Transport Simulations of Pion Production in Low Energy Au+Au Collisions

Master's Thesis

by

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AQTIVATE

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Outline

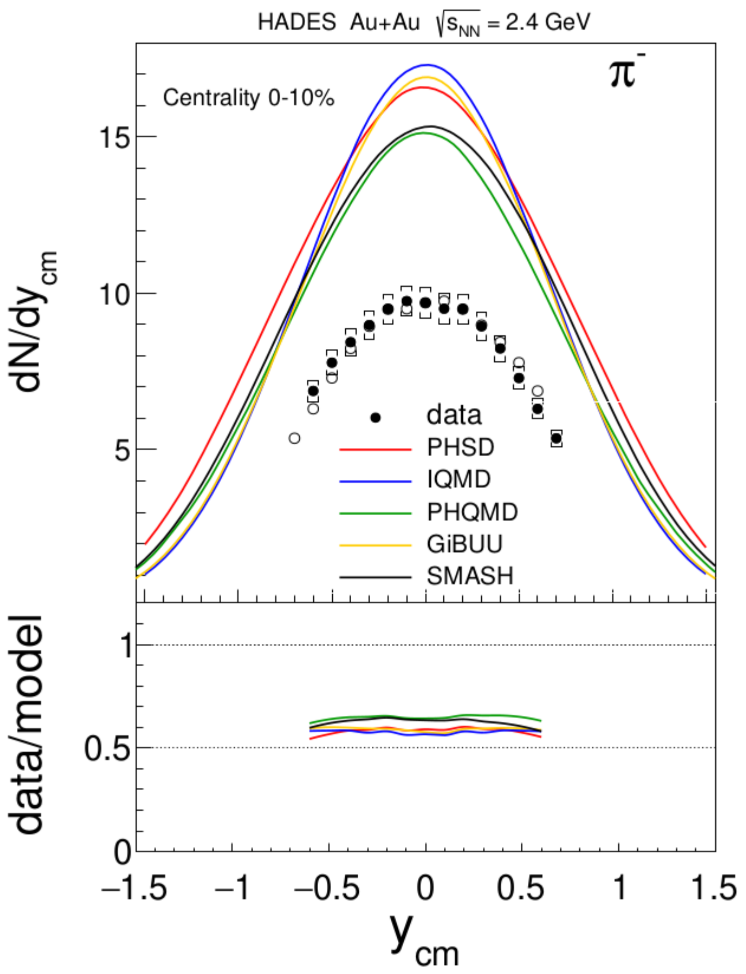
- Motivation
- GiBUU Transport Code
- Proton Rapidty Distributions
- Pion Spectra
- Dileptons
- Conclusions

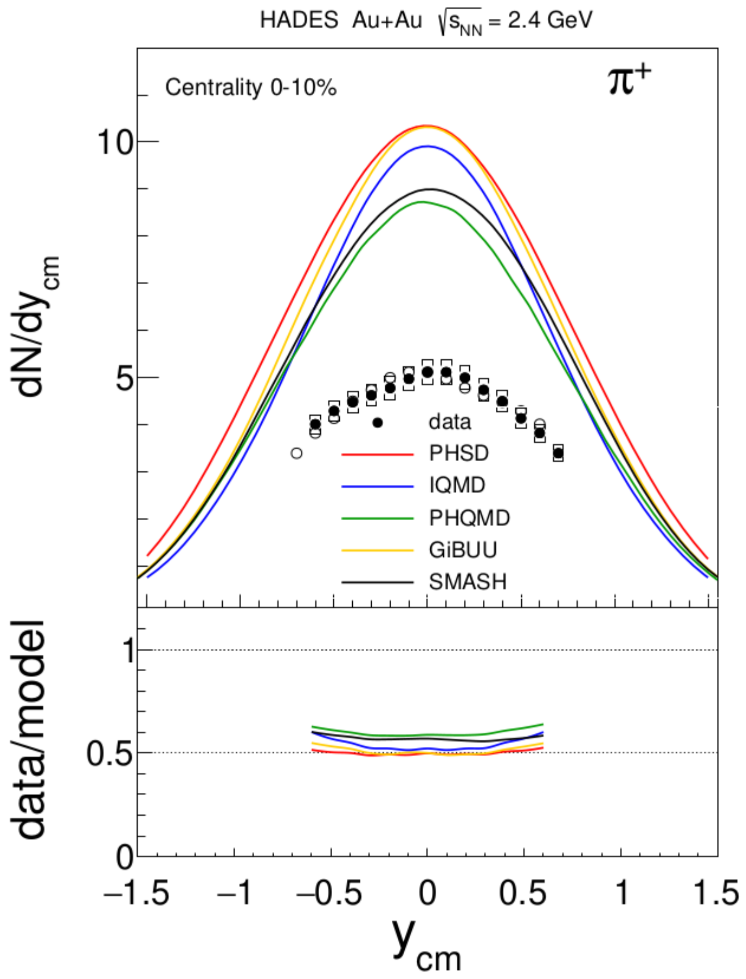
Based on: C. Kummer *et al.*, http://arxiv.org/abs/2309.09042

Motivation

- Strong nuclear force can be studied by Heavy-ion collisions (HIC)
- Transport models simulate HICs
- New experimental data from HADES [1] shows that transport theories produce an excess of pions

Motivation





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

GiBUU Transport Code

- Giessen Boltzmann-Uehling-Uhlenbeck Transport Code [2] combines two concepts
- Inclusion of Mean-Field
- Cascade Model

$$\frac{\partial f}{\partial t} + \boldsymbol{v} \cdot \boldsymbol{\nabla}_r f - \boldsymbol{\nabla}_r U \cdot \boldsymbol{\nabla}_p f = I_{\mathrm{coll}}$$

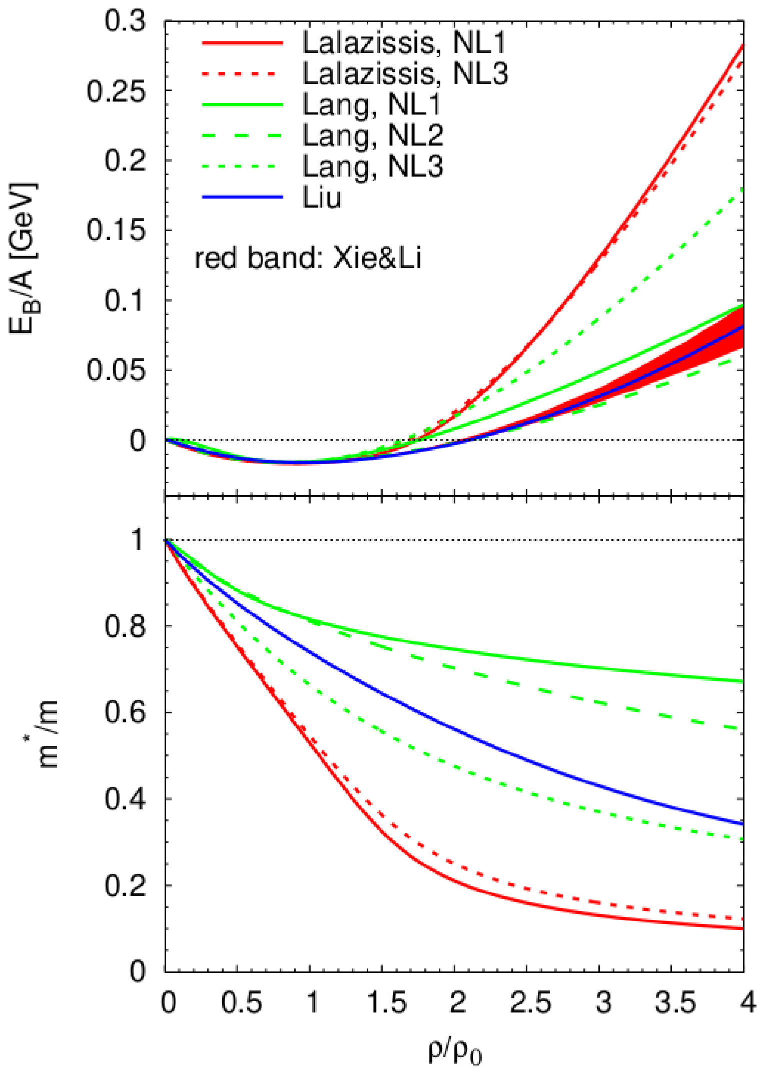
GiBUU Transport Code: Mean Field

- Relativistic Mean Field (RMF)
- Gives equation of state (EOS)
- Meson fields are included

$$m_N^* = m_N + S \qquad p^{*\mu} = p^\mu - V^\mu$$

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

[3-6]



GiBUU Transport Code: Cascade Model

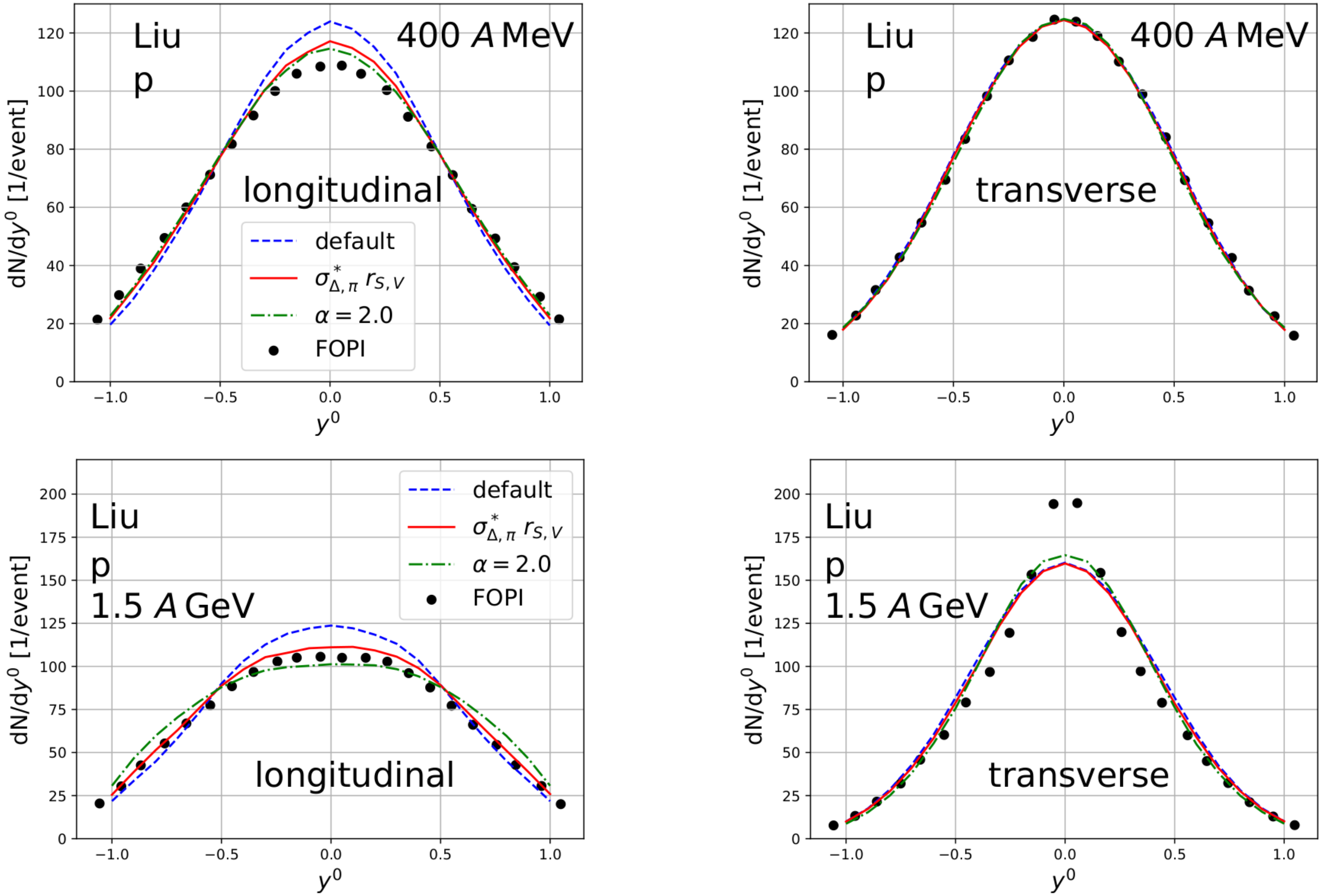
- Checks for Collisions
- Decides on the reaction channel by Monte Carlo (MC)
- Cross sections can be altered by
  - Effective Mass
  - Delta potential modifications
  - Exponential Suppression

Proton Rapidity Distributions

- Data from FOPI [7]

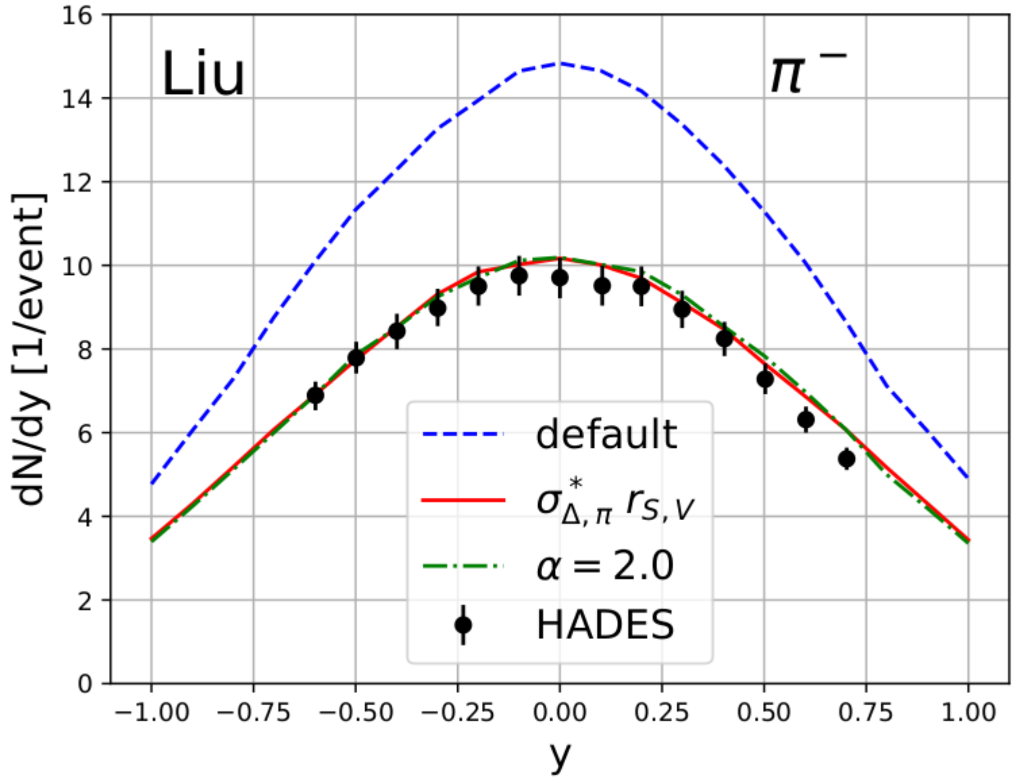
$$y_z = \frac{1}{2}\log\left(\frac{E+p_z}{E-p_z}\right)$$

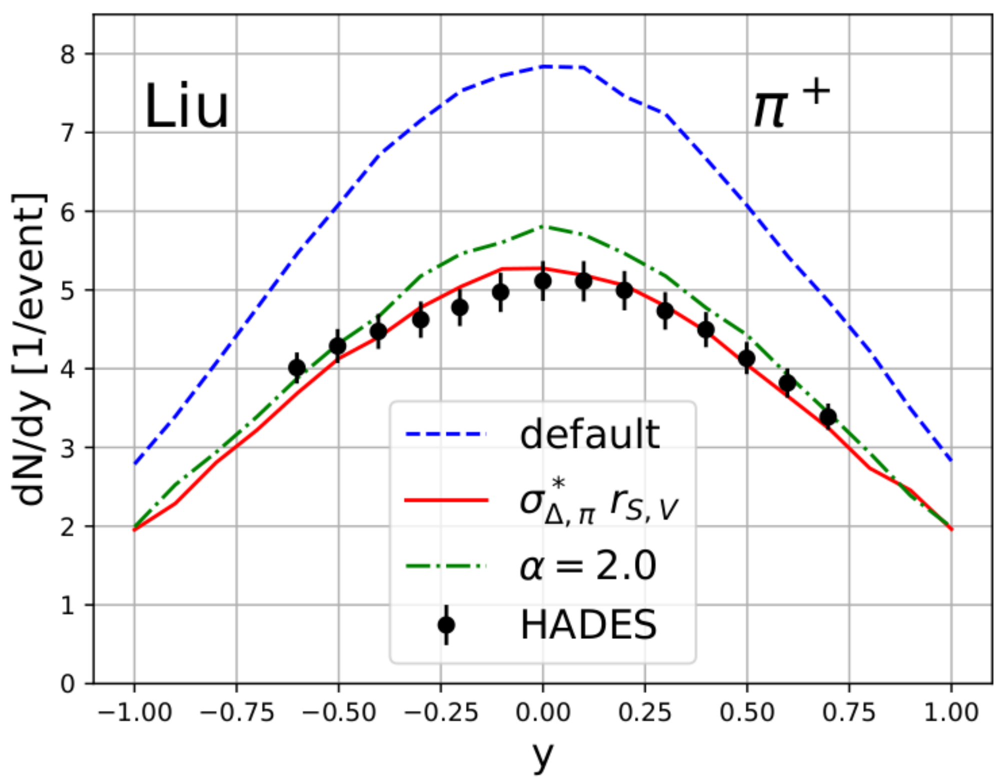
$$y_x = \frac{1}{2}\log\left(\frac{E+p_x}{E-p_x}\right)$$



Pion Spectra

- Data from HADES [1]





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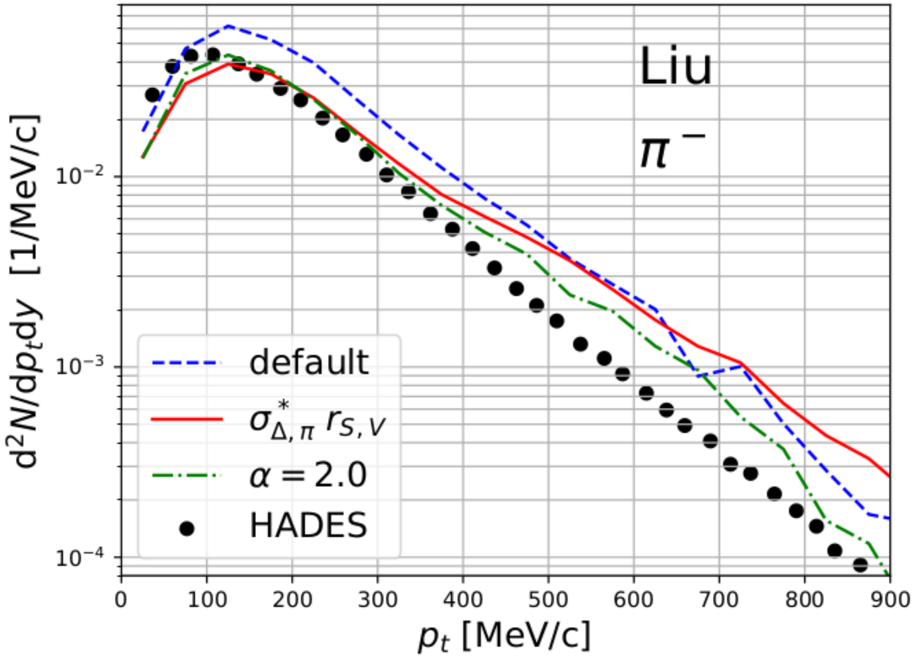
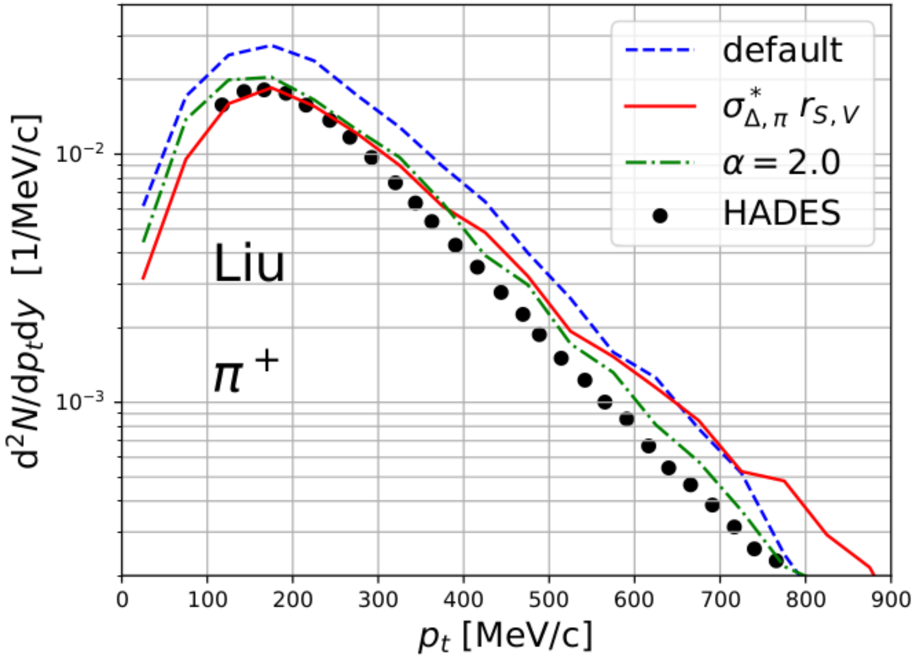
Pion Spectra





	default	$\sigma^*_{\Delta,\pi}\ r_{S,V}$	$\alpha = 2.0$	HADES
$M(\pi^-)$	24.462	17.188	16.999	17.1±1.8
$M(\pi^+)$	13.577	9.2364	9.7266	9.3±1.0
$M(\pi^-)/M(\pi^+)$	1.8017	1.8609	1.7476	1.83±0.17

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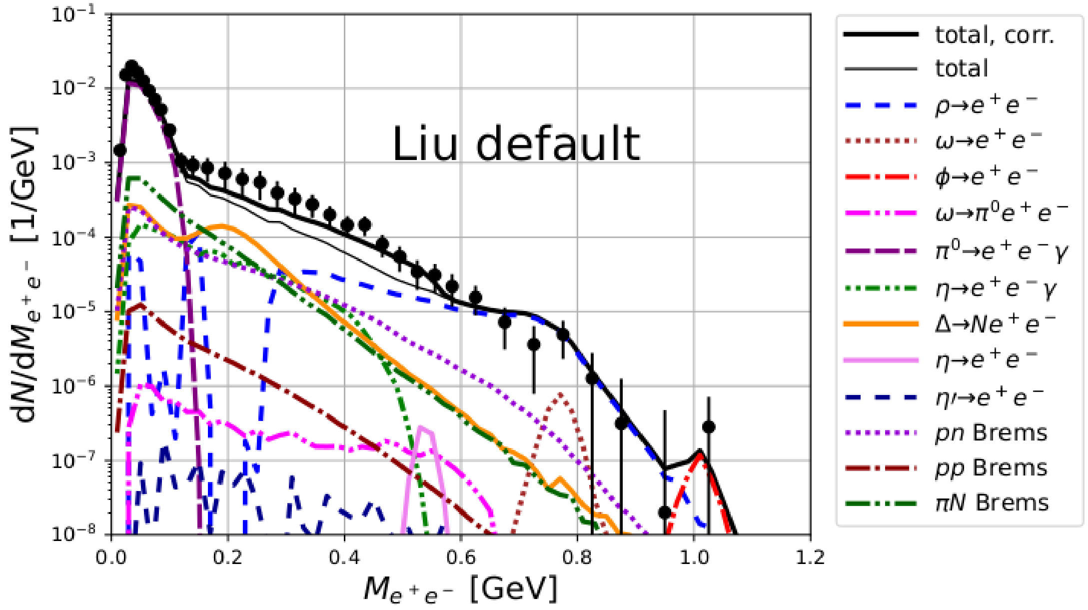
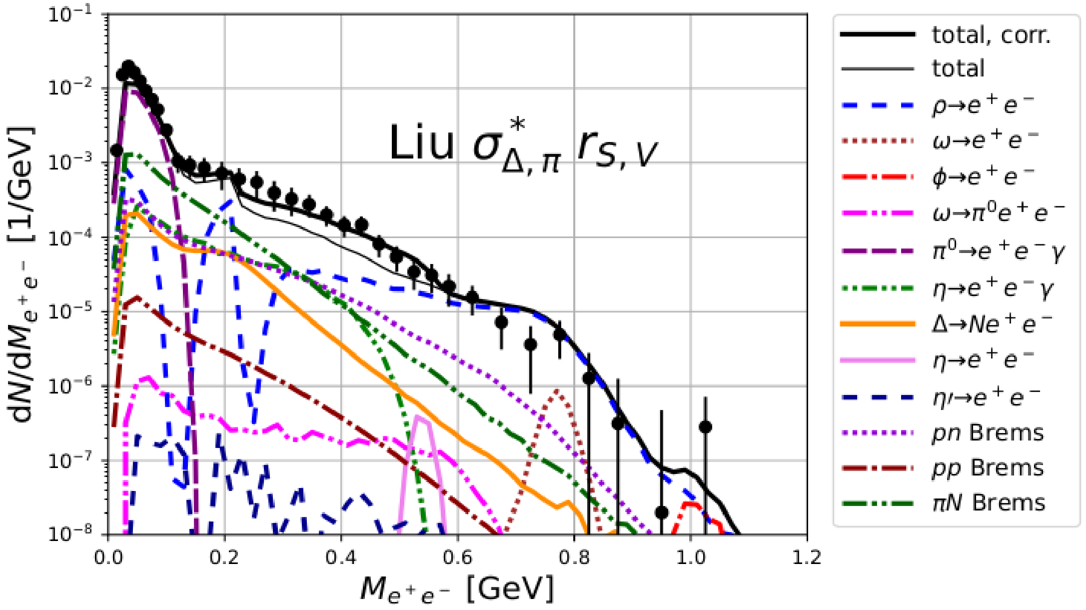
Dileptons

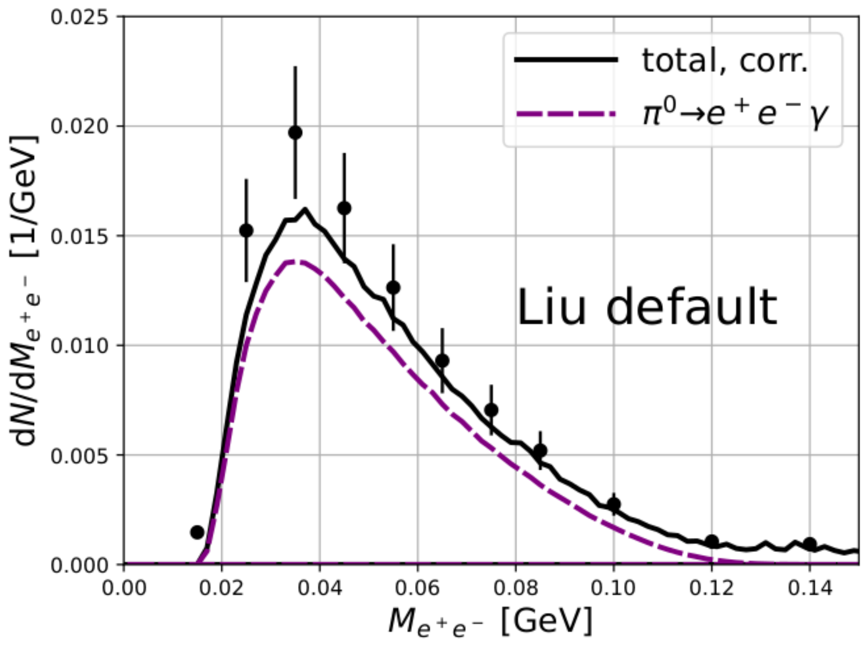
- Data from HADES [8]

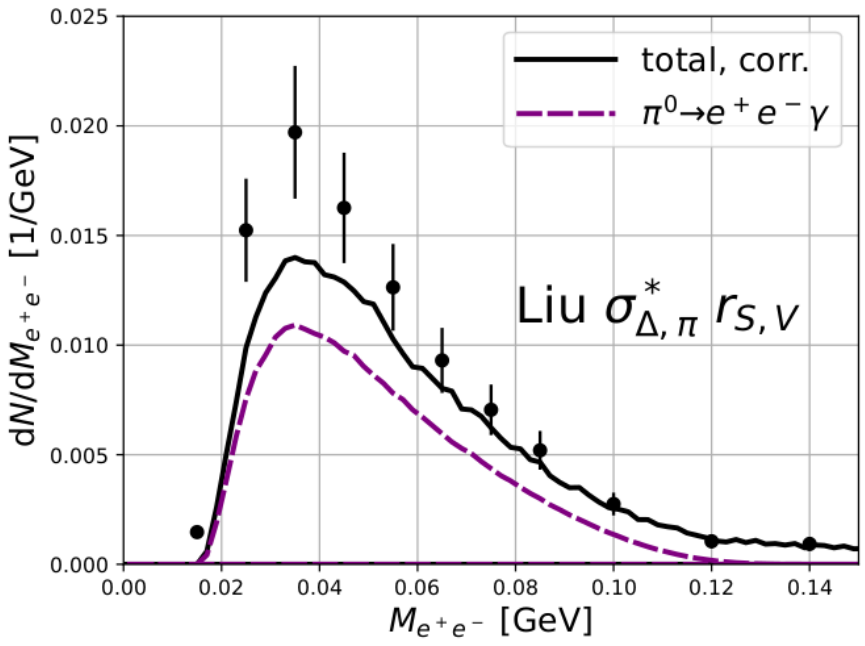




Dileptons

- Data from HADES [8]





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Conclusions

- Liu EOS describes the mean field well
- Modifications lower pion numbers drasticly
- Modifications are not just motivated by phenomenology
- Some problems remain (transverse momentum spectra and dileptons)
- Overall: Significant improvement and excellent agreement with rapidity spectra

Thank you

Bibliography

[1] J. Adamczweski-Musch *et al.*, EPJA 56, 259 (2020)

[2] O. Buss *et al.*, PR 512, 1 (2012)

[3] G.A. Lalazissis *et al.*, PRC 55, 540 (1997)

[4] A. Lang *et al.*, NPA 541, 507 (1992)

[5] B. Liu *et al.*, PRC 65, 045201 (2002)

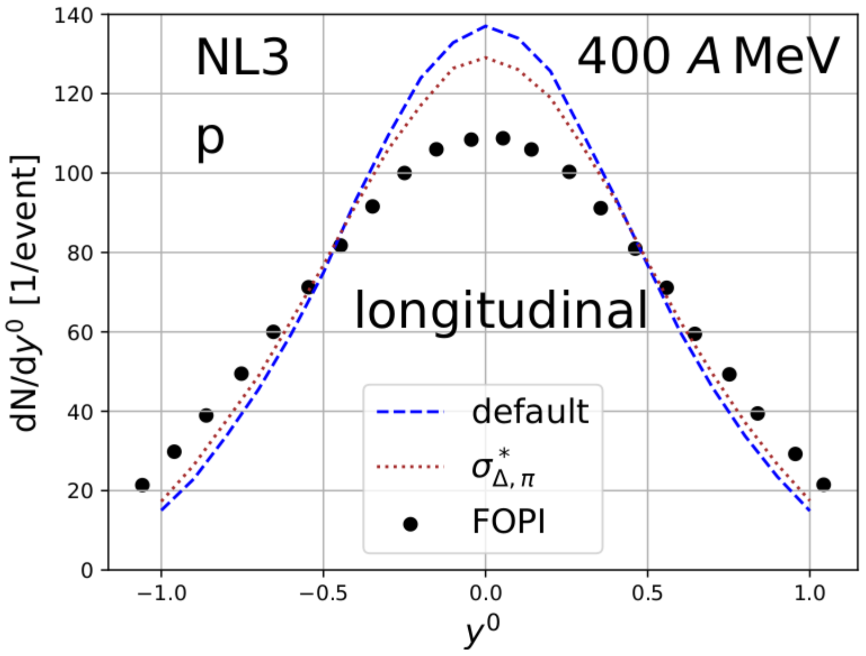
[6] W.J. Xie *et al.*, AJ 899.1, 4 (2020)

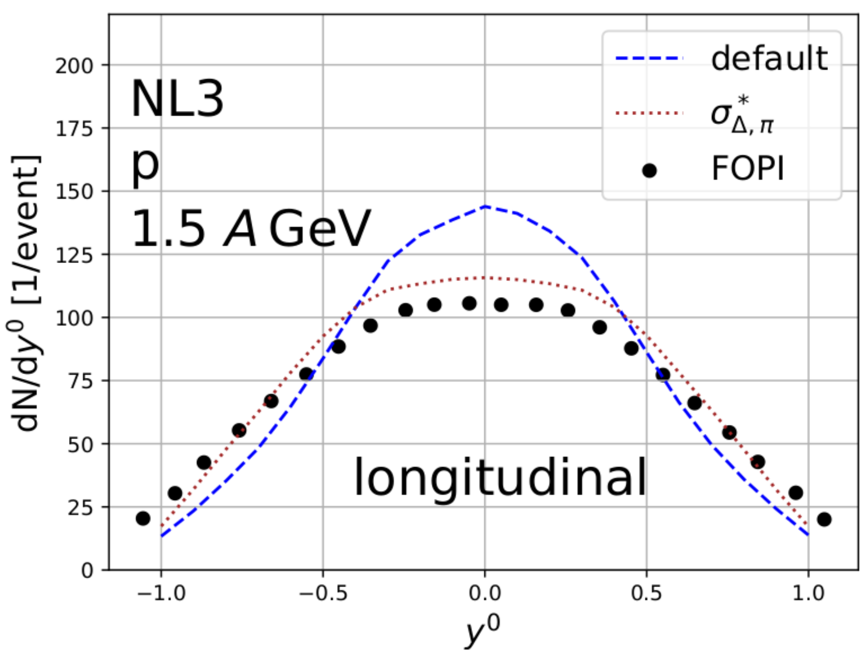
[7] W. Reisdorf *et al.*, PRL 92, 232301 (2004)

[8] J. Adamczewski-Musch *et al.*, Nature 15.10, 1040 (2019)

BACKUP

Proton Rapidity Distribution, NL3 Lalazissis EOS





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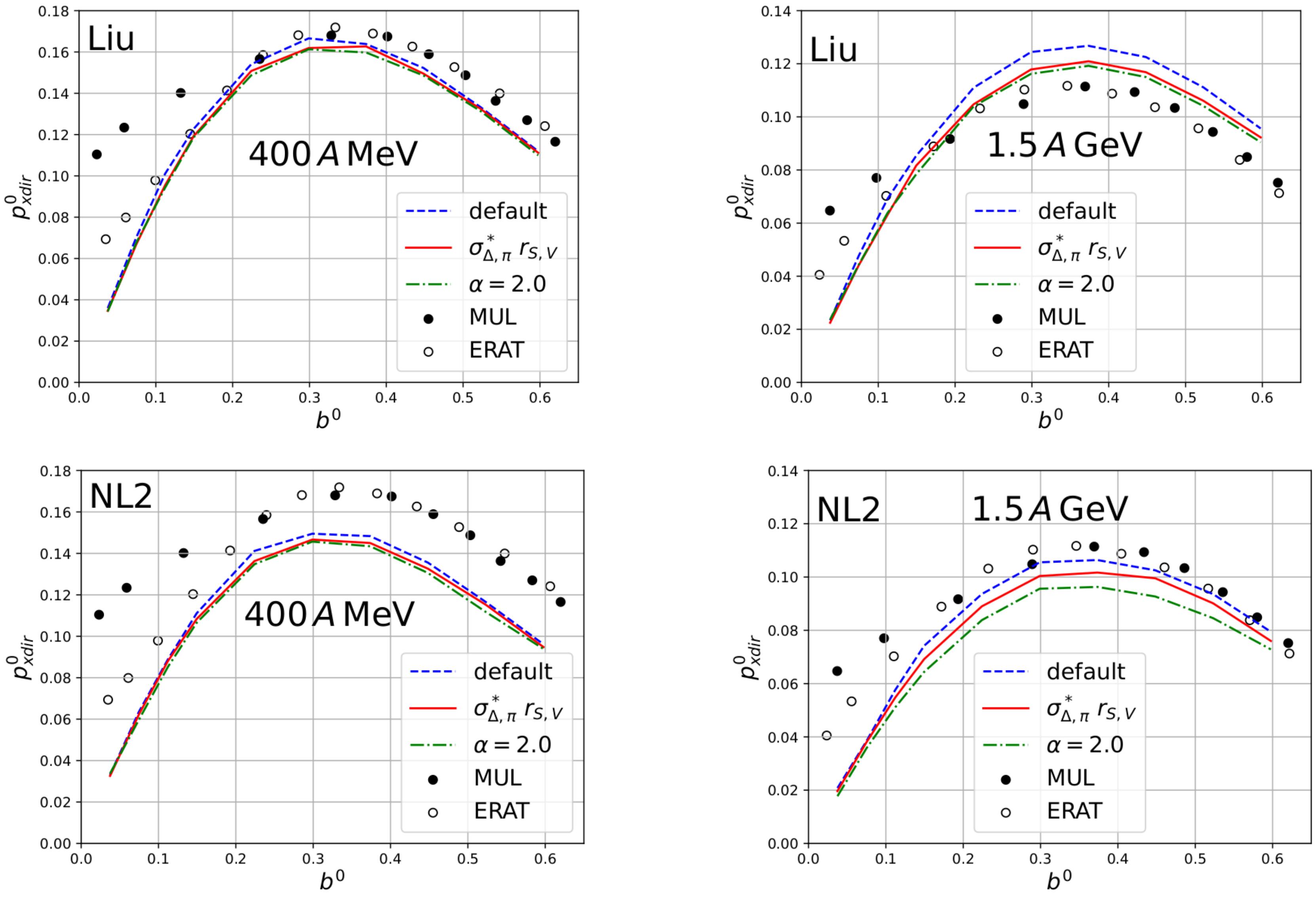
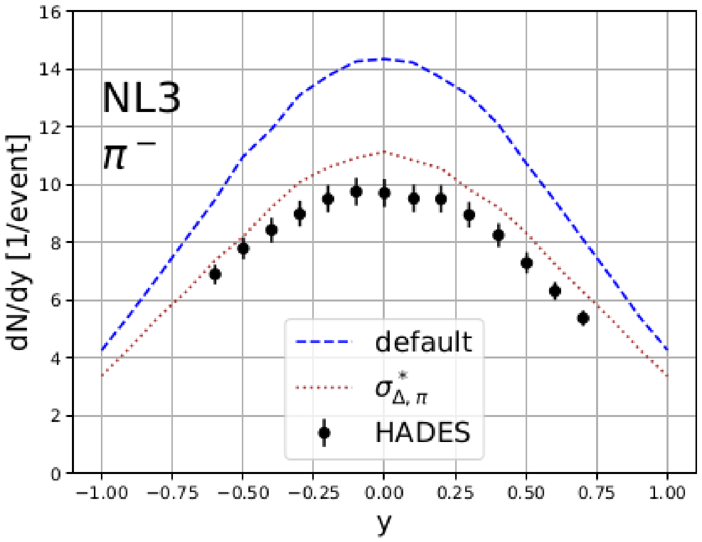
Sideflow

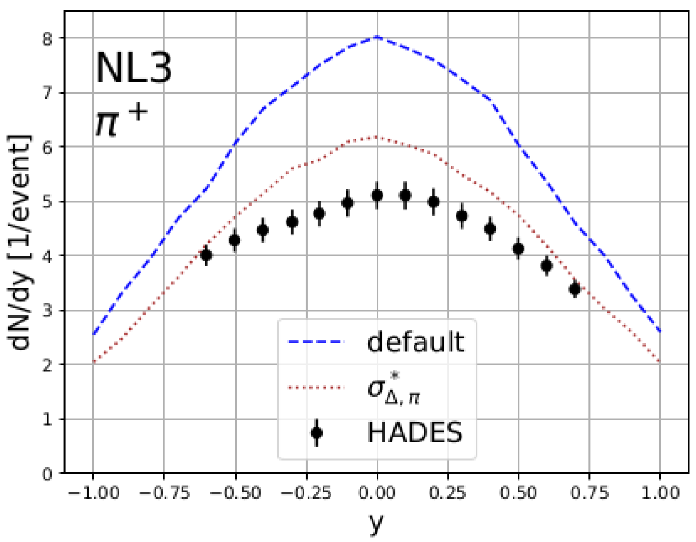
$$p^0_{xdir} = \frac{p_{xdir}}{u_{1\mathrm{cm}}}$$

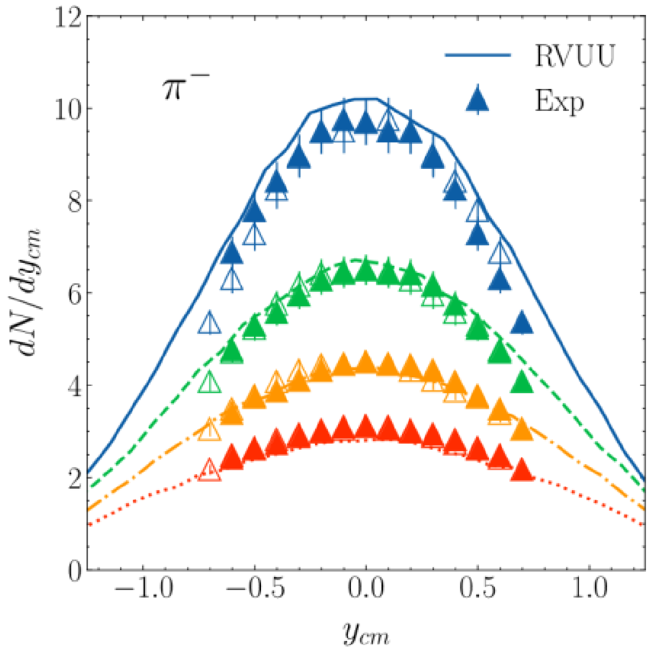
$$p_{xdir} = \frac{\sum \mathrm{sign}(y) Z u_x}{\sum Z}$$

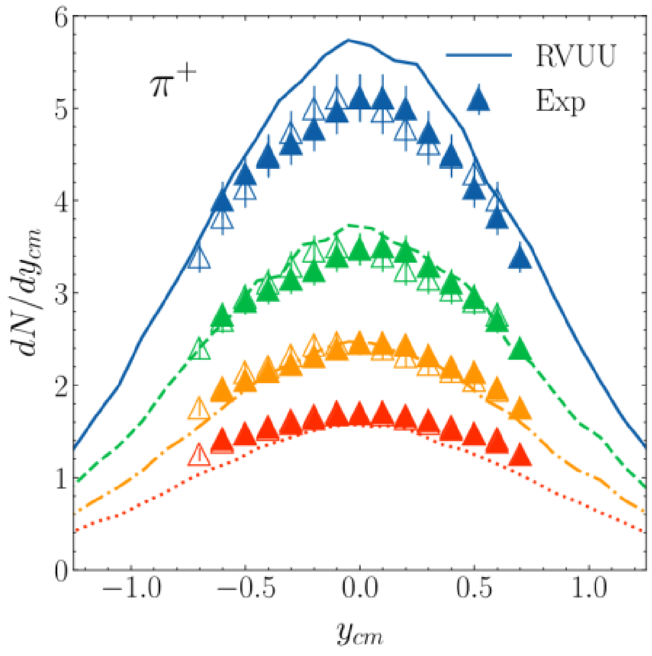


Pion rapidity spectra









$$\mathcal{L} = \overline{\psi}[\gamma_\mu(i\partial^\mu - g_\omega\omega^\mu - g_\rho\boldsymbol{\tau}\boldsymbol{\rho}^\mu - \frac{e}{2}(1+\tau^3)A^\mu) - m_N - g_\sigma\sigma]\psi$$
$$+ \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - U(\sigma) + \frac{1}{2}m_\omega^2\omega^2 + \frac{1}{2}m_\rho^2\boldsymbol{\rho}^2 - \frac{1}{16\pi}F_{\mu\nu}F^{\mu\nu}$$

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

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

$$f = \exp\left(-\alpha\left(\frac{\rho}{\rho_0}\right)^{\beta}\right)$$

$$\mathrm{d}\sigma^*_{12\to1'2'\ldots N'} = (2\pi)^4\delta^{(4)}\left(p_1 + p_2 - \sum_{i=1'}^{N'} p_i\right)\frac{n_1^* n_2^* \prod_{i=1'}^{N'} n_i^*}{4I_{12}^*}\overline{|\mathfrak{M}_{12\to1'2'\ldots N'}|^2}$$
$$\times\, \mathcal{S}_{1'2'\ldots N'}\prod_{i=1'}^{N'} A_i(p_i)\frac{\mathrm{d}^4 p_i}{(2\pi)^3 2p_i^{*0}}\ ,$$