Particle production at 1-2A GeV in GiBUU transport model

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Outline

Motivation: HADES data and an abundance of pions

Giessen Boltzmann-Uehling-Uhlenbeck model (GiBUU):
Brief Introduction

Proton rapidity distributions: Comparison with FOPI data

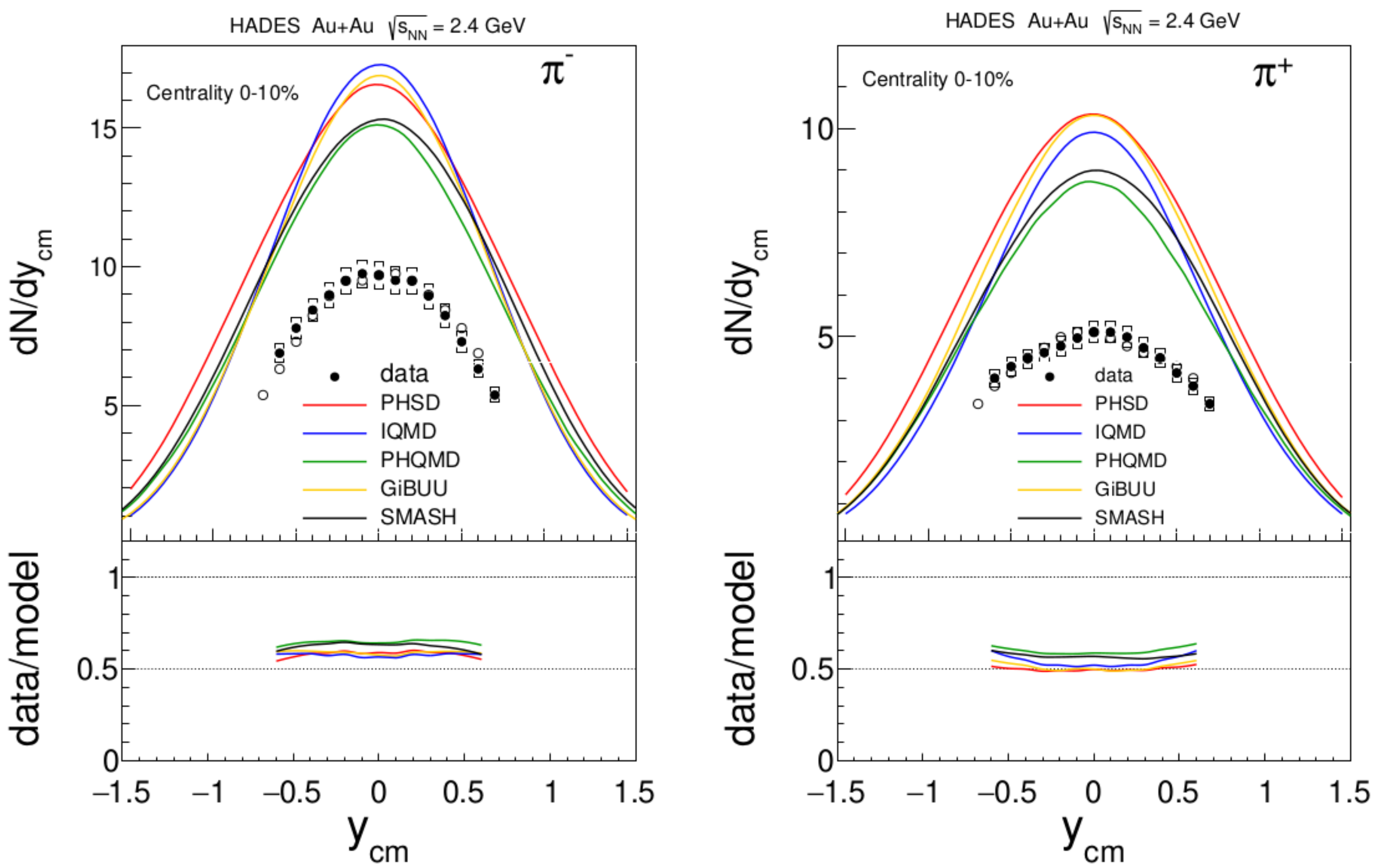
Pion p_t spectra: Comparison with FOPI and HADES data

Hadron yields and dilepton invariant mass spectra:
Comparison with HADES data

Conclusions

Motivation

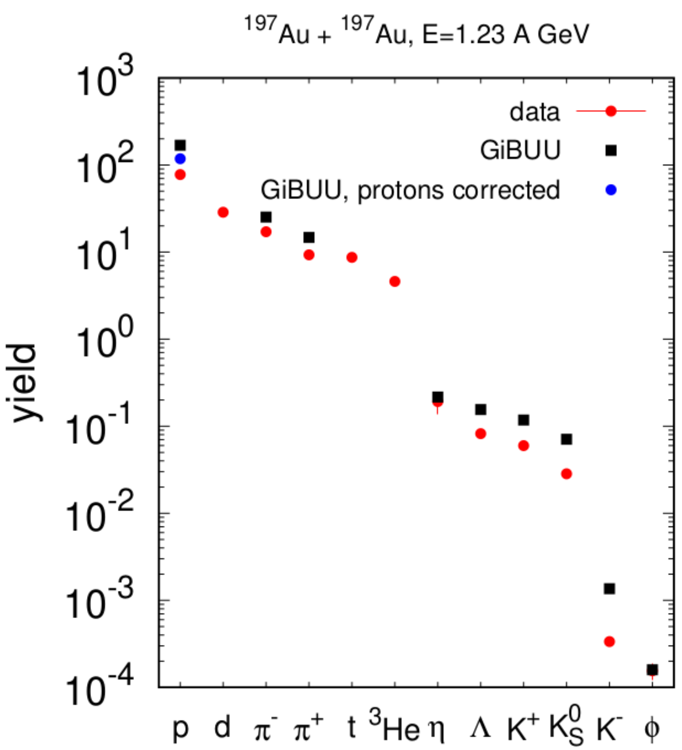
New experimental data from HADES shows that transport theories produce an excess of pions J. Adamczewski-Musch et al., EPJA 56, 259 (2020)



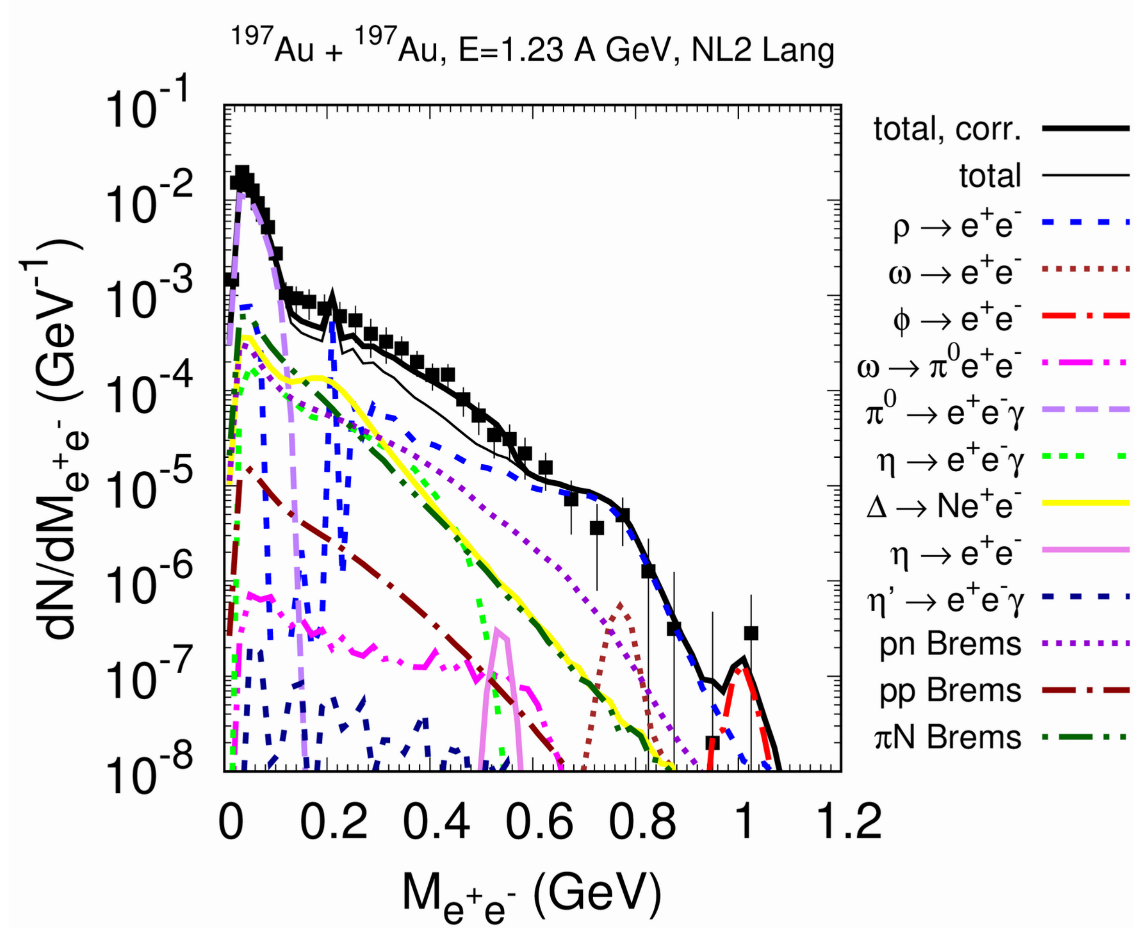
Rapidity spectra for 10% most central events

Other hadrons are overpredicted as well

However, the π^0 Dalitz decay agrees quite well with experiments
Larionov et al., PRC 102, 064913 (2020)



Hadron yields for the 10% or 20% most central events



Invariant mass distribution of dileptons (e^-e^+) for 40 % most central events

GiBUU: Brief Introduction

Lagrangian of the system

$$\mathcal{L} = \overline{\psi}[\gamma_\mu(i\partial^\mu - g_\omega\omega^\mu - g_\rho\vec{\tau}\vec{\rho}^\mu - \frac{e}{2}(1+\tau^3)A^\mu) - m_N - g_\sigma\sigma]\psi$$

$$+\frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - U(\sigma) + \frac{1}{2}m_\omega^2\omega^2 + \frac{1}{2}m_\rho^2\rho^2 - \frac{1}{16\pi}F_{\mu\nu}F^{\mu\nu}$$

The relativistic mean fields used in the Lagrangian are σ (isoscalar-scalar), ω^μ (isoscalar-vector) and $\vec{\rho}^\mu$ (isovector-vector)

$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ electromagnetic field strength tensor

$U(\sigma) = \frac{1}{2}m_\sigma^2\sigma^2 + \frac{1}{3}g_2\sigma^3 + \frac{1}{4}g_3\sigma^4$ Self-interaction of the scalar field

The Lagrangian leads to the following Dirac-style equations of motion (eom)

$$[\gamma_\mu(i\partial^\mu - g_\omega\omega^\mu - g_\rho\tau\rho^\mu - \frac{e}{2}(1+\tau^3)A^\mu) - m_N - g_\sigma\sigma]\psi \;=\; 0$$

$$\partial_\mu\partial^\mu\sigma + \frac{\partial U(\sigma)}{\partial\sigma} \;=\; -g_\sigma \boxed{\frac{2}{(2\pi)^3}\sum_{i=p,n,\bar{p},\bar{n}}\int\frac{d^3p}{p_i^{*\,0}}m^* f_i(x,p)}$$

Scalar density ρ_S

$$m_\omega^2\omega^\mu \;=\; g_\omega \boxed{\frac{2}{(2\pi)^3}\int d^3p\left(\sum_{i=p,n}\frac{p_i^{*\mu}}{p_i^{*\,0}}f_i(x,p) - \sum_{i=\bar{p},\bar{n}}\frac{p_i^{*\mu}}{p_i^{*\,0}}f_i(x,p)\right)}$$

Baryon current j_b^μ

$$m_\rho^2\rho^{3\,\mu} \;=\; g_\rho \boxed{\frac{2}{(2\pi)^3}\sum_{i=p,n,\bar{p},\bar{n}}\int\frac{d^3p}{p_i^{*\,0}}p_i^{*\mu}\tau_i^3 f_i(x,p)}$$

Isospin current $\vec{j}_I^\mu$

$$\partial_\mu\partial^\mu A^\nu \;=\; 4\pi e\boxed{\frac{1}{2}(j_b^\nu + j_I^{3\,\nu})}$$

Electromagnetic current j_c^ν

Kinematics

$$m^* = m_N + S$$

$$S = g_\sigma \sigma$$

$$p^* = p - V$$

$$V = g_\omega \omega + g_\rho \tau^3 \rho^3 + \frac{e}{2}(1 + \tau^3) A$$

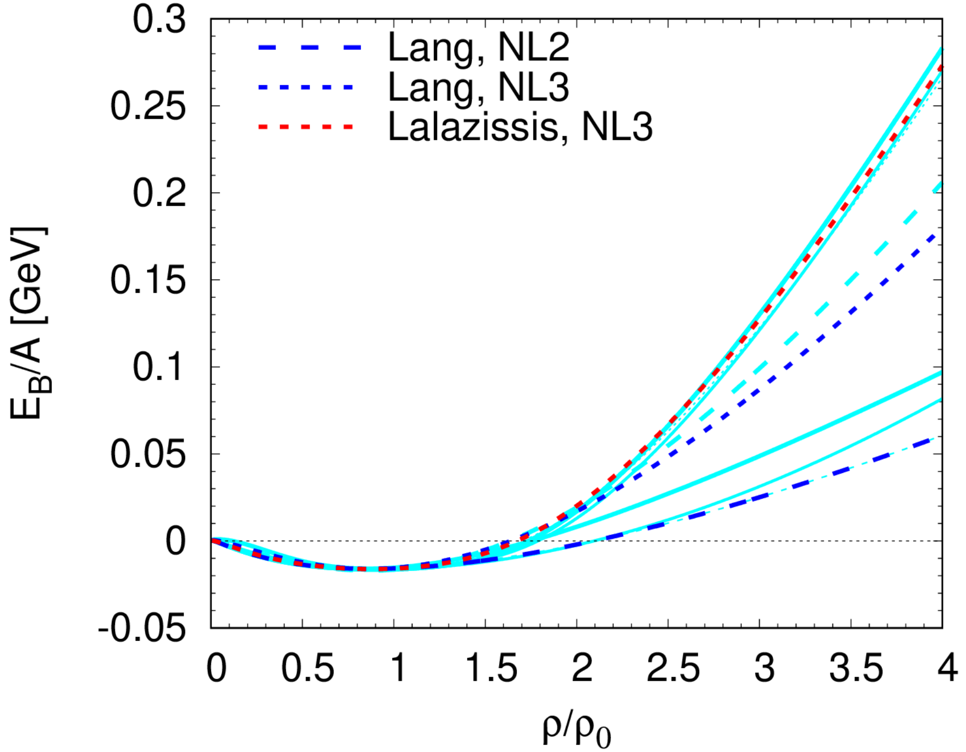
Dispersionrelation

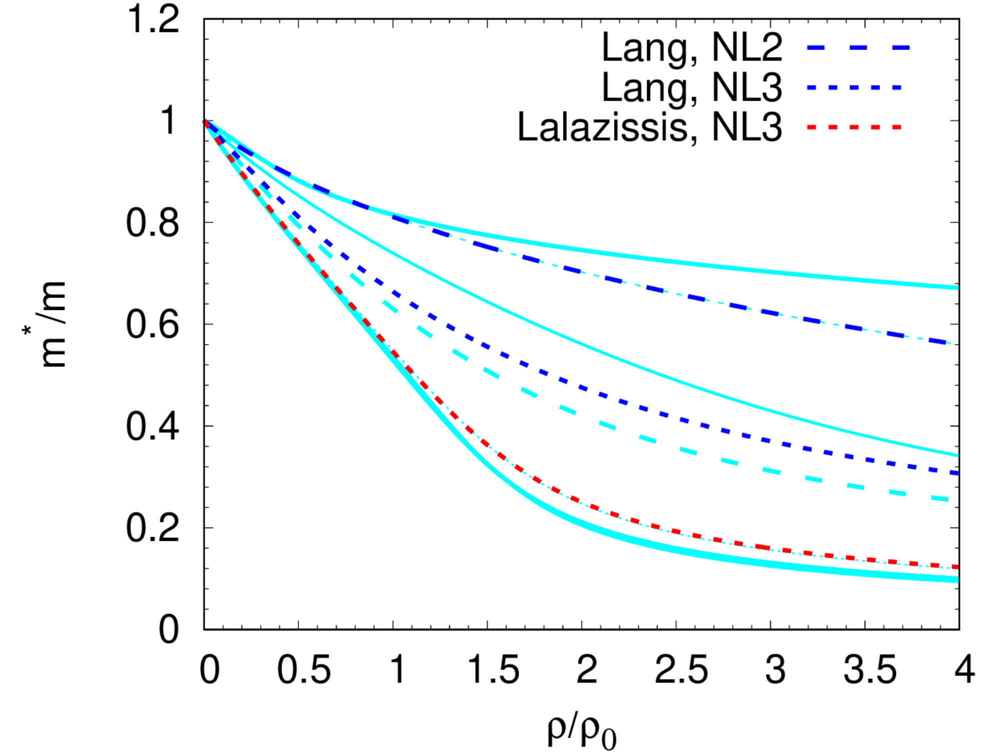
$$(p^*)^2 - (m^*)^2 = 0$$

Nonlinear (NL) Walecka models are considered: NL3 by Lalazissis and NL2 and NL3 by Lang represent the various eos.

Background: Lang considered HIC's (A. Lang et al., NPA 541, 507 (1992)), Lalazissis nuclear structure (G.A. Lalazissis et al., PRC 55, 540 (1997))

Smaller $\frac{m^*}{m}$ leads to repulsive optical potential: in-medium effects are enhanced





	NL2 Lang	NL3 Lang	NL3 Lalazissis
K [MeV]	210	380	272
m^*/m	0.83	0.70	0.60

The rmf's inside the nucleus lead to the modification of the baryon-baryon cross sections.

$$d\sigma^*_{12\to 1'2'\ldots N'} = (2\pi)^4 \delta^{(4)}\left(p_1 + p_2 - \sum_{i=1'}^{N'} p_i\right) \frac{\prod_{i=1'}^{N'} n_i^*}{4I^*_{12}} \overline{|\mathfrak{M}_{12\to 1'2'\ldots N'}|^2}$$

$$\times \mathcal{S}_{1'2'\ldots N'} \prod_{i=1'}^{N'} A_i(p_i) \frac{d^4 p_i}{(2\pi)^3 2p_i^{*0}}$$

n_i^* = $2m_i^*$ for baryons; = 1 for mesons

Three different cross sections are considered

- Vacuum cross sections
- All inelastic cross sections are modified (noted: σ^*)
- Only cross sections $NN \leftrightarrow NN\pi$ and $NN \leftrightarrow N\Delta$ are modified (noted: σ^*_Δ)

Elastic cross sections are never modified

FOPI measured the rapidity of proton-like particles for AuAu HIC's.

W. Reisdorf et al., PRL 92, 232301 (2004)

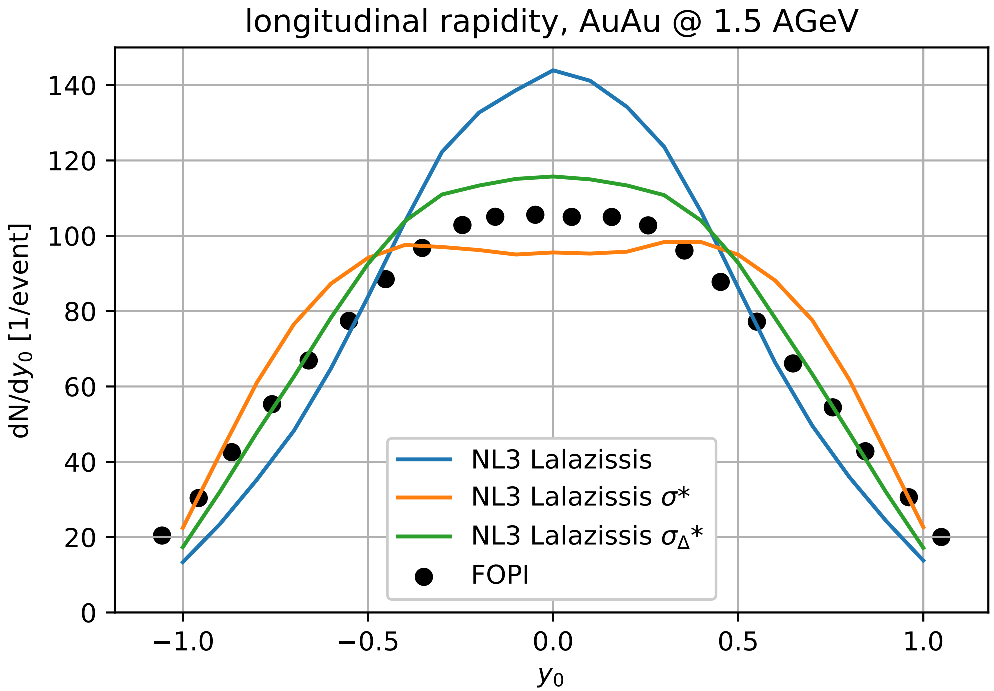
Longitudinal rapidity is given by

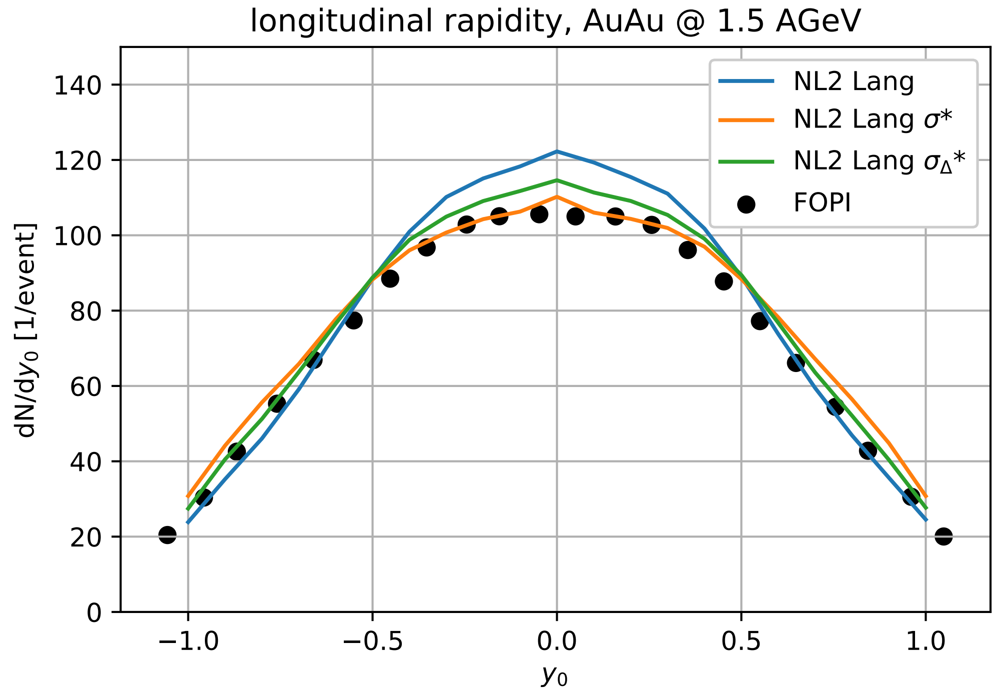
$$y = \frac{1}{2}\ln(\frac{E+p_z}{E-p_z})$$

$$y_0 = (y/y_p)_{c.m.}$$

NL2 Lang with in-medium modifications describes the System best

$$b_{max} = 1.15(A_p^{1/3} + A_t^{1/3})$$





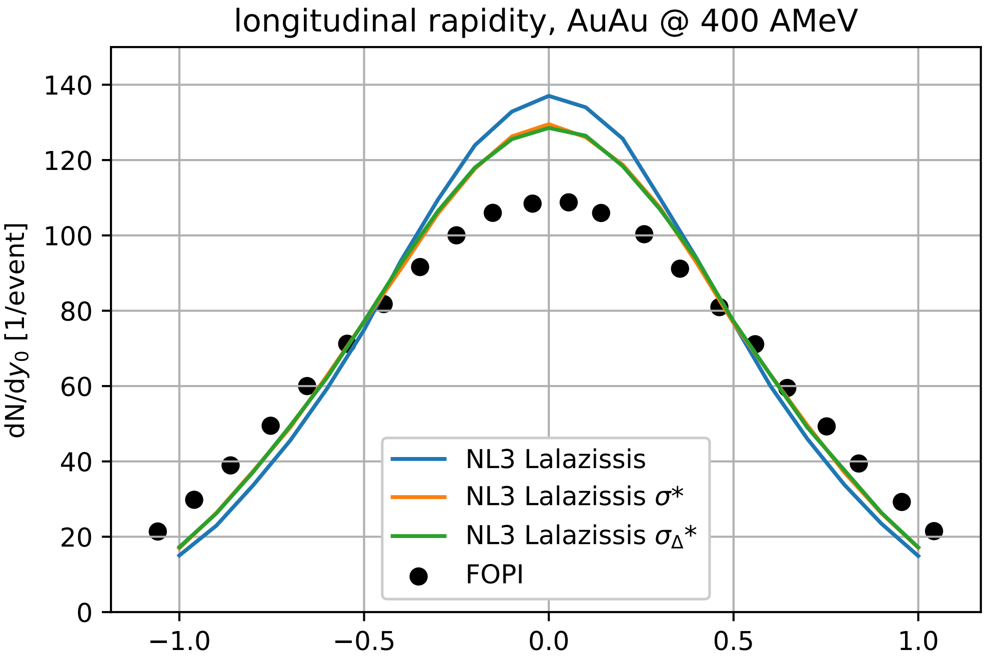
Rapidity of proton-like particles, for $b^0 < 0.15 b_{max}$

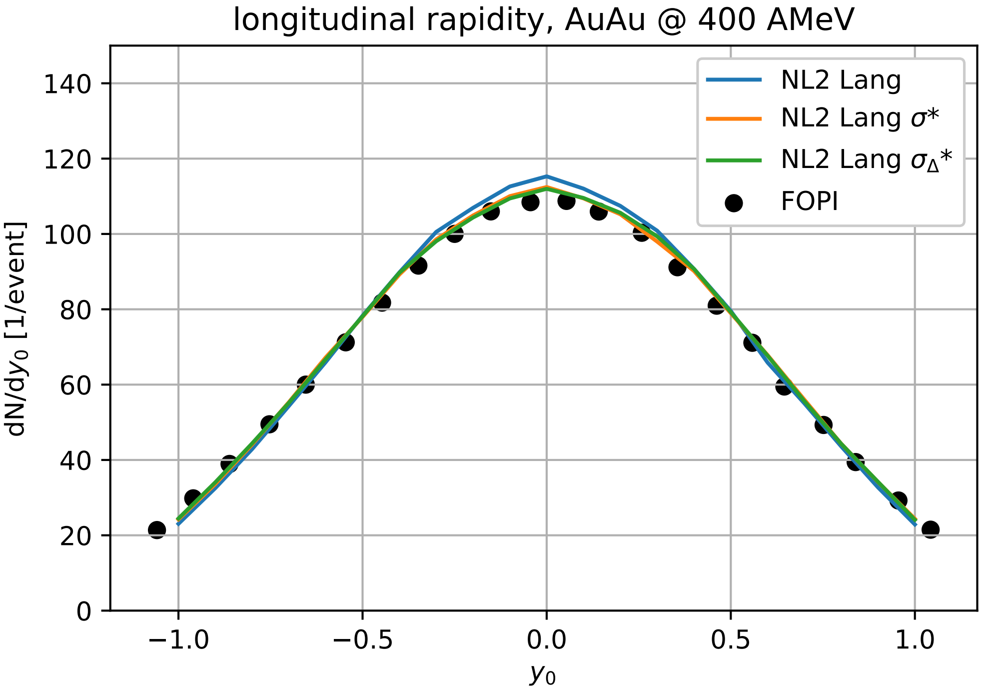
FOPI measured the rapidity of proton-like particles for AuAu HIC's.

W. Reisdorf et al., NPA 781, 459 (2007)

NL3 by Lalazissis overpredicts protons at midrapidity

The eos NL2 describes the distribution of proton-like particles well, even at lower energies



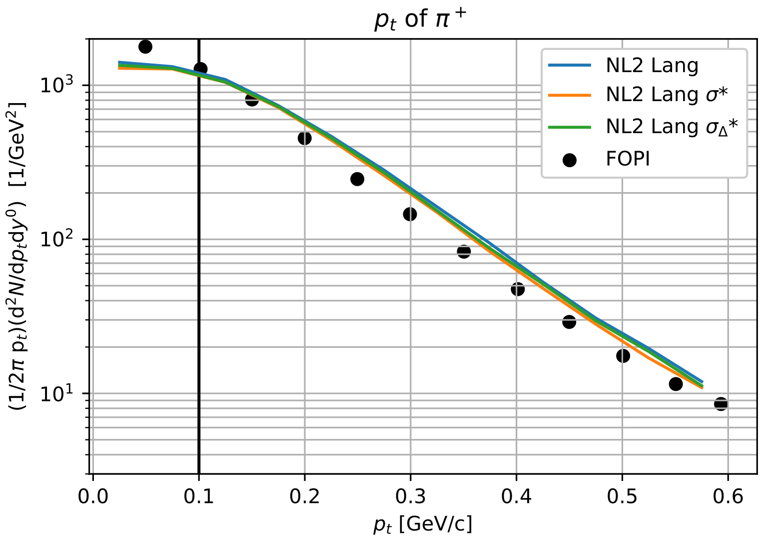


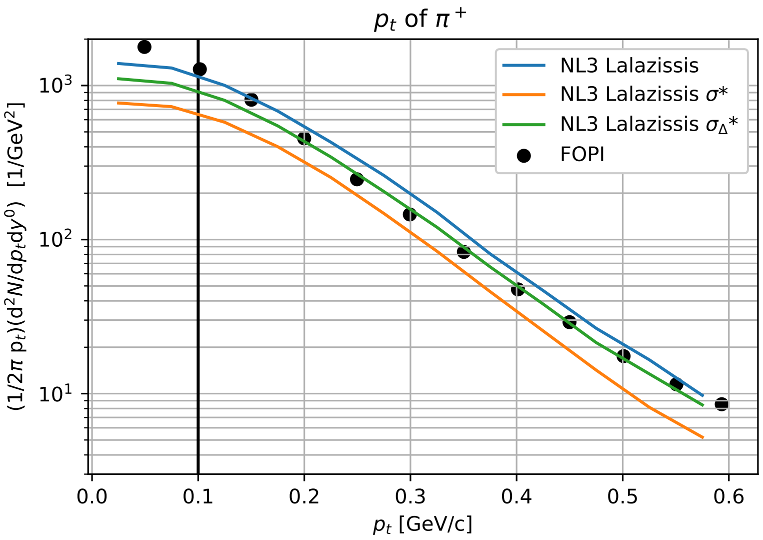
Rapidity of proton-like particles, for $b^0 < 0.15b_{max}$

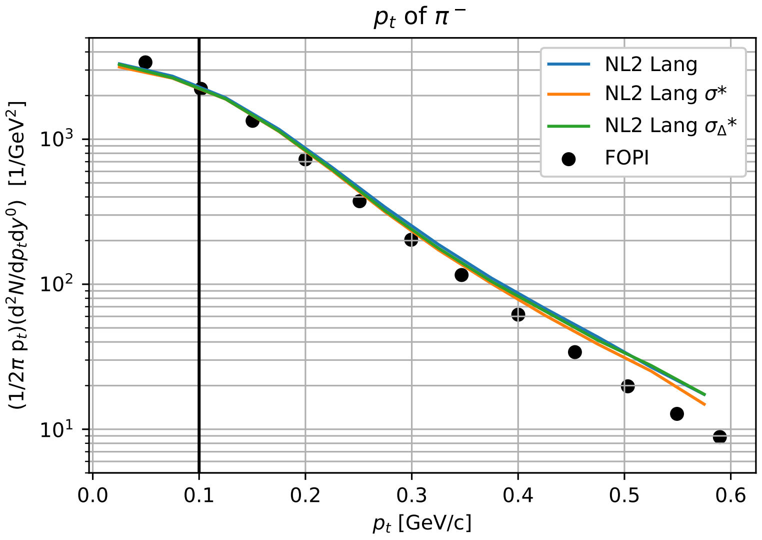
FOPI also measured the p_t spectra of charged pions. AuAu @ 1.5 AGeV
W. Reisdorf et al., NPA 781, 459 (2007)

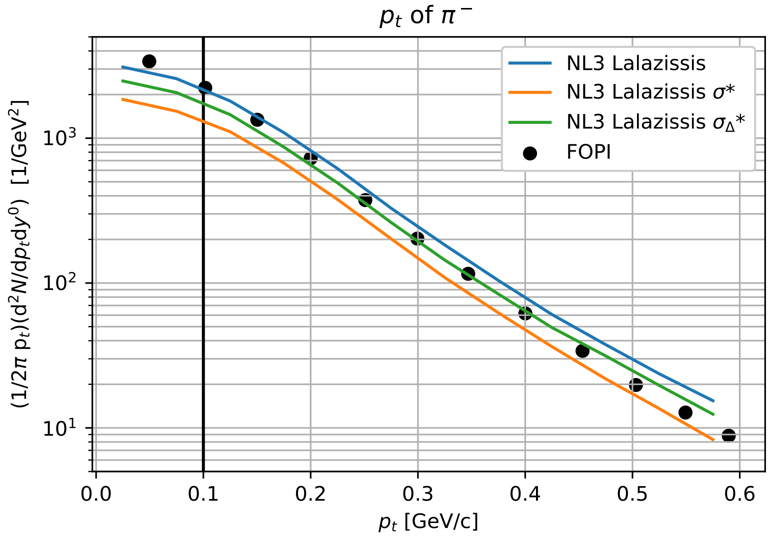
For pions NL3 by Lalazissis provides the best agreement with experiment.

Transverse momentum spectra of charged pions for $b^0 < 0.15 b_{max}$ integrated over rapidity. Data to the left of black line are extrapolated.



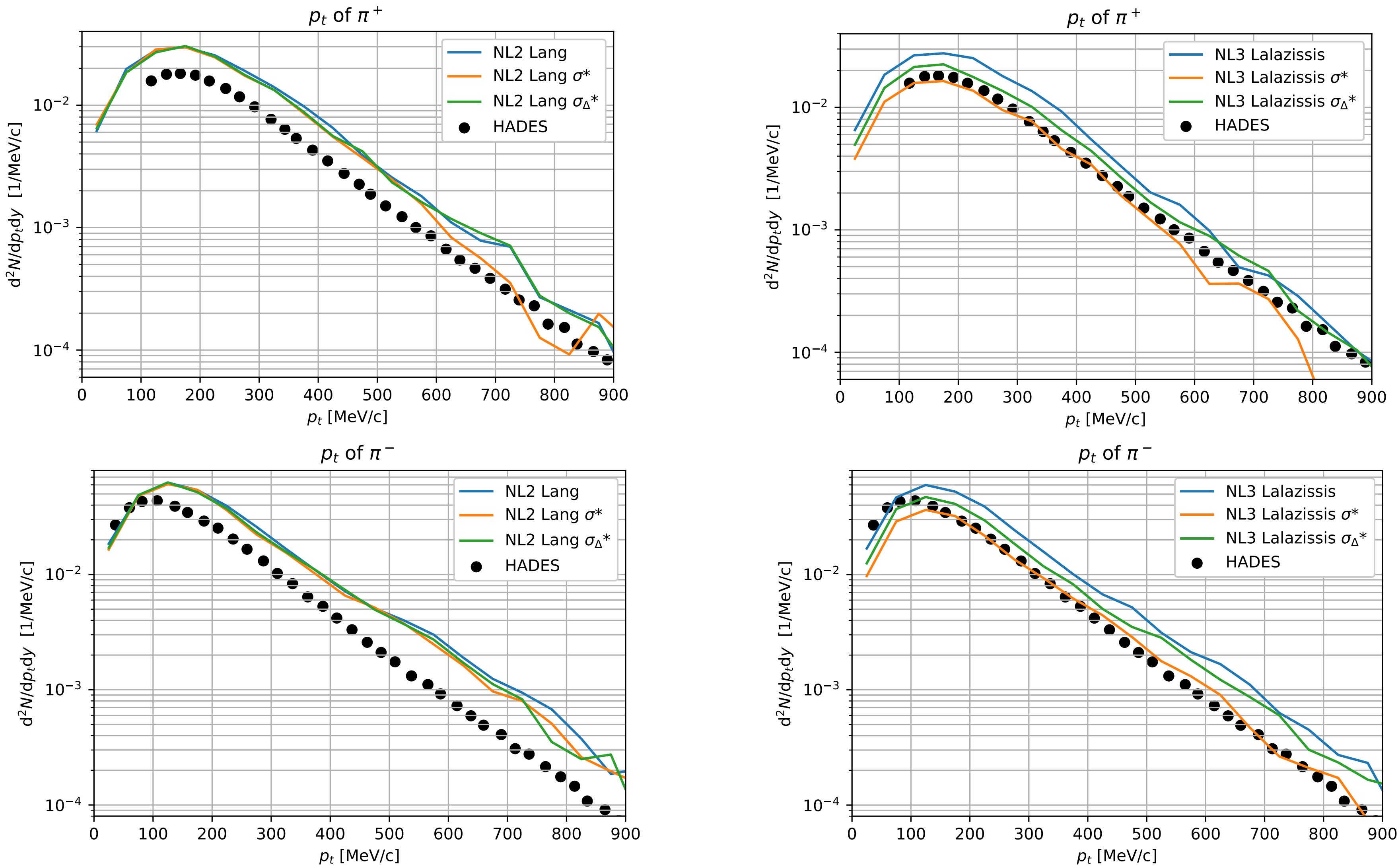






HADES measured the pion rapidity spectra and the transverse momentum spectra of charged pions. AuAu @ 1.23 AGeV J. Adamczewski-Musch et al., EPJA 56, 259 (2020)

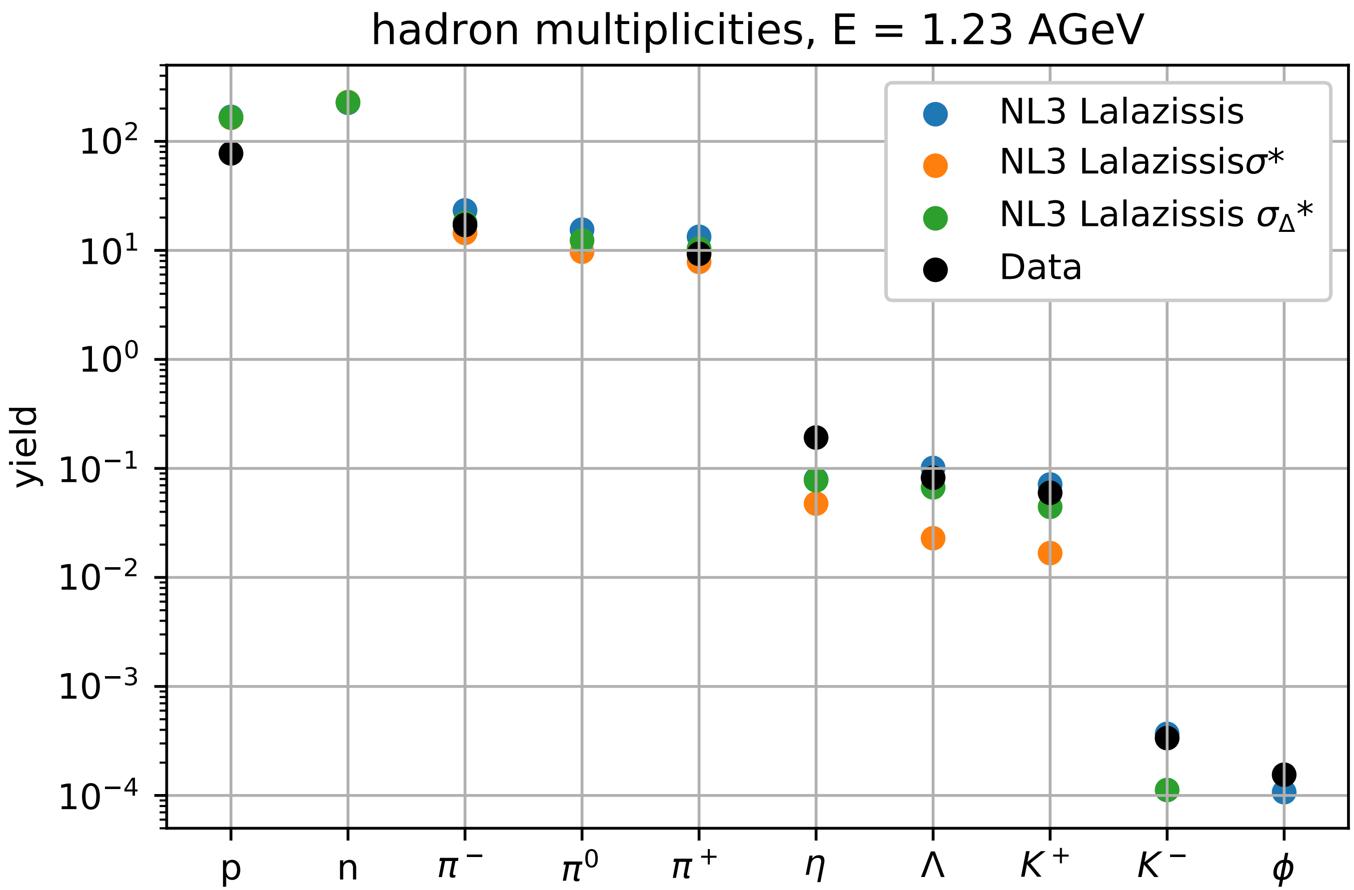
Transverse momentum spectra of charged pions
for 10 % most central events at midrapidity.



The yield for various hadrons can be reproduced well

By only modifying the cross sections related to Δ strangeness is comparable with experiments

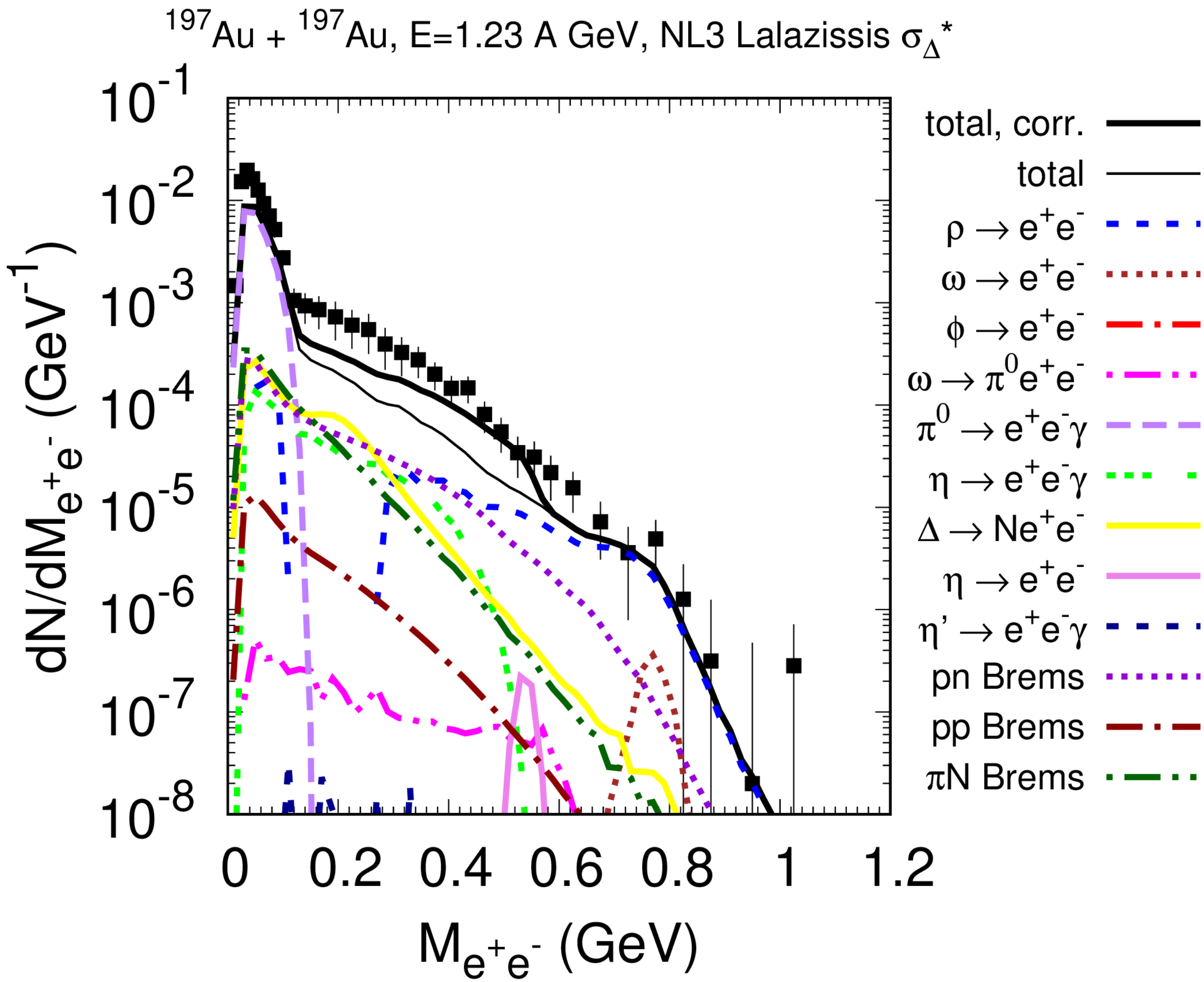
Larionov et al., PRC 102, 064913 (2020)



Hadron yields for the 10% or 20% most central events. AuAu @ 1.23 AGeV

Surprisingly, the π^0 Dalitz decay is now underpredicted

J. Adamczewski-Musch et al. (HADES), Nature



Invariant Mass spectra of dileptons for 40 % most central events

conclusion

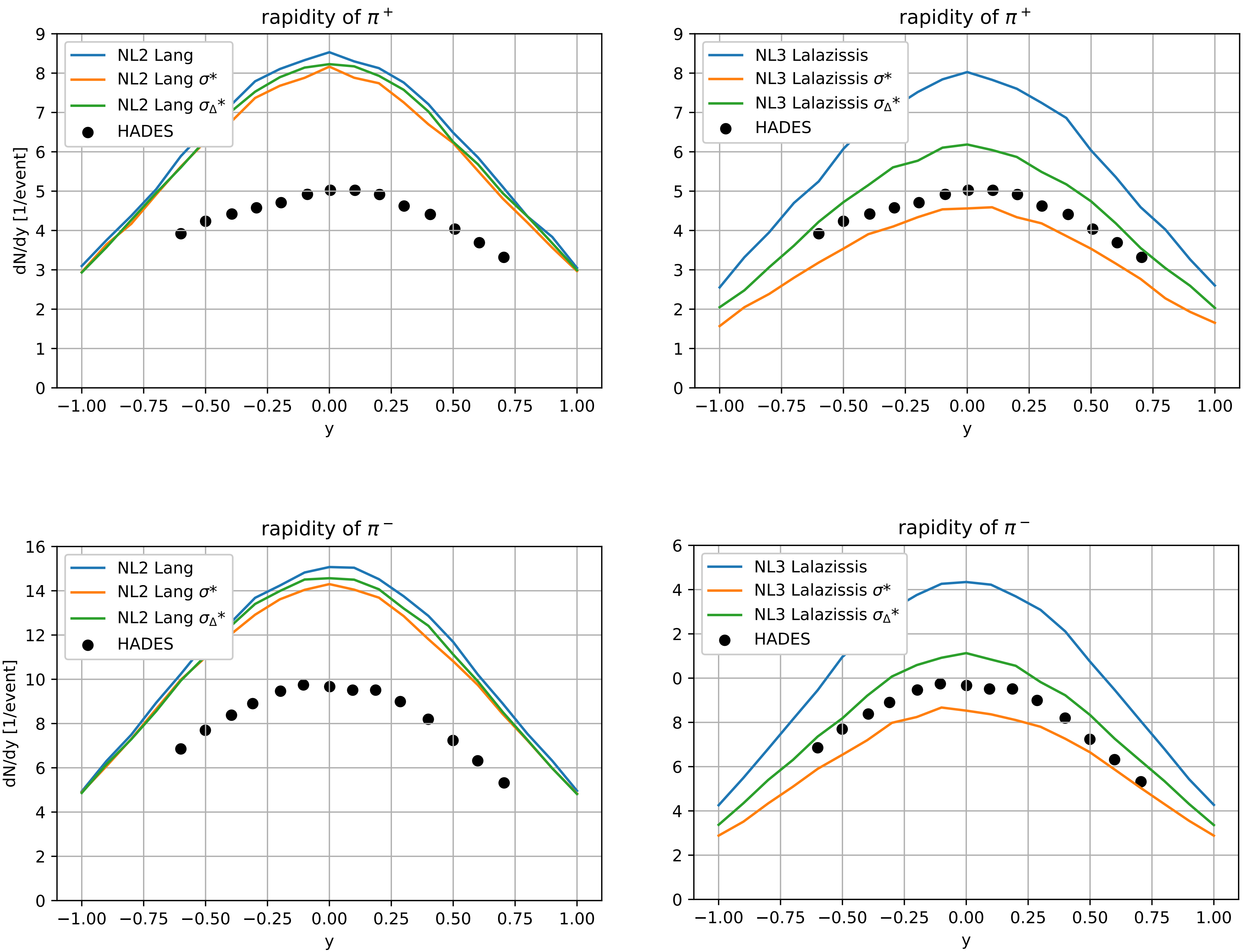
NL2 by Lang describes proton distributions in HIC's well, but creates an abundance of pions

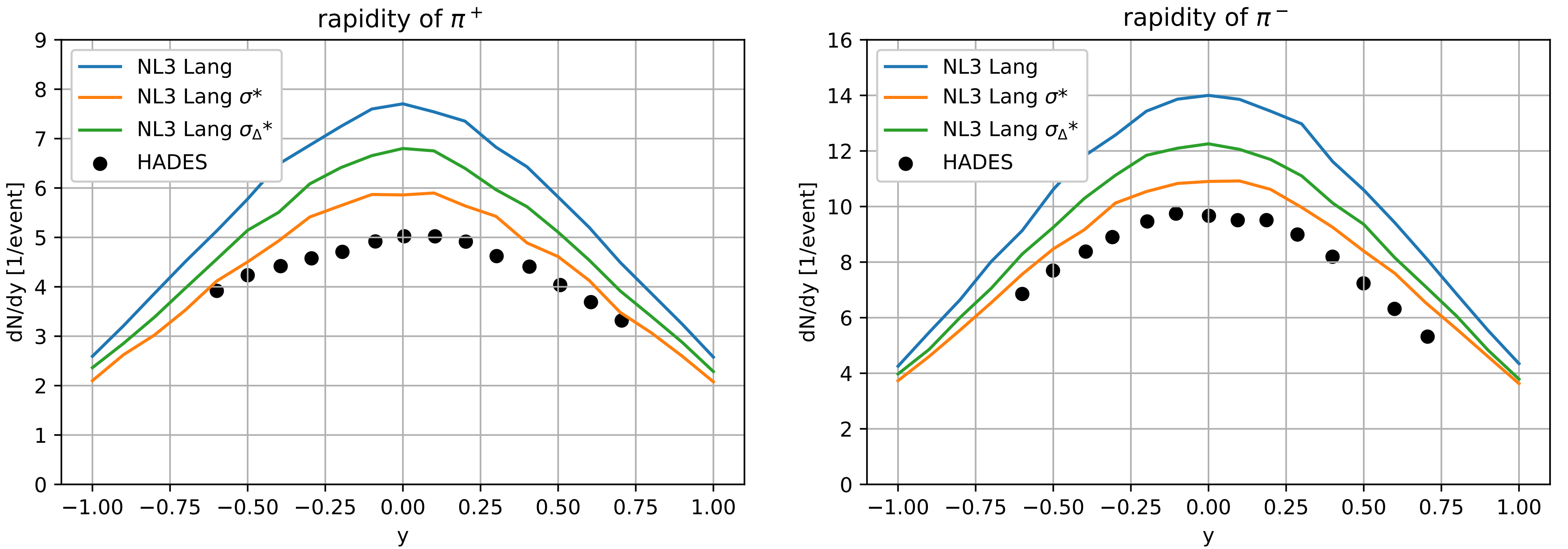
To lower pion yields, NL3 by Lalazissis with modifications of the Δ cross sections are used

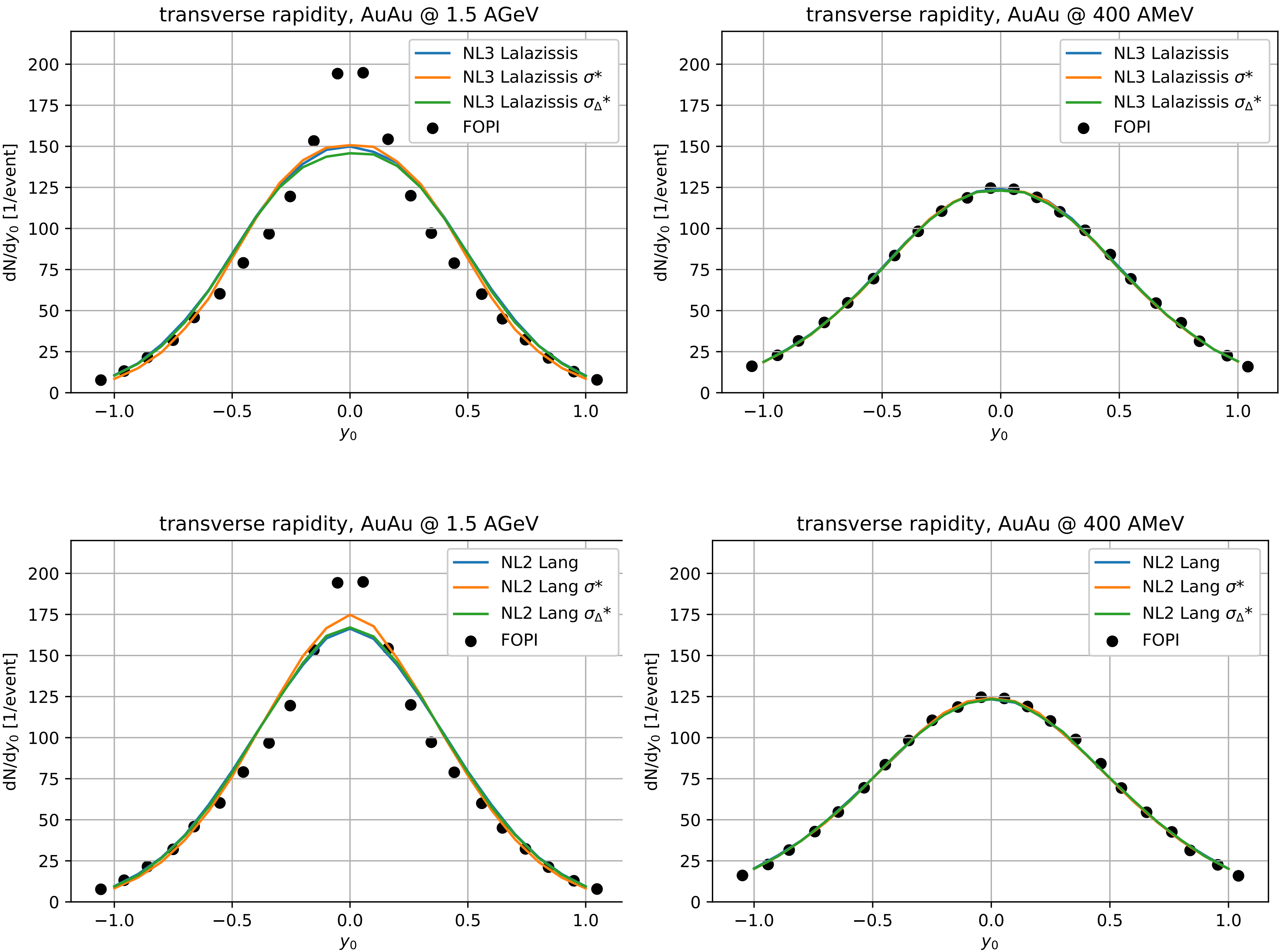
NL2 by Lang performs better at lower Energies (400 AMeV)

Reproducing the π^0 Dalitz decay leads to an excess of pions. Lowering the pion yield also lowers the π^0 Dalitz decay.

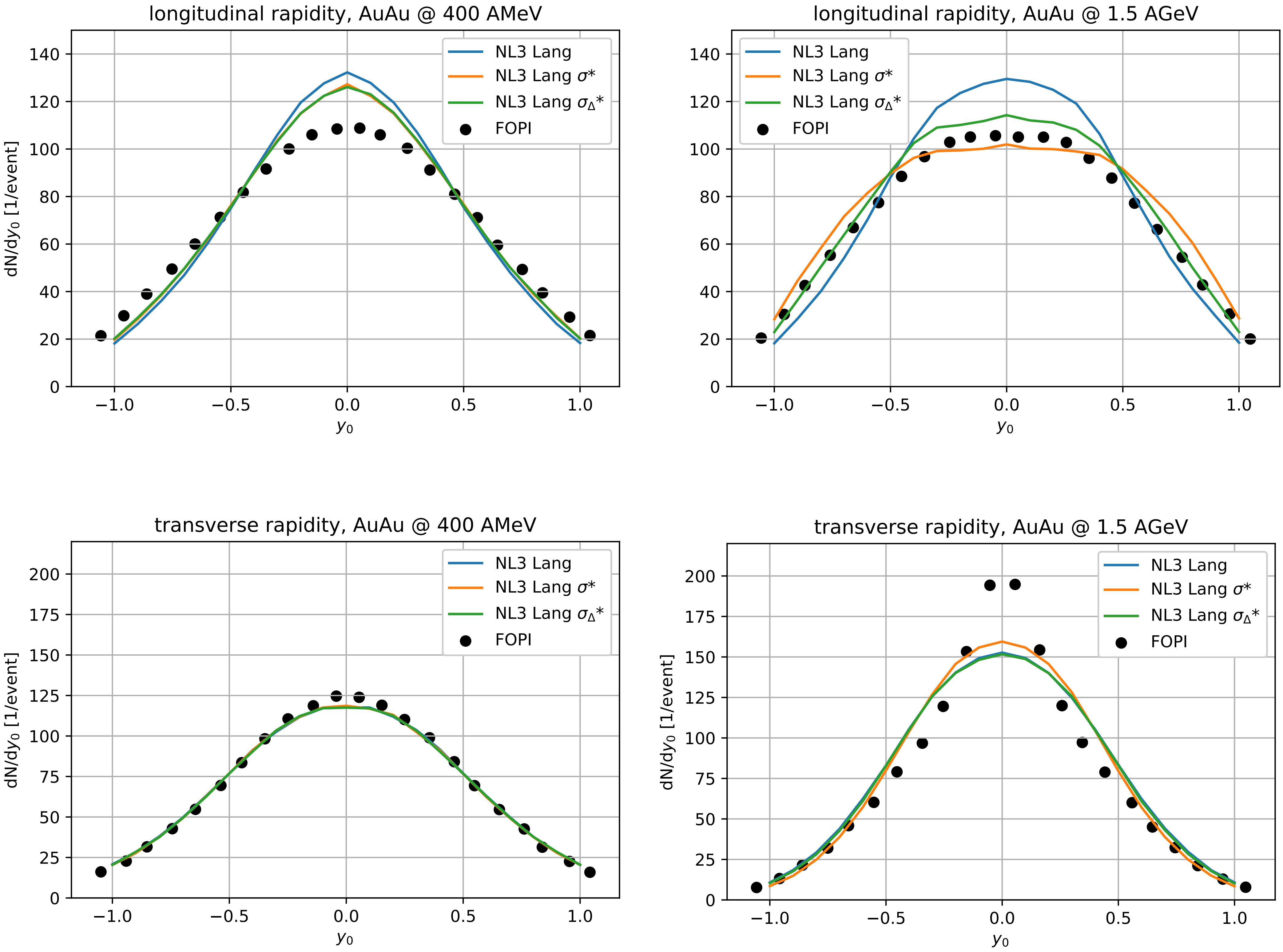
Backup


rapidity of π^+
NL2 Lang
NL2 Lang σ*
NL2 Lang σ_Δ*
HADES
dN/dy [1/event]
y
rapidity of π^+
NL3 Lalazissis
NL3 Lalazissis σ*
NL3 Lalazissis σ_Δ*
HADES
y
rapidity of π^-
NL2 Lang
NL2 Lang σ*
NL2 Lang σ_Δ*
HADES
dN/dy [1/event]
y
rapidity of π^-
NL3 Lalazissis
NL3 Lalazissis σ*
NL3 Lalazissis σ_Δ*
HADES
y

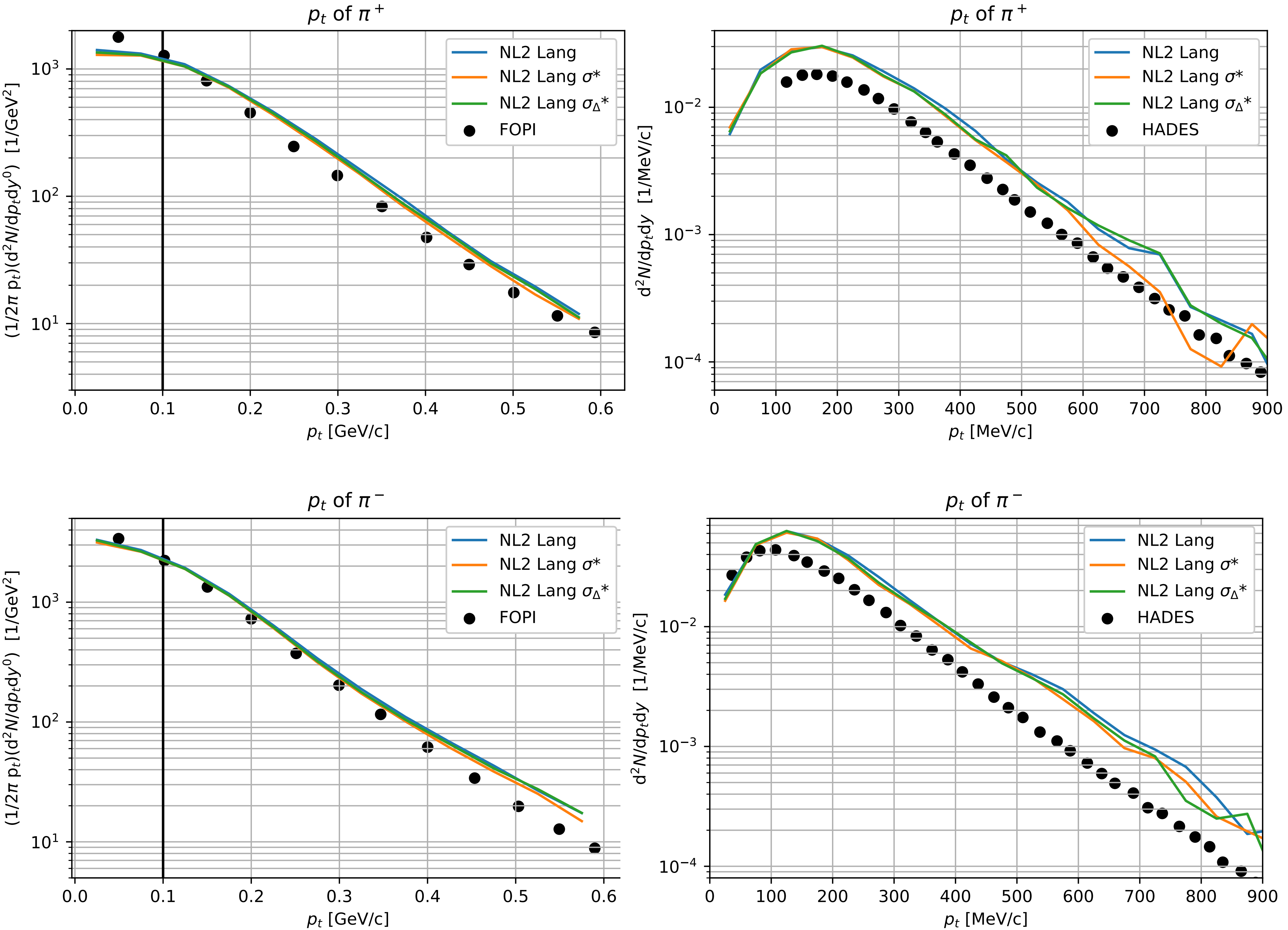

rapidity of π^+
rapidity of π^-
NL3 Lang
NL3 Lang σ*
NL3 Lang σ_Δ*
HADES
dN/dy [1/event]
y



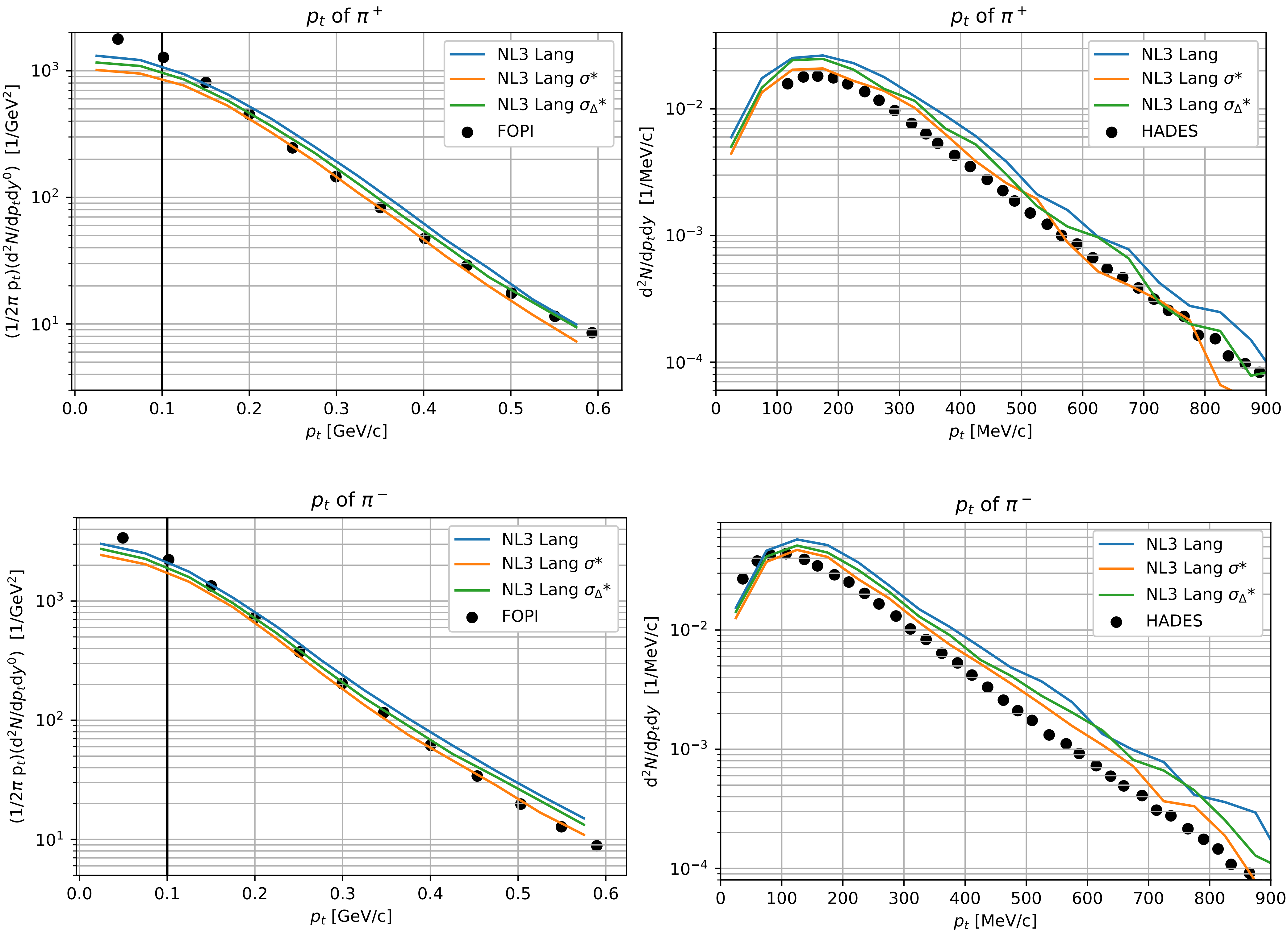
transverse rapidity, AuAu @ 1.5 AGeV
transverse rapidity, AuAu @ 400 AMeV
NL3 Lalazissis
NL3 Lalazissis σ*
NL3 Lalazissis σ_Δ*
FOPI
NL2 Lang
NL2 Lang σ*
NL2 Lang σ_Δ*
dN/dy₀ [1/event]
y₀



longitudinal rapidity, AuAu @ 400 AMeV
longitudinal rapidity, AuAu @ 1.5 AGeV
transverse rapidity, AuAu @ 400 AMeV
transverse rapidity, AuAu @ 1.5 AGeV
NL3 Lang
NL3 Lang σ*
NL3 Lang σ_Δ*
FOPI
dN/dy_0 [1/event]
y_0



p_t of π^+
NL2 Lang
NL2 Lang $\sigma*$
NL2 Lang $\sigma_\Delta*$
FOPI
$(1/2\pi\ p_t)(d^2N/dp_t dy^0)$ [1/GeV^2]
p_t [GeV/c]
p_t of π^+
NL2 Lang
NL2 Lang $\sigma*$
NL2 Lang $\sigma_\Delta*$
HADES
$d^2N/dp_t dy$ [1/MeV/c]
p_t [MeV/c]
p_t of π^-
NL2 Lang
NL2 Lang $\sigma*$
NL2 Lang $\sigma_\Delta*$
FOPI
$(1/2\pi\ p_t)(d^2N/dp_t dy^0)$ [1/GeV^2]
p_t [GeV/c]
p_t of π^-
NL2 Lang
NL2 Lang $\sigma*$
NL2 Lang $\sigma_\Delta*$
HADES
$d^2N/dp_t dy$ [1/MeV/c]
p_t [MeV/c]



p_t of π^+
NL3 Lang
NL3 Lang σ*
NL3 Lang σ_Δ*
FOPI
$(1/2\pi\ p_t)(d^2N/dp_t dy^0)$ [1/GeV^2]
p_t [GeV/c]
p_t of π^+
NL3 Lang
NL3 Lang σ*
NL3 Lang σ_Δ*
HADES
$d^2N/dp_t dy$ [1/MeV/c]
p_t [MeV/c]
p_t of π^-
NL3 Lang
NL3 Lang σ*
NL3 Lang σ_Δ*
FOPI
$(1/2\pi\ p_t)(d^2N/dp_t dy^0)$ [1/GeV^2]
p_t [GeV/c]
p_t of π^-
NL3 Lang
NL3 Lang σ*
NL3 Lang σ_Δ*
HADES
$d^2N/dp_t dy$ [1/MeV/c]
p_t [MeV/c]