p)/dy}$$



Core Corona Model

Good description of system size dependences of enhancement factor

Λ, $\bar{\Lambda}$, and Ξ^-

Transport models

dN/dy at mid-rapidity

OK for Λ

Slightly below $\bar{\Lambda}$

Too low for Ξ

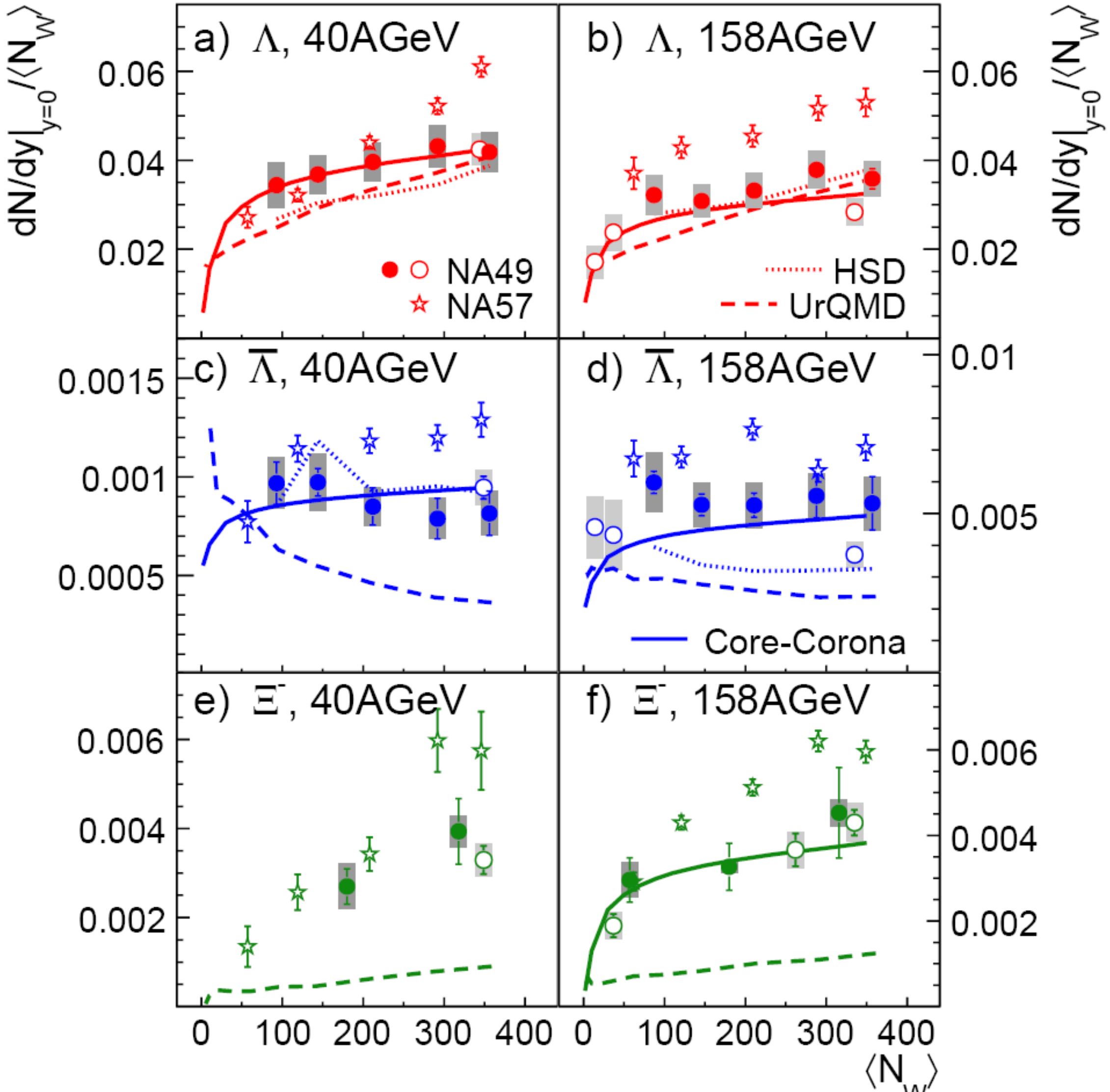
UrQMD: H. Petersen et al.
arXiv: 0903.0396

HSD: W. Cassing and
E. Bratkovskaya,
Phys. Rep. **308**, 65 (1999)
and private communication

Core Corona model

OK for Λ and Ξ

Also for $\bar{\Lambda}$?



Average Transverse Mass: $\langle m_t \rangle - m_0$

System size dependence similar to particle yields

Mid-rapidity data, (anti-)protons

Core Corona model

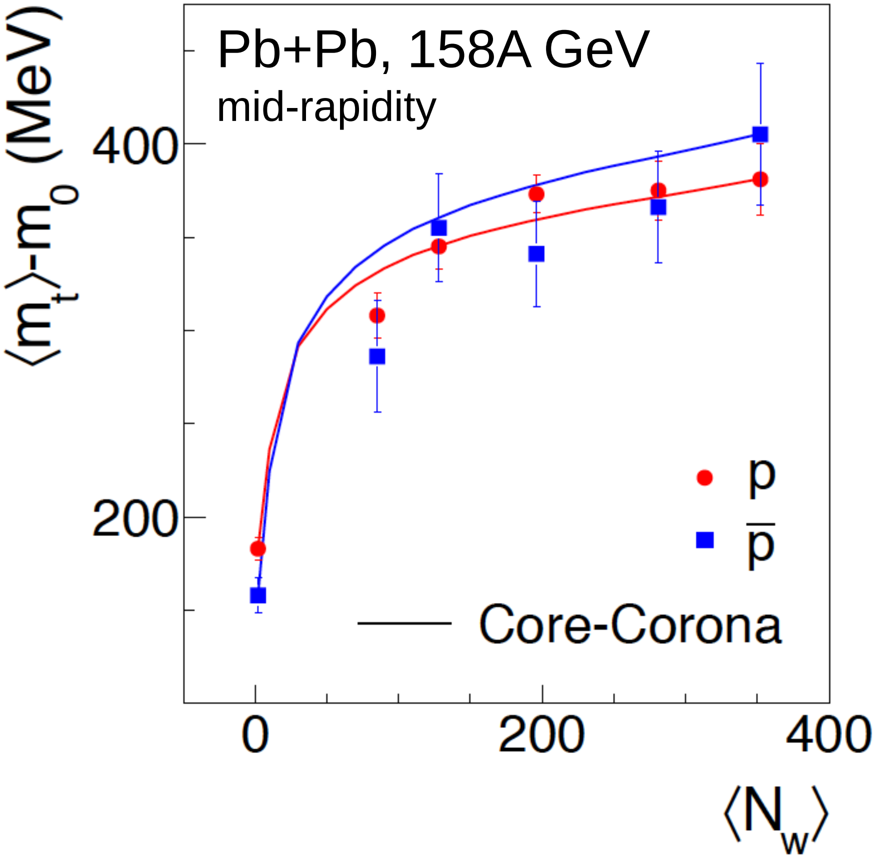
$f(N_W)$ = fraction of nucleons, that scatter more than once

$$\langle m_t \rangle (N_w) = N_w \left[f(N_w) \langle m_t \rangle_{core} + (1 - f(N_w)) \langle m_t \rangle_{corona} \right]$$

→ Reasonable description

NA49 data:

Phys. Rev. **C73**, 044910 (2006)

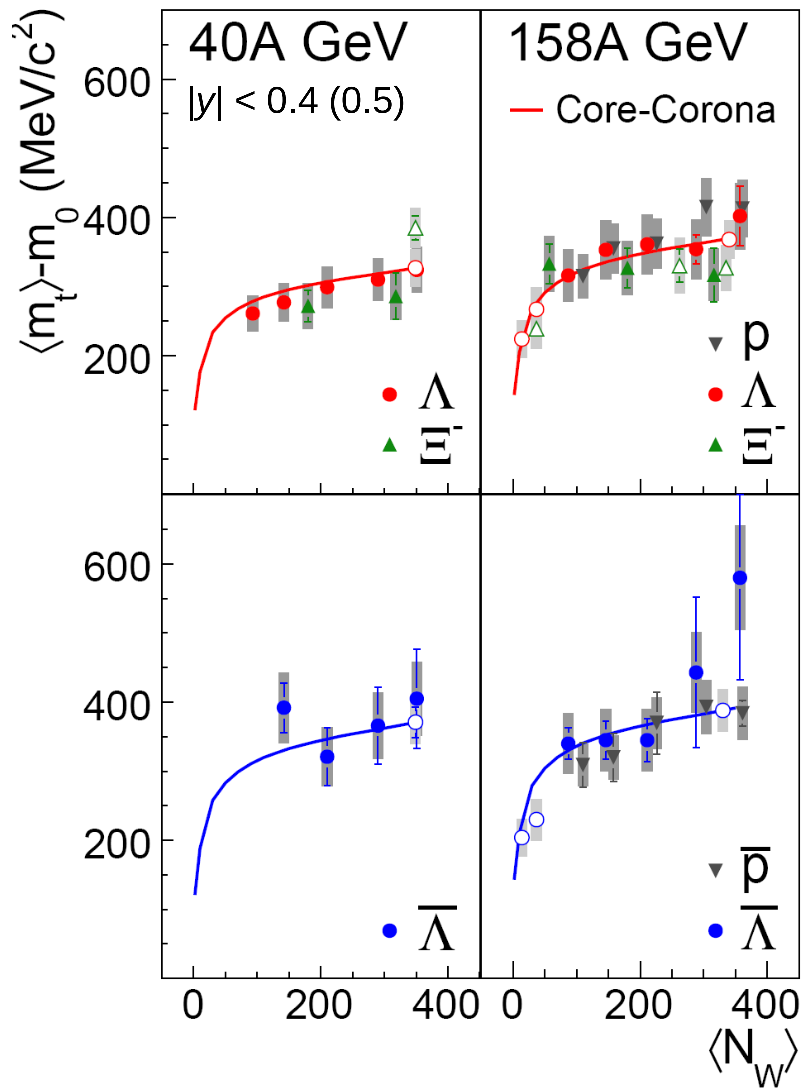


Average Transverse Mass: $\langle m_t \rangle - m_0$

System size dependence similar to particle yields
Mid-rapidity data, Hyperons

Core Corona model
→ Reasonable description also for Λ and Ξ

NA49 data:
Phys. Rev. **C80**, 034906 (2009)



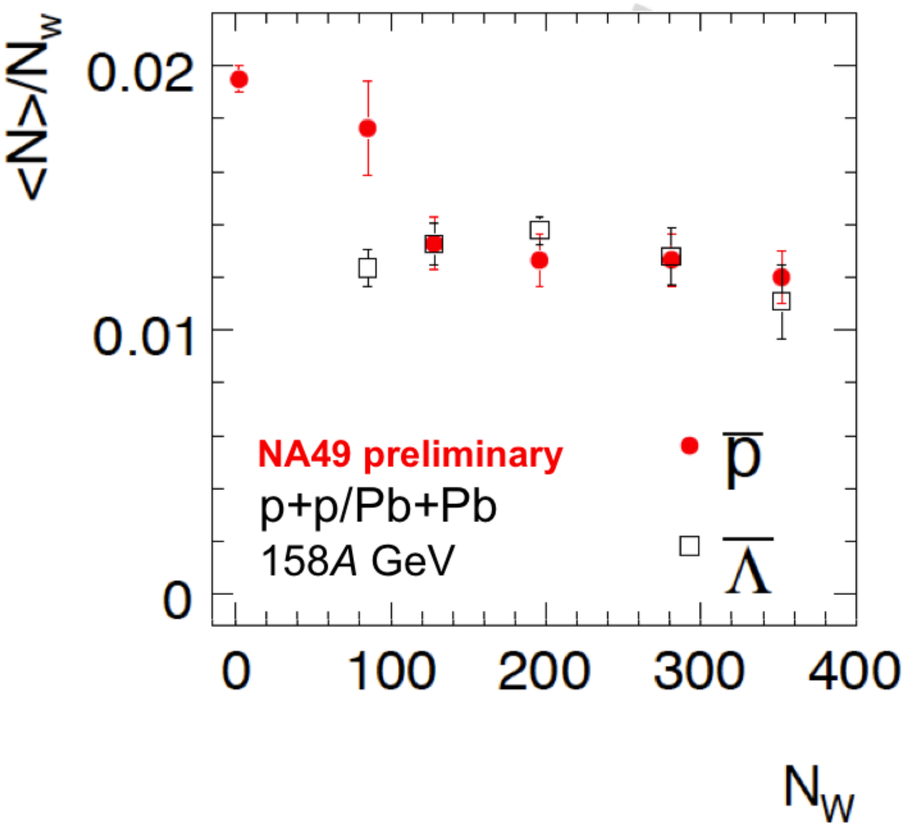
Antibaryons

4π yields of $\bar{p}$ and $\bar{\Lambda}$

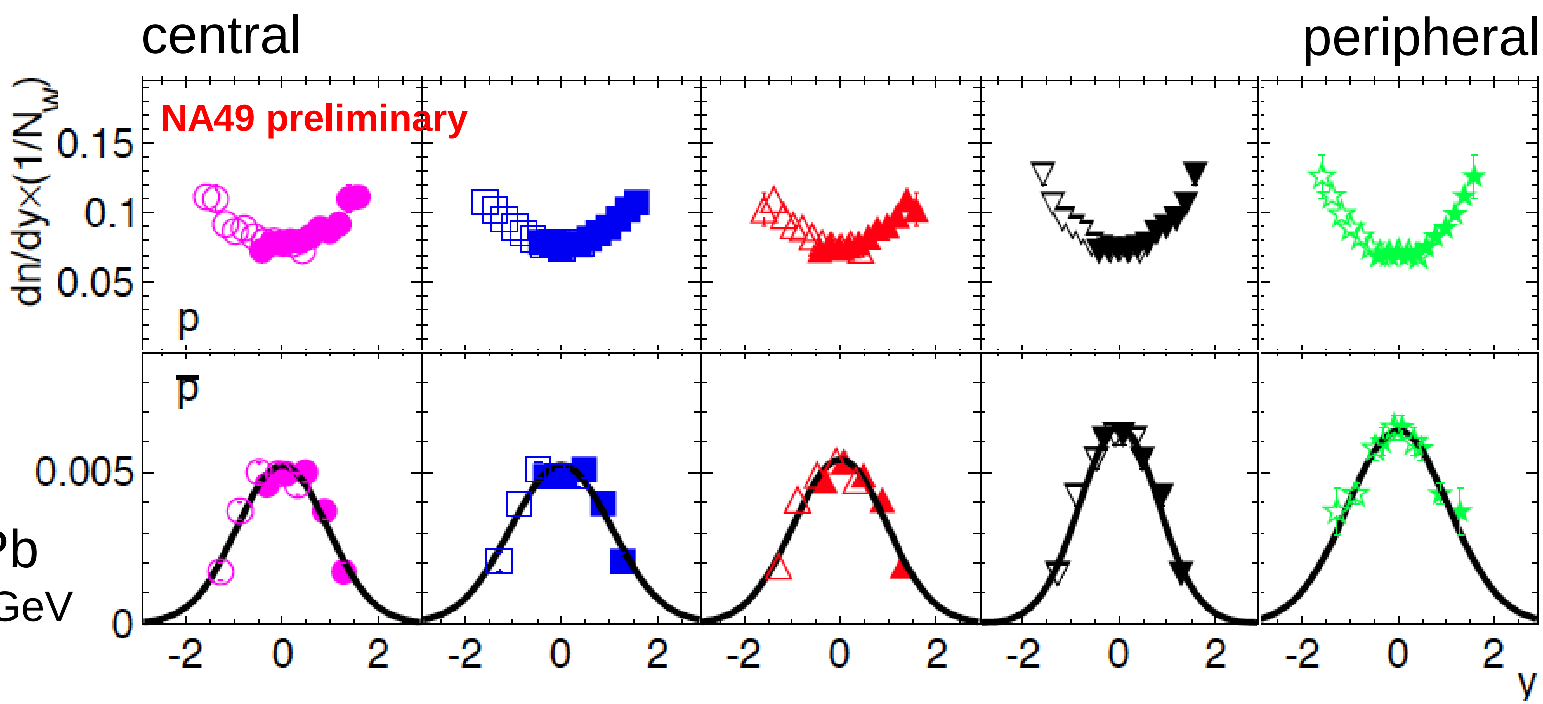
Different system size dependence compared to baryons

Absorption effects (?)

More complicated physics than in core-corona picture



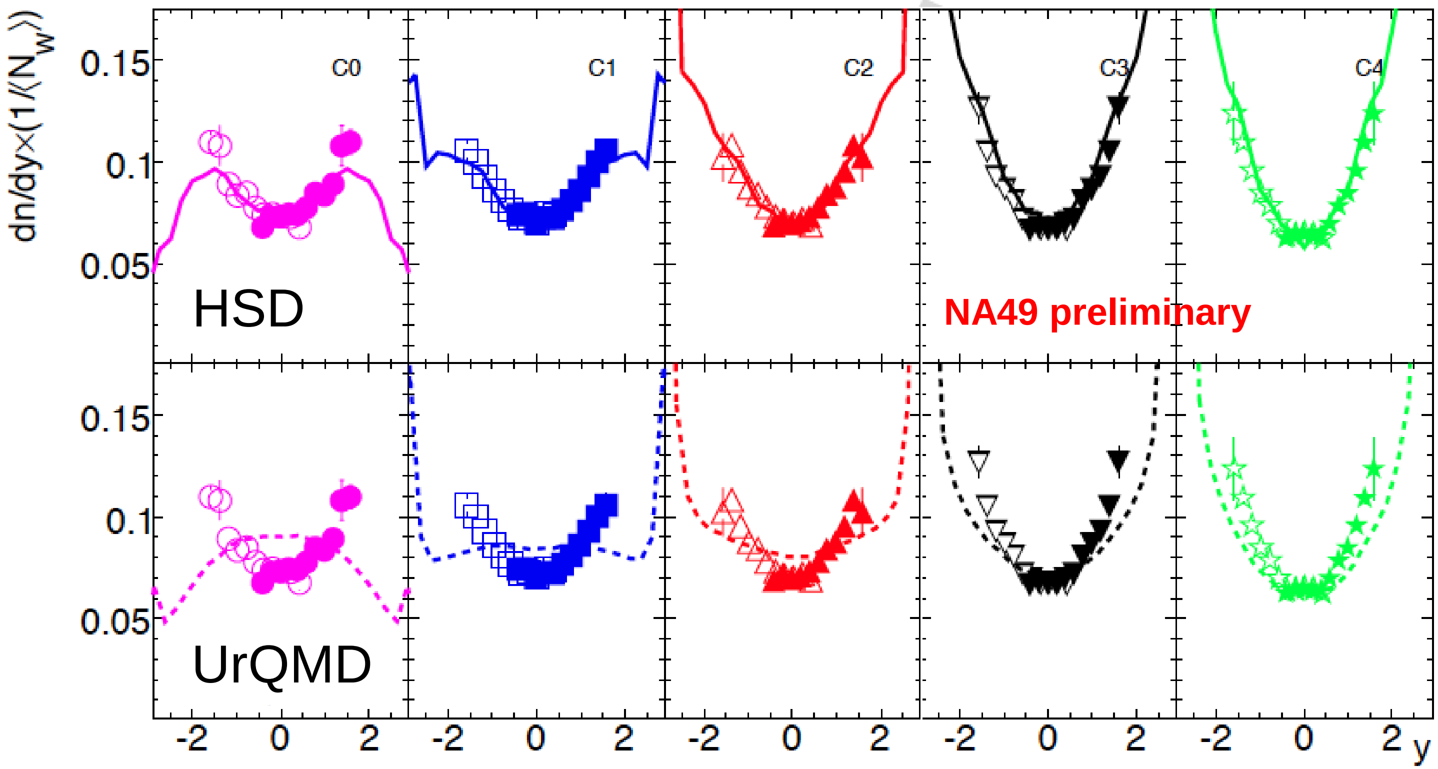
Rapidity Distributions: (Anti-)Protons



Pb+Pb
158*A* GeV

How about system size dependence away from mid-rapidity?
→ Net-protons (stronger variation of yields at forward rapidities)

Rapidity Distributions: (Anti-)Protons



Pb+Pb
158*A* GeV

Comparison to transport models
HSD and UrQMD

Non trivial evolution of longitudinal shapes

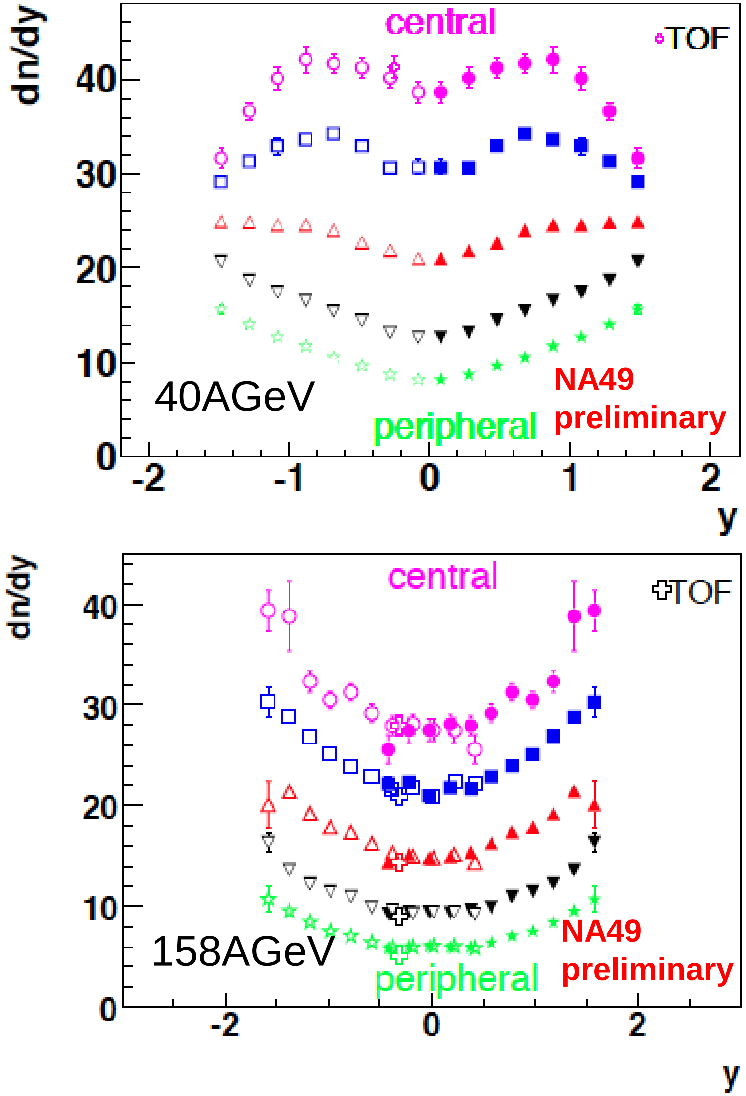
Rapidity Distributions: Net-Protons

Pb+Pb collisions
40*A* and 158*A* GeV

Stronger change of shape at 40*A* GeV
Dip → valley

At 158*A* GeV major change outside of measured *y* region

But p+p reference available at 158 GeV
T. Anticic et al.,
EPJC **65**, 9 (2010).



Mid-Rapidity ↔ Forward Rapidity

Comparison of net-protons

Mid-rapidity and forward rapidity

Core Corona model

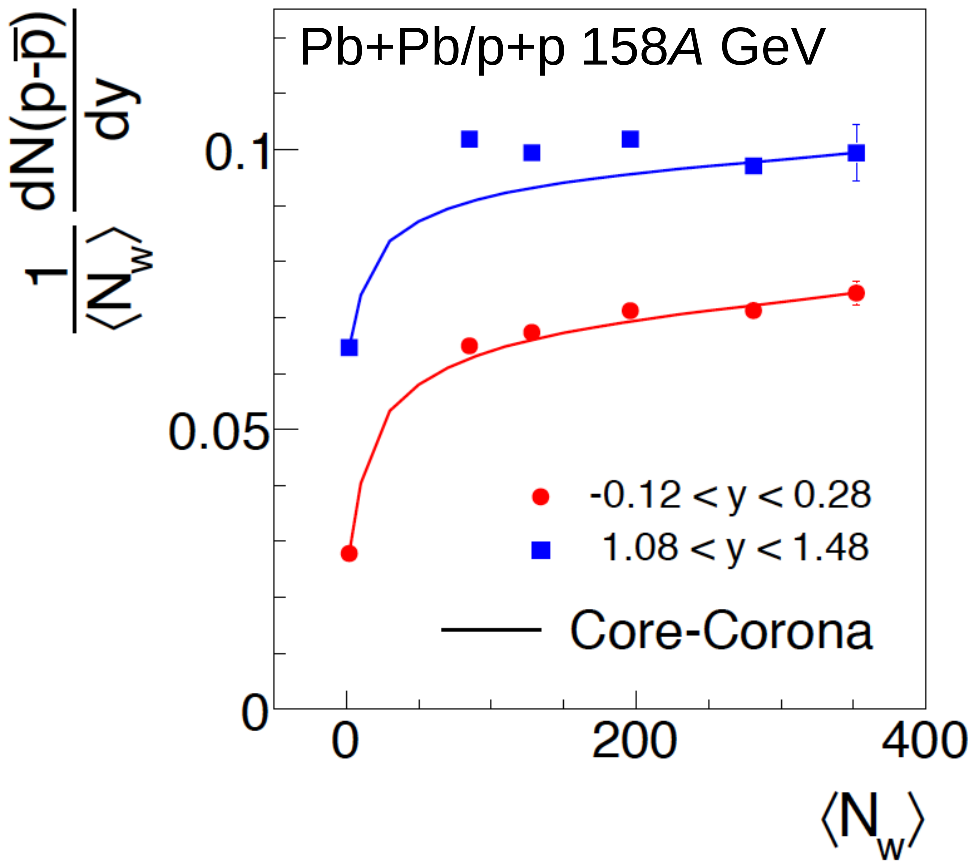
Works at mid-rapidity

Not as good at forward rapidities

Baryon stopping

Different physics involved than in particle production around mid-rapidity

Nucleon needs to be hit only once



Core-Corona: Central ↔ Peripheral

Core Corona model
$f(N_{part})$ = fraction of nucleons, that scatter more than once

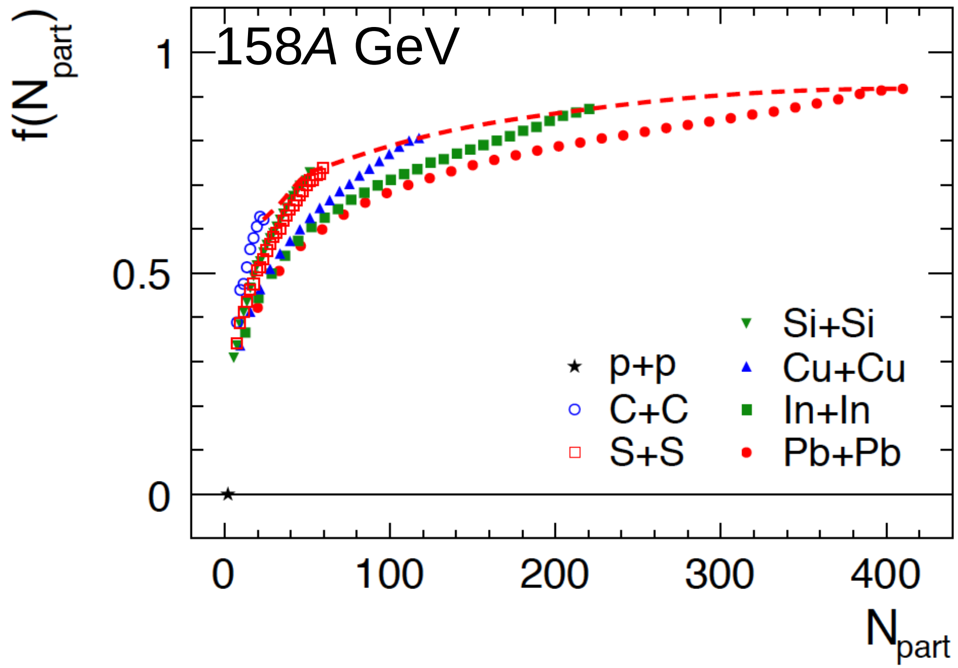
Centrality dependence
Stronger for smaller systems

Central reactions
Still clear change of f_{max} with system size

Compare f_{max}(Pb+Pb) ≈ 0.9
and f_{max}(C+C) ≈ 0.65

⇒ apparent change of $T + \mu_B$

Not real, just different mixture of core and corona



Different system sizes will not probe different T, μ_B
Different core corona mixtures, even for very central events

Core-Corona: Asymmetric Systems

Core Corona model

$f(N_{part})$ = fraction of nucleons, that scatter more than once

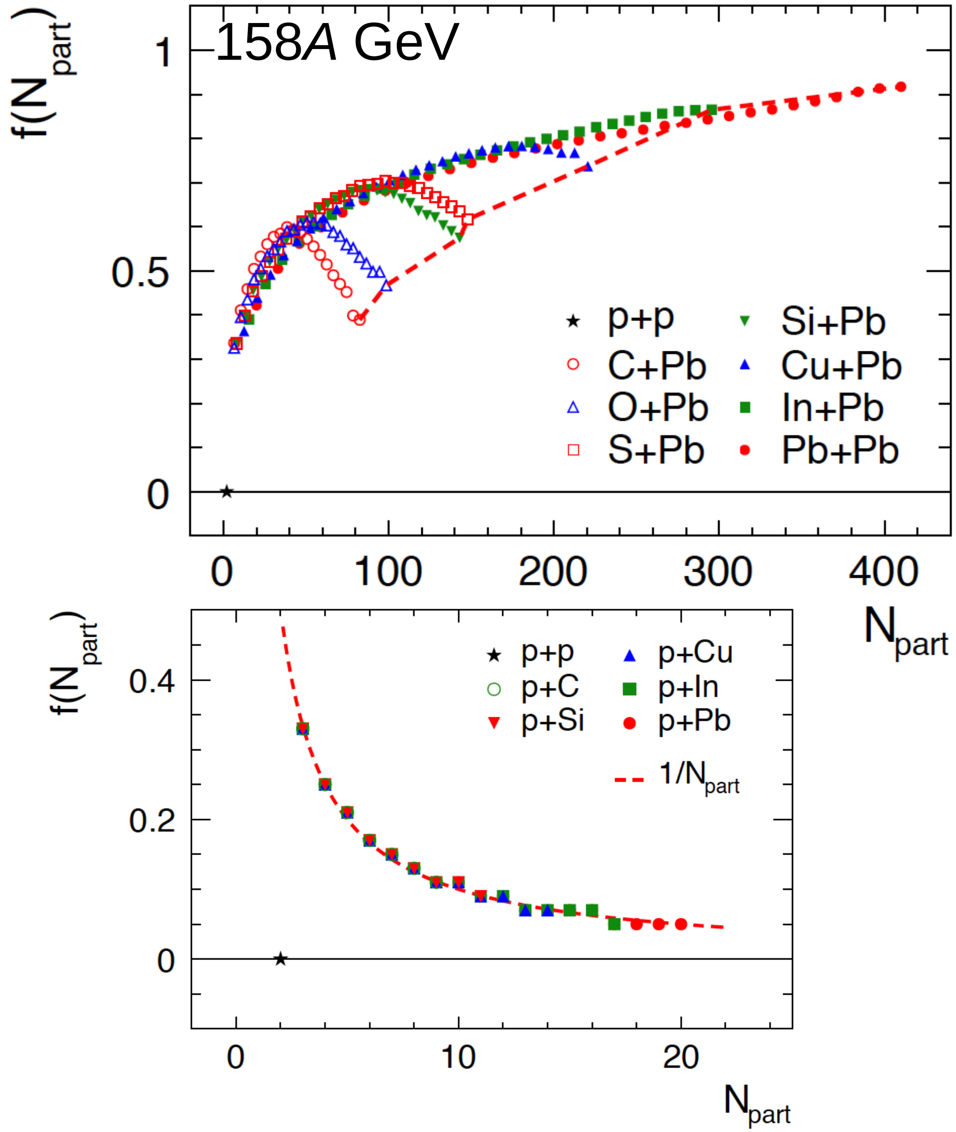
Centrality dependence

Peculiar shape for small projectiles (e.g. C, O, Si, S)

Limiting case: p + A

$f(N_{part}) = 1 / N_{part}$

Model applicable in p+A?
First attempt in T. Šuša et al., Nucl. Phys. **A698** (2002) 491c



p+A Collisions

No clear evidence for decrease with N_{part}

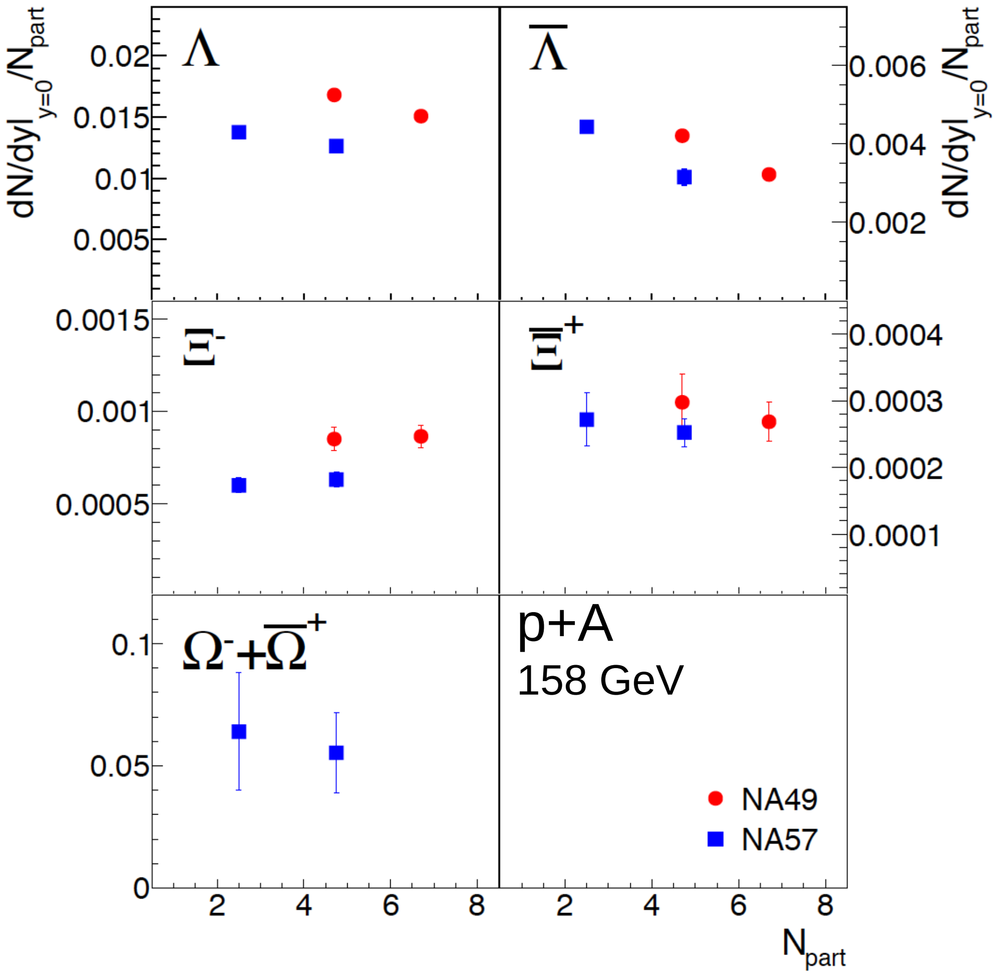
Significant decrease visible only for anti-lambda

Data not fully consistent

But also: incoming nucleon with N_{coll} > 1 not equivalent to central fireball in A+A (→ core)

NA57: F. Antinori et al., J. Phys. **G32** (2006) 427

NA49: T. Šuša et al., Nucl. Phys. **A698** (2002) 491c



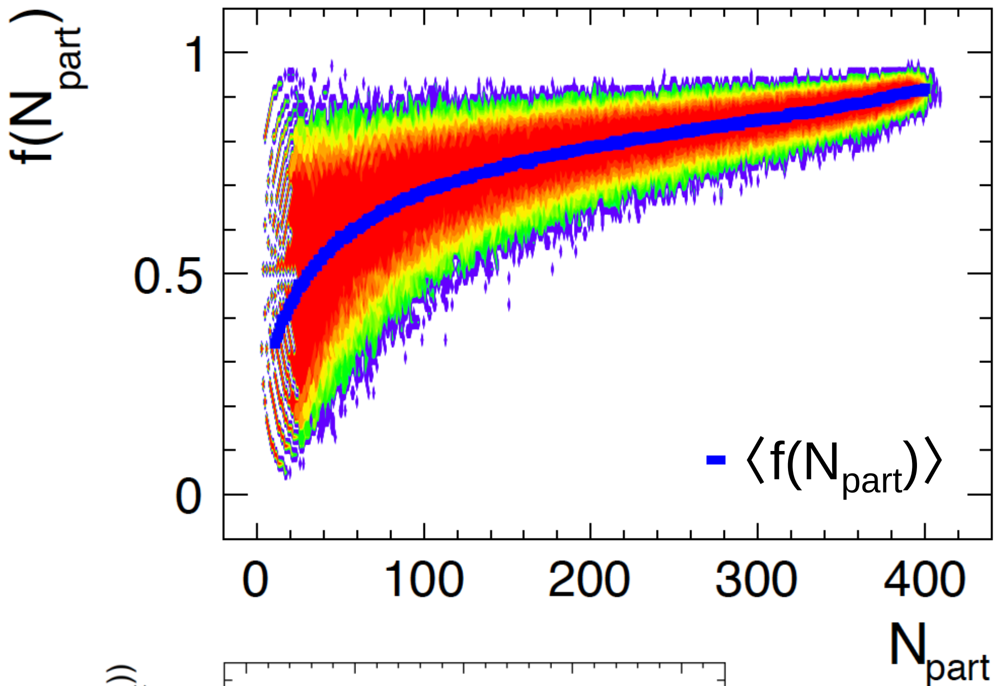
Fluctuations in Core Corona Approach

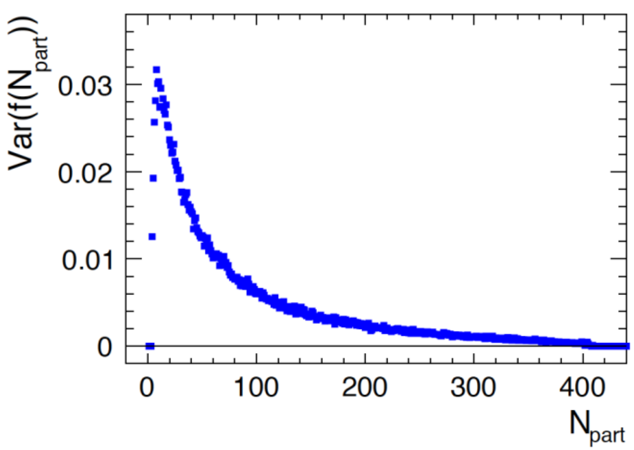
Var(*f*) increases towards peripheral

Creates multiplicity fluctuations

If d*n*/d*y*(core) and d*n*/d*y*(corona) are different

Also for perfect centrality selection (i.e. N_{part} = const.)





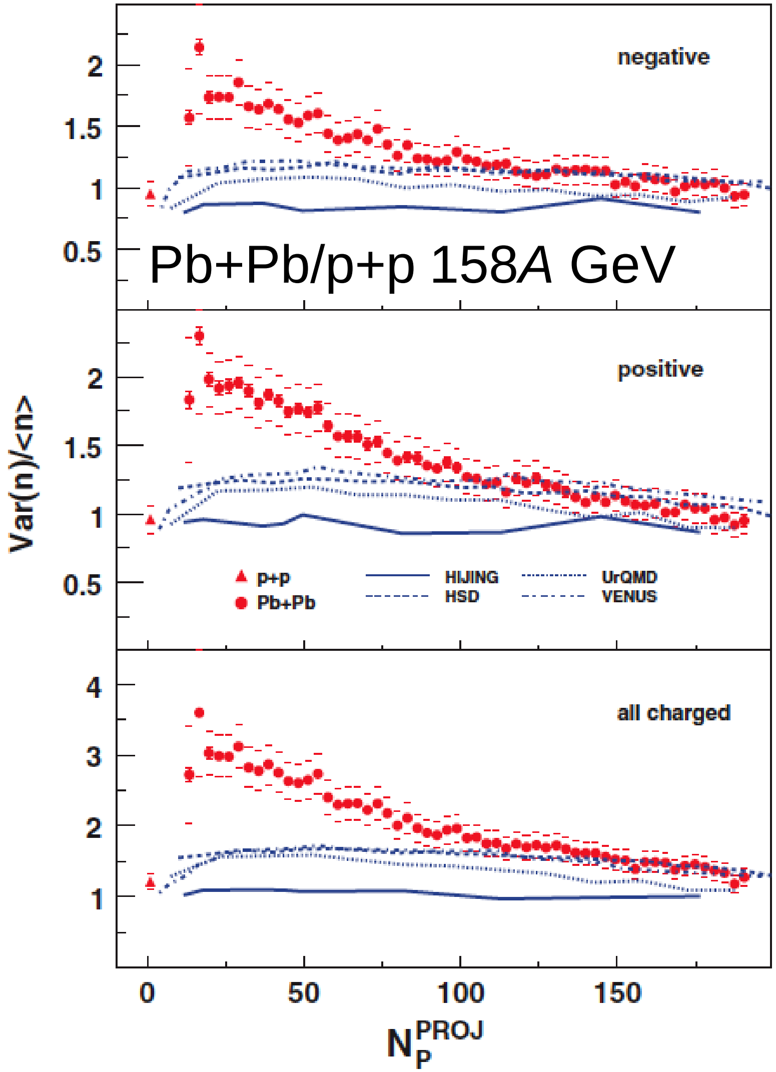
Multiplicity Fluctuations

Multiplicity fluctuations

Similar N_{part} dependence as Var(f)

NA49 data:

Phys. Rev. **C75**, 064904 (2007)



Toy Model Study

Core: large source

$$f(N_{part})N_{part}\frac{1}{N_{part}}\frac{dn}{dy}\bigg|_{core}$$

with: $\frac{1}{N_{part}}\frac{dn}{dy}\bigg|_{core} = 0.954$

($\pi^{\pm}$ in central Pb+Pb at 158A GeV)

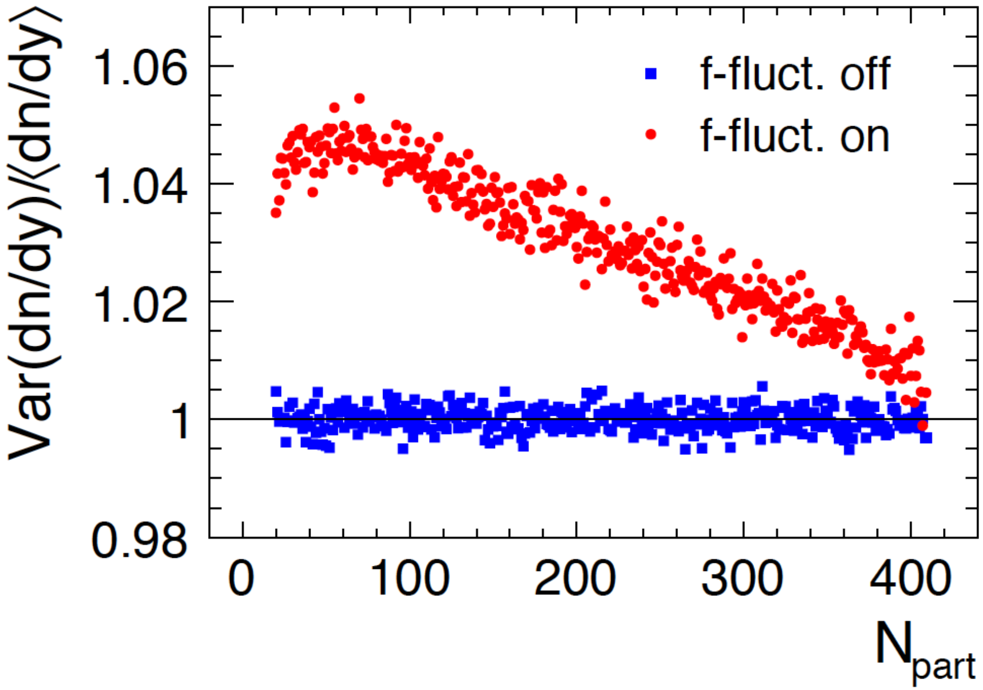
Corona: (1–*f*) sources

with: $\frac{1}{N_{part}}\frac{dn}{dy}\bigg|_{corona} = 0.707$

($\pi^{\pm}$/2 in p+p at 158A GeV)

Fluctuations:

Individual sources: Poisson
f : distributions from Glauber



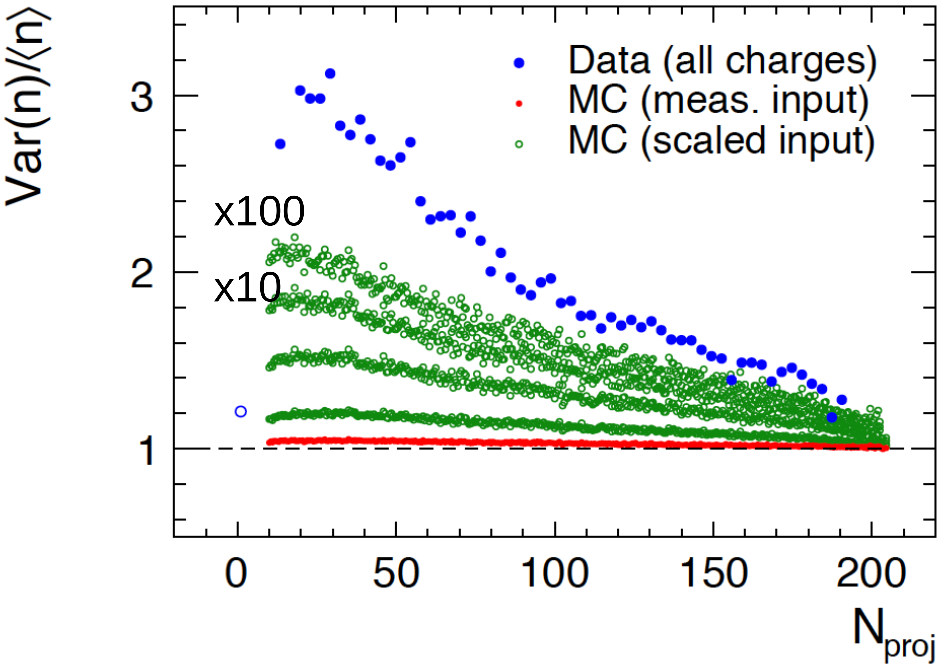
Comparison: Toy Model ↔ Data

MC way below data !
Dominated by volume (N_{part}) fluctuations

Scaled input

$$\frac{1}{N_{part}} \frac{dn}{dy}\bigg|_{core} = 1.0$$

$$\frac{1}{N_{part}} \frac{dn}{dy}\bigg|_{corona} = 0.5, \quad 0.25, \quad 0.1, \quad 0.01$$



Core corona fluctuations do not contribute significantly to observed multiplicity fluctuations

Conclusions

Common behavior of system size dependencies

Yields of produced (strange) particles

Average transverse masses

Exceptions: Antibaryons ($\bar{p}$, $\bar{\Lambda}$) → Absorption?

Net-protons of forward rapidities → Stopping

Core Corona Approach

Good description of most observable (with above exceptions)

Baseline for non-trivial effects

Could further be tested by asymmetric collisions

No significant contribution to multiplicity fluctuations

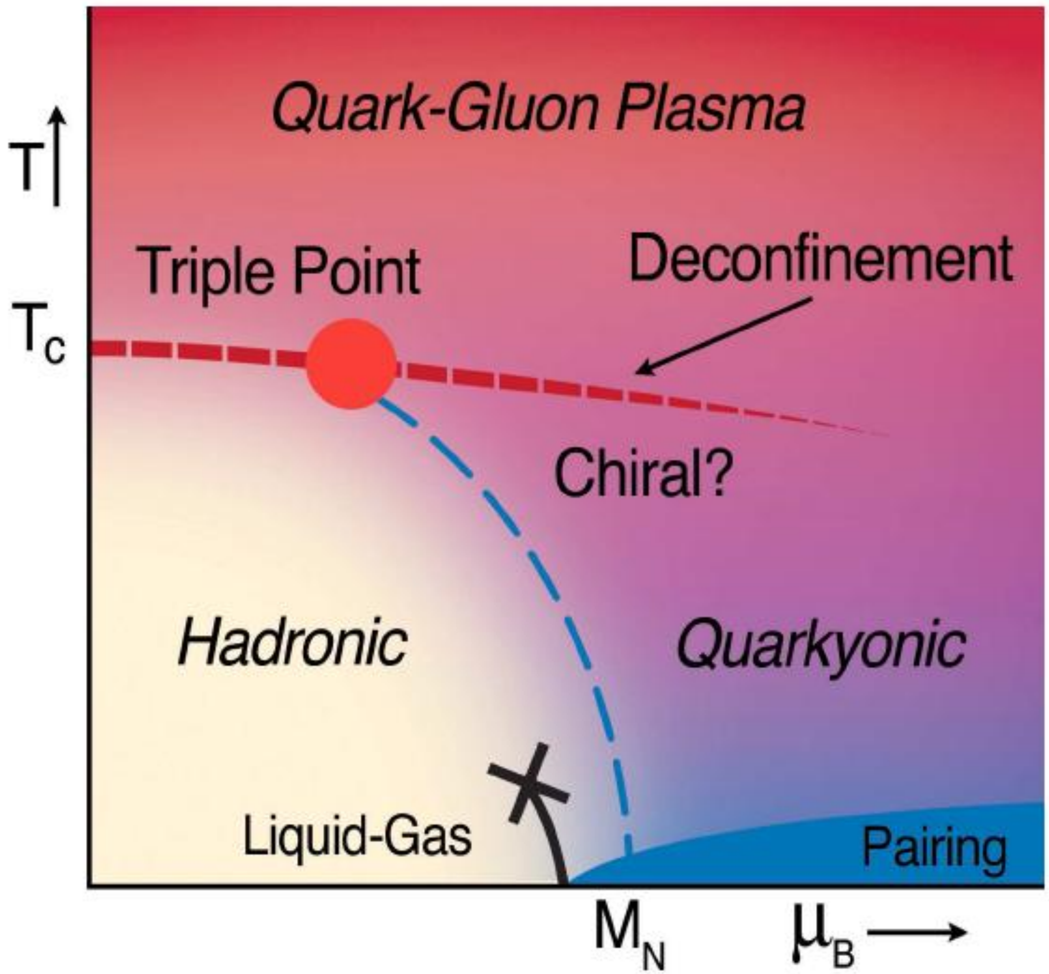
System size as control parameter for phase diagram

Changes only relative contribution of core and pp-like corona (if core-corona ansatz holds)

Change in T only apparent, μ_B = const.

Backup

QCD Phase Diagram



A. Andronic et al., arXiv: 0911.4806

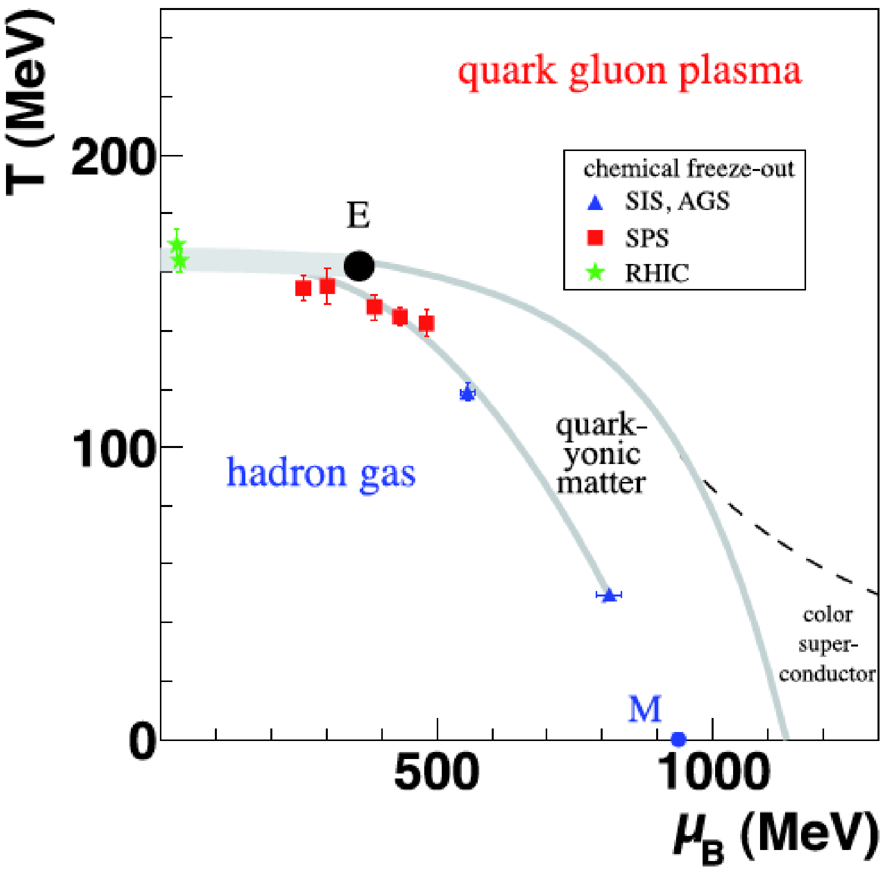
L. McLarren and R.D. Pisarski, Nucl. Phys. **A796,** 83 (2007).

Chemical Freeze-Out Points

Results from different beam energies

Analysis of particle yields with statistical models

Freeze-out points reach QGP phase boundary at top SPS energies



System Size Dependence
Net-Protons

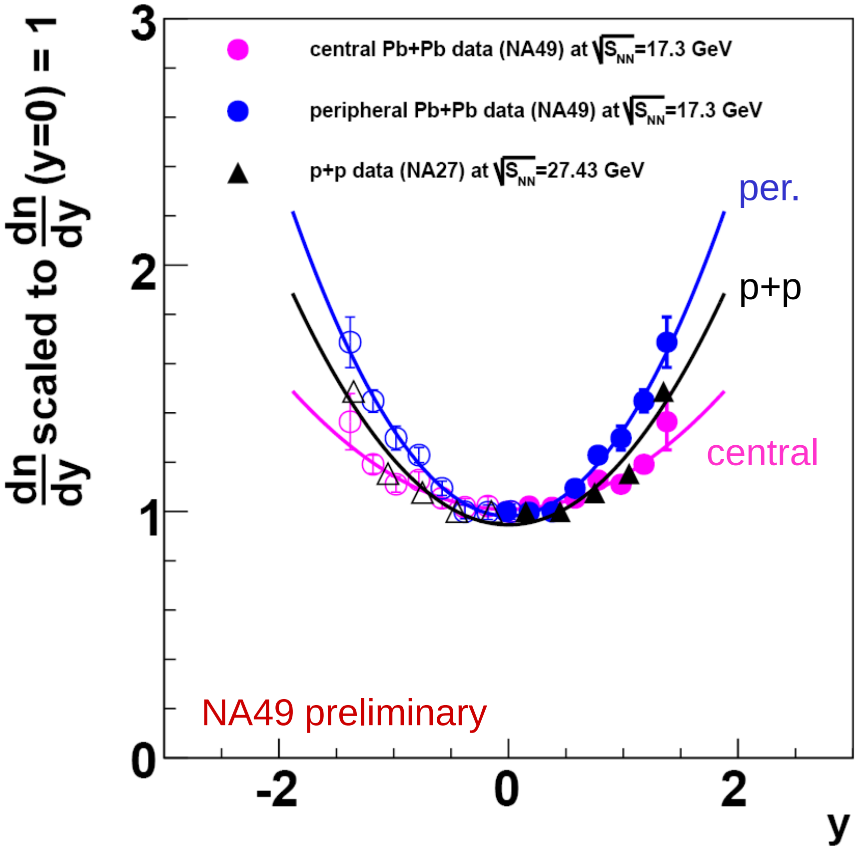
No strong system size dependence observed

Peripheral spectrum slightly more pronounced *y*-dependence than central one

Beam rapidity not measured!

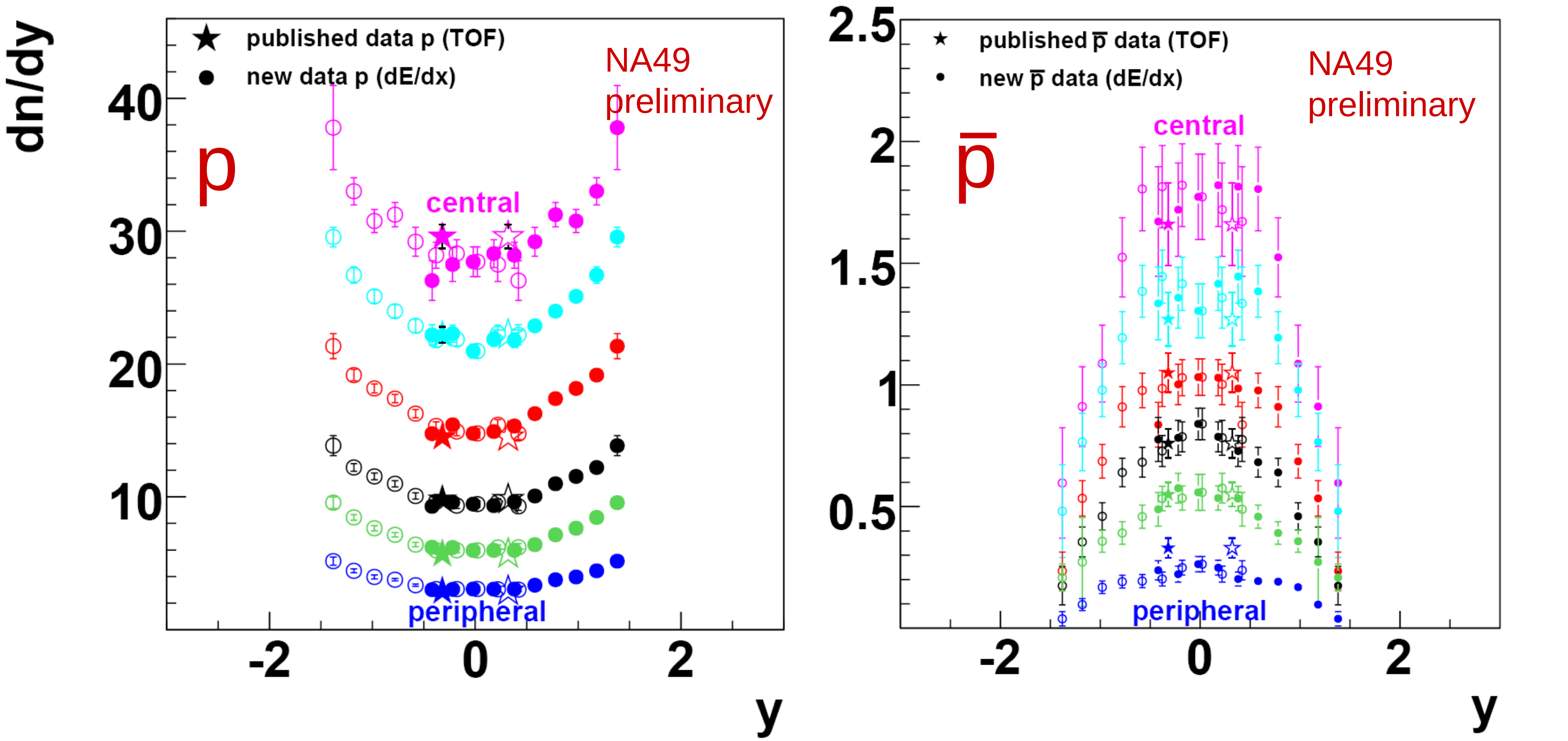
In measured rapdity range similar shape like p+p data

⇒ System size has no big influence on μ_B



p+p Data:
M. Aguilar-Benitz et al.,
Z. Phys. C 50 (1991), 405.

System Size Dependence
(Anti-)Proton *y*-Spectra



Preliminary data by NA49

Minimum bias Pb+Pb at 158*A* GeV

H. Ströbele et al.
arXiv:0908.2777

Energy Dependence

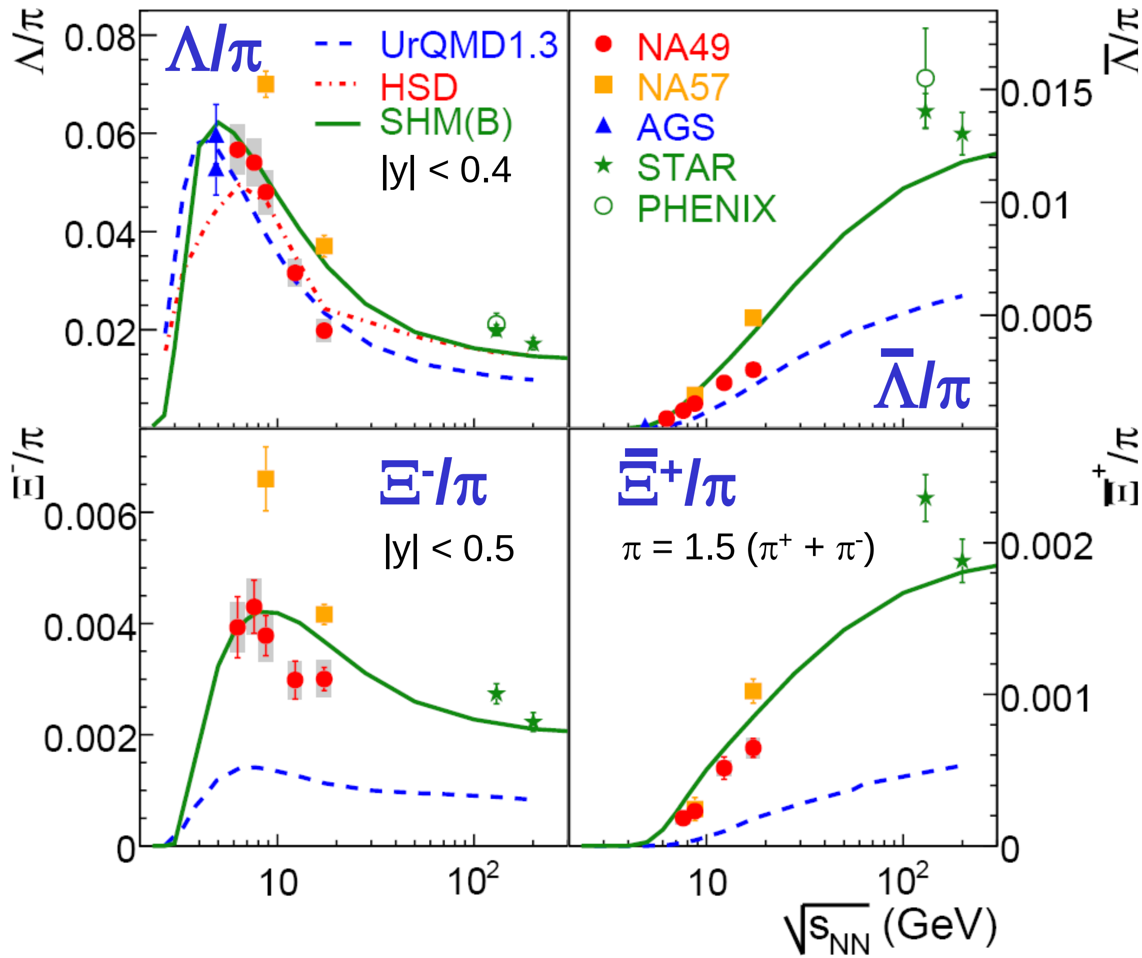
Example: Λ/π- and Ξ/π-Ratios

NA49 data
Phys. Rev. **C78**, 034918 (2008)

Statistical models
Generally good description at all energies

Fixes parameters T and μ_B

SHM(B): A. Andronic et al.
Nucl. Phys. A **772**, 167 (2006).
UrQMD: M. Bleicher et al.,
J. Phys. **G 25**, 1856 (1999)
and private communication
HSD: E. Bratkovskaya et al.,
Phys. Rev. **C69**, 054907 (2004)



Energy Dependence
Net-Baryon Distributions

Significant change of shape at SPS energies

Peak → dip structure

Rapid change of net-baryon density at *y* = 0

⇒ Strong variation of μ_B

Central Pb+Pb/Au+Au

158A GeV
Phys. Rev. Lett. 82 (1999), 2471

E802
Phys. Rev. C 60 (1999), 064901

BRAHMS
Phys. Rev. Lett. 93 (2004), 102301