Working Group 3

Reunião de 25/05/23

Preparação para o relatório

Fernando Navarra

Alberto Martinez

Renato Higa

- Rever os objetivos de cada WG
  - Mostrar os "deliverables" esperados (artigos, notas de análise, testes, instrumentos, etc.)

WG3 : aprender sobre QCD e teorias efetivas de interações hadrônicas

Inicialmente: Color Glass Condensate, estados exóticos, emaranhamento quântico na QCD

Incluido no período: mecanismos de produção de partículas, distribuição de multiplicidades

"Entregáveis": artigos publicados, publicações em proceedings, orientações concluidas

Sub-produto: melhorar o nível de discussão dentro do grupo e do IFUSP

O que a gente "entregou" neste um ano ?

2. Achievements in the considered period

7. List of publications in the period

Artigos Publicados

Multiplicity of $Z_{cs}(3985)$ in heavy ion collisions #1
L.M. Abreu (Bahia U. and Valencia U., IFIC), F.S. Navarra (Sao Paulo U.), M. Nielsen (Sao Paulo U.), H.P.L. Vieira (Bahia U.) (Mar 10, 2023)
e-Print: 2303.05990 [hep-ph]
PRD (2023)
pdf cite claim reference search 0 citations

D^* / D ratio in heavy ion collisions #1
L.M. Abreu (Bahia U.), F.S. Navarra (Bahia U.), H.P.L. Vieira (Sao Paulo U.) (Sep 8, 2022)
Published in: *Phys.Rev.D* 106 (2022) 7, 074028 • e-Print: 2209.03814 [hep-ph]
pdf DOI cite claim reference search 1 citation

Hadronic medium effects on $Z_{cs}(3985)$ production in heavy ion collisions #2
L.M. Abreu (Bahia U.), F.S. Navarra (Bahia U.), H.P.L. Vieira (Sao Paulo U.) (Jun 7, 2022)
Published in: *Phys.Rev.D* 106 (2022) 7, 076001 • e-Print: 2206.03399 [hep-ph]
pdf DOI cite claim reference search 1 citation

Multiplicity of the doubly charmed state T_{cc}^+ in heavy-ion collisions #3
Luciano M. Abreu (Bahia U.), Hildeson P.L. Vieira (Bahia U.), Fernando S. Navarra (Sao Paulo U.) (Feb 22, 2022)
Published in: *Phys.Rev.D* 105 (2022) 11, 116029 • e-Print: 2202.10882 [hep-ph]
pdf DOI cite claim reference search 17 citations

Energy dependence of the multiplicity moments at the LHC #4
G.R. Germano (Sao Paulo U.), F.S. Navarra (Sao Paulo U.) (Oct 22, 2021)
Published in: *Phys.Rev.D* 105 (2022) 1, 014005, *Phys.Rev.D* 105 (2022) 1 • e-Print: 2110.12028 [hep-ph]
pdf DOI cite claim reference search 6 citations

Interactions of the doubly charmed state T_{cc}^+ with a hadronic medium #5
L.M. Abreu (Bahia U.), F.S. Navarra (Sao Paulo U.), M. Nielsen (Sao Paulo U.), H.P. L. Vieira (Bahia U.) (Oct 21, 2021)
Published in: *Eur.Phys.J.C* 82 (2022) 4, 296, *Eur.Phys.J.C* 82 (2022) 296 • e-Print: 2110.11145 [hep-ph]
pdf DOI cite claim reference search 17 citations

$D_1(2420)$ and its interactions with a kaon: Open charm states with strangeness

#1

Brenda B. Malabarba (Sao Paulo U.), K.P. Khemchandani (Sao Paulo U.), A. Martinez Torres (Sao Paulo U.), E. Oset (Valencia U. and Valencia U., IFIC) (Nov 29, 2022)

Published in: *Phys.Rev.D* 107 (2023) 3, 036016 • e-Print: 2211.16222 [hep-ph]

pdf DOI cite claim reference search 0 citations

Exotic states with triple charm

#2

M. Bayar (Kocaeli U. and Valencia U. and Valencia U., IFIC), A. Martinez Torres (Valencia U. and Valencia U., IFIC and Sao Paulo U.), K.P. Khemchandani (Valencia U. and Valencia U., IFIC and Sao Paulo U.), R. Molina (Valencia U. and Valencia U., IFIC), E. Oset (Valencia U. and Valencia U., IFIC) (Nov 16, 2022)

Published in: *Eur.Phys.J.C* 83 (2023) 1, 46 • e-Print: 2211.09294 [hep-ph]

pdf DOI cite claim reference search 1 citation

Exotic properties of N^*(1895) and its impact on photoproduction of light hyperons

#3

K.P. Khemchandani (Unlisted, BR), A. Martinez Torres (Sao Paulo U.), Sang-Ho Kim (Pukyong Nat. U.), Seung-il Nam (Pukyong Nat. U. and APCTP, Pohang), A. Hosaka (Osaka U., Res. Ctr. Nucl. Phys. and JAERI, Tokai) (Sep, 2022)

Published in: *Acta Phys.Polon.A* 142 (2022) 3, 329-336, *Acta Phys.Polon.A* 142 (2022) 3, 329-336 • Contribution to: 4th Jagiellonian Symposium on Advances in Particle Physics and Medicine, 4th Jagiellonian Symposium on Advances in Particle Physics and Medicine, 329-336 • e-Print: 2211.14167 [nucl-th]

pdf DOI cite claim reference search 0 citations

Theoretical study of the $\gamma d \to \pi^0 \eta d$ reaction

#4

A. Martinez Torres (Sao Paulo U. and Valencia U., IFIC), K.P. Khemchandani (Sao Paulo U. and Valencia U., IFIC), E. Oset (Valencia U., IFIC) (May 2, 2022)

Published in: *Phys.Rev.C* 107 (2023) 2, 025202 • e-Print: 2205.00948 [nucl-th]

pdf DOI cite claim reference search 3 citations

Coupled-channels treatment of $^7Be(p,\gamma)^8B$ in effective field theory

#1

Renato Higa (Sao Paulo U., Sao Carlos), Pradeepa Premarathna (Mississippi State U.), Gautam Rupak (Mississippi State U.) (Jul 5, 2022)

Published in: *Phys.Rev.C* 106 (2022) 1, 014601

DOI cite claim reference search 0 citations

Total:
11 artigos

Proceedings

Exotics from QCD Sum Rules #2
Marina Nielsen (Sao Paulo U.), Fernando S. Navarra (Sao Paulo U.) (Mar, 2023)
Published in: *Nucl.Part.Phys.Proc.* 324-329 (2023) 59-63 • Contribution to: QCD 22
DOI | cite | claim | reference search | 0 citations

Production of T_{cc}^{+} in heavy ion collisions #3
L.M. Abreu (Bahia U.), F.S. Navarra (Sao Paulo U.), M. Nielsen (Sao Paulo U.), H.P.L. Vieira (Bahia U.) (Mar, 2023)
Published in: *Nucl.Part.Phys.Proc.* 324-329 (2023) 40-43 • Contribution to: QCD 22
DOI | cite | claim | reference search | 0 citations

Production of T_{cc}^{+} in heavy ion collisions #5
L.M. Abreu (Bahia U.), F.S. Navarra (Sao Paulo U.), M. Nielsen (Sao Paulo U.), H.P.L. Vieira (Bahia U.) (Sep 8, 2022)
Contribution to: QCD 22 • e-Print: 2209.03862 [hep-ph]
pdf | cite | claim | reference search | 1 citation

System size dependence of the K^*/K ratio at LHC energies #6
Chiara Le Roux (Sao Paulo U.), Fernando Silveira Navarra (Sao Paulo U.), Luciano Melo Abreu (Bahia U.) (Aug 1, 2022)
Published in: *PoS* XVHadronPhysics (2022) 043 • Contribution to: Hadron Physics 2020, 043
pdf | DOI | cite | claim | reference search | 0 citations

Multiplicity moments at the LHC: how bad is the negative binomial distribution ? #7
Guilherme Germano (U. Sao Paulo (main)), Fernando Silveira Navarra (U. Sao Paulo (main)) (Aug 1, 2022)
Published in: *PoS* XVHadronPhysics (2022) 063 • Contribution to: Hadron Physics 2020, 063
pdf | DOI | cite | claim | reference search | 0 citations

A Simple Approach to the Charmonium Spectrum #8
Ríchard Terra (U. Sao Paulo (main)), Fernando Silveira Navarra (U. Sao Paulo (main)) (Aug 1, 2022)
Published in: *PoS* XVHadronPhysics (2022) 056 • Contribution to: Hadron Physics 2020, 056
pdf | DOI | cite | claim | reference search | 0 citations

Absorptive corrections in leading neutron production #9
Fabiana Carvalho (Sao Paulo U.), Victor Goncalves (Pelotas U.), Fernando Silveira Navarra (Sao Paulo U.), Diego Spiering (Sao Paulo U.) (Aug 1, 2022)
Published in: *PoS* XVHadronPhysics (2022) 053 • Contribution to: Hadron Physics 2020, 053
pdf | DOI | cite | claim | reference search | 0 citations

The tension between radius and deformability in quark stars #10
Milena Bastos Albino (Sao Paulo U.), Fernando Silveira Navarra (Unlisted, BR), Ricardo Fariello (Sao Paulo U.) (Aug 1, 2022)
Published in: *PoS* XVHadronPhysics (2022) 044 • Contribution to: Hadron Physics 2020, 044
pdf | DOI | cite | claim | reference search | 0 citations

Magnetic transitions in ultraperipheral collisions

#11

Isabella Danhoni (Sao Paulo U.), F. Navarra (Sao Paulo U.) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 067 • Contribution to: Hadron Physics 2020, 067

pdf DOI cite claim reference search 0 citations

Parton branching in the low x regime and multiplicity distributions at the LHC

#14

G.R. Germano (Sao Paulo U.), F.S. Navarra (Sao Paulo U.) (2022)

Published in: *J.Phys.Conf.Ser.* 2340 (2022) 1, 012019 • Contribution to: 44th Brazilian Workshop on Nuclear Physics

pdf DOI cite claim reference search 0 citations

The origin of the K * suppression at the LHC

#15

C. Le Roux (Sao Paulo U.), F.S. Navarra (Sao Paulo U.) (2022)

Published in: *J.Phys.Conf.Ser.* 2340 (2022) 1, 012010 • Contribution to: 44th Brazilian Workshop on Nuclear Physics

pdf DOI cite claim reference search 0 citations

How to measure the magnetic field in relativistic heavy-ion collisions

#16

I. Danhoni (Sao Paulo U.), F.S. Navarra (Sao Paulo U.) (2022)

Published in: *J.Phys.Conf.Ser.* 2340 (2022) 1, 012020 • Contribution to: 44th Brazilian Workshop on Nuclear Physics

pdf DOI cite claim reference search 0 citations

The nature of the quark-hadron phase transition in hybrid stars and the mass-radius diagram

#17

M.B. Albino (Sao Paulo U.), F.S. Navarra (Sao Paulo U.), R. Fariello (Sao Paulo U. and Unlisted, BR), G. Lugones (ABC Federal U.) (2022)

Published in: *J.Phys.Conf.Ser.* 2340 (2022) 1, 012015 • Contribution to: 44th Brazilian Workshop on Nuclear Physics

pdf DOI cite claim reference search 0 citations

Exotic heavy hadrons with a three-body nature
#6

Alberto Torres Martinez (Sao Paulo U.), Brenda Bertotto Malabarba (Sao Paulo U.), Xiu-Lei Ren (Mainz U., Inst. Kernphys. and U. Mainz, PRISMA), Kanchan Khemchandani (Unlisted, BR), Li-Sheng Geng (Beihang U.) (May 2, 2022)

Published in: *PoS* XVHadronPhysics (2022) 004 • Contribution to: Hadron Physics 2020, 004, Hadron Physics 2020 • e-Print: 2205.01195 [hep-ph]

pdf DOI cite claim reference search 0 citations

Kaon, Nucleon and Δ^* Resonances with Hidden Charm
#7

Brenda B. Malabarba (Sao Paulo U.), Alberto Martínez Torres (Sao Paulo U.), Kanchan Khemchandani (Diadema, Sao Paulo Fed. U.), Xiu-Lei Ren (Mainz U., Inst. Kernphys.), Li-Sheng Geng (Beihang U.) (Apr 4, 2022)

Published in: *PoS* XVHadronPhysics (2022) 029 • Contribution to: Hadron Physics 2020, 029, Hadron Physics 2020 • e-Print: 2204.01658 [hep-ph]

pdf DOI cite claim reference search 0 citations

The decay of N_* (1895) to light hyperon resonances
#8

Kanchan Pradeepkumar Khemchandani (Sao Paulo U.), A. Martínez Torres (Sao Paulo U.), Sang-Ho Kim (Pukyong Nat. U.), Seung-il Nam (Pukyong Nat. U. and APCTP, Pohang), H. Nagahiro (Nara Women's U.) et al. (Jan 17, 2022)

Published in: *Rev.Mex.Fis.Suppl.* 3 (2022) 3, 0308063 • Contribution to: HADRON 2021, HADRON 2021 • e-Print: 2201.06471 [hep-ph]

pdf DOI cite claim reference search 1 citation

Kaon and nucleon states with hidden charm
#9

Brenda B. Malabarba (Sao Paulo U.), A. Martínez Torres (Sao Paulo U.), K.P. Khemchandani (Unlisted, BR), Xiu-Lei Ren (Mainz U., Inst. Kernphys. and U. Mainz, PRISMA), Li-Sheng Geng (Beihang U.) (Dec 29, 2021)

Published in: *Rev.Mex.Fis.Suppl.* 3 (2022) 3, 0308041 • Contribution to: HADRON 2021 • e-Print: 2112.14542 [hep-ph]

pdf links DOI cite claim reference search 0 citations

Testing the molecular nature of ϕ(2170)
#10

Alberto Martinez Torres (Sao Paulo U.), Brenda Bertotto Malabarba (Sao Paulo U.), Xiu-Lei Ren (U. Mainz, PRISMA), Kanchan Khemchandani (Sao Paulo U.) (Dec 22, 2021)

Published in: *Rev.Mex.Fis.Suppl.* 3 (2022) 3, 0308071 • Contribution to: HADRON 2021, HADRON 2021 • e-Print: 2112.12003 [hep-ph]

pdf DOI cite claim reference search 0 citations

Total:
18 artigos

6. Participation in scientific events

QCD 2022 Montpellier

Heavy Flavor 2023 Torino

POETIC 2023 São Paulo

QCD 2023 Montpellier

Extreme QCD 2023 Coimbra

HADRONS 2023 Genova

Organization of Scientific Events

XXX Reunião de Trabalho sobre Interações Hadrônicas (RETINHA 30)

- Listar/discutir as realizações no primeiro ano do projeto

Trabalhos em andamento

Progresso na pesquisa da produção de exóticos em UPCs :

Visita à Texas U&M - Commerce (fevereiro de 2023)

Reativação da colaboração com o Prof. Carlos Bertulani

Engajamento do pós-doc Ricardo Fariello e do novo aluno de mestrado Fernando César Sobrinho.

Production of exotic charmonium in ultra-peripheral nuclear collisions

C.A. Bertulani[2,3], R. Fariello[4] and F.S. Navarra[1]
[1]Instituto de Física, Universidade de São Paulo, C.P. 66318, 05315-970 São Paulo, SP, Brazil
[2]Department of Physics and Astronomy, Texas A&M University-Commerce, Commerce, Texas 75429, USA
[3]Department of Physics and Astronomy, Texas A&M University, College Station, Texas 77843, USA
[4] Departamento de Ciências da Computação, Universidade Estadual de Montes Claros, Avenida Rui Braga, sn, Vila Mauricéia, CEP 39401-089, Montes Claros, MG, Brazil.
(Dated: May 25, 2023)

Artigo a ser concluido em breve

Progresso na pesquisa da produção de exóticos em colisões AA centrais

Continuação da colaboração com o Prof. Luciano Abreu e com André Britto

O Prof. Luciano Abreu está visitando o IFUSP por 6 meses

Interactions of the $\chi_{c1}(4274)$ state with light mesons

A.L.M. Britto*

Centro de Ciências Exatas e Tecnológicas, Universidade Federal do Recôncavo da Bahia, R. Rui Barbosa, Cruz das Almas, 44380-000, Bahia, Brazil and Instituto de Física, Universidade Federal da Bahia, Campus Universitário de Ondina, 40170-115, Bahia, Brazil

L.M. Abreu†

Instituto de Física, Universidade Federal da Bahia, Campus Universitário de Ondina, 40170-115, Bahia, Brazil and Instituto de Física Corpuscular, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Aptdo. 22085, 46071 Valencia, Spain

F. S. Navarra‡

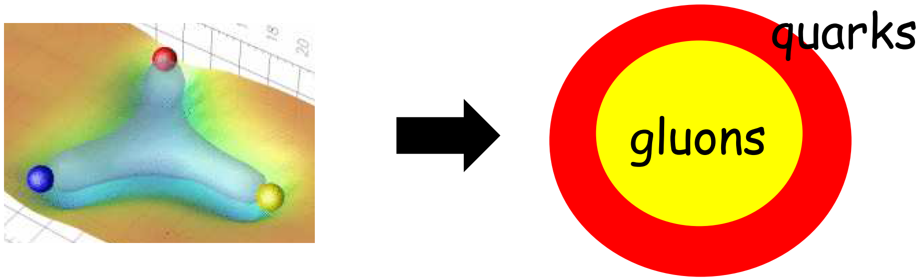
Instituto de Física, Universidade de São Paulo, Rua do Matão, 1371, CEP 05508-090, São Paulo, SP, Brazil

Artigo a ser concluido em breve

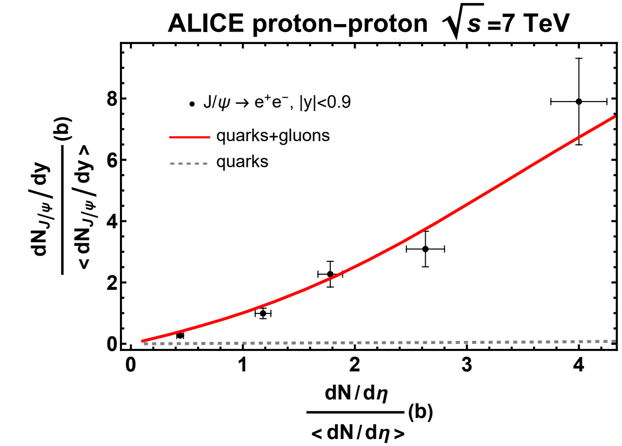
Engajamento do aluno de mestrado Richard Terra

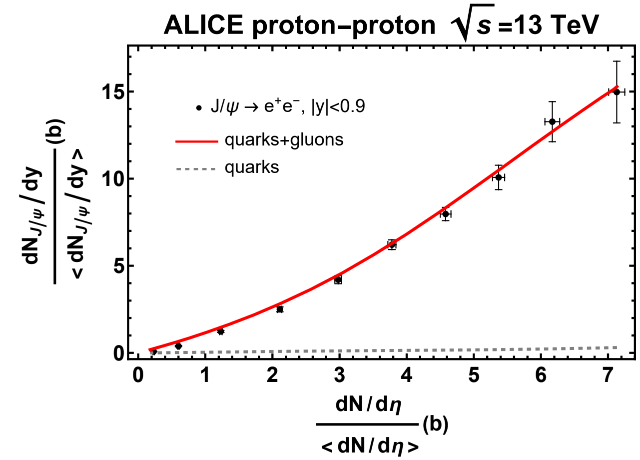
Produção de charmonium em colisões pp ultra-centrais

Estrutura do proton: core-corona



$$\sigma(gg \rightarrow c\bar{c}) >> \sigma(q\bar{q} \rightarrow c\bar{c})$$





Charm production in high multiplicity pp collisions and the structure of the proton

R. Terra de Oliveira[1] and F. S. Navarra[1]
[1]*Instituto de Física, Universidade de São Paulo, Rua do Matão, 1371, CEP 05508-090, São Paulo, SP, Brazil*

Artigo a ser concluido em breve

Criação do "Grupo de Distribuição de Multiplicidades"

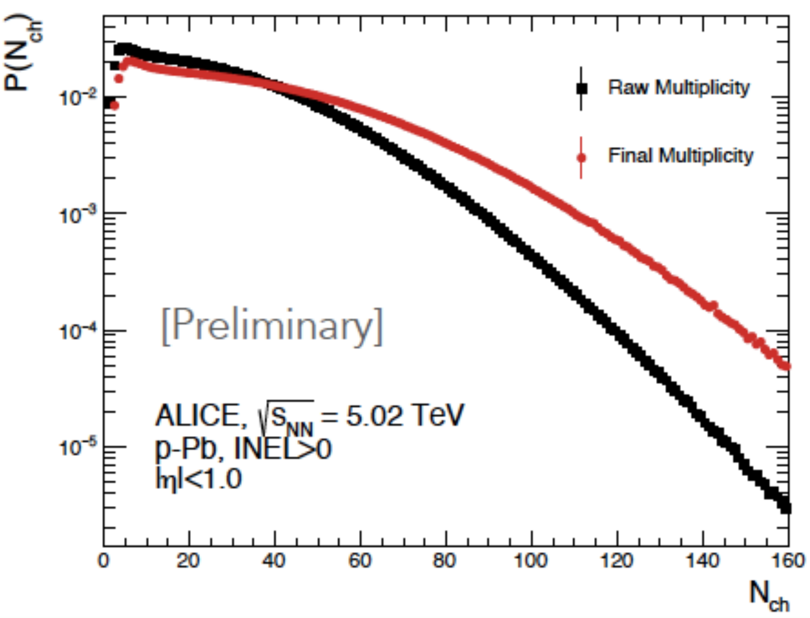
Mestrado da Eliana Marroquin

Multiplicity Distribution of Charged-Particles in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

- The multiplicity analysis of proton-Lead collisions at 5.02 TeV in the central pseudo-rapidity range $|\eta| < 1.0$ was performed in collaboration with D. Chinellato (UNICAMP) and V. Zaccolo (University of Trieste and INFN);

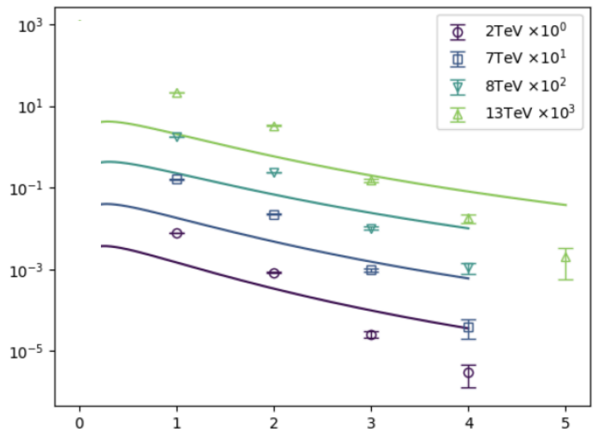
- The analysis aims to obtain the Boltzmann Entropy from the multiplicity distributions to study further the Parton Entanglement in pA systems;

- The Analysis Note is available in the ALICE repository and the Paper Proposal of the analysis was approved at the Physics Forum in February.

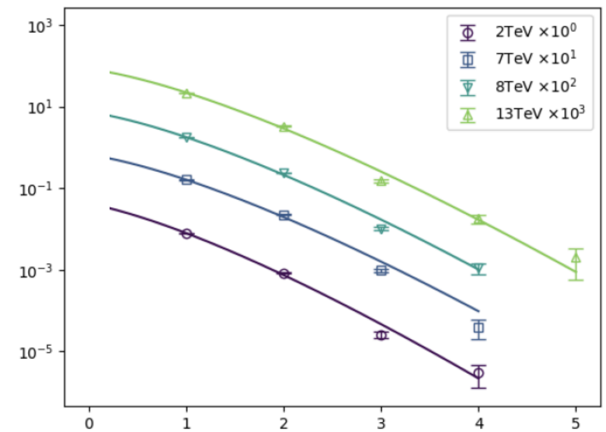


Distribuição de multiplicidade de mesons com charme em proton-proton

Jhoão Arneiro e Guilherme Germano (PYTHIA + Fits)



Binomial Negativa não funciona



Poisson funciona

Previsão do PYTHIA : charme tem outra dinâmica !

Multiplicity distributions of charm particles in high energy collisions

J. Arneiro, G. Germano, E. Marroquin, M. Munhoz, F.S. Navarra, A. Suaide

Instituto de Física, Universidade de São Paulo,
Rua do Matão 1371 - CEP 05508-090,
São Paulo, SP, Brazil

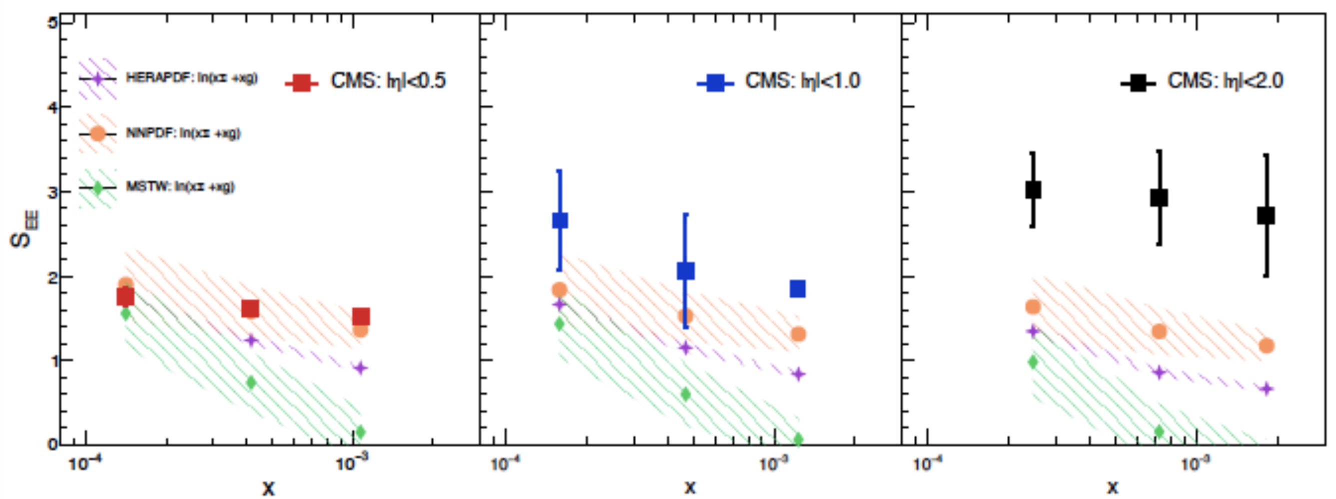
algum dia vai...

Distribuições de multiplicidade e emaranhamento quântico

Mestrado da Eliana Marroquin

- The equivalence between the initial and final state entropies should indicate quantum entanglement in high energy processes: $\ln(xG(x;Q^2)+x\Sigma(x;Q^2)) = S_{parton}(x) \leq S_{hadron} = -\sum P(N)\ln P(N)$

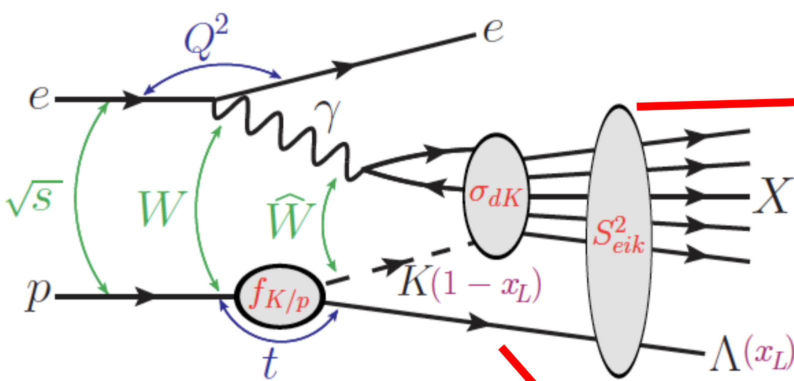
- The final state entropy is computed from multiplicity distributions and has been studied for deep inelastic scattering and proton-proton collisions. Our proposal is to study the parton entanglement in proton-nucleus collisions with ALICE



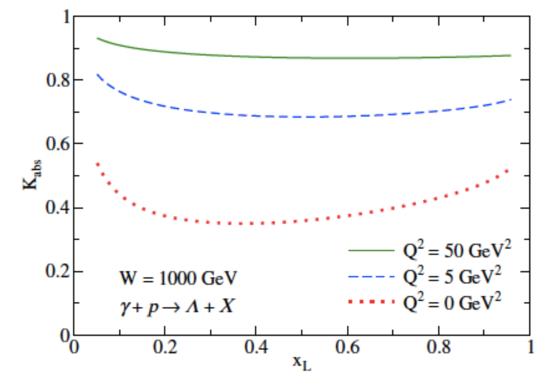
Reproducing the pp analysis from arXiv:1904.11974, now using sea-quark distributions

Leading neutrons e leading Lambdas no Electron Ion Collider

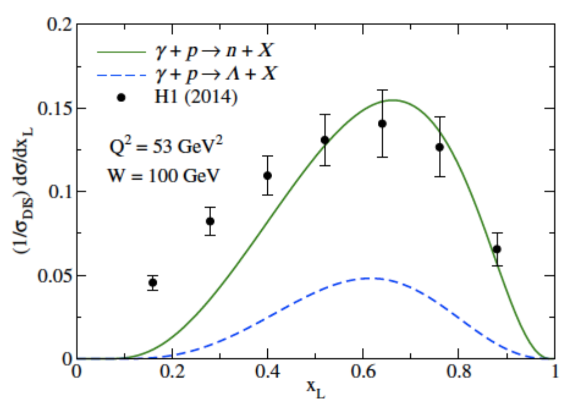
Diego Spiering (pós-doc)

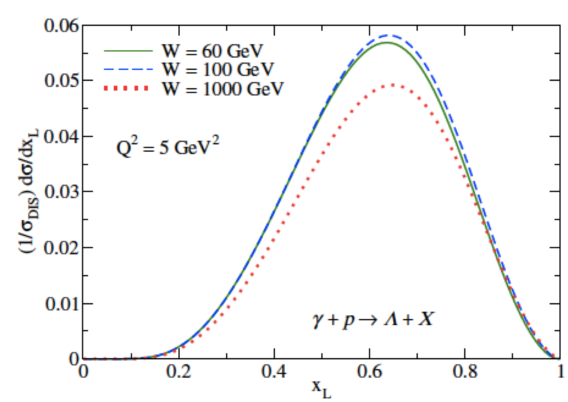


Absorção



Espectro de partícula dominante





Seminário apresentado na POETIC 2023

Absorptive corrections in leading Λ production in high energy collisions

F. Carvalho[1], V.P. Gonçalves[2], K. P. Khemchandani[1], F.S. Navarra[3], D. Spiering[3], A. Martínez Torres[3]

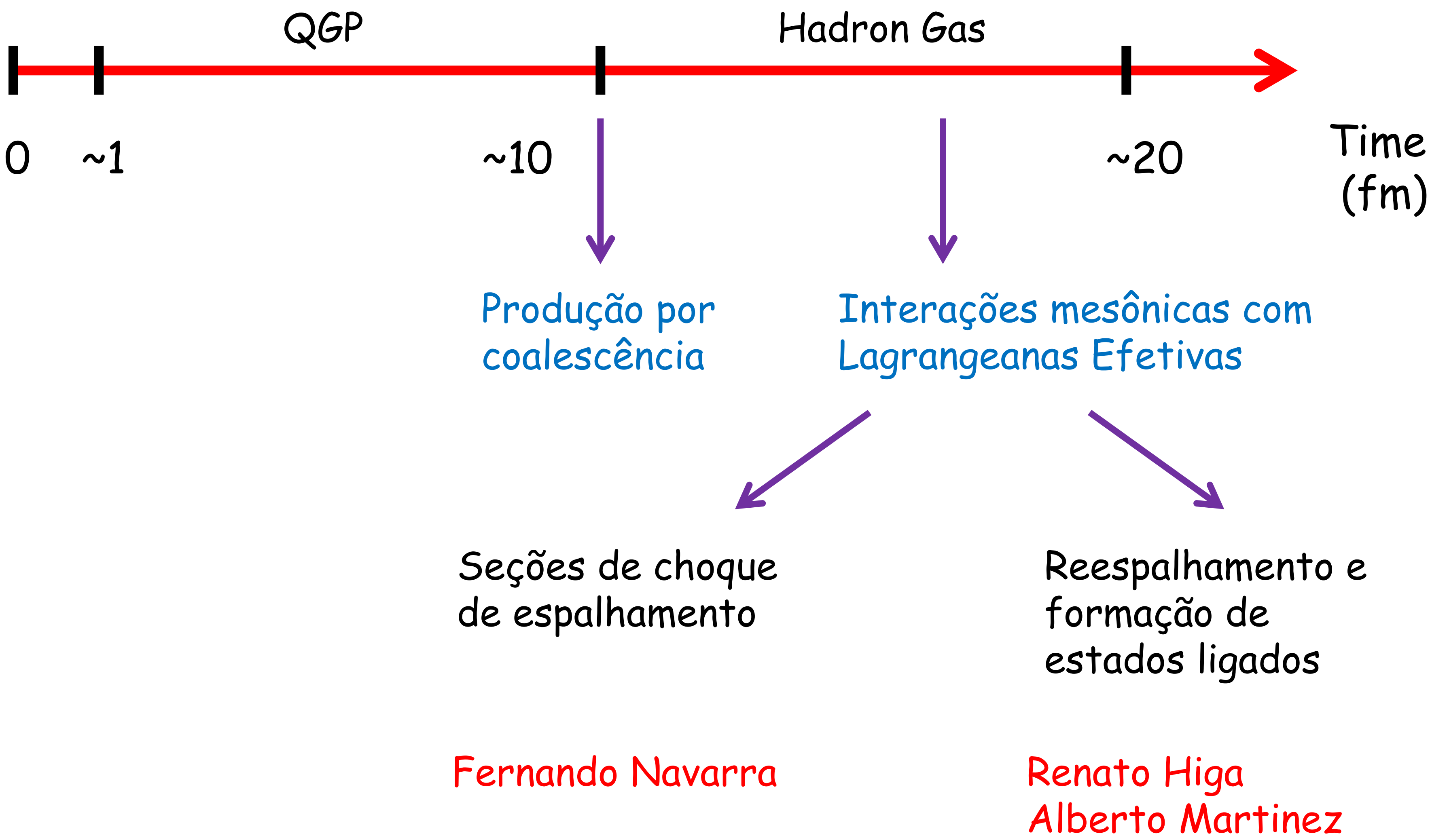
[1]*Departamento de Ciências Exatas e da Terra,*
Universidade Federal de São Paulo,
Campus Diadema, Rua Prof. Artur Riedel, 275,
Jd. Eldorado, 09972-270, Diadema, SP, Brazil.

[2] *High and Medium Energy Group,*
Instituto de Física e Matemática,
Universidade Federal de Pelotas
Caixa Postal 354, 96010-900, Pelotas, RS, Brazil.

[3]*Instituto de Física, Universidade de São Paulo,*
C.P. 66318, 05315-970 São Paulo, SP, Brazil.

Artigo a ser
concluido em breve

Linha do tempo de uma colisão de ions pesados

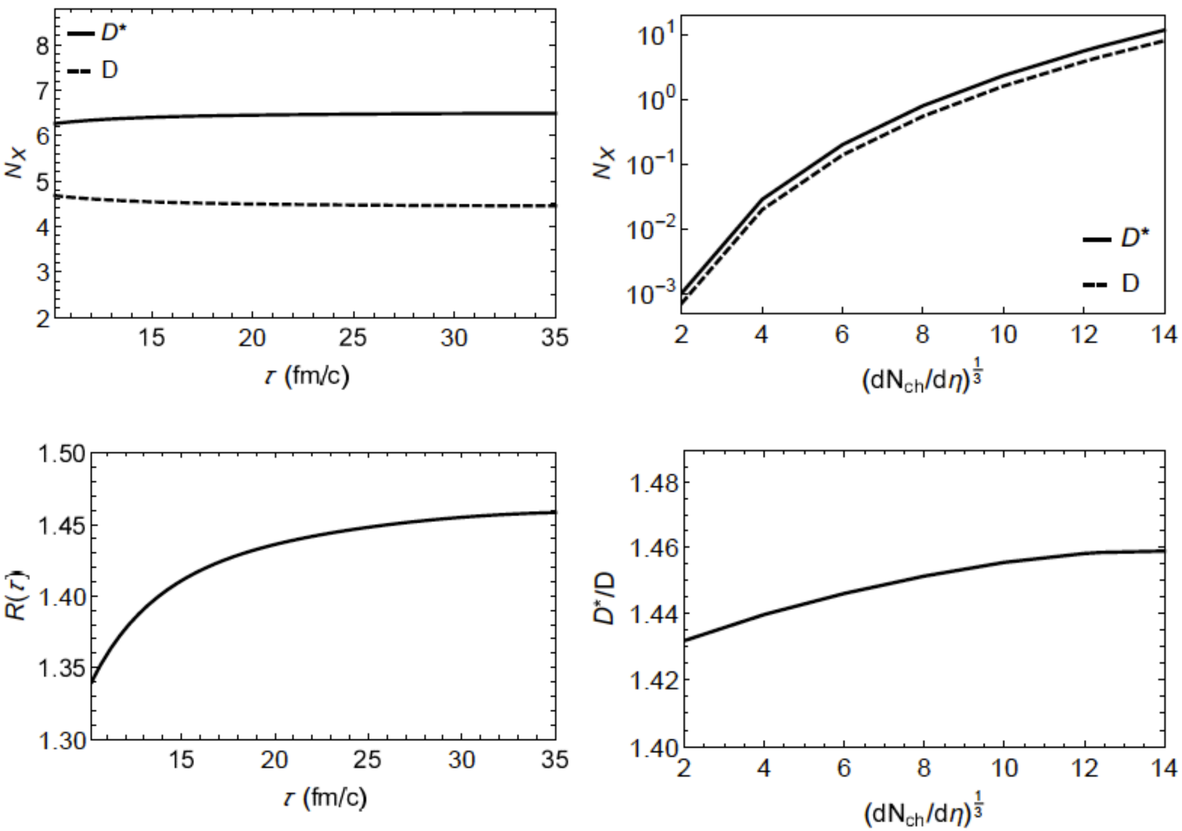


Fernando Navarra

Trabalhos e andamento e publicados

Estudo da produção e interações do Zcs (3985) : em andamento

Estudo da produção e interações do D* e D : concluido e publicado



Interação melhorada com regras de soma da QCD

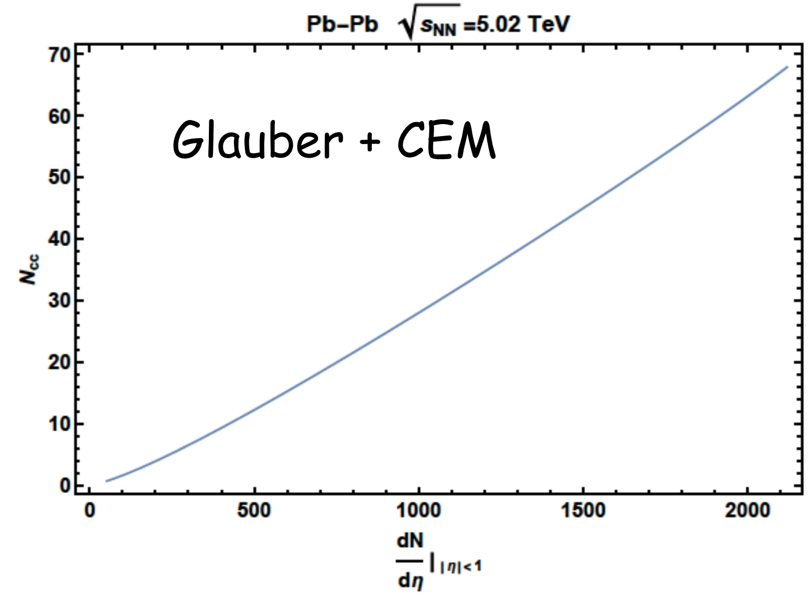
Abreu, FSN and Vieira,
Phys. Rev. D 106, 074028 (2022)

Produção de exóticos com charme no modelo de coalescência

Trabalho de mestrado de Richard Terra

Número de pares c-cbar em função do tamanho do sistema

Melhoria do trabalho da colaboração EXHIC



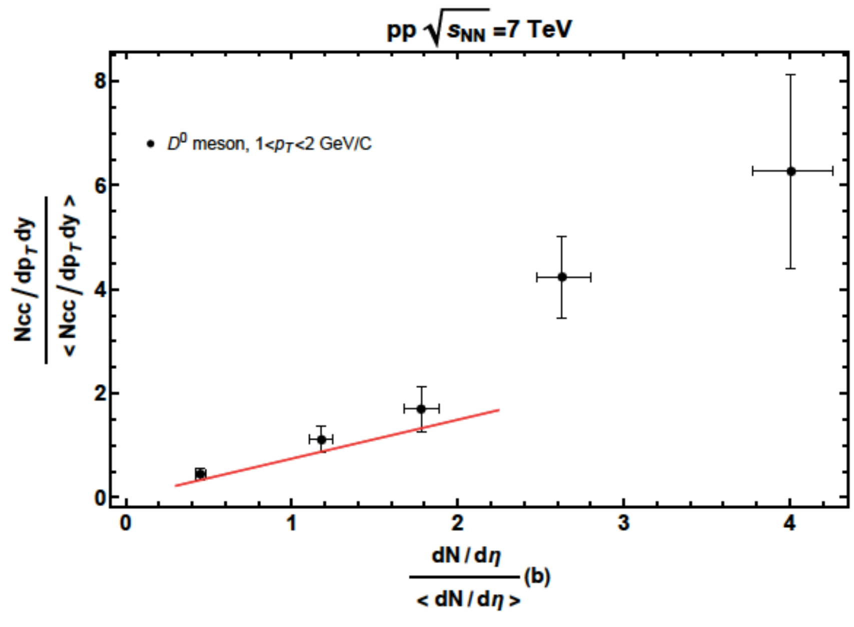
Produção de charme em proton - proton

Crescimento mais rápido do que o esperado

Color Glass Condensate?

Hidrodinâmica?

Multiple parton scattering?



Distribuição de multiplicidade de mesons com charme em proton-proton

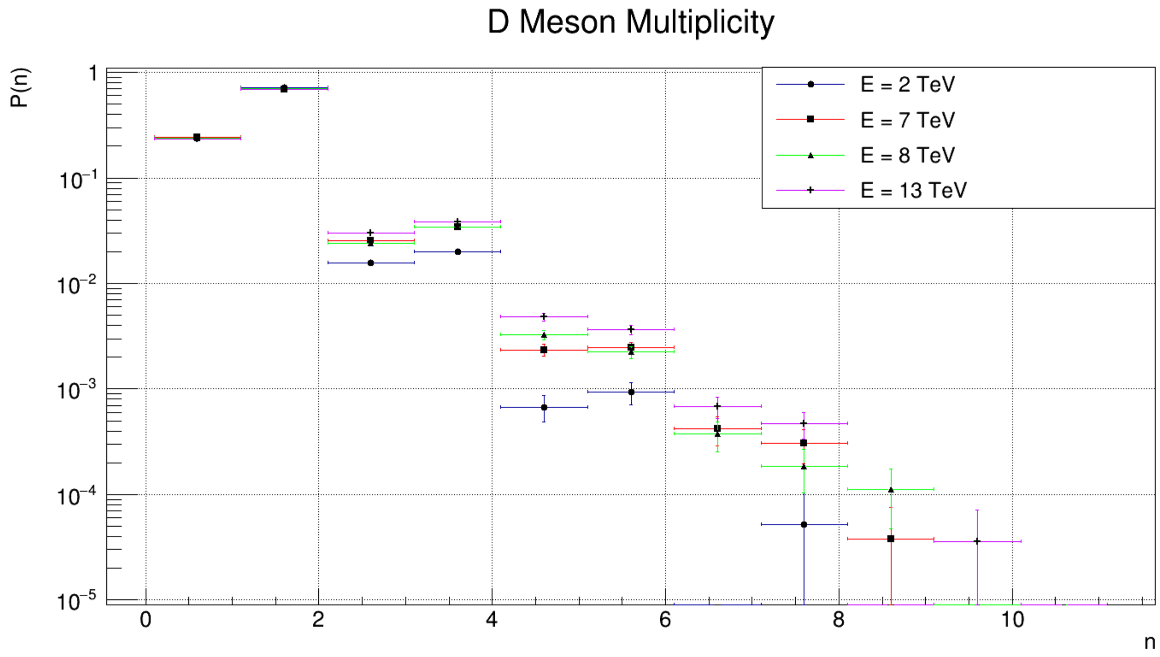
Trabalho de Jhoão Arneiro (doutorando do Suaide)

Simulação com PYTHIA

Comparação com NBD

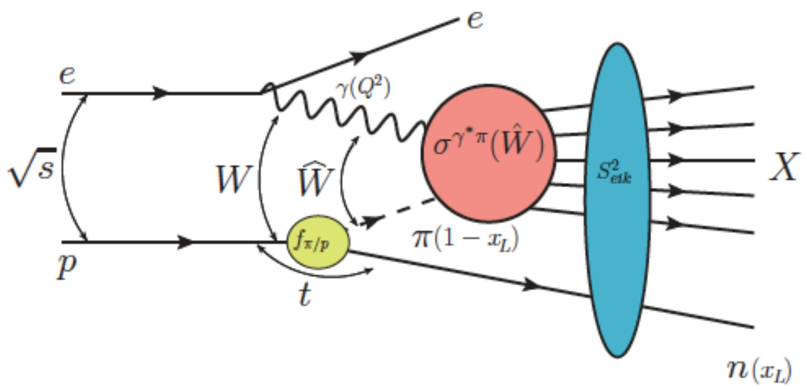
Altas densidades ?

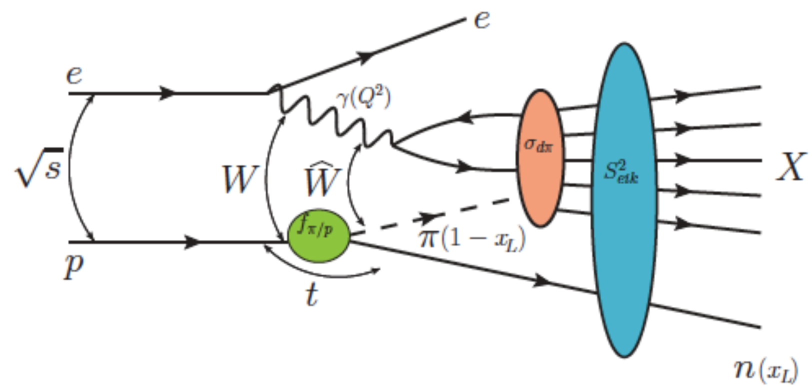
Multiple parton scattering ?

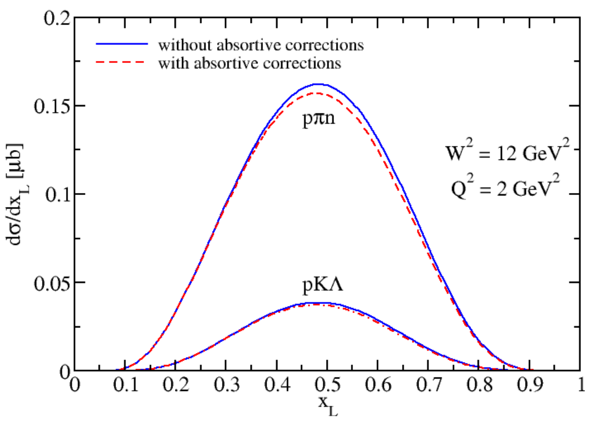


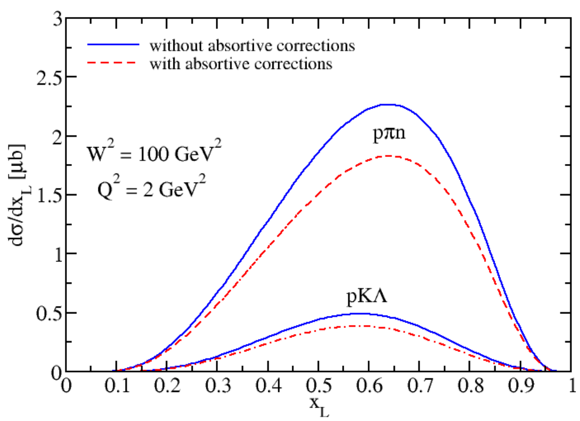
Leading neutrons e leading Lambdas no Electron Ion Collider

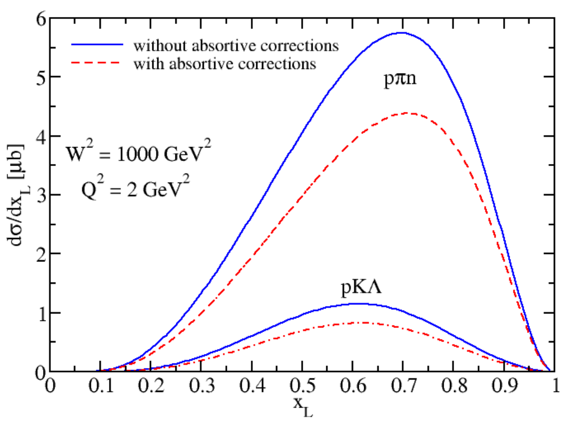
Trabalho de Diego Spiering (pós-doc)











Publicações em Proceedings

System size dependence of the K^*/K ratio at LHC energies #3

Chiara Le Roux (Sao Paulo U.), Fernando Silveira Navarra (Sao Paulo U.), Luciano Melo Abreu (Bahia U.) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 043 • Contribution to: Hadron Physics 2020, 043

pdf DOI cite claim reference search 0 citations

Multiplicity moments at the LHC: how bad is the negative binomial distribution ? #4

Guilherme Germano (U. Sao Paulo (main)), Fernando Silveira Navarra (U. Sao Paulo (main)) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 063 • Contribution to: Hadron Physics 2020, 063

pdf DOI cite claim reference search 0 citations

A Simple Approach to the Charmonium Spectrum #5

Ríchard Terra (U. Sao Paulo (main)), Fernando Silveira Navarra (U. Sao Paulo (main)) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 056 • Contribution to: Hadron Physics 2020, 056

pdf DOI cite claim reference search 0 citations

Absorptive corrections in leading neutron production #6

Fabiana Carvalho (Sao Paulo U.), Victor Goncalves (Pelotas U.), Fernando Silveira Navarra (Sao Paulo U.), Diego Spiering (Sao Paulo U.) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 053 • Contribution to: Hadron Physics 2020, 053

pdf DOI cite claim reference search 0 citations

The tension between radius and deformability in quark stars #7

Milena Bastos Albino (Sao Paulo U.), Fernando Silveira Navarra (Unlisted, BR), Ricardo Fariello (Sao Paulo U.) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 044 • Contribution to: Hadron Physics 2020, 044

pdf DOI cite claim reference search 0 citations

Magnetic transitions in ultraperipheral collisions #8

Isabella Danhoni (Sao Paulo U.), F. Navarra (Sao Paulo U.) (Aug 1, 2022)

Published in: *PoS* XVHadronPhysics (2022) 067 • Contribution to: Hadron Physics 2020, 067

pdf DOI cite claim reference search 0 citations

Participação em conferências

QCD-22, Montpellier, França, julho de 2022

Heavy Flavor - 22, Torino, Itália, julho de 2022

Non-Equilibrium Dynamics - 22, Krabi, Tailândia, dezembro de 2022

Orientações

Guilherme Germano (doutoramento)

Richard Terra (mestrado)

Fernando César Sobrinho (mestrado)

Henrique Fontes (mestrado)

Renato Higa

Participação em conferências

Reunião de Trabalho em Física Nuclear no Brasil

Simpósio do INCT-FNA

Orientações

Alberto Fernandez (iniciação científica)

Efeito de canais acoplados e estrutura analítica da matriz S aplicada ao X(3872)

Alberto Martinez

Trabalhos publicados e submetidos

1) Exotic states with triple charm
M. Bayar, A. Martínez Torres, K. P. Khemchandani, R. Molina, E. Oset,
arxiv: 2211.09294 [hep-ph]

2) $D_1(2420)$ and its interactions with a kaon: open charm states with strangeness
Brenda B. Malabarba, K. P. Khemchandani, A. Martínez Torres, E. Oset,
arxiv: 2211.16222 [hep-ph]

Publicações em Proceedings

1) Exotic properties of $N^*(1895)$ and its impact on the photo production of light hyperons,
K. P. Khemchandani, A. Martínez Torres, Sang-Ho Kim, Seung-il Nam, A. Hosaka,
Acta Physical. Polon. A 142, 329 (2022)

2) Studying the process $\gamma d\to\pi^0\eta d$,
A. Martínez Torres, K. P. Khemchandani, E. Oset,
Acta Physical. Polon. A 142, 378 (2022).

Participação em conferências

1) 4th Jagiellonian Symposium on Advances in Particle Physics and Medicine,
10-15 July 2022, Krakow, Poland

Visitas científicas

21 Agosto-10 Setembro 2022, IFIC-Universidade de Valencia, Valencia, Espanha.

4-15 Novembro 2022, Universidade Complutense de Madri, Madri, Espanha.

Orientações

Brenda Malabarba, doutoramento

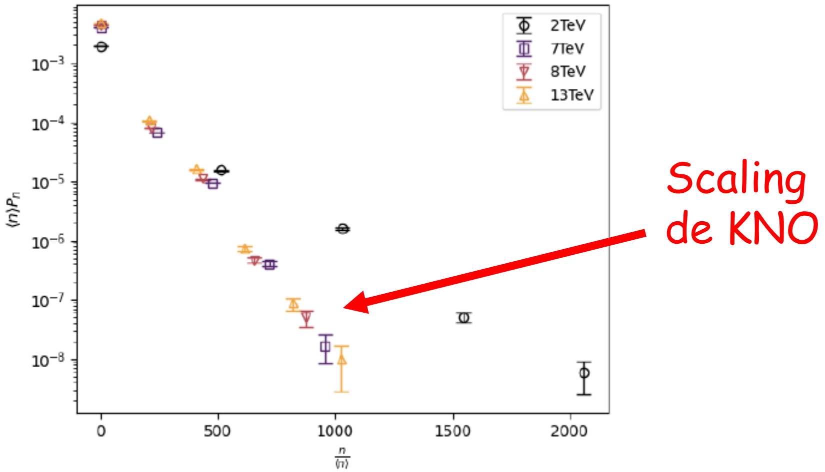
Victor Roberto Soares da Silva, iniciação científica

Novo projeto

Estudo do estado $\phi(2170) = \phi\,\bar{K}\,K$

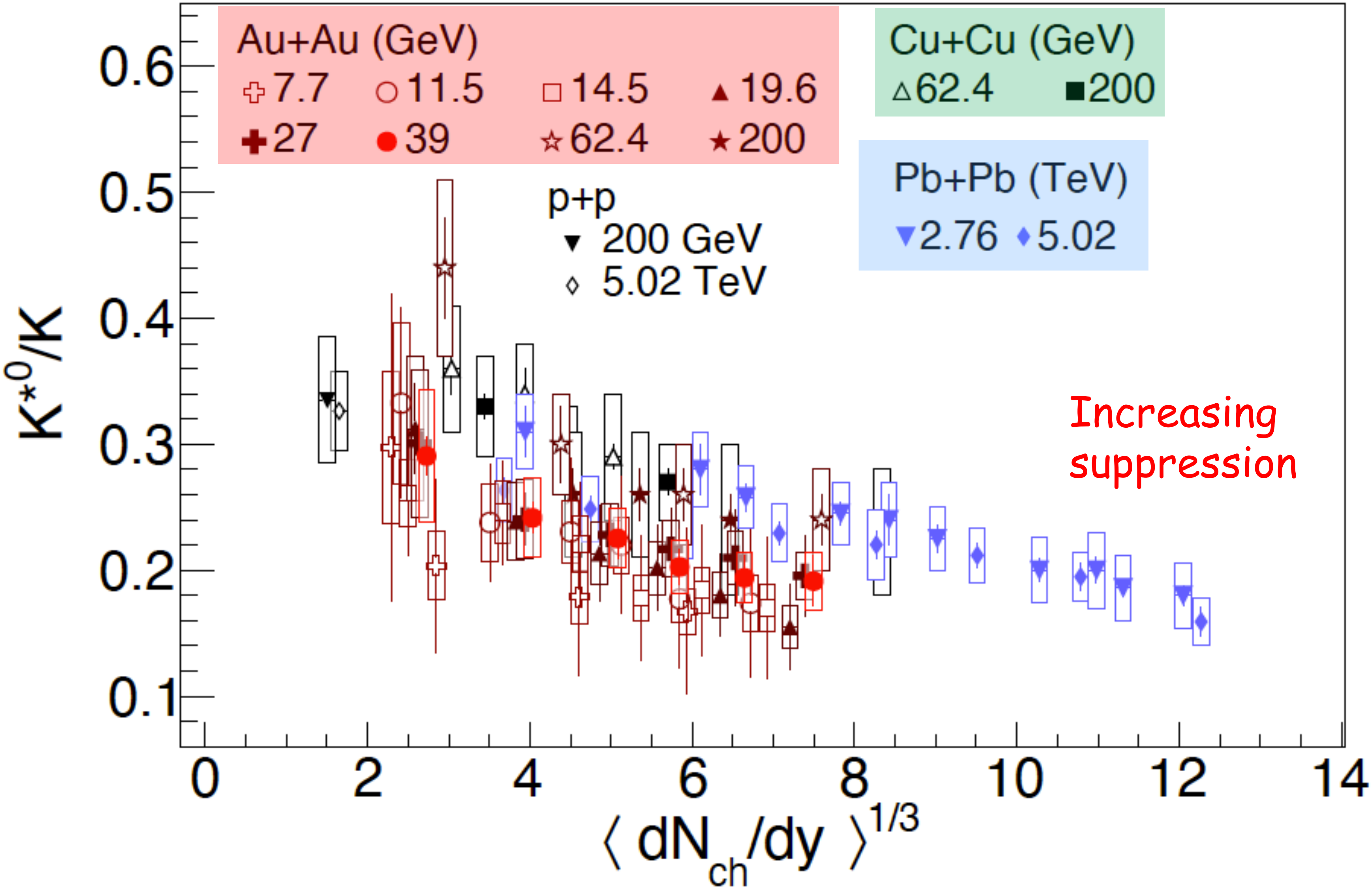
$$\phi(2170) = \phi\,\bar{K}\,K$$

Estudo do decaimento de $\phi(2170)$ a $\phi\eta$ e $\phi\eta^\prime$. Recentemente, as colaborações Belle e BESIII tem medido o decaimento de $\phi(2170)$ a $\phi\eta$ e $\phi\eta^\prime$ como um jeito de obter informação da natureza do estado $\phi(2170)$. Os dados obtidos mostram que o estado $\phi(2170)$ não seria compatível com as predições que existem para esses decaimentos considerando $\phi(2170)$ como estado quark-antiquark ou híbrido. No nosso modelo, $phi(2170)$ seria um estado molecular de $\phi K\bar K$ que poderia decair em $\phi\eta$ e $\phi\eta^\prime$ através da formação de $f_0(980)$ no sistema $K\bar K$, $\pi\pi$, $\eta\eta$ e $\eta\eta^\prime$.



Produção de charme tem outra dinâmica !

...to a wealthy of data



STAR, arXiv:2210.02909

What can we learn from this ratio?

Interactions of K and K* in a hot hadron gas

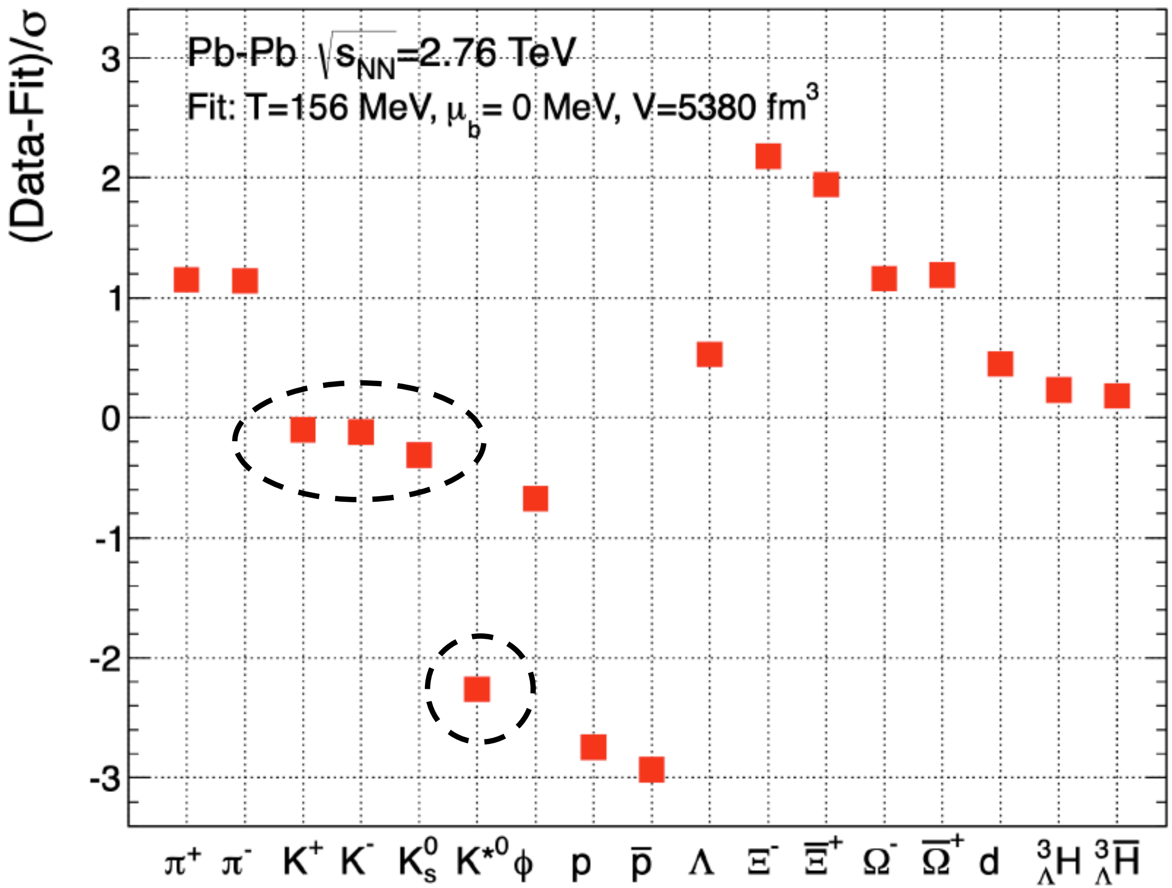
Emergence of chemical equilibrium (freeze-out)

Kinetic freeze-out: lifetime of the hadron gas phase

Confirm the existence of a hot hadron gas

Do we have a good theory ?

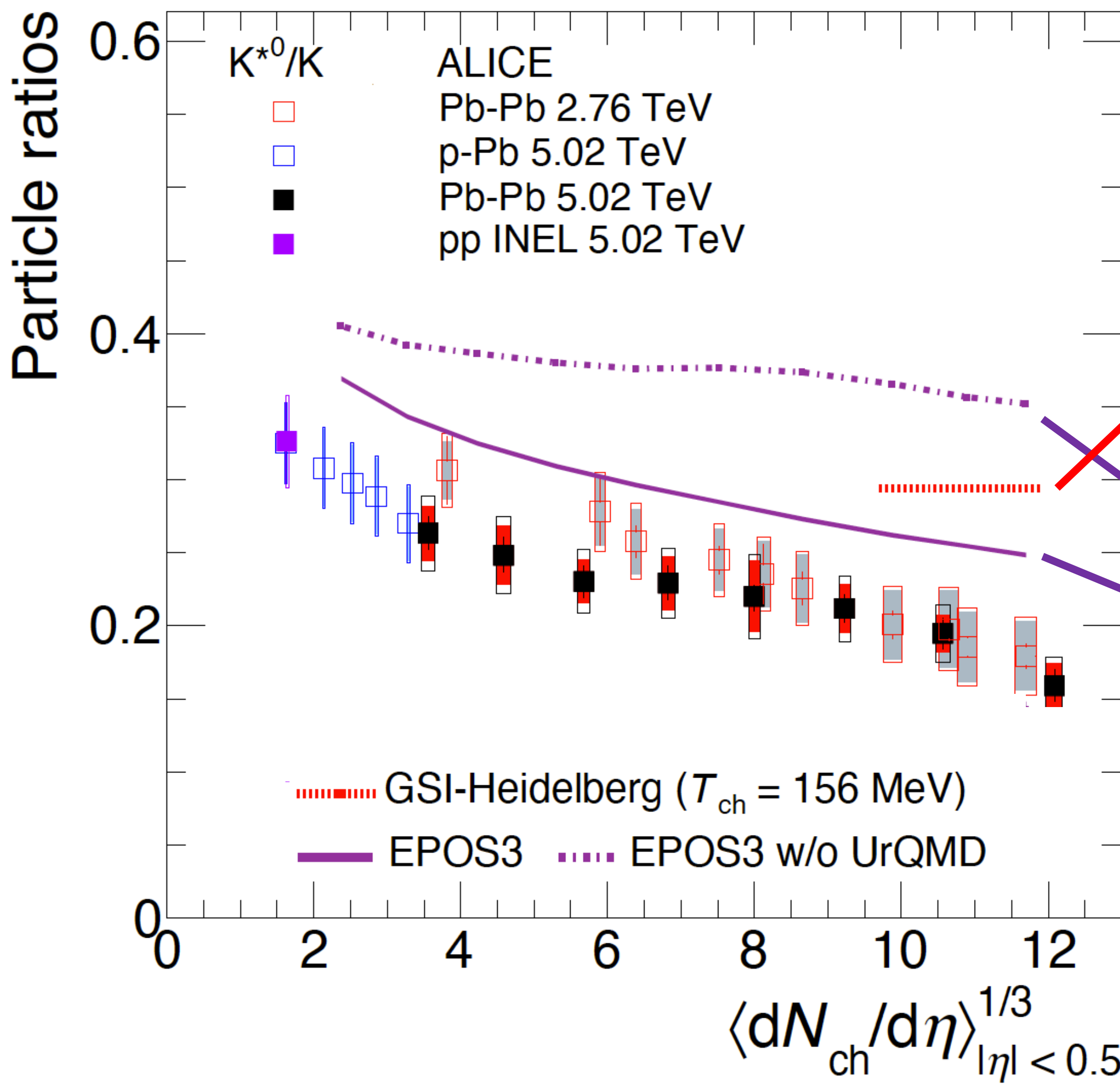
Statistical Hadronization Model fails...



Stachel et al., arXiv:1311.4662

We must include rescattering and/or decay !

ALICE, arXiv:1910.14419

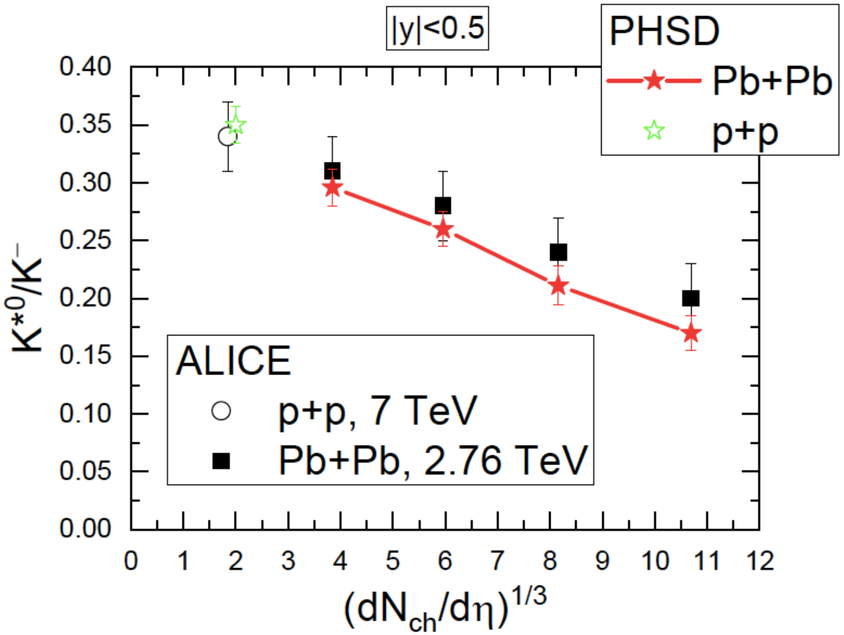


Stachel et al., arXiv:1311.4662

SHM

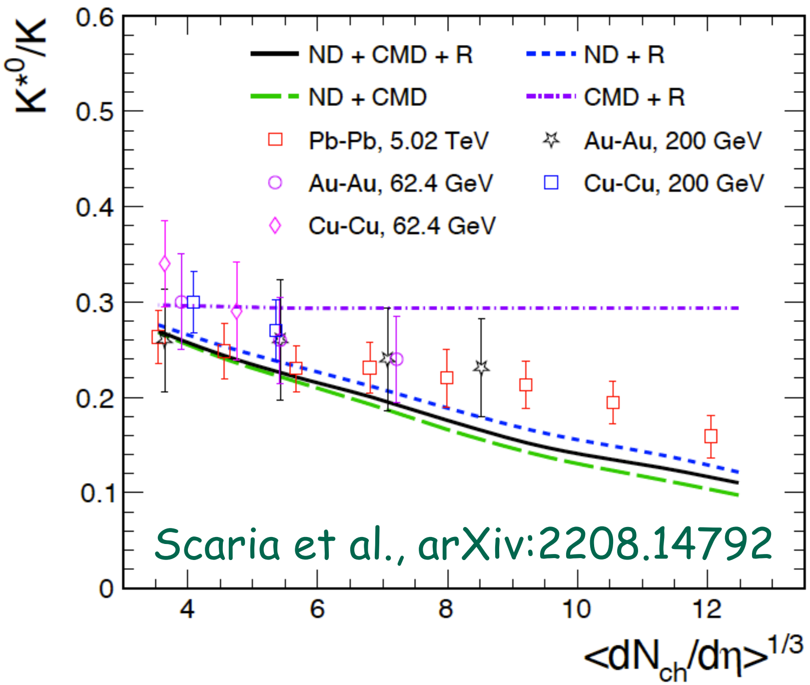
Knospe, Markert, Werner, Steinheimer, Bleicher, arXiv:1509.07895

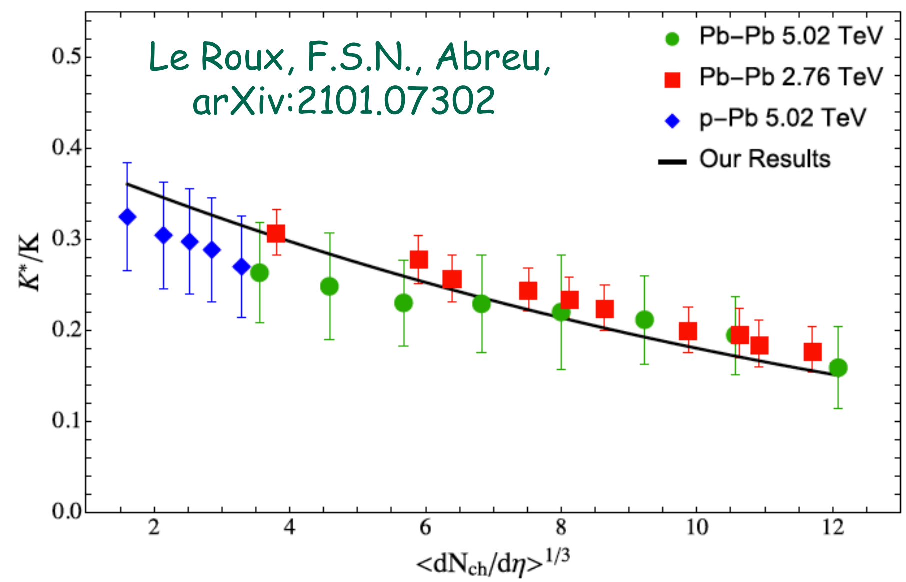
Interactions with the hadron gas improve agreement with data !



Ilner, Cabrera, Markert, Bratkovskaya, arXiv:1609.02778

Ilner, Blair, Cabrera, Markert, Bratkovskaya, arXiv:1707.00060





The hadron gas contribution

Start with the multiplicities at the hadronization

Study the changes produced by interactions in the hadron gas

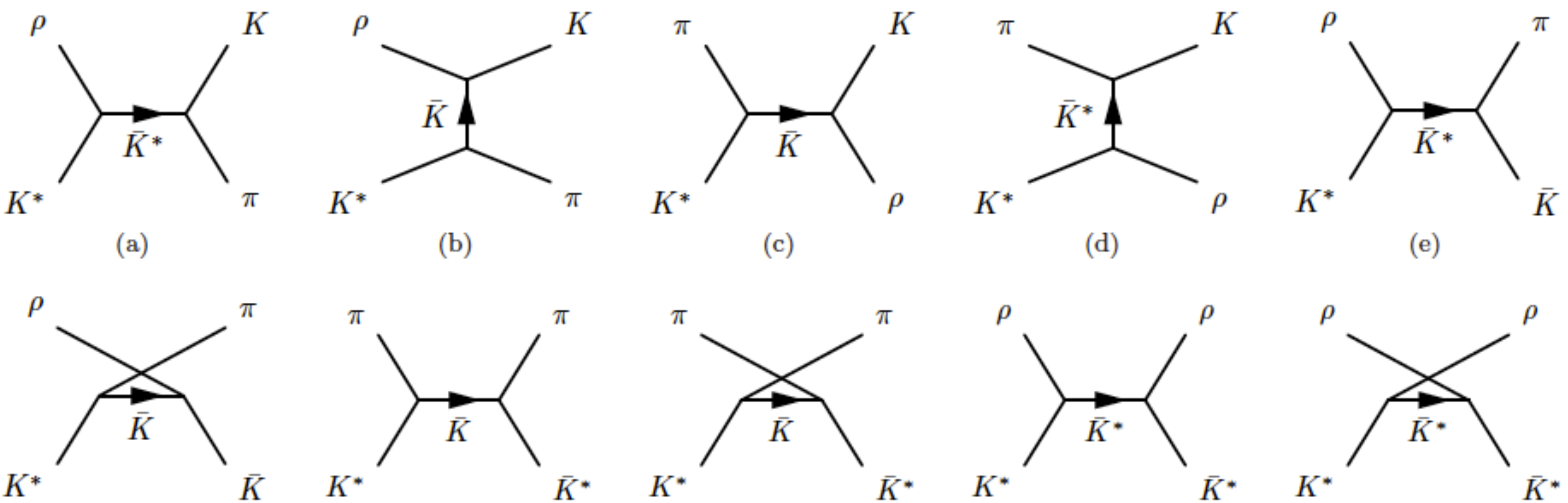
Lagrangians -> Amplitudes -> Cross Sections -> Thermal Cross Sections

Evolution equations -> Expansion and cooling -> Freeze-out

K and K* interactions with light hadrons

$$
\begin{aligned}
\mathcal{L}_{\pi K K^*} &= i g_{\pi K^* K} K^{*\mu} \vec{\tau} \cdot (\bar{K} \partial_\mu \vec{\pi} - \partial_\mu \bar{K} \vec{\pi}) \\
\mathcal{L}_{\rho K K} &= i g_{\rho K K} (K \vec{\tau} \partial_\mu \bar{K} - \partial_\mu K \vec{\tau} \bar{K}) \cdot \vec{\rho}^\mu, \\
\mathcal{L}_{\rho K^* K^*} &= i g_{\rho K^* K^*} \, [(\partial_\mu K^{*\nu} \vec{\tau} \bar{K}^*_\nu - K^{*\nu} \vec{\tau} \partial_\mu \bar{K}^*_\nu) \cdot \vec{\rho}^\mu \\
&+ (K^{*\nu} \vec{\tau} \cdot \partial_\mu \vec{\rho}_\nu - \partial_\mu K^{*\nu} \vec{\tau} \cdot \vec{\rho}_\nu) \bar{K}^{*\mu} \\
&+ K^{*\mu} (\vec{\tau} \cdot \vec{\rho}^\nu \partial_\mu \bar{K}^*_\nu - \vec{\tau} \cdot \partial_\mu \vec{\rho}^\nu \bar{K}^*_\nu)],
\end{aligned}
$$

S. Cho and S.H. Lee, arXiv:1509.04092



Cross Sections : $\sigma = \frac{1}{64\pi^2 s g_1 g_2} \frac{|\vec{p}_f|}{|\vec{p}_i|} \int d\Omega \overline{|\mathcal{M}|^2} F^4$

Form Factors : $F_{u,t}(\vec{q}) = \frac{\Lambda^2 - m_{ex}^2}{\Lambda^2 + \vec{q}^2}$ $\Lambda = 1.8\,\mathrm{GeV}$

Thermal Cross Sections : $\langle \sigma_{ab\to cd}\, v_{ab} \rangle = \frac{\int d^3\mathbf{p}_a d^3\mathbf{p}_b\, f_a(\mathbf{p}_a)\, f_b(\mathbf{p}_b)\, \sigma_{ab\to cd}\ v_{ab}}{\int d^3\mathbf{p}_a d^3\mathbf{p}_b\, f_a(\mathbf{p}_a)\, f_b(\mathbf{p}_b)}$

$$f_i(\vec{p}_i) = \frac{1}{e^{\sqrt{\vec{p}_i^{\,2} + m_i^2}/T} - 1} \qquad v_{ab} = \sqrt{(p_a \cdot p_b)^2 - m_a^2 m_b^2}/(E_a E_b)$$

Inverse processes with detailed balance:

$$g_a g_b |\vec{p}_{ab}|^2 \sigma_{ab\to cd}(s) = g_c g_d |\vec{p}_{cd}|^2 \sigma_{cd\to ab}(s)$$

Rate equations

$$\frac{dN_{K^*}}{d\tau} = \langle\sigma_{K\rho\to K^*\pi} v_{K\rho}\rangle n_\rho(\tau) N_K(\tau) - \langle\sigma_{K^*\pi\to K\rho} v_{K^*\pi}\rangle n_\pi(\tau) N_{K^*}(\tau) + \langle\sigma_{K\pi\to K^*\rho} v_{K\pi}\rangle n_\pi(\tau) N_K(\tau)$$
$$- \langle\sigma_{K^*\rho\to K\pi} v_{K^*\rho}\rangle n_\rho(\tau) N_{K^*}(\tau) + \langle\sigma_{\pi\rho\to K^*\bar{K}} v_{\pi\rho}\rangle n_\pi(\tau) N_\rho(\tau) - \langle\sigma_{K^*\bar{K}\to\rho\pi} v_{K^*\bar{K}}\rangle n_{\bar{K}}(\tau) N_{K^*}(\tau)$$
$$+ \langle\sigma_{\pi\pi\to K^*\bar{K}^*} v_{\pi\pi}\rangle n_\pi(\tau) N_\pi(\tau) - \langle\sigma_{K^*\bar{K}^*\to\pi\pi} v_{K^*\bar{K}^*}\rangle n_{\bar{K}^*}(\tau) N_{K^*}(\tau) + \langle\sigma_{\rho\rho\to K^*\bar{K}^*} v_{\rho\rho}\rangle n_\rho(\tau) N_\rho(\tau)$$
$$- \langle\sigma_{K^*\bar{K}^*\to\rho\rho} v_{K^*\bar{K}^*}\rangle n_{\bar{K}^*}(\tau) N_{K^*}(\tau) + \langle\sigma_{K\pi\to K^*} v_{K\pi}\rangle n_\pi(\tau) N_K(\tau) - \langle\Gamma_{K^*}\rangle N_{K^*}(\tau),$$

$$\frac{dN_K}{d\tau} = \langle\sigma_{\pi\pi\to K\bar{K}} v_{\pi\pi}\rangle n_\pi(\tau) N_\pi(\tau) - \langle\sigma_{K\bar{K}\to\pi\pi} v_{K\bar{K}}\rangle n_{\bar{K}}(\tau) N_K(\tau) + \langle\sigma_{\rho\rho\to K\bar{K}} v_{\rho\rho}\rangle n_\rho(\tau) N_\rho(\tau)$$
$$- \langle\sigma_{K\bar{K}\to\rho\rho} v_{K\bar{K}}\rangle n_{\bar{K}}(\tau) N_K(\tau) + \langle\sigma_{K^*\pi\to K\rho} v_{K^*\pi}\rangle n_\pi(\tau) N_{K^*}(\tau) - \langle\sigma_{K\rho\to K^*\pi} v_{K\rho}\rangle n_\rho(\tau) N_K(\tau)$$
$$+ \langle\sigma_{K^*\rho\to K\pi} v_{K^*\rho}\rangle n_\rho(\tau) N_{K^*}(\tau) - \langle\sigma_{K\pi\to K^*\rho} v_{K\pi}\rangle n_\pi(\tau) N_K(\tau) + \langle\sigma_{\pi\rho\to K^*\bar{K}} v_{\pi\rho}\rangle n_\pi(\tau) N_\rho(\tau)$$
$$- \langle\sigma_{K^*\bar{K}\to\rho\pi} v_{K^*\bar{K}}\rangle n_{\bar{K}}(\tau) N_{K^*}(\tau) + \langle\Gamma_{K^*}\rangle N_{K^*}(\tau) - \langle\sigma_{K\pi\to K^*} v_{K\pi}\rangle n_\pi(\tau) N_K(\tau).$$

$$n_i(\tau) = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 dp}{e^{\sqrt{p_i^2+m_i^2}/T(\tau)} - 1} \simeq \frac{g_i}{2\pi^2} m_i^2 T(\tau) K_2\left(\frac{m_i}{T(\tau)}\right) \qquad N_i = n_i V$$

Expansion and Cooling :

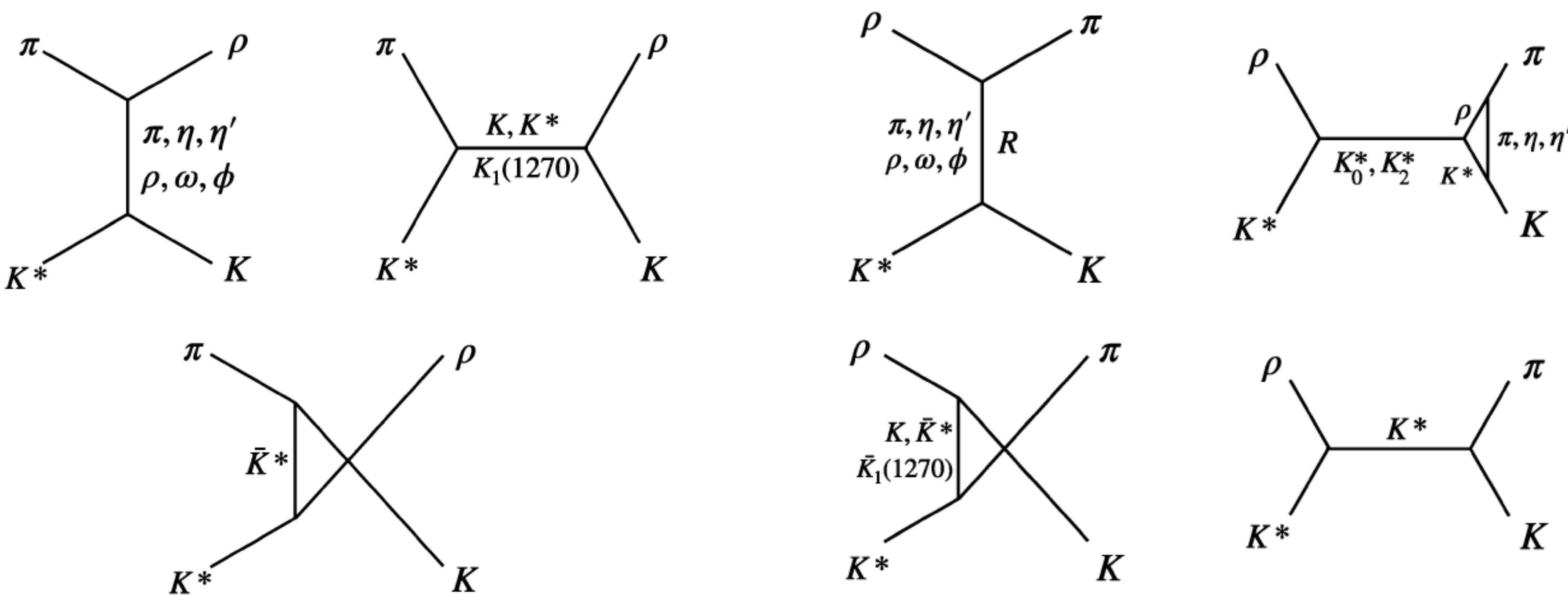
$$\begin{cases} V(\tau) = \pi[R_c + v_c(\tau-\tau_c) + a_c/2(\tau-\tau_c)^2]^2 \tau c, \\ T(\tau) = T_c - (T_h - T_f)\left(\dfrac{\tau-\tau_h}{\tau_f-\tau_h}\right)^{4/5}, \end{cases}$$

K and K* interactions with light hadrons improved

Martinez Torres, Khemchandani, Abreu, F.S.N., Nielsen, arXiv:1708.05784

Inclusion of anomalous parity VVP interactions

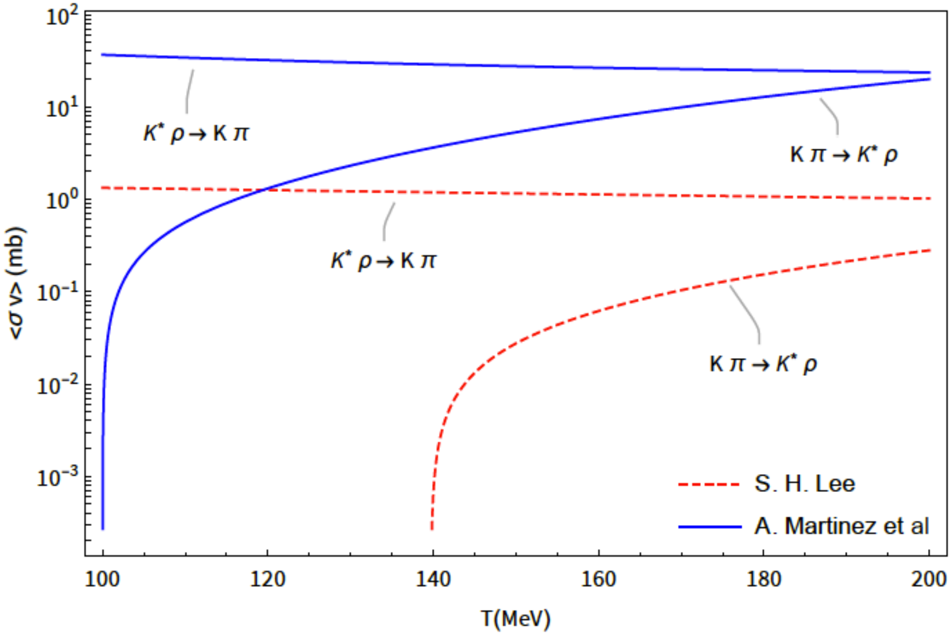
Exchange of axial resonances



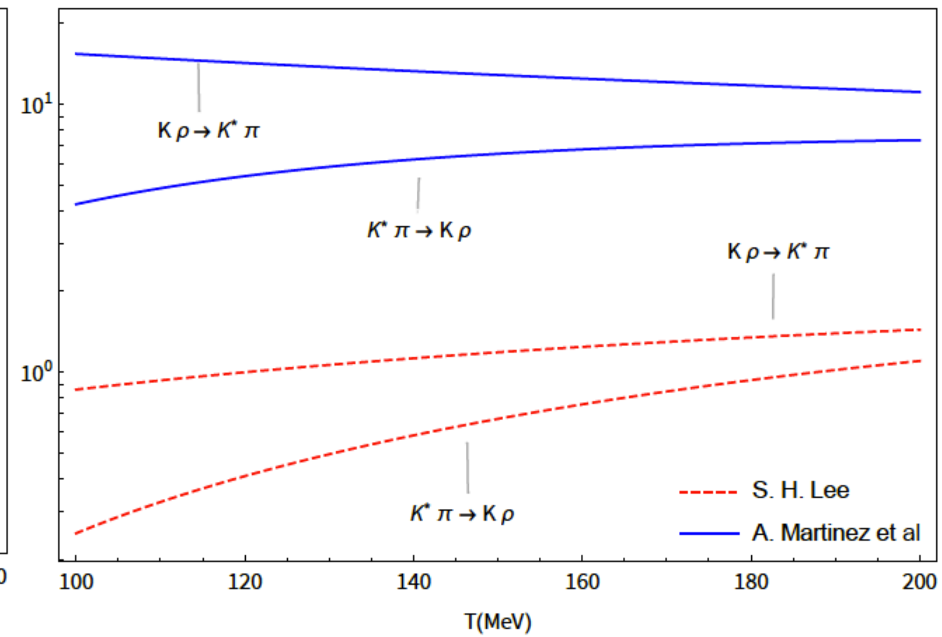
Many processes but only 3 are really important:

$$\begin{cases} K^* \rho \leftrightarrow K \pi \\ K^* \pi \leftrightarrow K \rho \\ K^* \leftrightarrow K + \pi \end{cases}$$

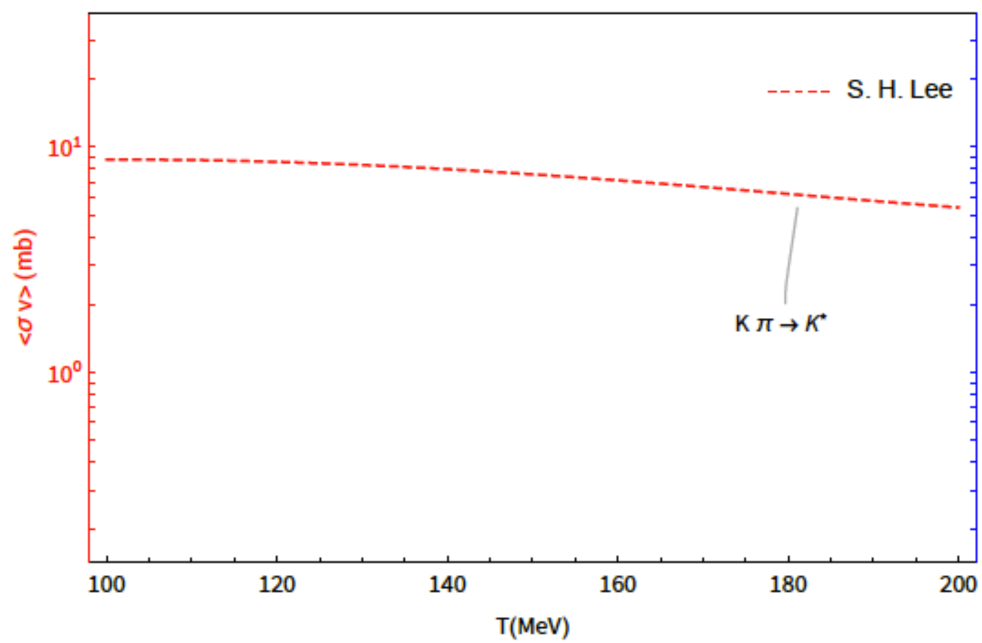
$K^* \rho \leftrightarrow K \pi$



$K^* \pi \leftrightarrow K \rho$



$K^* \leftrightarrow K + \pi$



Simplified evolution equations :

$$\begin{cases} \dfrac{dN_{K^*}(\tau)}{d\tau} = \gamma_K N_K(\tau) - \gamma_{K^*} N_{K^*}(\tau), \\ \dfrac{dN_K(\tau)}{d\tau} = -\gamma_K N_K(\tau) + \gamma_{K^*} N_{K^*}(\tau), \end{cases}$$

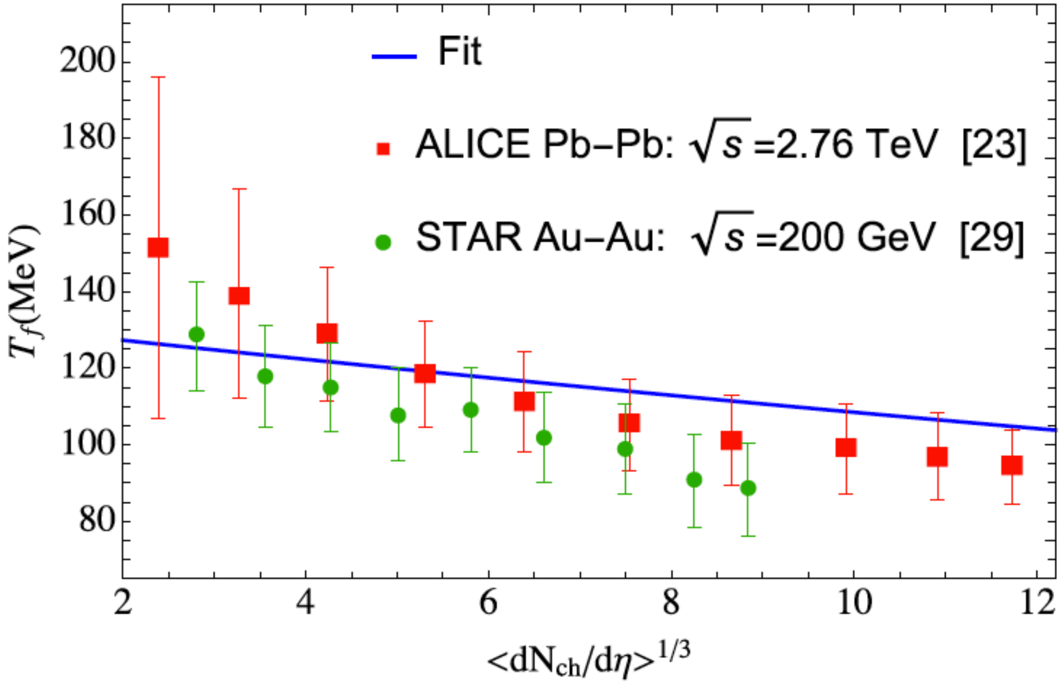
$$\gamma_K = \langle \sigma_{K\pi\to K^*\rho} v_{K\pi} \rangle n_\pi + \langle \sigma_{K\rho\to K^*\pi} v_{K\rho} \rangle n_\rho + \langle \sigma_{K\pi\to K^*} v_{K\pi} \rangle n_\pi ,$$

$$\gamma_{K^*} = \langle \sigma_{K^*\rho\to K\pi} v_{K^*\rho} \rangle n_\rho + \langle \sigma_{K^*\pi\to K\rho} v_{K^*\pi} \rangle n_\pi + \langle \Gamma_{K^*} \rangle .$$

Bjorken cooling : $T = T_h \left(\dfrac{\tau_h}{\tau}\right)^{1/3}$ → $\tau_f = \tau_h \left(\dfrac{T_h}{T_f}\right)^3$

T_f depends on the system size : $T_f = T_f\left(\dfrac{dN}{d\eta}(\eta = 0)\right)$

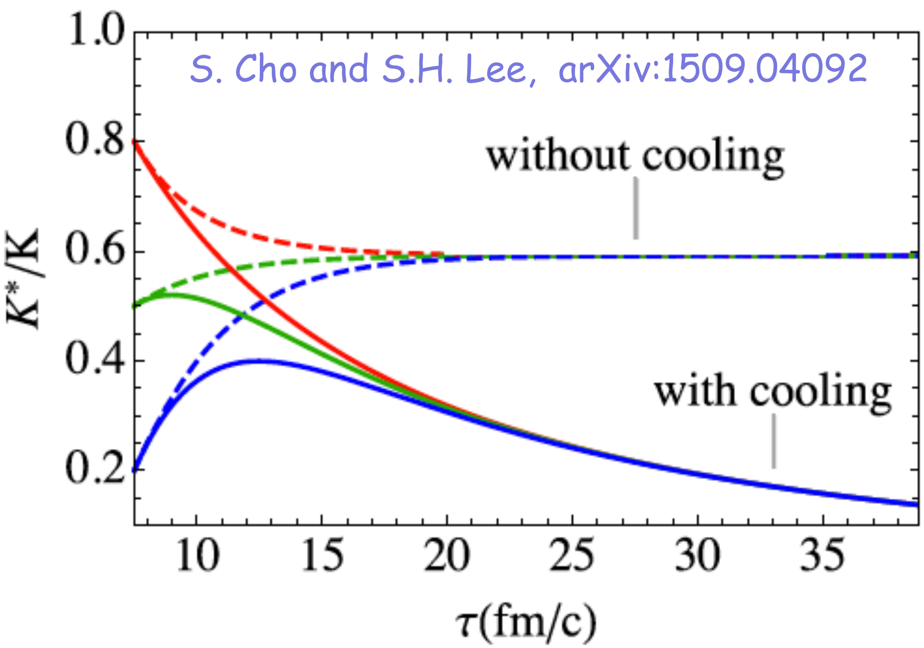
System size dependent freeze-out temperature

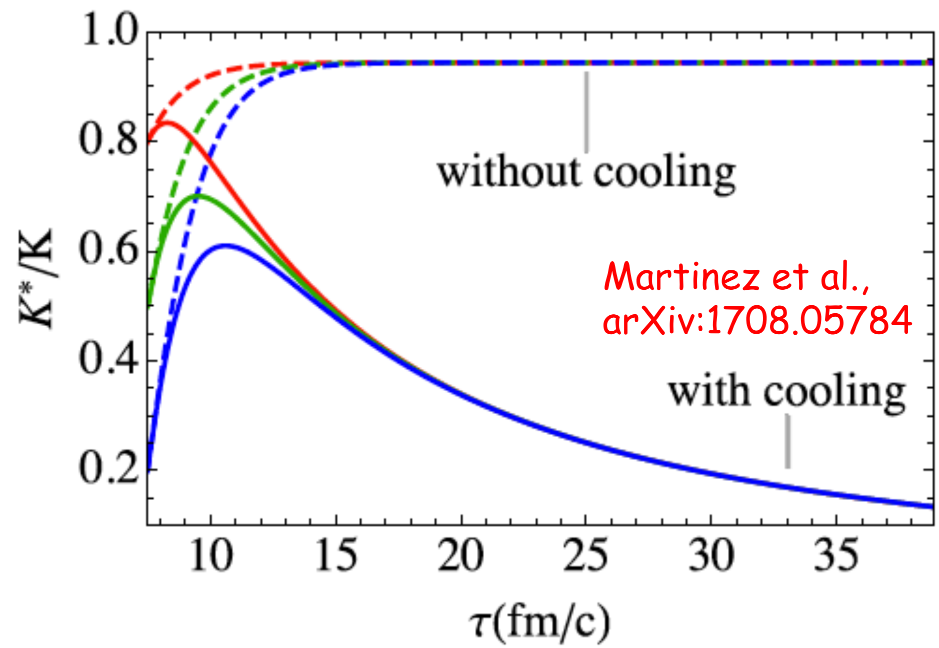


ALICE, arXiv:1303.0737

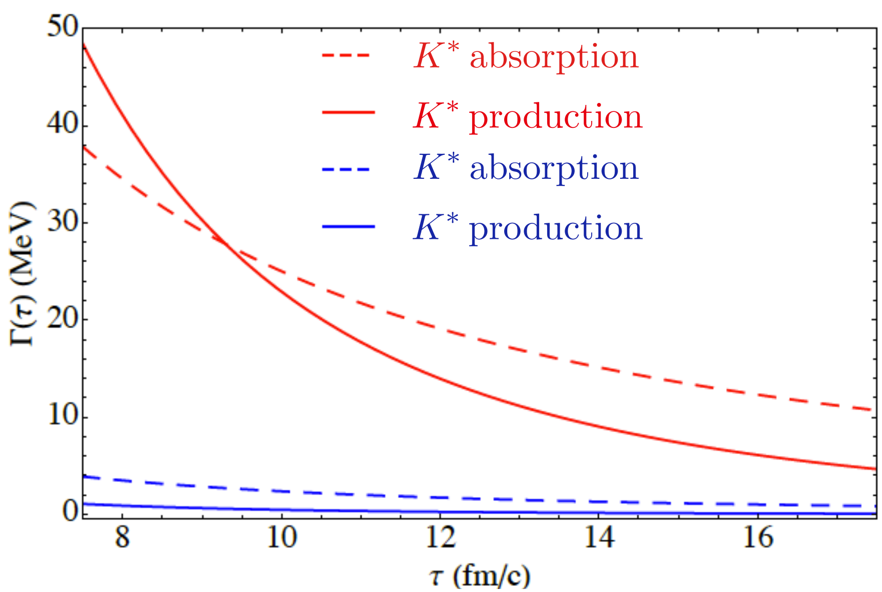
$$T_f = T_{f0}\, e^{-b\mathcal{N}}$$

$$\mathcal{N} = \left[\left(\frac{dN}{d\eta}\right)_{\eta=0}\right]^{1/3}$$





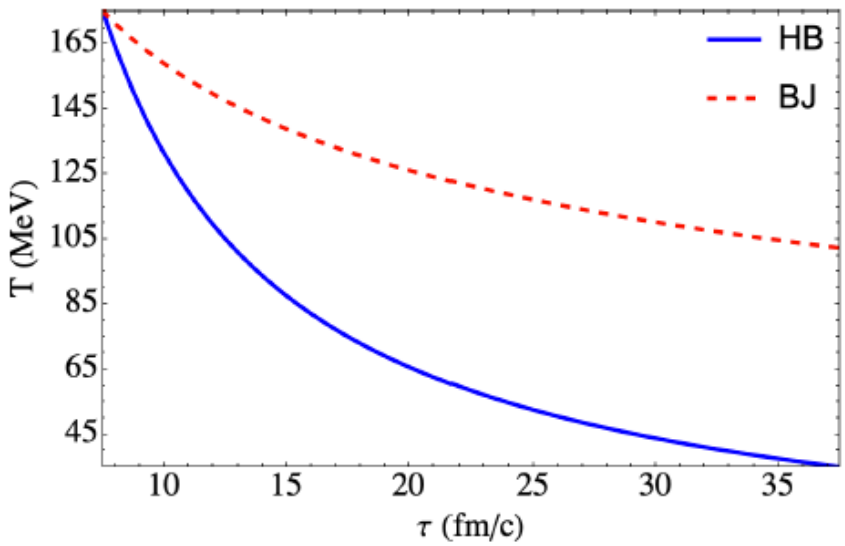
Reaction
Rate



Martinez et al.,
arXiv:1708.05784

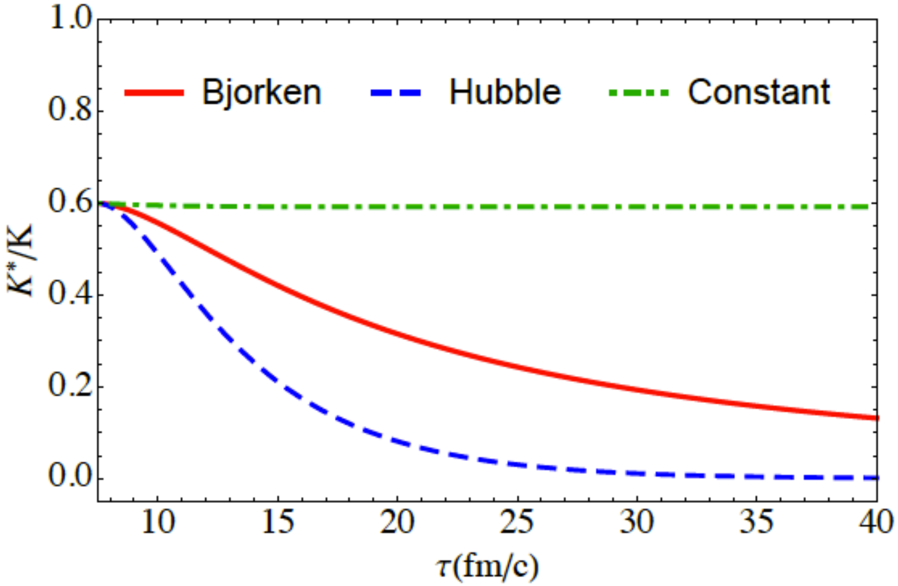
S. Cho,S.H. Lee,
arXiv:1509.04092

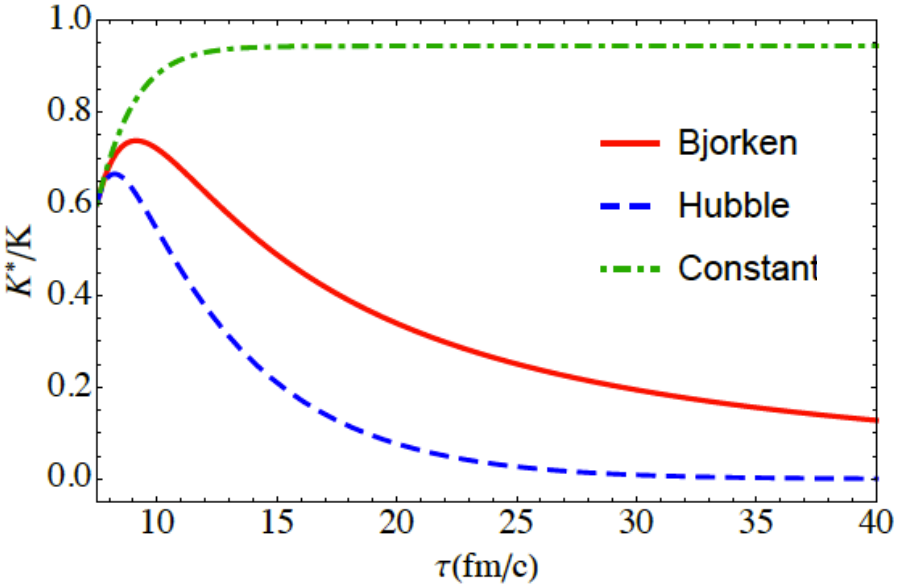
Effect of cooling



$$T(\tau) = T_h \left(\frac{\tau_h}{\tau}\right)^{\frac{1}{3}}$$ Bjorken

$$T(\tau) = T_h \left(\frac{\tau_h}{\tau}\right)$$ Hubble



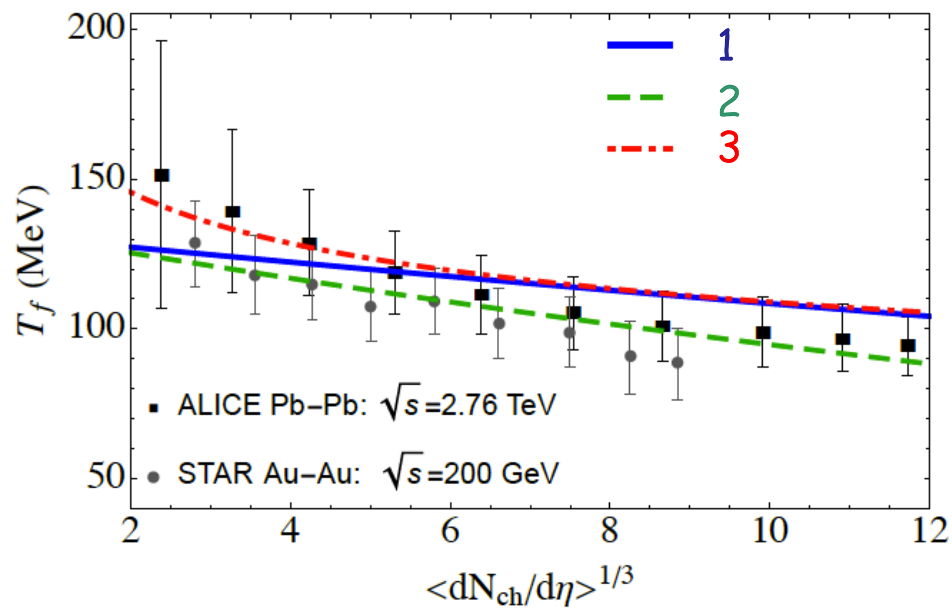


Effect of the parametrization of T_f

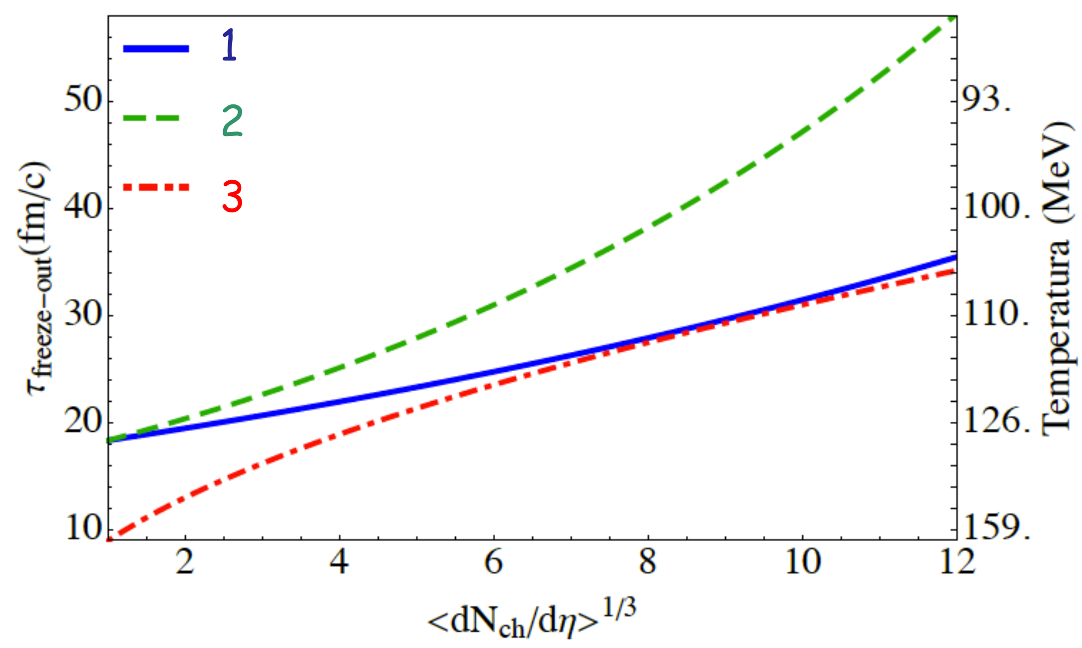
1 $T_f = 132\, e^{-0.02\,\mathcal{N}}$

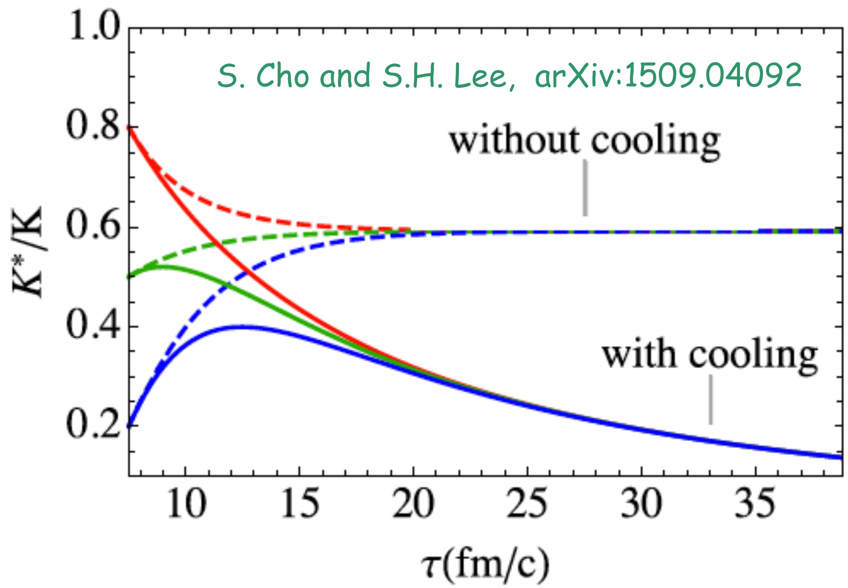
2 $T_f = 134\, e^{-0.035\,\mathcal{N}}$

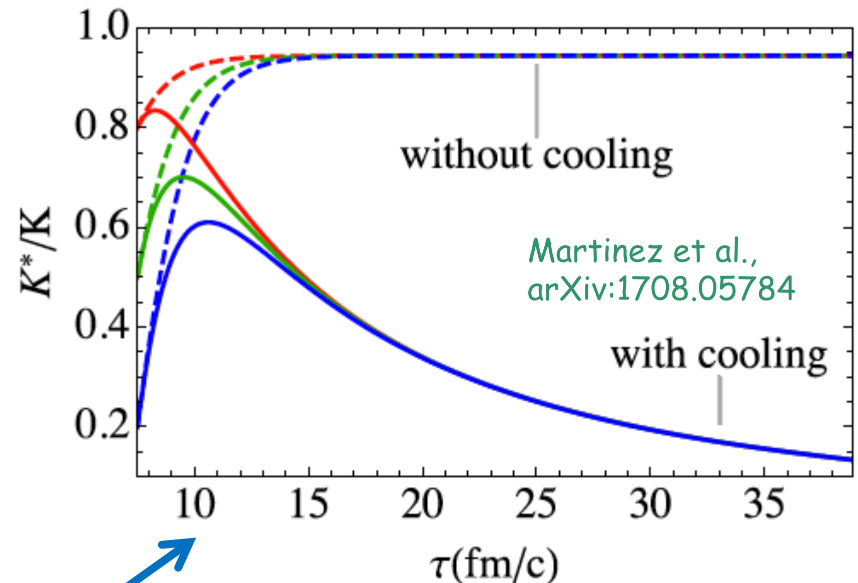
3 $T_f = 165\, e^{-0.18\,\mathcal{N}}$



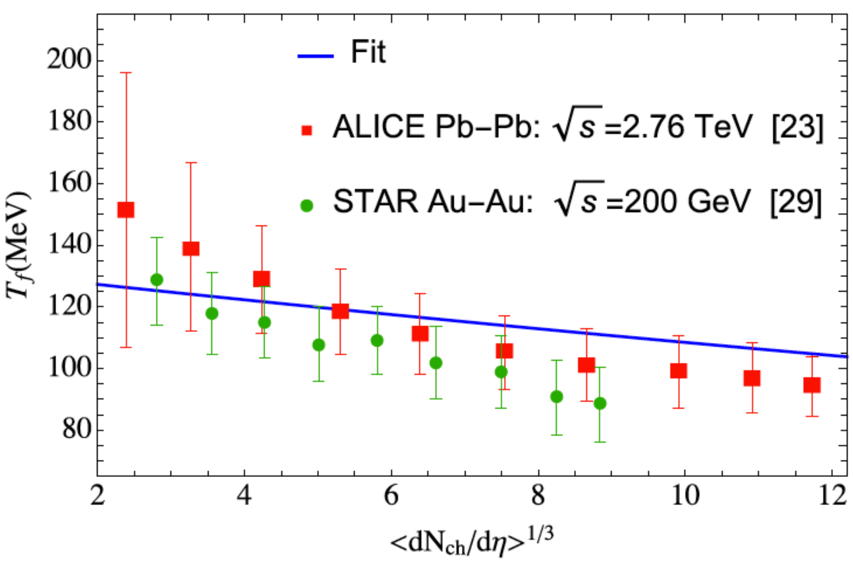
$$\tau_f = \tau_h \left(\frac{T_h}{T_f}\right)^3$$

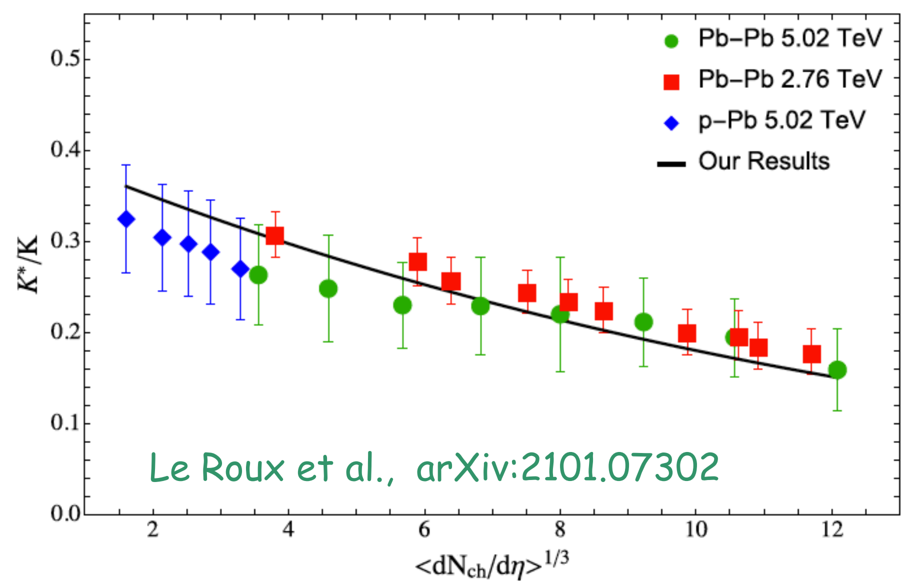






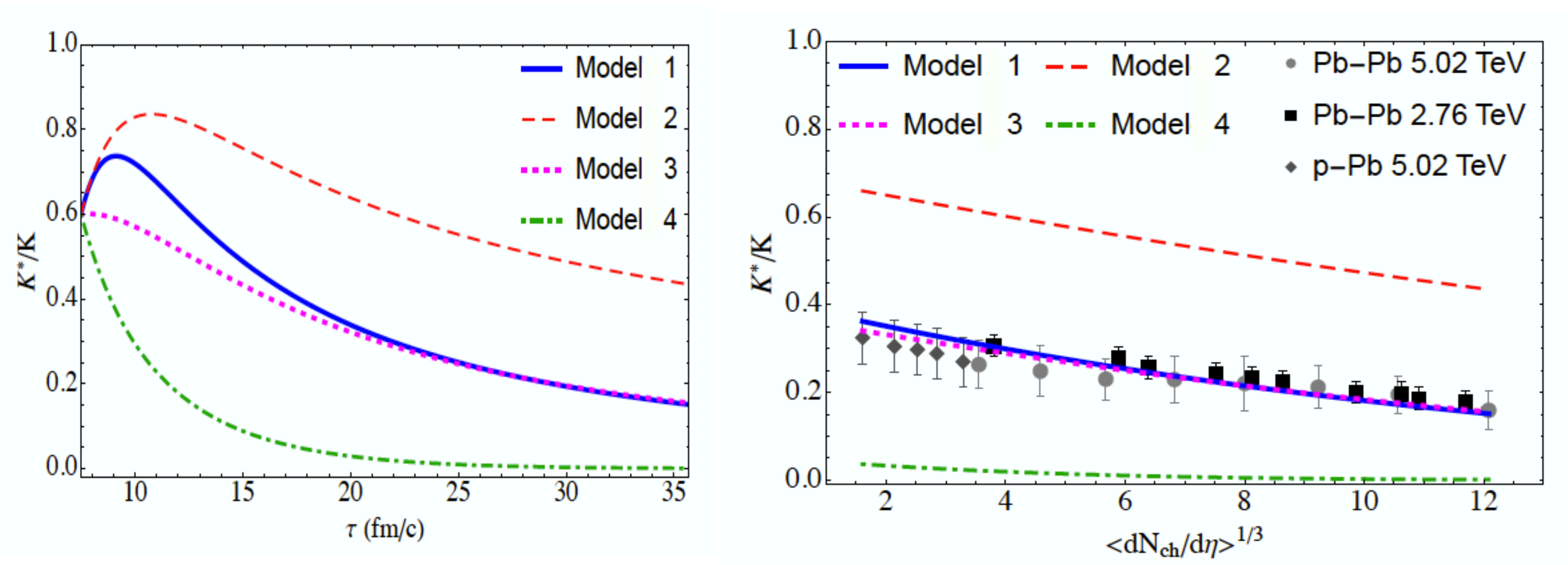
$$\tau_f = \tau_h \left(\frac{T_h}{T_f}\right)^3$$





Which reaction is more important?

	$K^*\pi \leftrightarrow K\rho$	$K^*\rho \leftrightarrow K\pi$	$K^* \to K\pi$	$K\pi \to K^*$
Model 1	✓	✓	✓	✓
Model 2	✓	✓		
Model 3			✓	✓
Model 4			✓	



C.~Le Roux and F.~S.~Navarra, J. Phys. Conf. Ser. {2340}, 012010 (2022)

D* / D Ratio

Lagrangians -> Amplitudes -> Cross Sections -> Thermal Cross Sections

Evolution equations -> Expansion and cooling -> Freeze-out

Abreu, FSN and Vieira, arXiv:2209.03814

Decay: $D^* \to D + \pi$ $\Gamma(D^*) \simeq 1\,\mathrm{MeV}$ $\tau_{life} = \frac{1}{\Gamma(D^*)} \simeq 200\,\mathrm{fm}$

Not relevant !

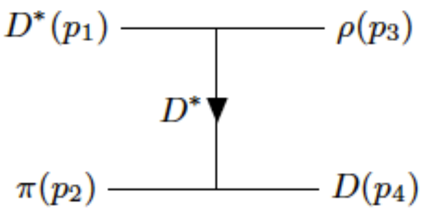
Interactions with rhos and pions

$$
\begin{aligned}
\mathcal{L}_{\pi DD^*} &= i g_{\pi DD^*} D^{*\mu} \vec{\tau} \cdot (\bar{D}\partial_\mu \vec{\pi} - \partial_\mu \bar{D} \vec{\pi}) \\
\mathcal{L}_{\rho DD} &= i g_{\rho DD} (D \vec{\tau} \partial_\mu \bar{D} - \partial_\mu D \vec{\tau} \bar{D}) \cdot \vec{\rho}^\mu , \\
\mathcal{L}_{\rho D^* D^*} &= i g_{\rho D^* D^*} \left[(\partial_\mu D^{*\nu} \vec{\tau} \bar{D}^*_\nu - D^{*\nu} \vec{\tau} \partial_\mu \bar{D}^*_\nu) \cdot \vec{\rho}^\mu \right. \\
&\quad + (D^{*\nu} \vec{\tau} \cdot \partial_\mu \vec{\rho}_\nu - \partial_\mu D^{*\nu} \vec{\tau} \cdot \vec{\rho}_\nu) \bar{D}^{*\mu} \\
&\quad \left. + D^{*\mu} (\vec{\tau} \cdot \vec{\rho}^\nu \partial_\mu \bar{D}^*_\nu - \vec{\tau} \cdot \partial_\mu \vec{\rho}^\nu \bar{D}^*_\nu) \right] , \\
\mathcal{L}_{\pi D^* D^*} &= - g_{\pi D^* D^*} \epsilon^{\mu\nu\alpha\beta} \partial_\mu D^*_\nu \pi \partial_\alpha \bar{D}^*_\beta , \\
\mathcal{L}_{\rho DD^*} &= - g_{\rho DD^*} \epsilon^{\mu\nu\alpha\beta} (D \partial_\mu \rho_\nu \partial_\alpha \bar{D}^*_\beta + \partial_\mu D^*_\nu \partial_\alpha \rho_\beta \bar{D})
\end{aligned}
$$

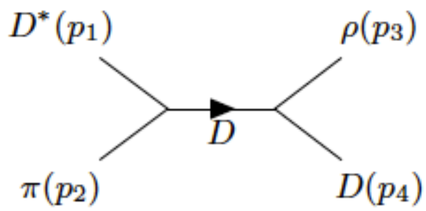
All couplings and form factors calculated with QCD sum rules!

M.~E.~Bracco, M.~Chiapparini, F.~S.~Navarra and M.~Nielsen, arXiv:1104.2864

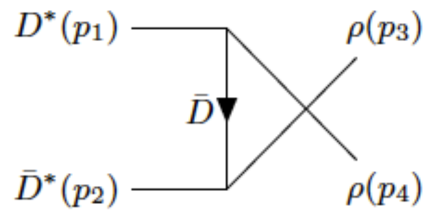
Amplitudes



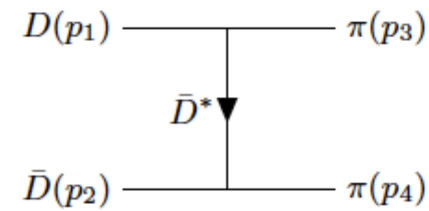
(1.a)



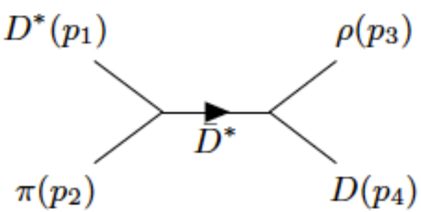
(1.b)



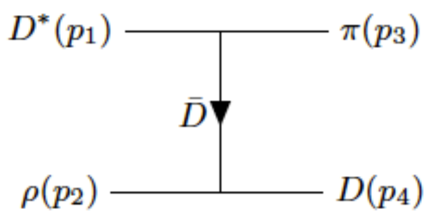
(5.d)



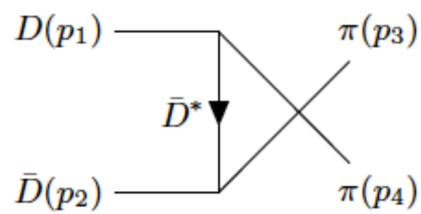
(6.a)



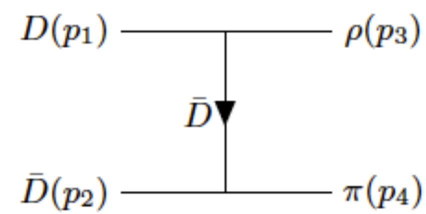
(1.c)



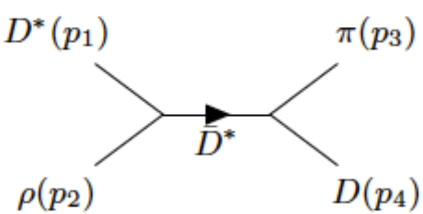
(2.a)

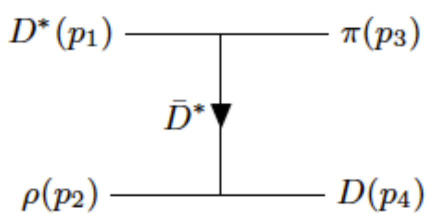


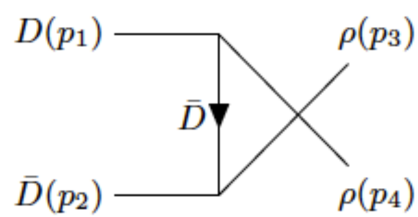
(6.b)

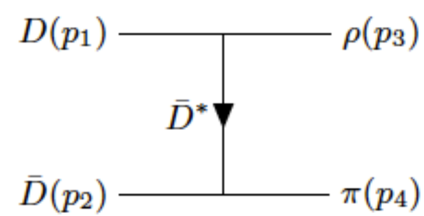


(7.a)









Expansion, cooling and initial conditions

$$T(\tau) = T_C - (T_H - T_F)\left(\frac{\tau - \tau_H}{\tau_F - \tau_H}\right)^{\frac{4}{5}},$$

$$V(\tau) = \pi\left[R_C + v_C(\tau - \tau_C) + \frac{a_C}{2}(\tau - \tau_C)^2\right]^2 \tau c,$$

TABLE II. Parameters used in Eq. (12) for central $Pb - Pb$ collisions at $\sqrt{s_{NN}} = 5$ TeV [25].

v_C (c)	a_C (c^2/fm)	R_C (fm)
0.5	0.09	11
τ_C (fm/c)	τ_H (fm/c)	τ_F (fm/c)
7.1	10.2	21.5
T_C(MeV)	T_H(MeV)	T_F(MeV)
156	156	115
N_c	$N_\pi(\tau_F)$	$N_\rho(\tau_F)$
14	2410	179
$N_D(\tau_H)$	$N_{D^*}(\tau_H)$	
4.7	6.3	

EXHIC, arXiv:1702.00486

Time evolution and multiplicities

$$\frac{dN_{D^*}}{d\tau} = \langle\sigma_{D\rho\to D^*\pi}v_{D\rho}\rangle n_\rho(\tau)N_D(\tau) - \langle\sigma_{D^*\pi\to D\rho}v_{D^*\pi}\rangle n_\pi(\tau)N_{D^*}(\tau) + \langle\sigma_{D\pi\to D^*\rho}v_{D\pi}\rangle n_\pi(\tau)N_D(\tau)$$
$$- \langle\sigma_{D^*\rho\to D\pi}v_{D^*\rho}\rangle n_\rho(\tau)N_{D^*}(\tau) + \langle\sigma_{\pi\rho\to D^*\bar{D}}v_{\pi\rho}\rangle n_\pi(\tau)N_\rho(\tau) - \langle\sigma_{D^*\bar{D}\to\rho\pi}v_{D^*\bar{D}}\rangle n_{\bar{D}}(\tau)N_{D^*}(\tau)$$
$$+ \langle\sigma_{\pi\pi\to D^*\bar{D}^*}v_{\pi\pi}\rangle n_\pi(\tau)N_\pi(\tau) - \langle\sigma_{D^*\bar{D}^*\to\pi\pi}v_{D^*\bar{D}^*}\rangle n_{\bar{D}^*}(\tau)N_{D^*}(\tau) + \langle\sigma_{\rho\rho\to D^*\bar{D}^*}v_{\rho\rho}\rangle n_\rho(\tau)N_\rho(\tau)$$
$$- \langle\sigma_{D^*\bar{D}^*\to\rho\rho}v_{D^*\bar{D}^*}\rangle n_{\bar{D}^*}(\tau)N_{D^*}(\tau) + \langle\sigma_{D\pi\to D^*}v_{D\pi}\rangle n_\pi(\tau)N_D(\tau) - \langle\Gamma_{D^*}\rangle N_{D^*}(\tau),$$

$$\frac{dN_D}{d\tau} = \langle\sigma_{\pi\pi\to D\bar{D}}v_{\pi\pi}\rangle n_\pi(\tau)N_\pi(\tau) - \langle\sigma_{D\bar{D}\to\pi\pi}v_{D\bar{D}}\rangle n_{\bar{D}}(\tau)N_D(\tau) + \langle\sigma_{\rho\rho\to D\bar{D}}v_{\rho\rho}\rangle n_\rho(\tau)N_\rho(\tau)$$
$$- \langle\sigma_{D\bar{D}\to\rho\rho}v_{D\bar{D}}\rangle n_{\bar{D}}(\tau)N_D(\tau) + \langle\sigma_{D^*\pi\to D\rho}v_{D^*\pi}\rangle n_\pi(\tau)N_{D^*}(\tau) - \langle\sigma_{D\rho\to D^*\pi}v_{D\rho}\rangle n_\rho(\tau)N_D(\tau)$$
$$+ \langle\sigma_{D^*\rho\to D\pi}v_{D^*\rho}\rangle n_\rho(\tau)N_{D^*}(\tau) - \langle\sigma_{D\pi\to D^*\rho}v_{D\pi}\rangle n_\pi(\tau)N_D(\tau) + \langle\sigma_{\pi\rho\to D^*\bar{D}}v_{\pi\rho}\rangle n_\pi(\tau)N_\rho(\tau)$$
$$- \langle\sigma_{D^*\bar{D}\to\rho\pi}v_{D^*\bar{D}}\rangle n_{\bar{D}}(\tau)N_{D^*}(\tau) + \langle\Gamma_{D^*}\rangle N_{D^*}(\tau) - \langle\sigma_{D\pi\to D^*}v_{D\pi}\rangle n_\pi(\tau)N_D(\tau),$$

$$n_i(\tau) \approx \frac{1}{2\pi^2}\gamma_i g_i m_i^2 T(\tau) K_2\left(\frac{m_i}{T(\tau)}\right) \qquad N_i = n_i V$$

$$\tau_f = \tau_h\left(\frac{T_H}{T_F}\right)^3 \qquad T_F = T_{F0}e^{-b\mathcal{N}} \quad \longrightarrow \quad \tau_F \propto e^{3b\mathcal{N}}$$

Summary

K* / K ratio can be well understood with a hadron gas phase

K* decay and formation are the dominant reactions

Cooling and system size dependence of the freeze-out are crucial

Predictions for the D* / D ratio

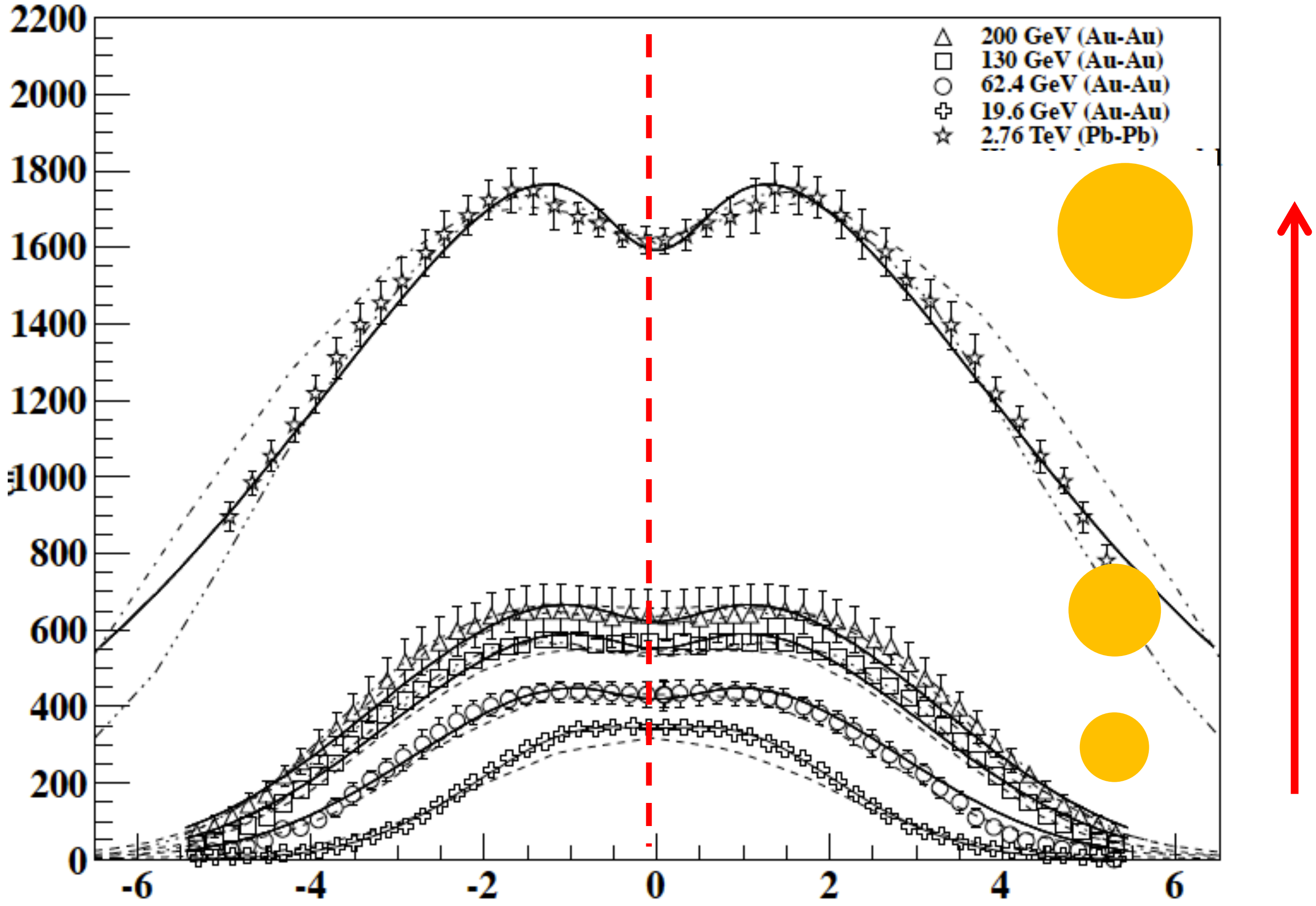
Thank you very much !!!

Back-ups

System Size

$$\left(\frac{dN}{d\eta}\right)_{\eta=0} \qquad \mathcal{N} = \left[\left(\frac{dN}{d\eta}\right)_{\eta=0}\right]^{1/3}$$

$$\frac{dN}{d\eta}$$

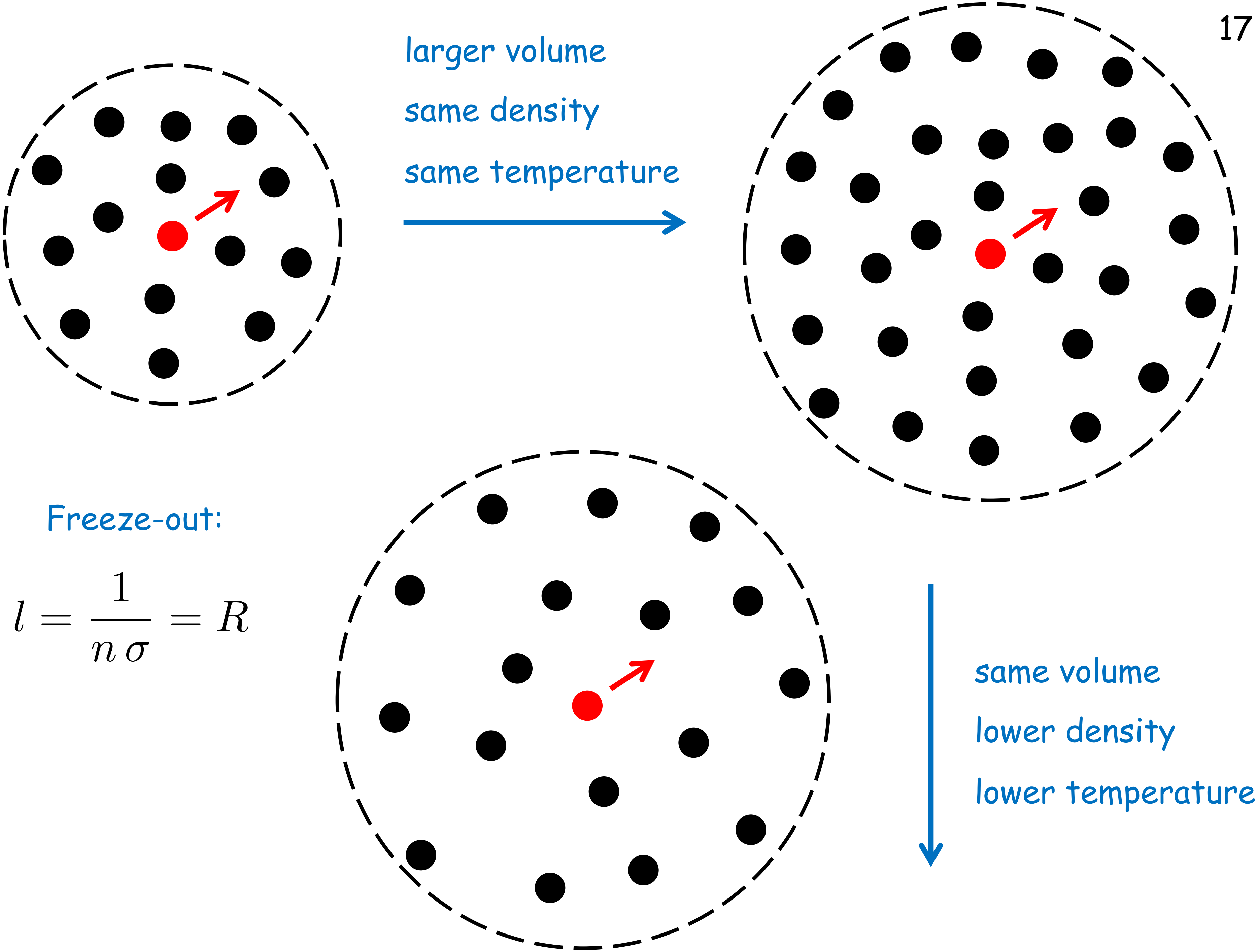


$$\eta$$

More mesons produced

Larger volume

Lives longer



Freeze-out:

$$l = \frac{1}{n\,\sigma} = R$$

Back to Giorgio

$$\Gamma(D^*) \simeq 1\,\mathrm{MeV} \quad \tau_{life} = \frac{1}{\Gamma(D^*)} \simeq 200\,\mathrm{fm}$$

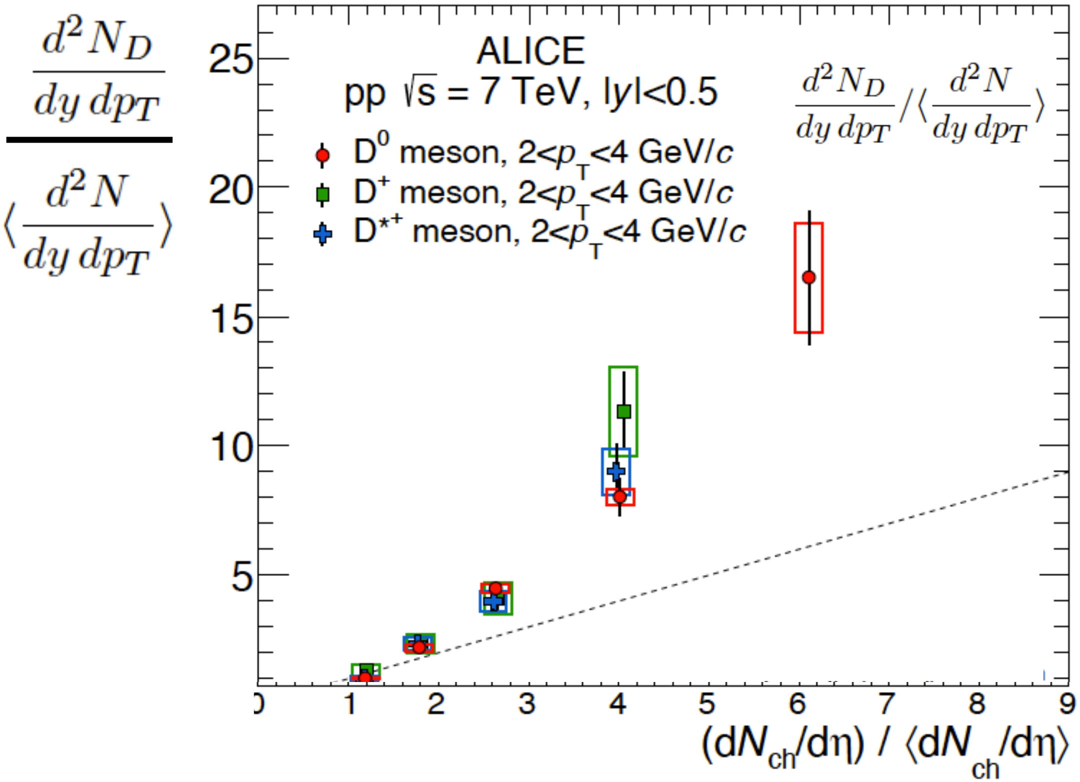
Rapidity and pt dependence of R

Freeze-out e tamanho

SU(4)

Gamma térmico = loops

System size and number of charm quarks



ALICE, JHEP (2015), arXiv:1505.00664

$$\frac{d^2N_D}{dy\,dp_T}/\langle\frac{d^2N}{dy\,dp_T}\rangle = \alpha' \left(\frac{dN_{ch}}{d\eta}/\langle\frac{dN_{ch}}{d\eta}\rangle\right)^{\beta}$$

$$\beta = 1.6$$

Assume that:

$$N_D \propto (\mathcal{N}^3)^{\beta}$$

$$N_c \propto (\mathcal{N}^3)^{\beta}$$

Fix the constant using EXHIC estimates:

$$N_c = 7.9 \times 10^{-5}\,\mathcal{N}^{4.8}$$

Lifetime as a function of the size