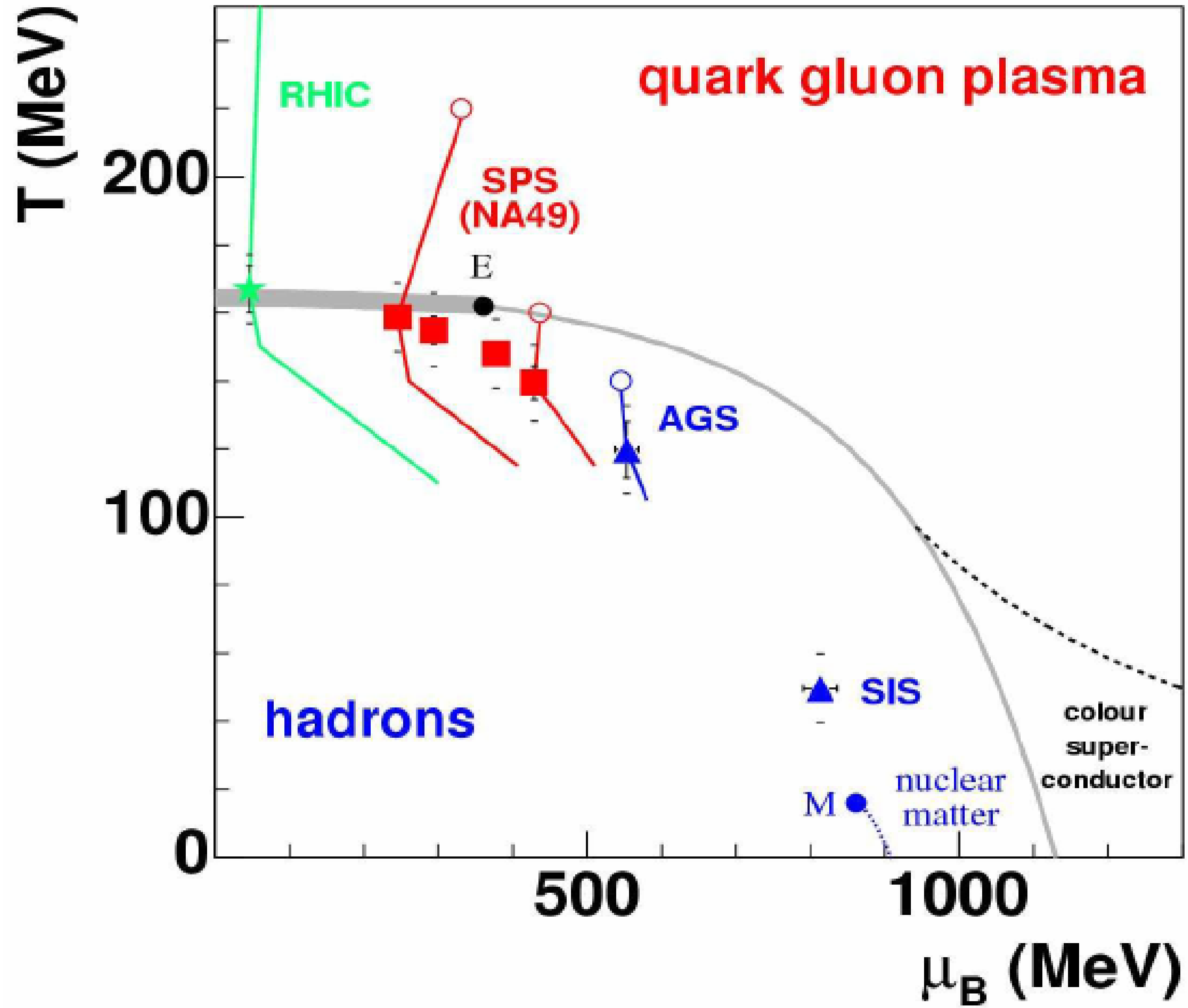
Multiplicity Fluctuations in Nucleus-Nucleus Collisions: Statistical and Transport Models

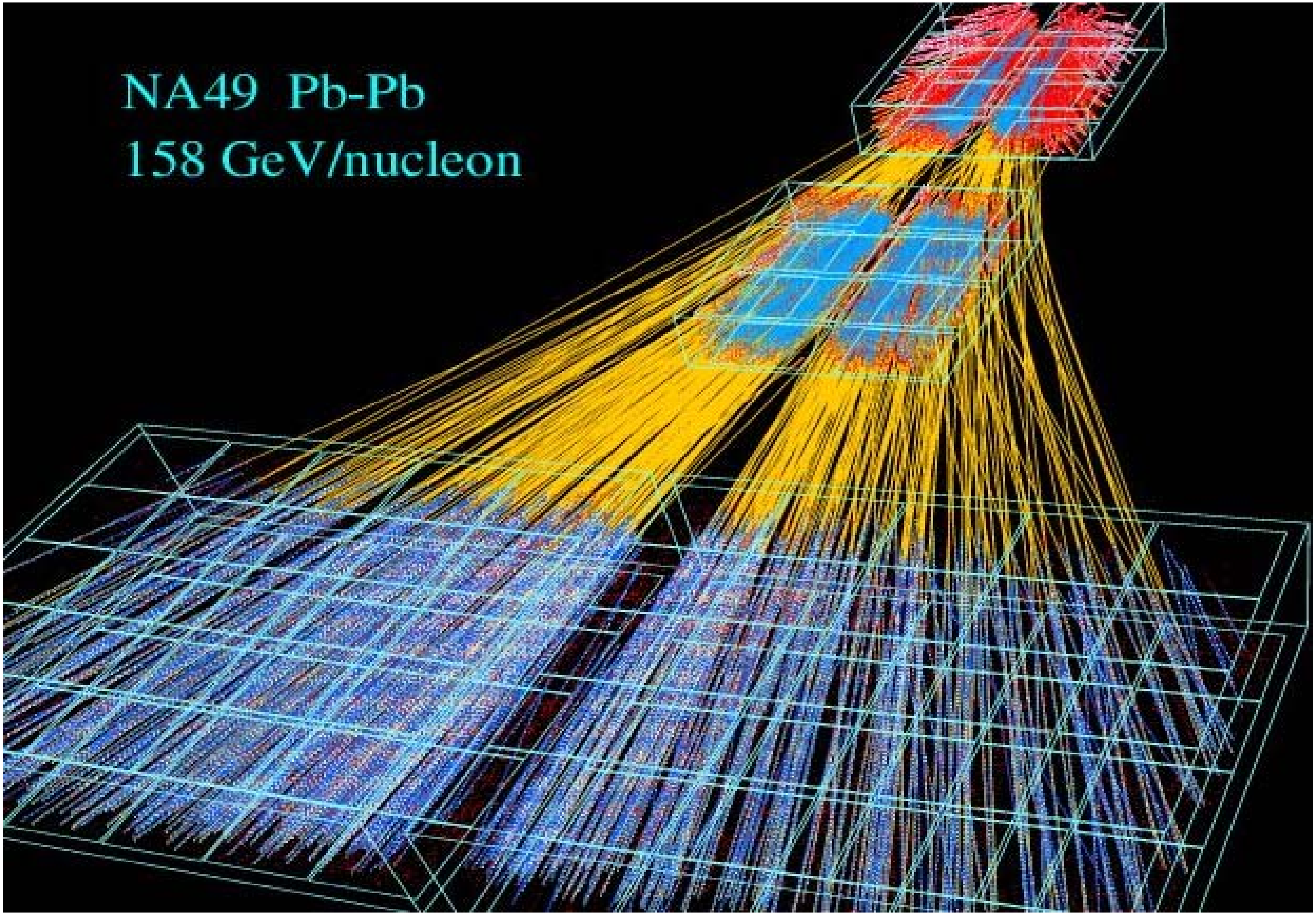
Mark Gorenstein

Bogolyubov Institute for Theoretical Physics
Kiev, Ukraine

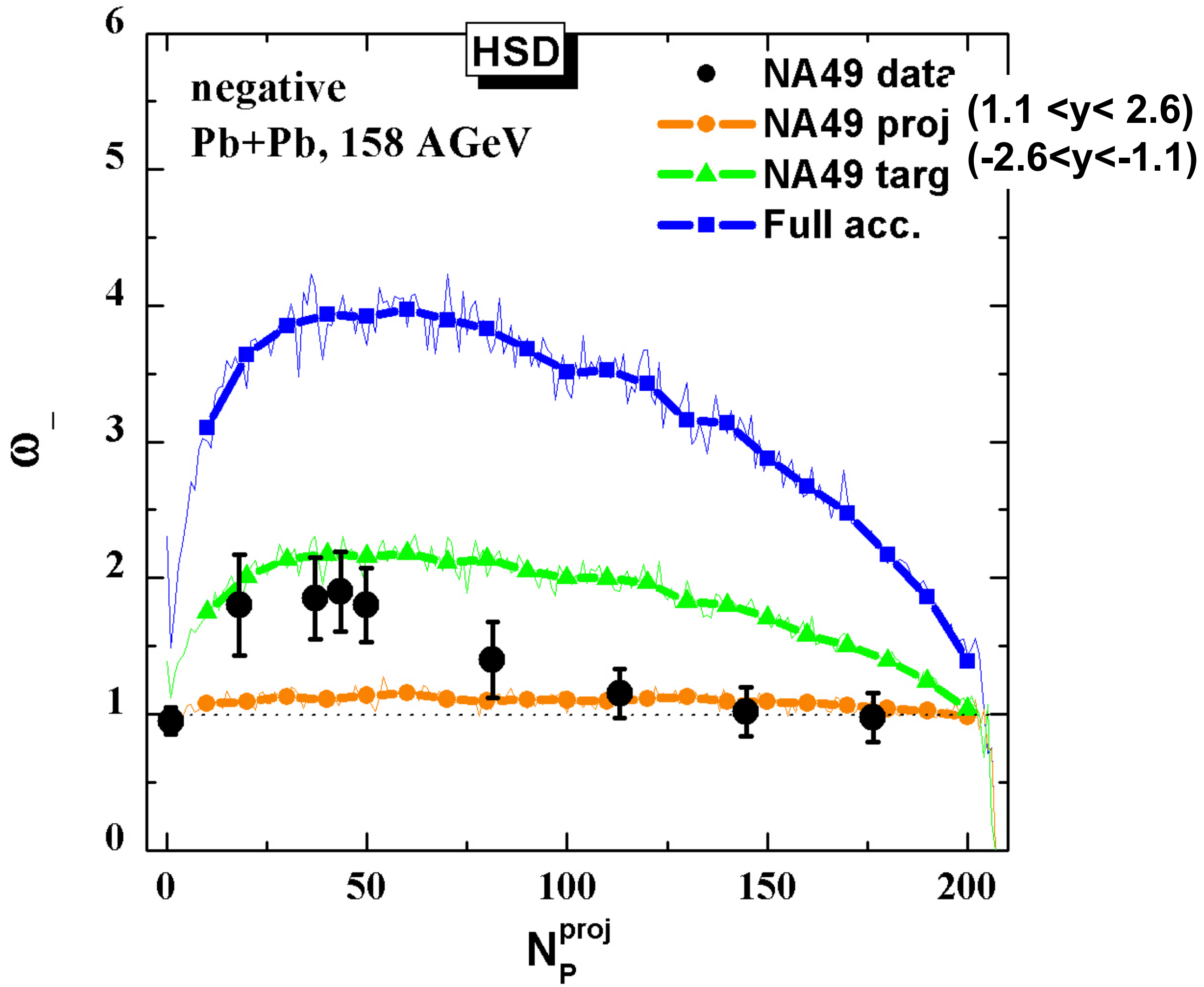
1. Motivation
2. Statistical Model: a) Exact Conservation Laws
   b) Resonance decays
3. Transport Models (HSD, UrQMD)
4. Transparency, mixing and reflection
5. Comparison with data, conclusions…


T (MeV)
200
100
0
500
1000
μ_B (MeV)
quark gluon plasma
RHIC
SPS
(NA49)
E
AGS
SIS
hadrons
colour
super-
conductor
nuclear
matter
M

NA49 at SPS – a dedicated facility to study event-by-event fluctuations in nuclear collisions



Transport Models (see details in the talk of Volodymyr Konchakovski)



Konchakovski, Hausler, M.I.G., Bratkovskaya, Bleicher, Stoecker
Phys. Rev. C (2006)

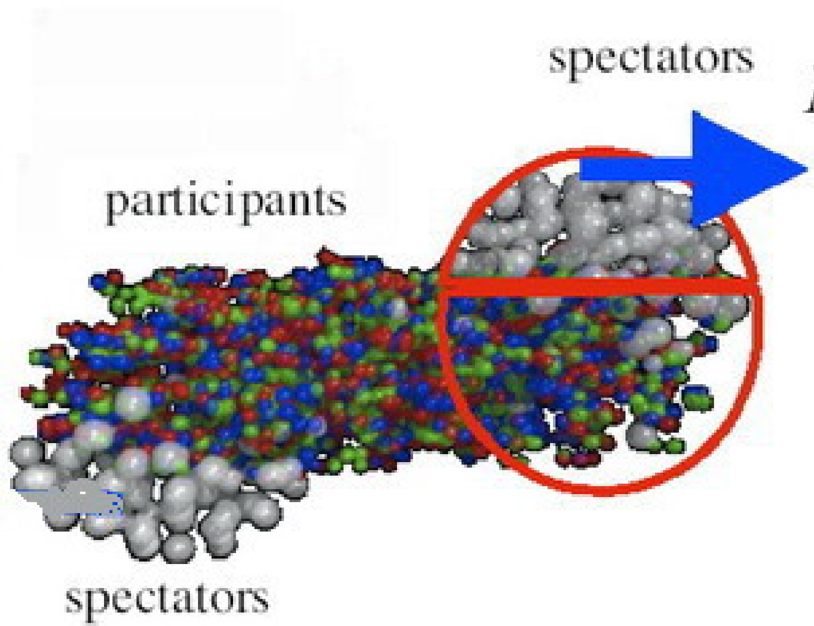
Scaled variance

$$\omega_i = \frac{\langle N_i^2 \rangle - \langle N_i \rangle^2}{\langle N_i \rangle}, \quad \text{where} \quad i = -, +, ch$$

$\omega = 1$ for Poisson distribution

Nucleons: participants and spectators.

Pb-Pb
158 AGeV



N_S^{proj}

N_S^{tar}

$$N_P^{proj} = A^{proj} - N_S^{proj}$$

NA49 Measured by ZDC

Independent Sources

Number of Sources is Proportional to Number of Participants

$$n_i = \frac{\langle \overline{\overline{N}}_i \rangle}{\langle N_P \rangle}$$ - the particle number of i-th type per participant

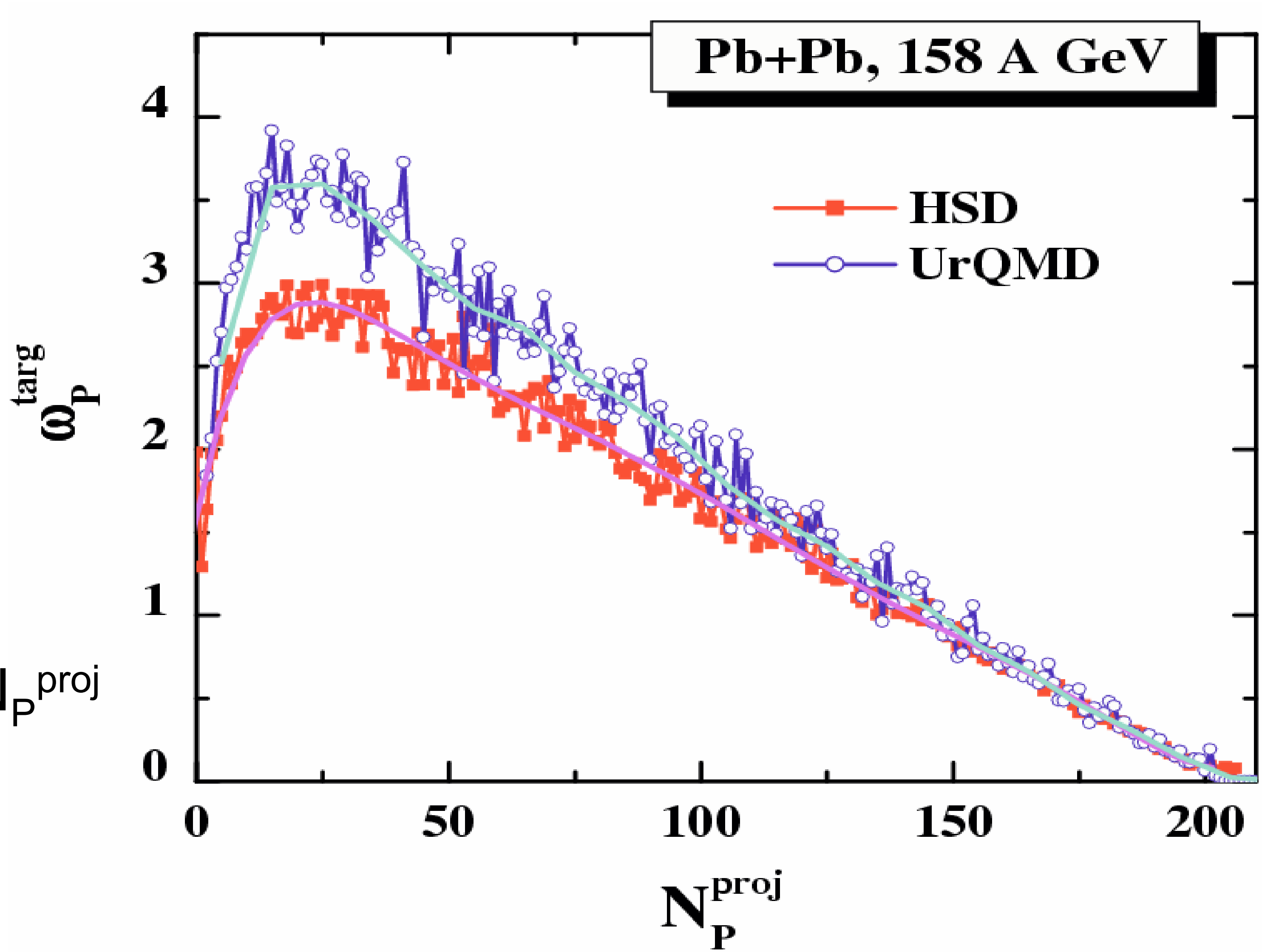
$$\boxed{\omega_i = \omega_i^* + \tfrac{1}{2}\,\omega_P^{tar}\, n_i}$$, where $i = -, +, ch$

HSD
N+N
158 GeV

the fluctuation from a single source

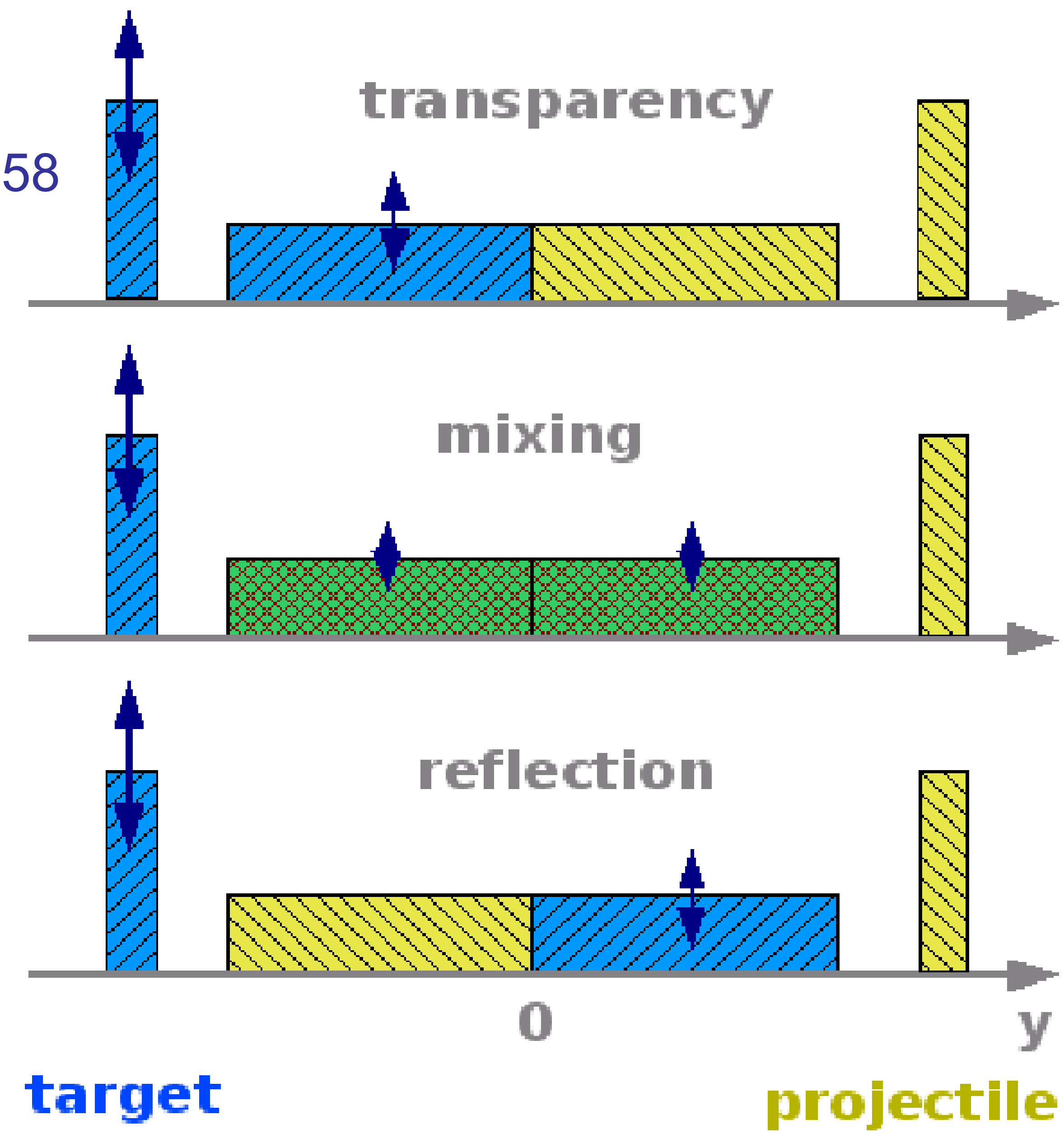
$$\omega_-^* = 1.5$$
$$\omega_+^* = 1.1$$
$$\omega_{ch}^* = 2.5$$

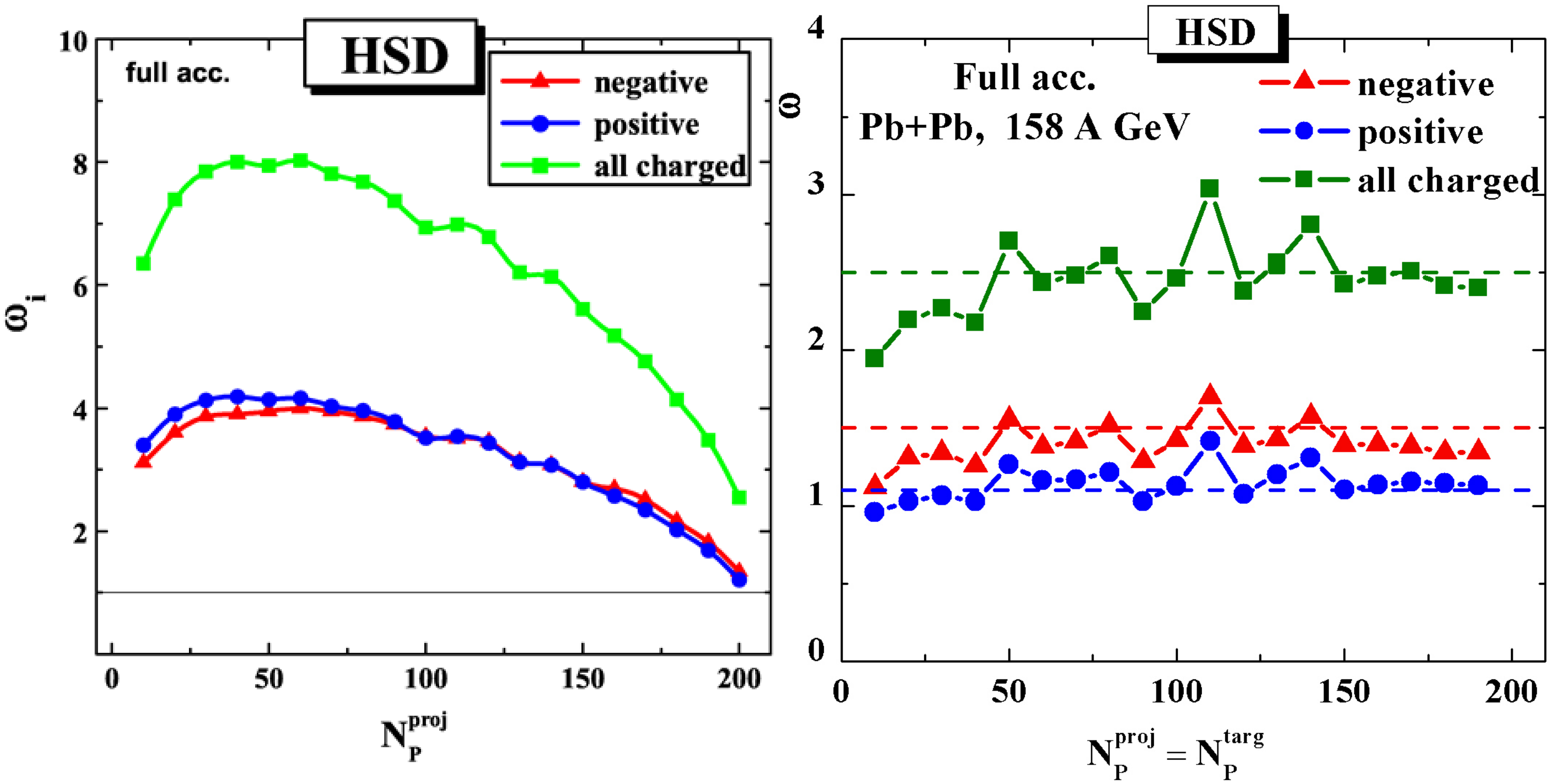
$\langle N_P^{targ} \rangle = N_P^{proj}$



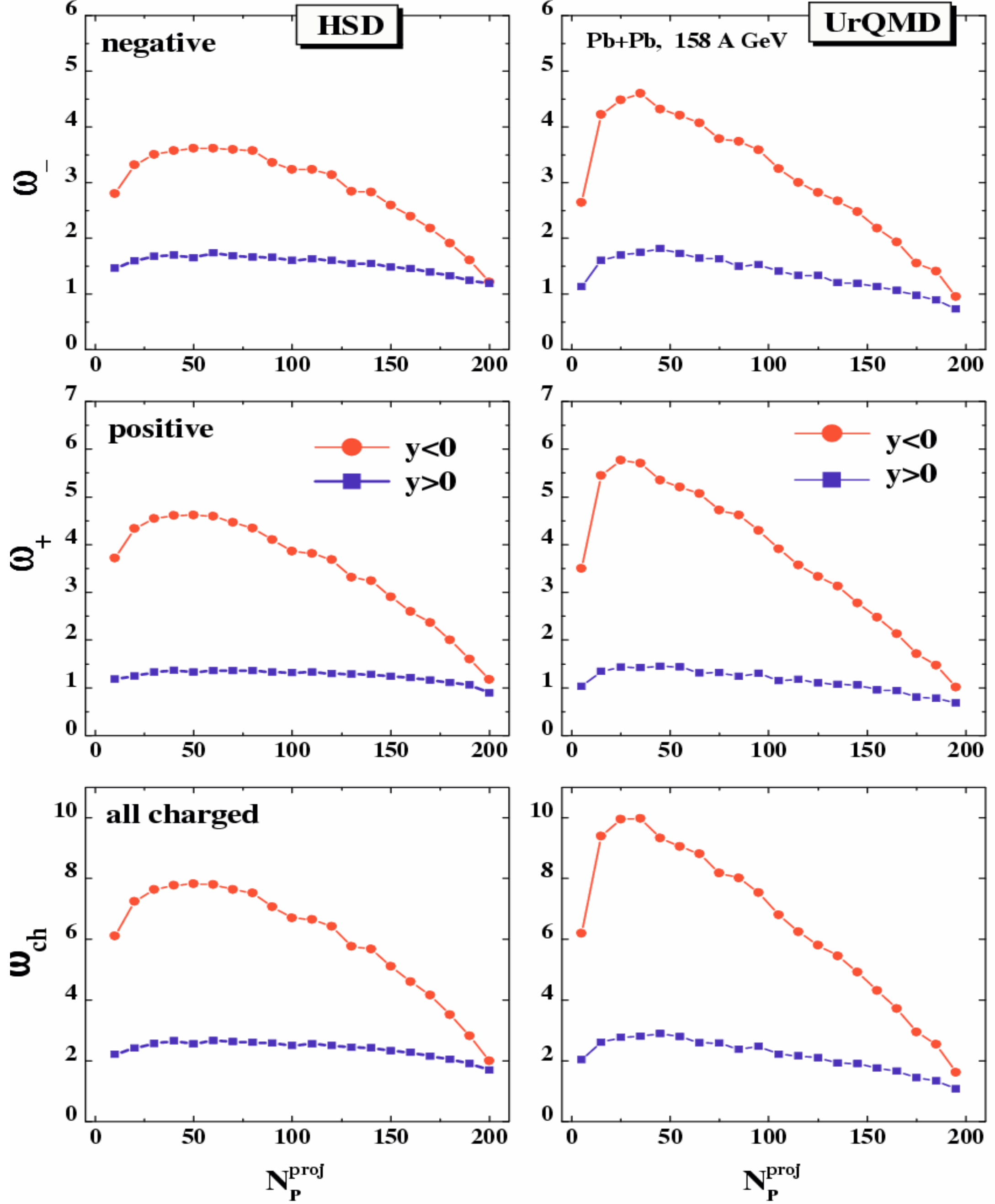
Konchakovski, Hausler, M.I.G., Bratkovskaya, Bleicher, Stoecker, Phys. Rev. C (2006)

Gazdzicki
and M.I.G.
hep-ph/0511058
Phys. Lett. B
(2006)

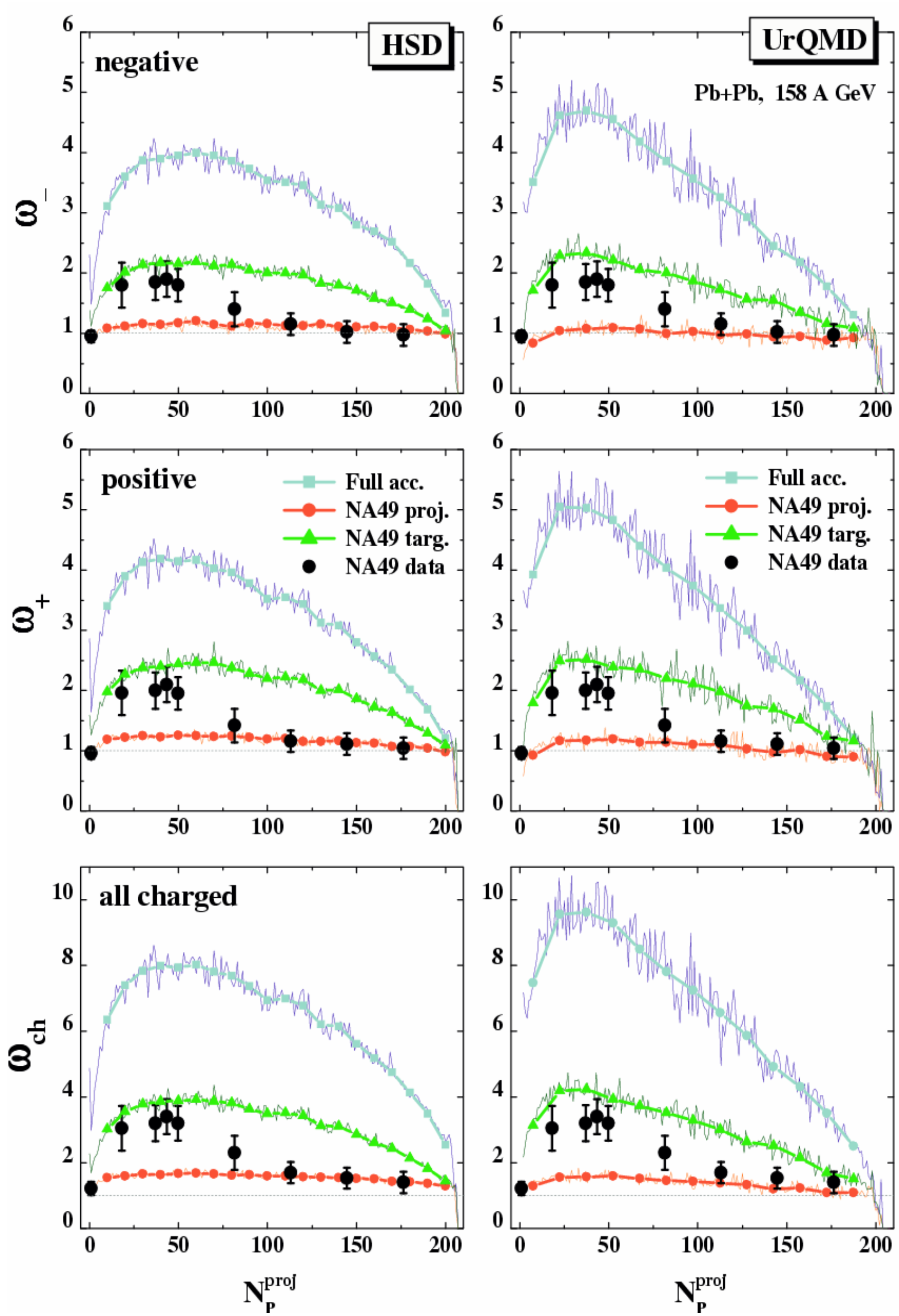


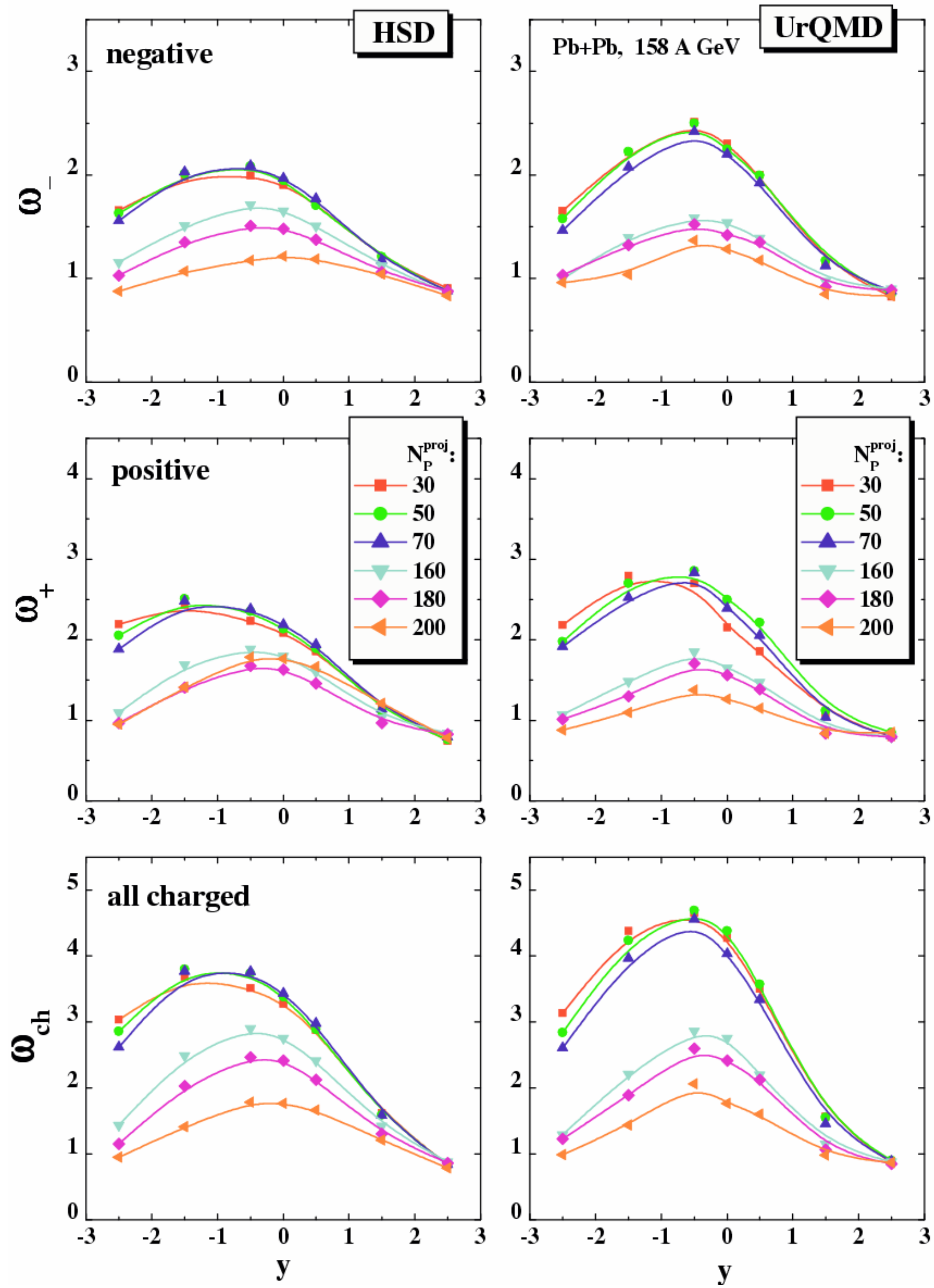

HSD
full acc.
negative
positive
all charged
ω_i
N_P^{proj}
HSD
Full acc.
Pb+Pb, 158 A GeV
negative
positive
all charged
ω
$N_P^{proj} = N_P^{targ}$

HSD is close to T-models for pion sources



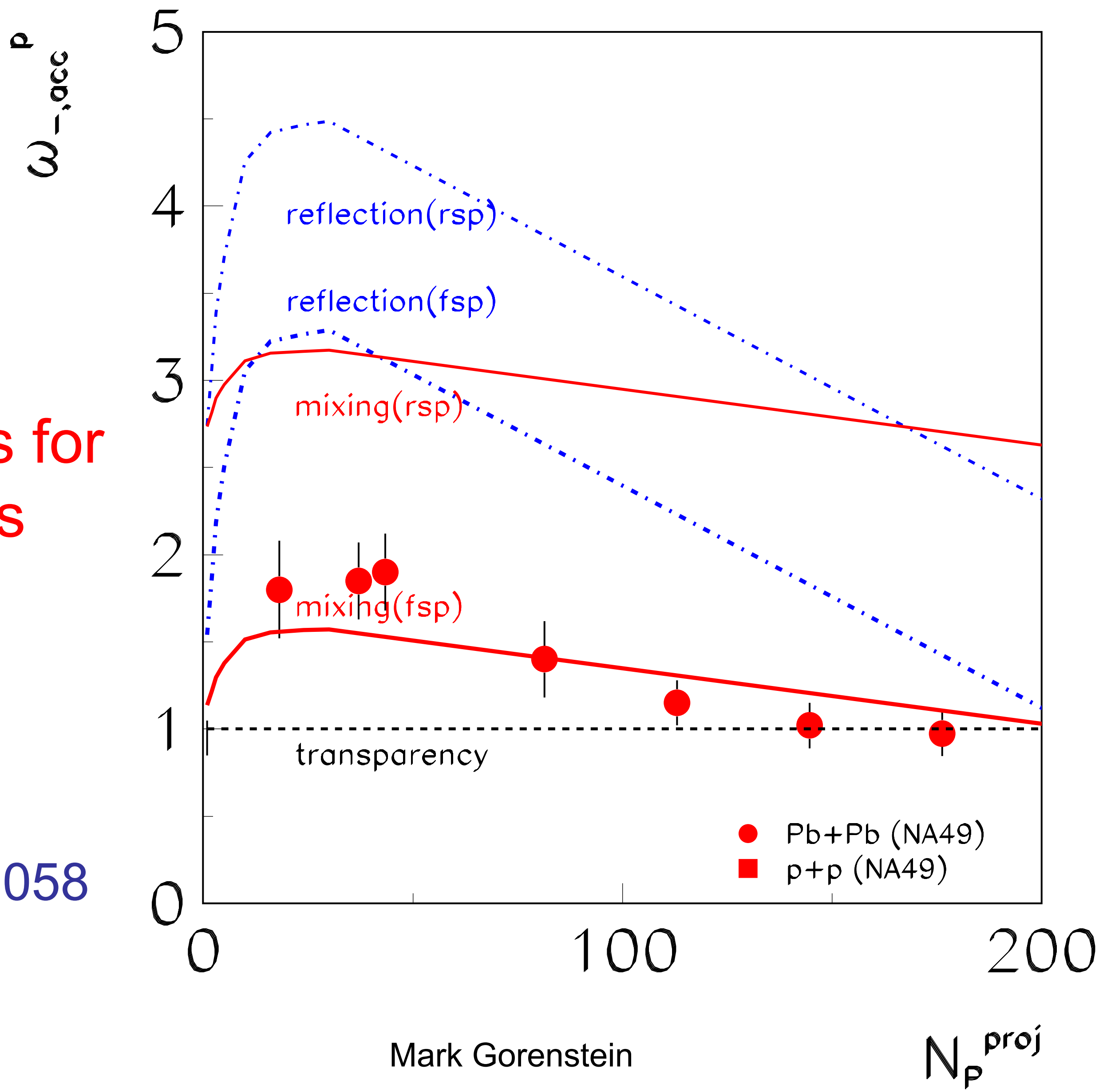
Konchakovski, Hausler M.I.G., Bratkovskaya, Bleicher, Stoecker, Phys. Rev. C (2006)


HSD
UrQMD
Pb+Pb, 158 A GeV
negative
positive
all charged
Full acc.
NA49 proj.
NA49 targ.
NA49 data
ω_-
ω_+
ω_{ch}
N_P^{proj}



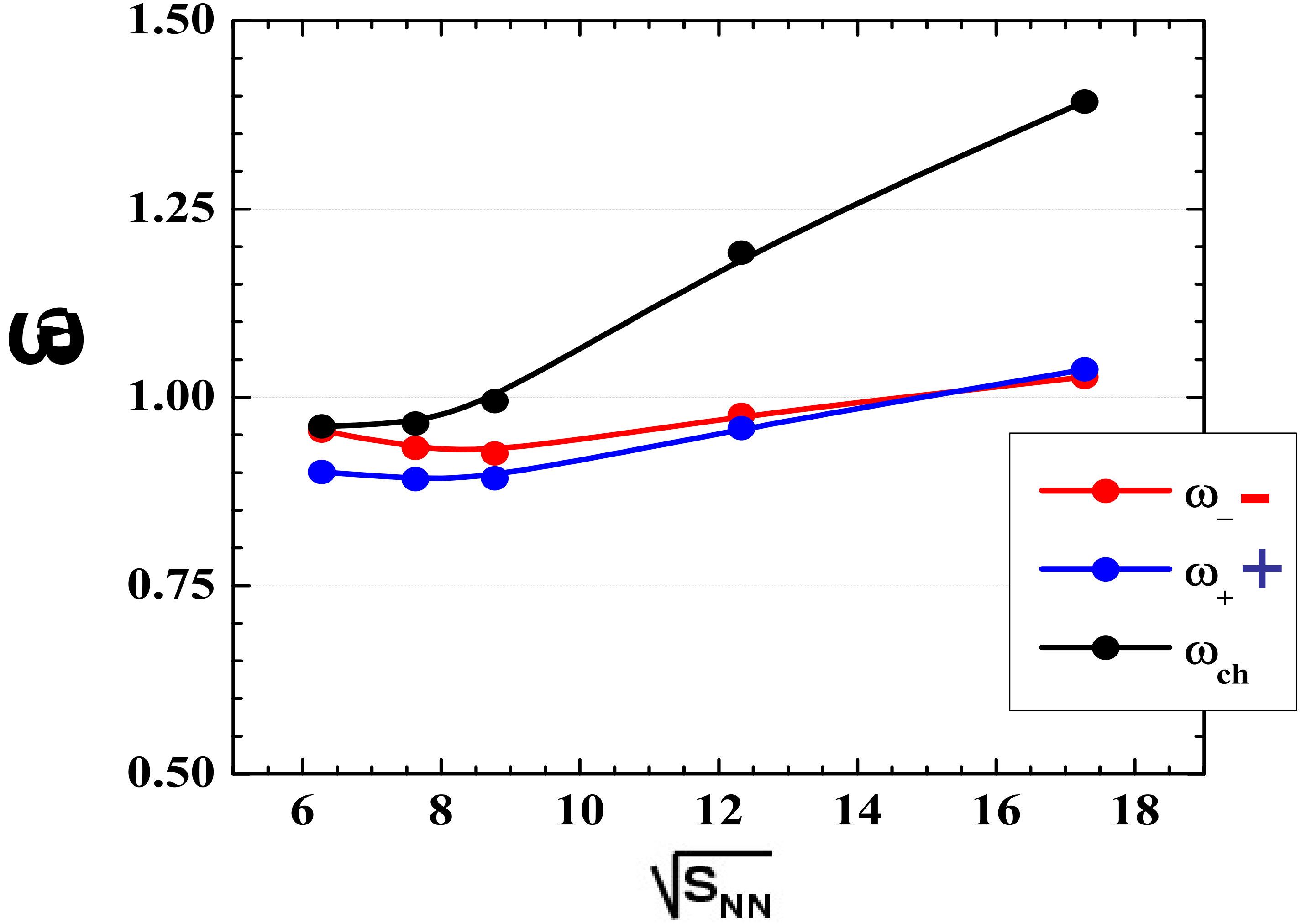
HSD
UrQMD
Pb+Pb, 158 A GeV
negative
positive
all charged
ω_-
ω_+
ω_{ch}
N_P^{proj}:
30
50
70
160
180
200
y
y

NA49 data are close to M-models for pion sources



Gazdzicki and M.I.G. hep-ph/0511058

Scaled Variances in HSD for $N_P^{proj} = 180 - 200$



Multiplicity Fluctuations in Hadron-Resonance Gas: CE and MCE

$$\omega^- = \frac{\langle(\Delta N_-)^2\rangle}{\langle N_-\rangle}, \qquad \omega^+ = \frac{\langle\left(\Delta N_+\right)^2\rangle}{\langle N_+\rangle},$$

Begun, Gazdzicki, M.I.G., Zozulya Phys. Rev. C (2004)

$$\langle N_i\rangle = \langle N_i^*\rangle + \sum_R \langle N_R\rangle \sum_r b_r^R n_{i,r}^R \equiv \langle N_i^*\rangle + \sum_R \langle N_R\rangle \langle n_i\rangle_R$$

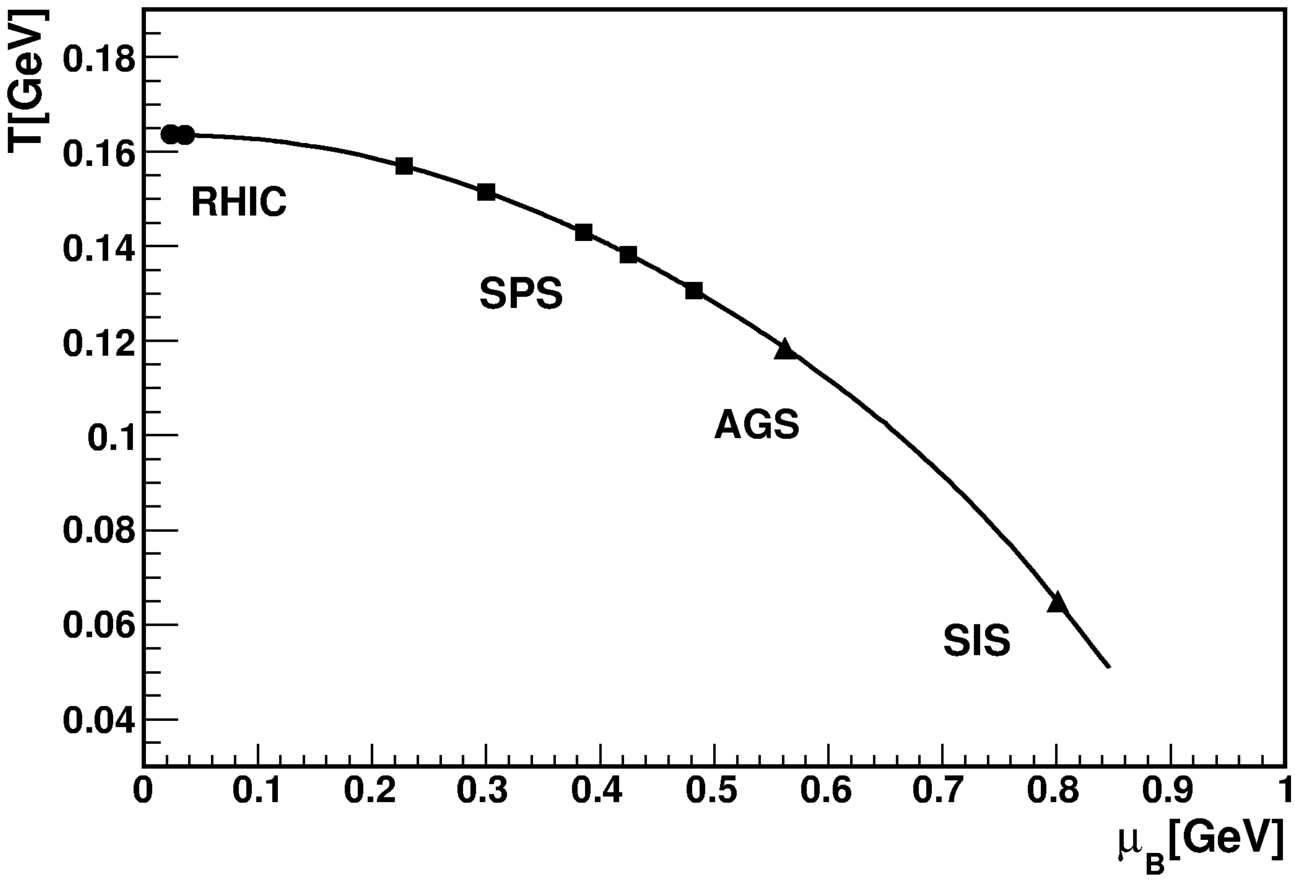
$$\langle \Delta N_i \, \Delta N_j\rangle = \langle \Delta N_i^* \Delta N_j^*\rangle + \sum_R \left[\langle \Delta N_R^2\rangle \, \langle n_i\rangle_R \, \langle n_j\rangle_R + \langle N_R\rangle \, \langle \Delta n_i \Delta n_j\rangle_R\right],$$

<...> GCE **Stephanov, Rajagopal, Shuryak, Phys. Rev. B (1999)**
Jeon, Koch, Phys. Rev. Lett. (1999)

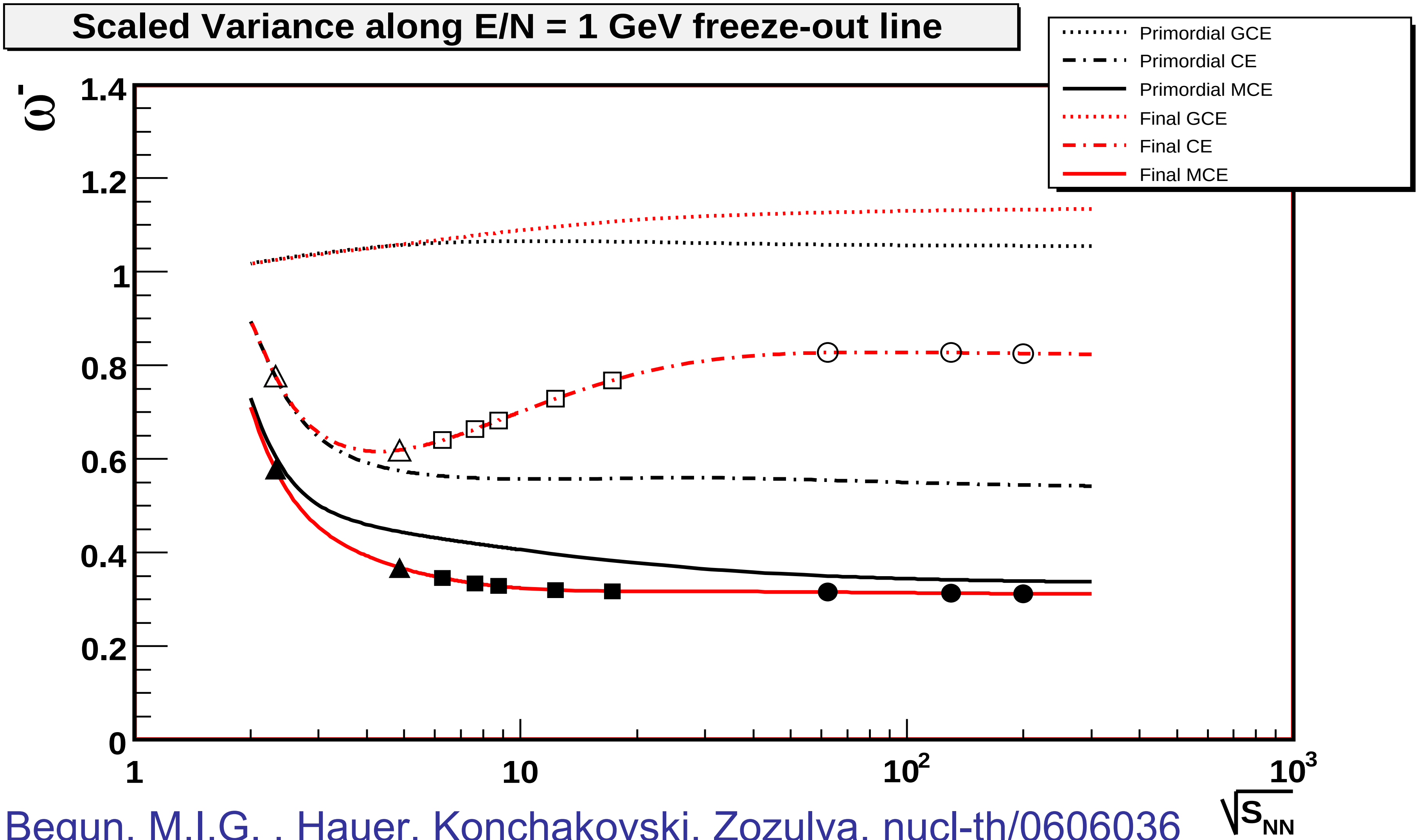
$$\langle \Delta N_i \, \Delta N_j\rangle_{c.e.} = \langle \Delta N_i^* \Delta N_j^*\rangle_{c.e.} + \sum_R \langle N_R\rangle \, \langle \Delta n_i \, \Delta n_j\rangle_R + \sum_R \langle \Delta N_i^* \, \Delta N_R\rangle_{c.e.} \, \langle n_j\rangle_R + \sum_R \langle \Delta N_j^* \, \Delta N_R\rangle_{c.e.} \, \langle n_i\rangle_R + \sum_{R,R'} \langle \Delta N_R \, \Delta N_{R'}\rangle_{c.e.} \, \langle n_i\rangle_R \, \langle n_j\rangle_{R'} \, .$$

$<\ldots>_{c.e.}$ **CE** **Begun, M.I.G., Hauer, Konchakovski, Zozulya, nucl-th/0606036**

Line of the chemical freeze-out

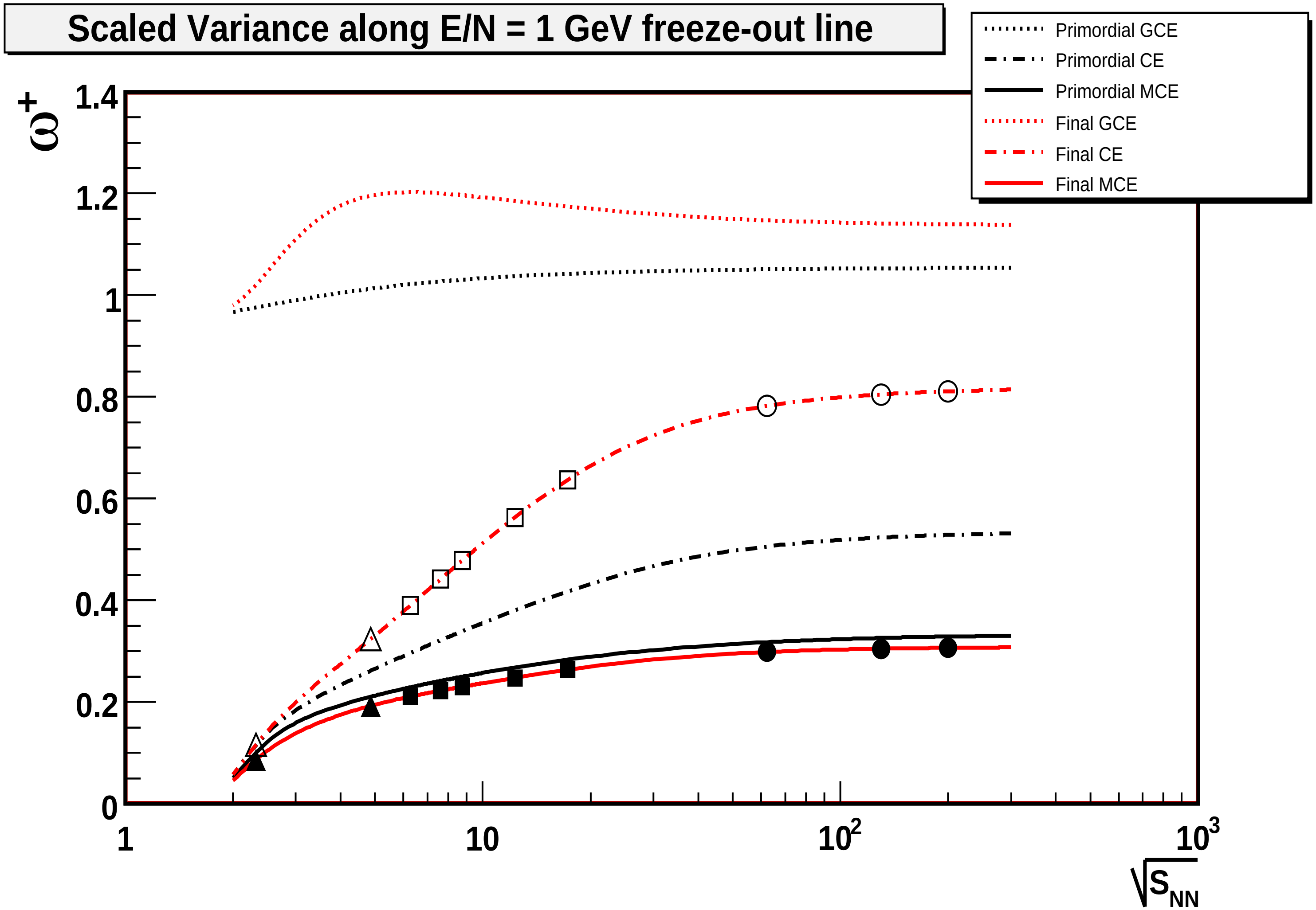


E/N = 1 GeV Cleymans and Redlich, PRL 81 (1998)

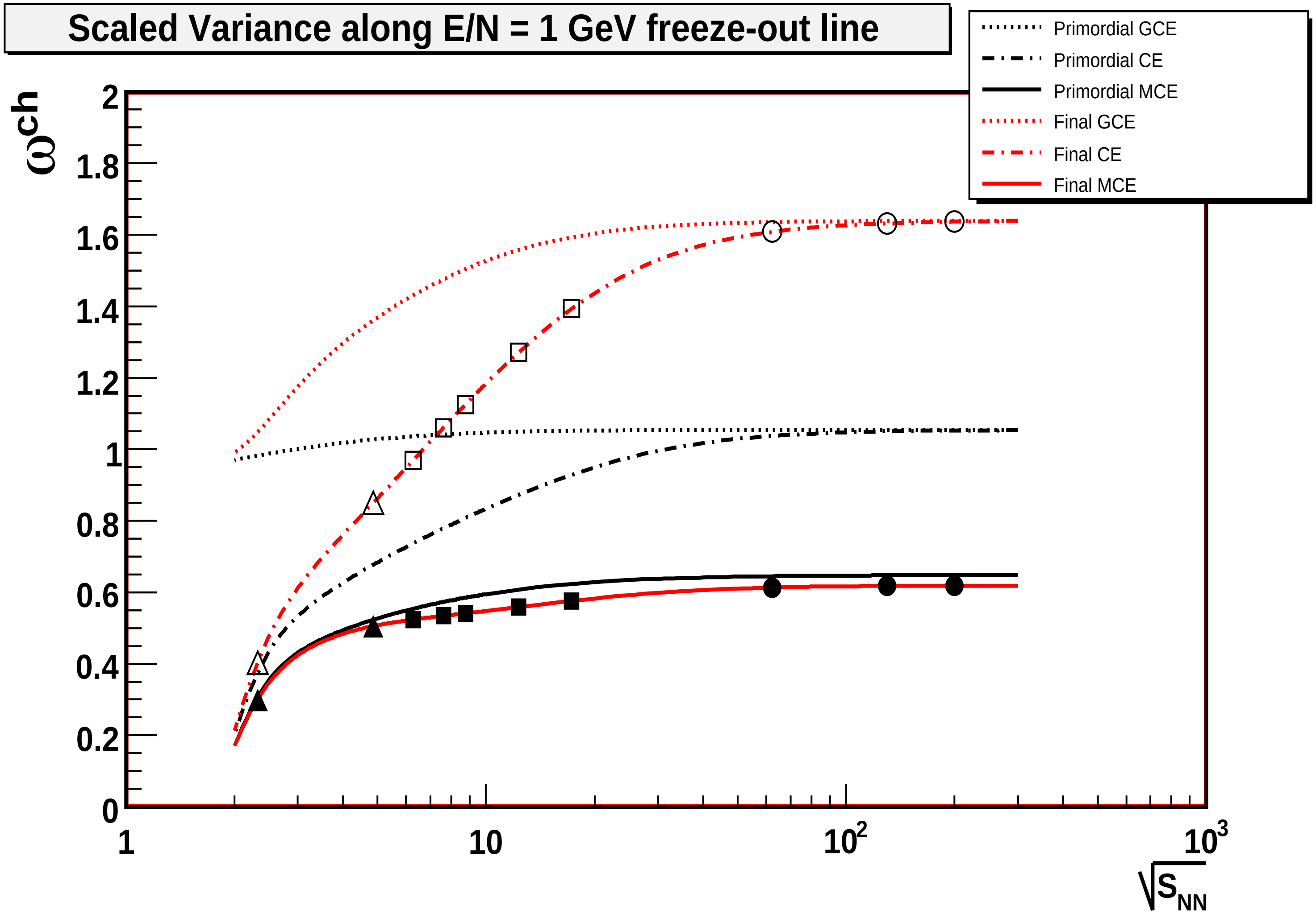


Begun, M.I.G. , Hauer, Konchakovski, Zozulya, nucl-th/0606036

Phys. Rev. C (2006)



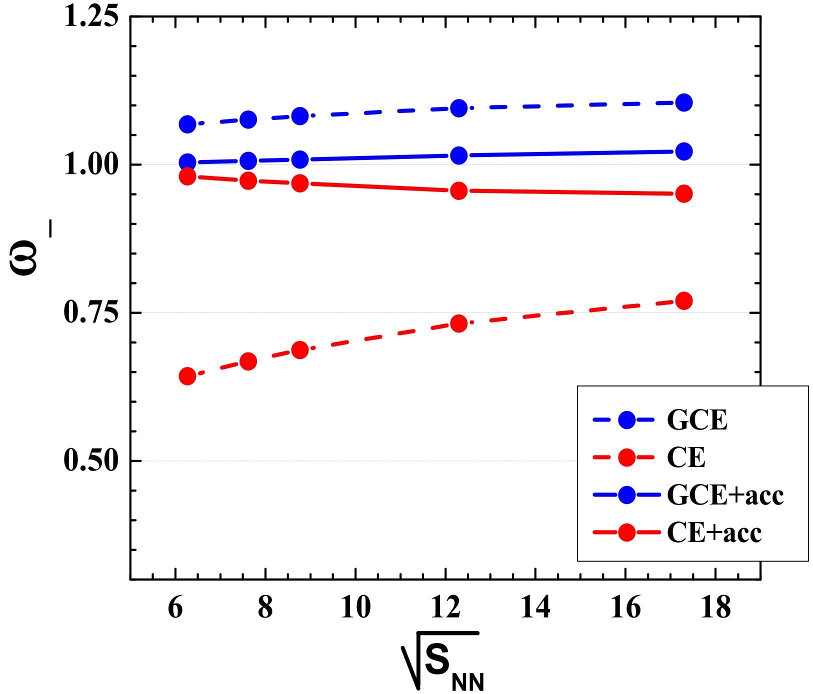
Scaled Variance along E/N = 1 GeV freeze-out line
Primordial GCE
Primordial CE
Primordial MCE
Final GCE
Final CE
Final MCE
ω+
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10^2
10^3
√S_NN



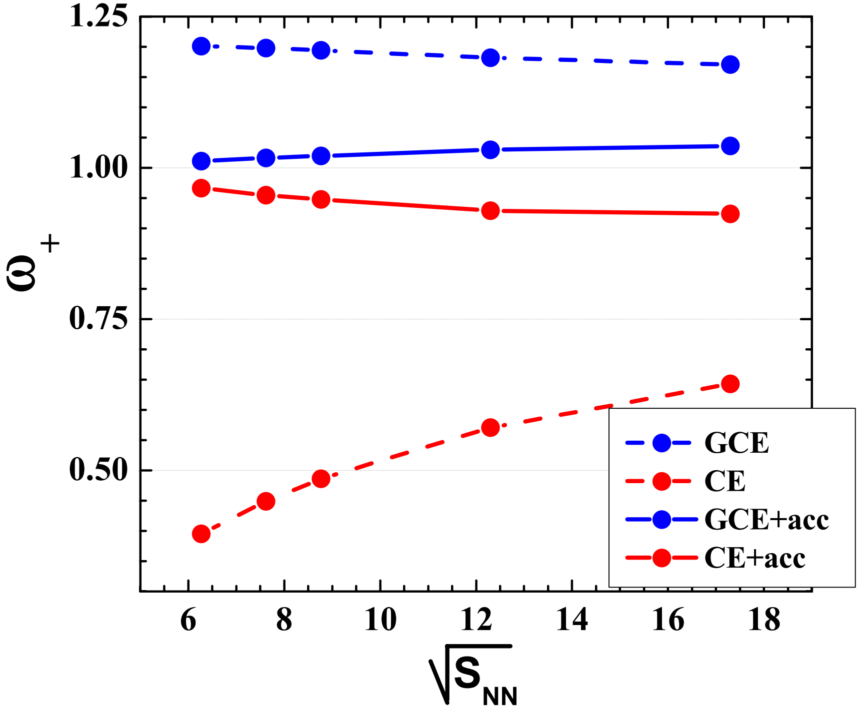
Scaled Variance along E/N = 1 GeV freeze-out line
Primordial GCE
Primordial CE
Primordial MCE
Final GCE
Final CE
Final MCE
ω^ch
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10^2
10^3
√s_NN

Scaled Variances in Thermal Model

Negative hadrons



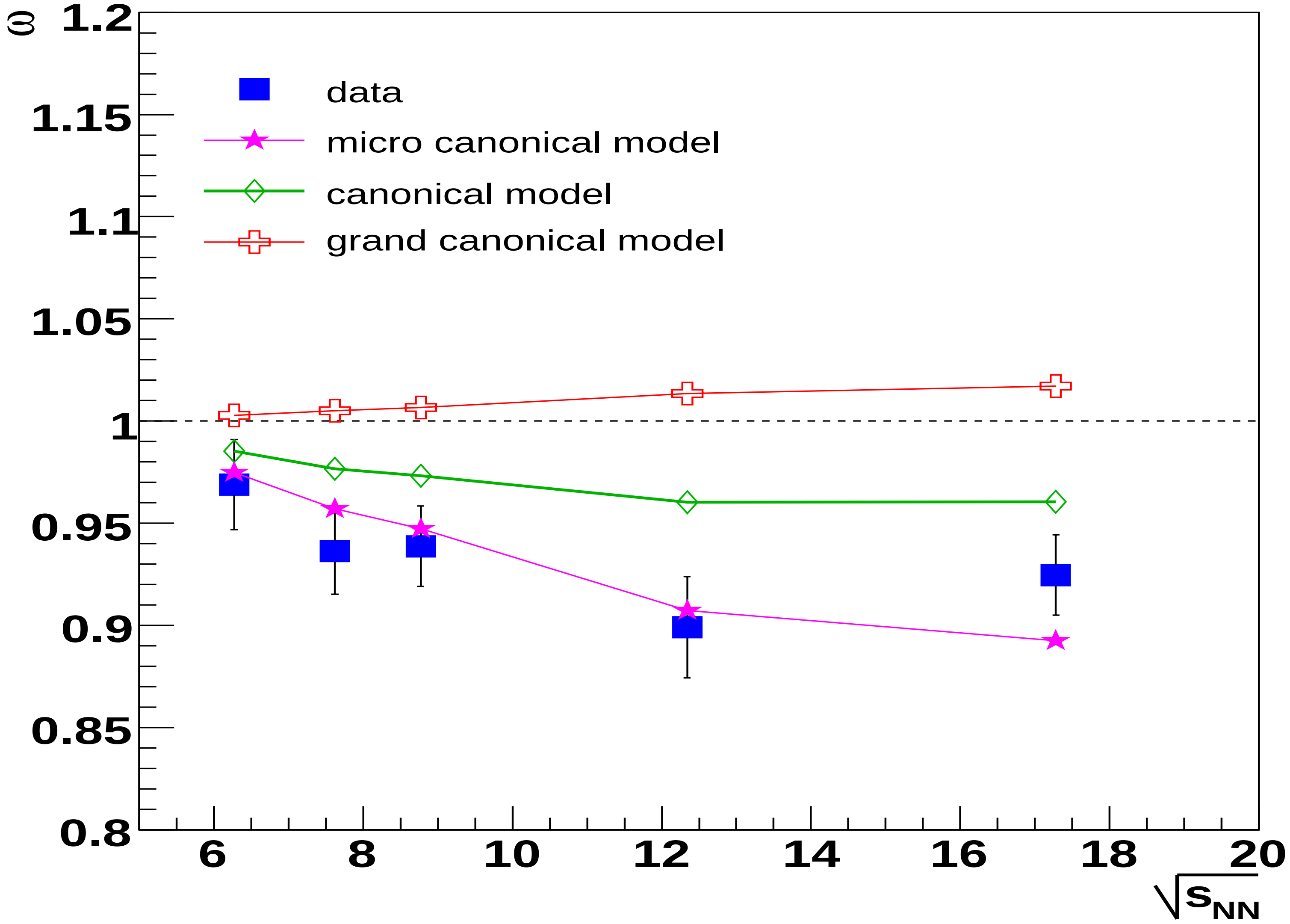
Positive hadrons



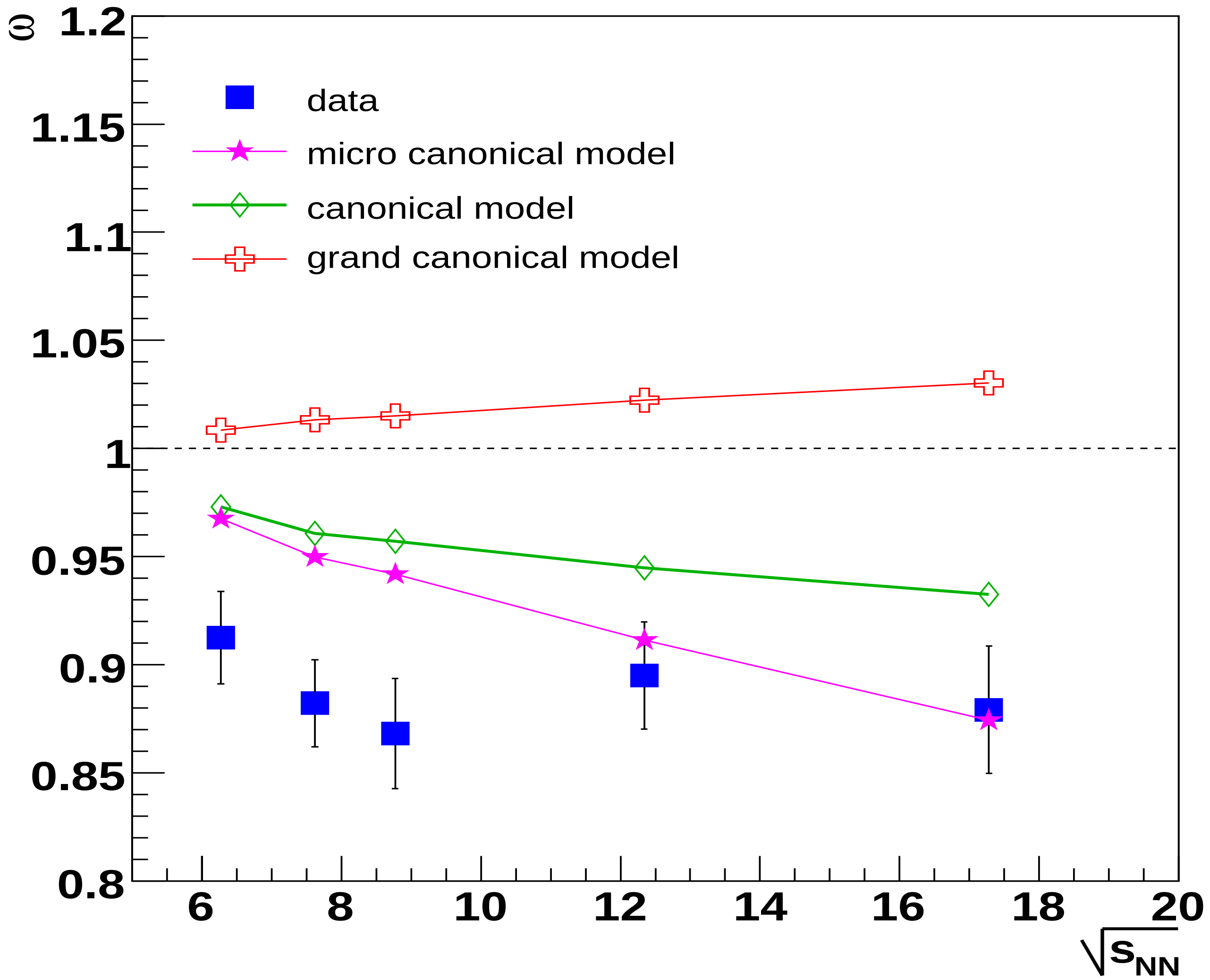
$$\omega_{4\pi}^{\pm} \equiv \frac{\langle (\Delta N_{\pm})^2 \rangle}{\langle N_{\pm} \rangle}$$

$$\omega_{acc}^{\pm} = 1 - q + q\omega_{4\pi}^{\pm}$$

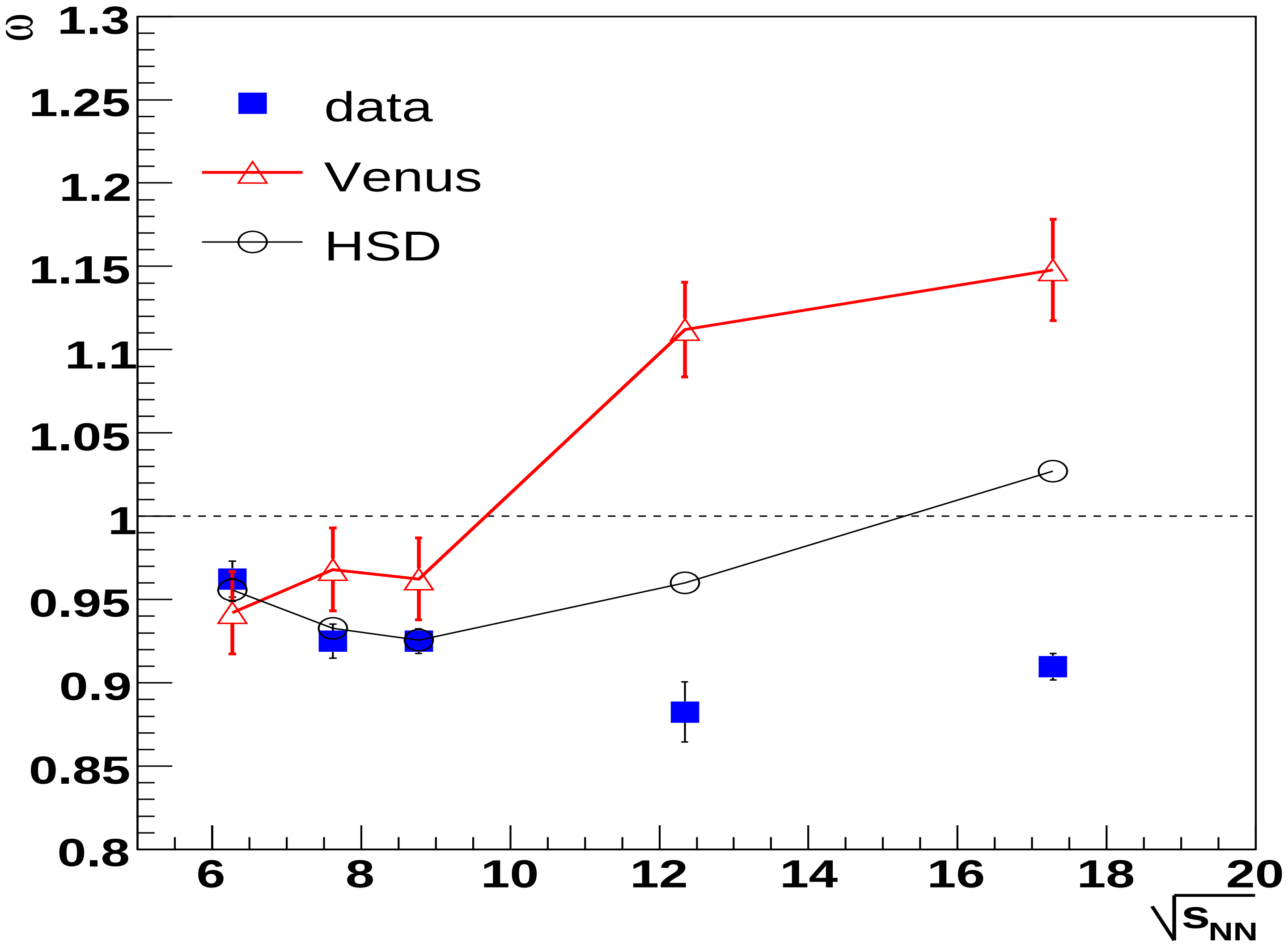
Negative Hadrons



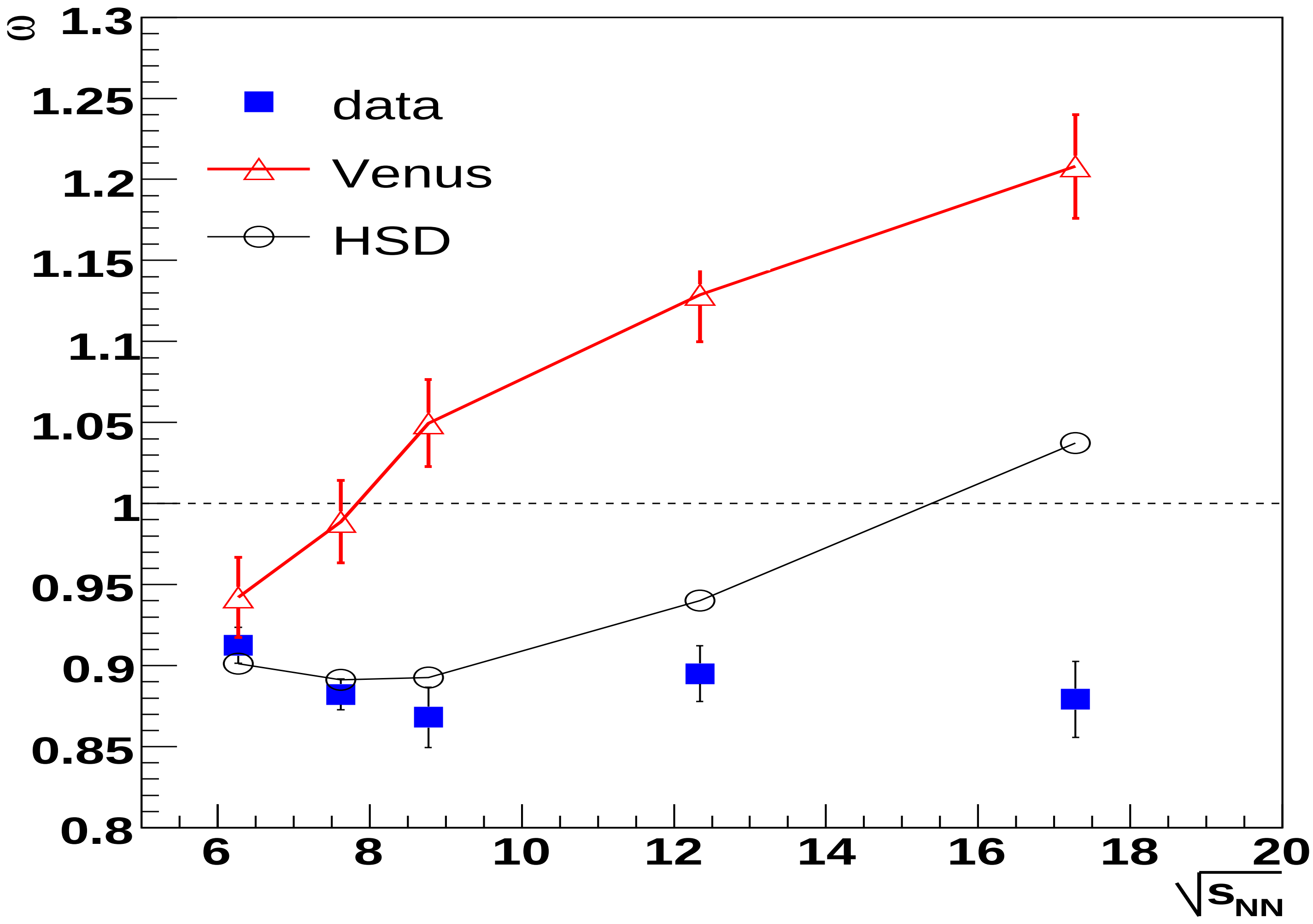
Positive Hadrons



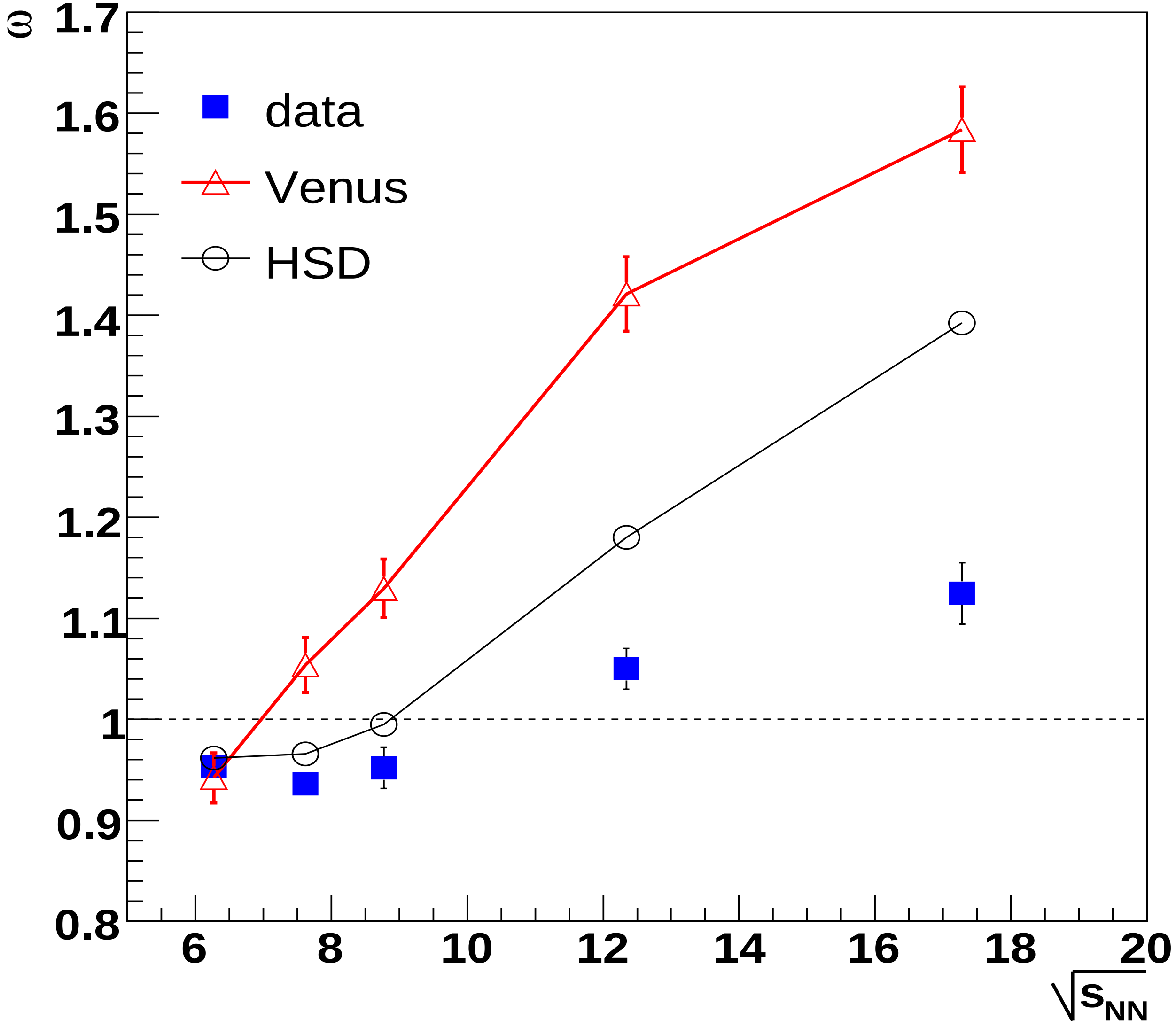
Negative Hadrons



Positive Hadrons



Charged Hadrons



Conclusions

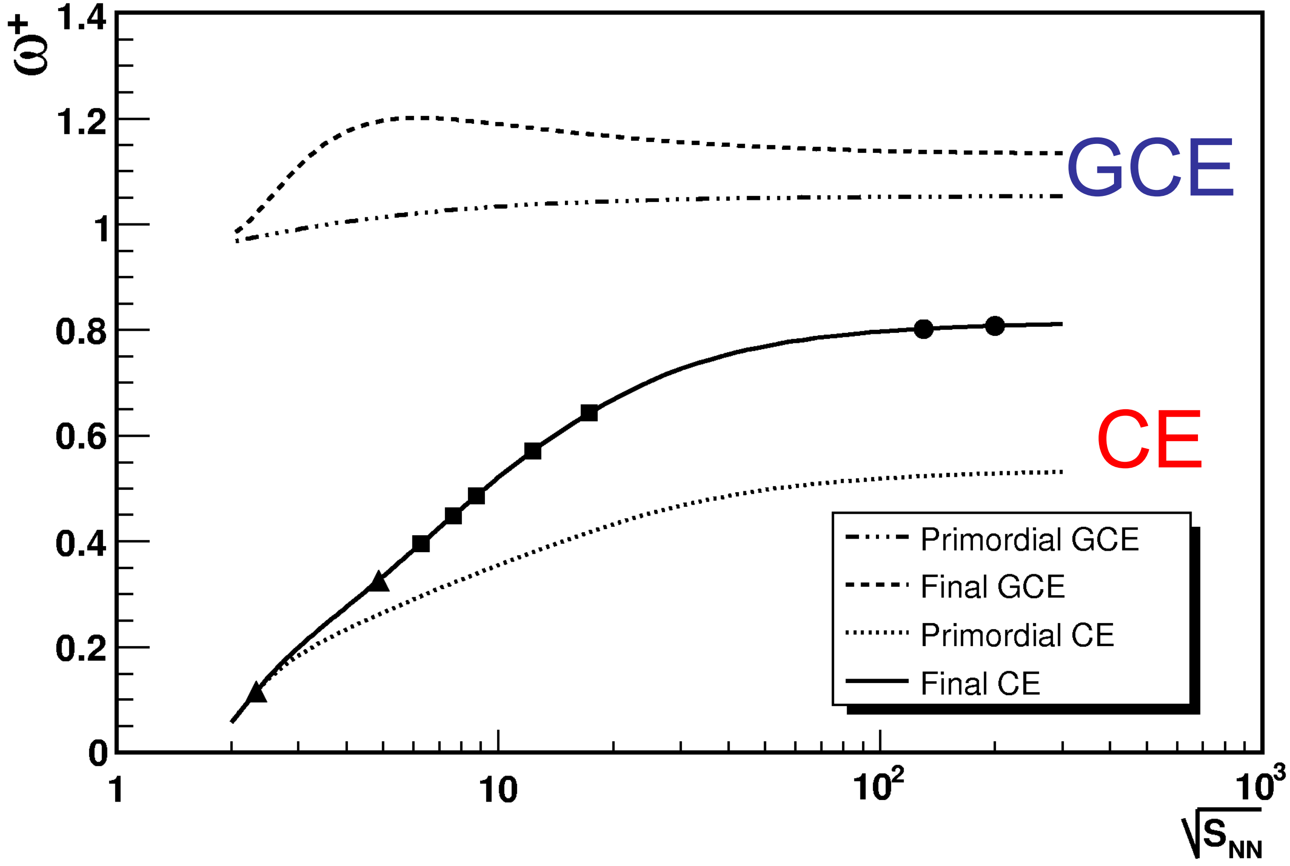
1. Study of fluctuations gives a unique possibility to investigate the early stage dynamics of initial flows.The existing models are divided into 3 limiting groups: T-, M-, R- models.

3. HSD and UrQMD are close to T-models.
4. NA49 data for charged hadron multiplicity fluctuations are consistent with M-models.

5. Statistical fluctuations in A+A can be clearly seen in most central collisions, $N_P^{proj} = 180 - 200$ (< 1%).
6. Scaled variances are very different in the GCE, CE and MCE.

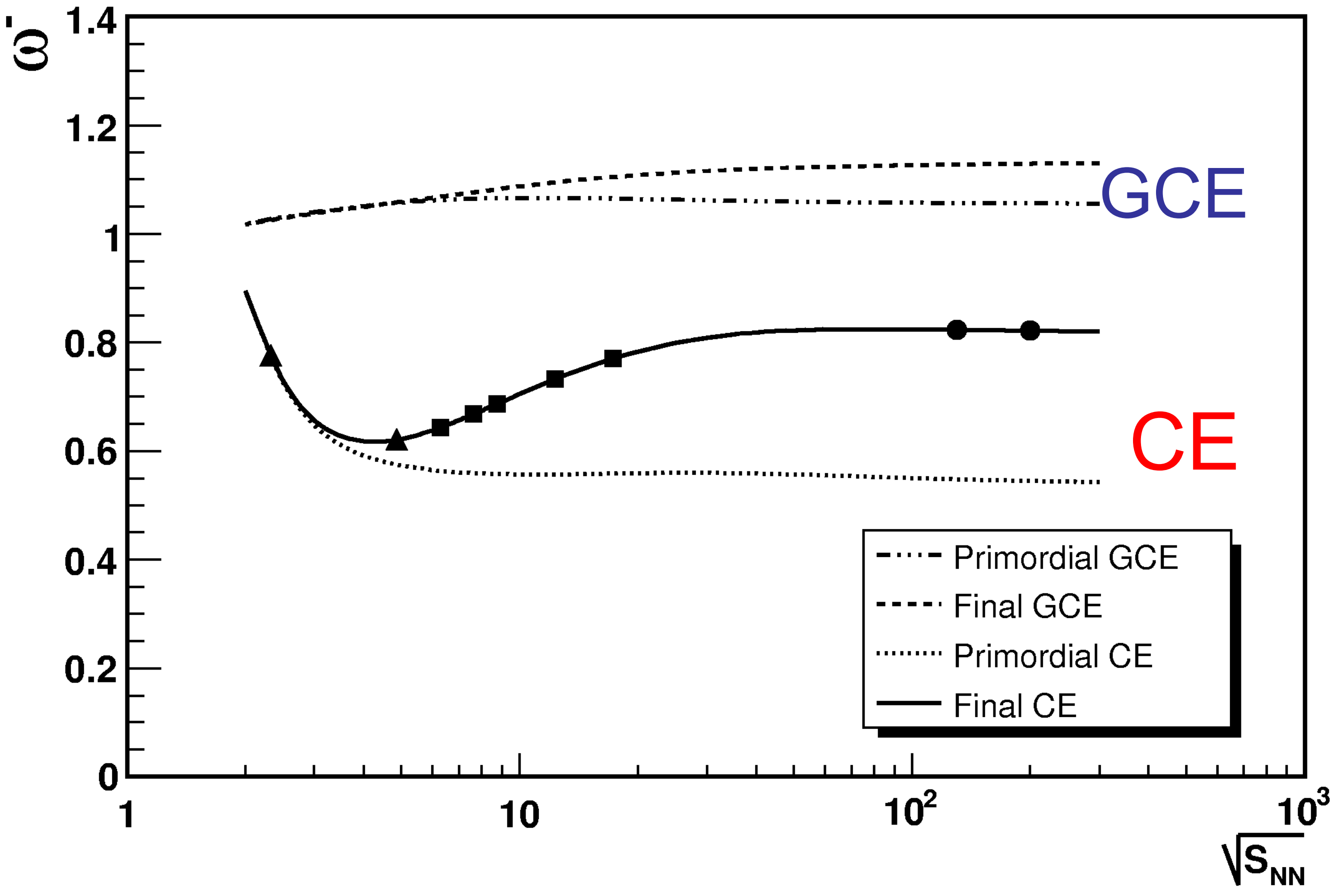
   NA49 data in most central Pb+Pb collisions are close to the MCE statistical results.

Scaled Variance for positive hadrons



Begun, M.I.G. , Hauer, Konchakovski, Zozulya, nucl-th/0606036

Scaled Variance for negative hadrons



Begun, M.I.G. , Hauer, Konchakovski, Zozulya, nucl-th/0606036