Working Group 3

Reunião de 22/02/24

Alberto Martinez (de manhã)

Fernando Navarra

Renato Higa

WG3 : aprender física de hadrons no LHC (QCD, QGP, CGC, espectros...)

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

O que aconteceu entre 06/23 e 02/24 ?

8 Artigos Publicados

inspirehep.net

$\chi_{c1}(4274)$ multiplicity in heavy-ion collisions #4
L.M. Abreu (Bahia U. and Sao Paulo U.), A.L.M. Britto (Bahia U.), F.S. Navarra (Sao Paulo U.), H.P.L. Vieira (Bahia U.) (Oct 5, 2023)
Published in: *Phys.Rev.D* 109 (2024) 1, 014041 • e-Print: 2310.03948 [hep-ph]
pdf DOI cite claim reference search 0 citations

Unveiling the properties of the dimuonium at the energies available at the Large Hadron Collider at CERN #5
C.A. Bertulani (Darmstadt, Tech. Hochsch.), D. Bhandari (Texas A-M, Commerce), F.S. Navarra (Sao Paulo U.) (Jul 23, 2023)
e-Print: 2307.12387 [hep-ph] EPJA(2024)
pdf cite claim reference search 0 citations

Charmonium production in high multiplicity pp collisions and the structure of the proton #6
R. Terra (Sao Paulo U.), F.S. Navarra (Sao Paulo U.) (Jun 25, 2023)
Published in: *Phys.Rev.D* 108 (2023) 5, 054002 • e-Print: 2306.14298 [hep-ph]
pdf DOI cite claim reference search 0 citations

Two- and three-photon fusion into charmonium in ultraperipheral nuclear collisions #7
R. Fariello (Unlisted, BR and Sao Paulo U.), D. Bhandari (Texas A-M, Commerce), C.A. Bertulani (Texas A-M, Commerce and Darmstadt, Tech. Hochsch.), F.S. Navarra (Texas A-M, Commerce and Sao Paulo U.) (Jun 18, 2023)
Published in: *Phys.Rev.C* 108 (2023) 4, 044901 • e-Print: 2306.10642 [hep-ph]
pdf DOI cite claim reference search 0 citations

Leading Λ production in future electron-proton colliders #8
F. Carvalho (Diadema, Sao Paulo Fed. U.), K.P. Khemchandani (Diadema, Sao Paulo Fed. U.), V.P. Gonçalves (Munster U., ITP), F.S. Navarra (Sao Paulo U.), D.S. Spiering (Sao Paulo U.) et al. (Jun 16, 2023)
Published in: *Phys.Rev.D* 108 (2023) 9, 094034 • e-Print: 2306.09813 [hep-ph]
pdf DOI cite claim reference search 0 citations

Interactions of the $\chi_{c1}(4274)$ state with light mesons #9
A.L.M. Britto (Bahia U.), L.M. Abreu (Bahia U.), F.S. Navarra (Bahia U.) (Jun 12, 2023)
Published in: *Phys.Rev.D* 108 (2023) 9, 096028 • e-Print: 2306.07446 [hep-ph]

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)
Published in: *Phys.Rev.D* 107 (2023) 11, 114013 • e-Print: 2303.05990 [hep-ph]
pdf DOI cite claim reference search 3 citatio

$\phi(2170)$ decaying to $\phi\eta$ and $\phi\eta'$ #3

Brenda B. Malabarba (Sao Paulo U.), K.P. Khemchandani (Sao Paulo U.), A. Martinez Torres (Sao Paulo U.) (May 5, 2023)

Published in: *Phys.Rev.D* 108 (2023) 3, 036010 • e-Print: 2305.03885 [hep-ph]

pdf DOI cite claim reference search 2 citations

3 Proceedings

ARTICLE IN PRESS

Nucl. Part. Phys. Proc. xxx (xxxx) xxx

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Contents lists available at ScienceDirect

Nuclear and Particle Physics Proceedings

journal homepage: www.elsevier.com/locate/nppp

Remarks on charmonium production in ultra-peripheral collisions

R. Fariello [a], F.S. Navarra [b,*], C.A. Bertulani [c], D. Bhandari [c]

[a] Departamento de Ciências da Computação, Universidade Estadual de Montes Claros, Avenida Rui Braga, sn, Vila Mauricéia, CEP 39401-089, Montes Claros, MG, Brazil
[b] Instituto de Física, Universidade de São Paulo, Rua do Matão 1371 - CEP 05508-090, Cidade Universitária, São Paulo, SP, Brazil
[c] Department of Physics and Astronomy, Texas A&M University-Commerce, Commerce, TX 75429, USA

Exotic properties of N^*(1895) and its impact on photoproduction of light hyperons #6

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

Studying the process $\gamma d \to \pi^0 \eta d$ #7

A. Martínez Torres (Sao Paulo, IFT and Valencia U., IFIC and Sao Paulo U. and Unlisted, BR), K.P. Khemchandani (Sao Paulo U. and Valencia U., IFIC and Unlisted, BR), E. Oset (Valencia U. and Unlisted, BR) (Sep, 2022)

Published in: *Acta Phys.Polon.A* 142 (2022) 3, 378-385, *Acta Phys.Polon.A* 142 (2022) 3, 378-385 • Contribution to: 4th Jagiellonian Symposium on Advances in Particle Physics and Medicine, 4th Jagiellonian Symposium on Advances in Particle Physics and Medicine, 378-385 • e-Print: 2211.14148 [nucl-th]

pdf DOI cite claim reference search 0 citations

3 Teses concluidas

Breno Garcia (mestrado - Renato Higa)

Richard Terra (mestrado – Fernando Navarra)

Brenda Malabarba (doutorado – Alberto Martinez)

4 Artigos Submetidos

The $X(3872)$ to $\psi(2S)$ yield ratio in heavy-ion collisions #1

L.M. Abreu, F.S. Navarra, H.P.L. Vieira (Jan 20, 2024)

e-Print: 2401.11320 [hep-ph]

pdf cite claim reference search 0 citations

Can femtoscopic correlation function shed light on the nature of the lightest, charm, axial mesons? #2

K.P. Khemchandani, Luciano M. Abreu, A. Martinez Torres, F.S. Navarra (Dec 18, 2023)

e-Print: 2312.11811 [hep-ph]

pdf cite claim reference search 0 citations

Interaction of exotic states in a hadronic medium: the $Z_c(3900)$ case #3

L.M. Abreu, R.O. Magalhães, F.S. Navarra, H.P.L. Vieira (Oct 28, 2023)

e-Print: 2310.18747 [hep-ph]

pdf cite claim reference search 1 citation

The Four-Boson First-Excited State Near Two-Body Unitarity #1

Feng Wu (Arizona U.), T. Frederico (Sao Paulo, Inst. Tech. Aeronautics), R. Higa (Sao Paulo U.), U. van Kolck (IJCLab, Orsay and Arizona U.) (Oct 25, 2023)

e-Print: 2310.17079 [physics.atom-ph]

pdf cite claim reference search 0 citations

9 Participações em Conferências

The present and future of flavour and exotic hadron spectroscopy
26/05 - 02/06 (2023) Munique, Alemanha (Alberto Martinez))

QCD 2023, 06/07 – 10/07 (2023) Montpellier, França (F. Navarra)

Extreme QCD 2023, 28/07 -30/07 (2023) Coimbra, Portugal (F. Navarra)

1st Inha – Pukyong Workshop on Hadron Physics and Chiral Dynamics, 11/08 -15/08 (2023)
Inha, Coréia (Alberto Martinez))

HADRONS 2023, (2023) Genova, Itália (Alberto Martinez)

Nagoya Workshop on Exotic Hadrons, 13/11 – 17/11 (2023) Nagoya, Japão (F. Navarra)

UPC 23 International Workshop on the Physics of Ultra-peripheral Collisons,
12/12 – 15/12 (2023), Playa del Carmen, México (F. Navarra)

XLV Symposium on Nuclear Physics, Cocoyoc, México,
08/01 - 11/01 (2024) Cocoyoc, México (Alberto Martinez))

1 Workshop on Baryon Dynamics from RHIC to EIC, 22/01 – 24/01 (2024)
Stony Brook, EUA (F. Navarra)

Organização de Eventos Científicos

POETIC 2023 IFT-UNESP (Fernando Navarra)

LIGHT CONE 2023 CBPF (Fernando Navarra)

RETINHA 31 CBPF (Fernando Navarra)

O que aconteceu de importante ?

Progresso na pesquisa da produção de exóticos em UPCs :

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

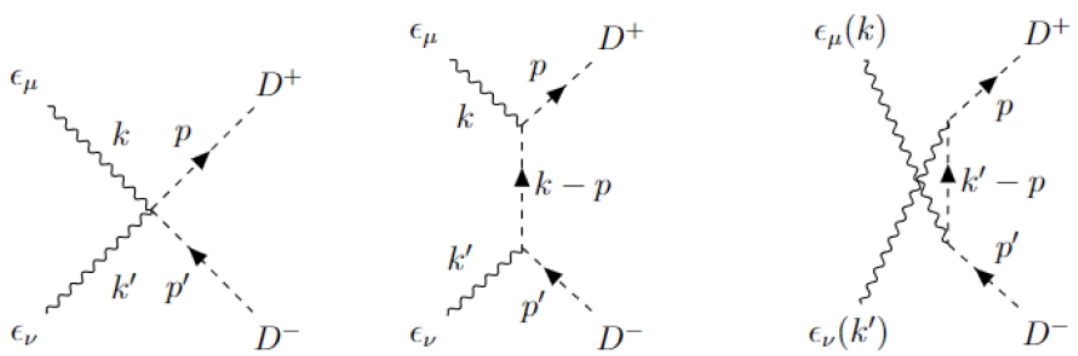
Reativação da colaboração com o Prof. Carlos Bertulani

Pós-doc Ricardo Fariello, mestrando Fernando César Sobrinho, Luciano Abreu

2 papers publicados, 1 Proceeding, um paper em fase de conclusão

Production of meson molecules in ultra-peripheral heavy ion collisons

F.C. Sobrinho[1], L.M. Abreu[1,2], C.A. Bertulani[3,4], F.S. Navarra[1]
[1]Instituto de Física, Universidade de São Paulo, Rua do Matão 1371 - CEP 05508-090, Cidade Universitária, São Paulo, SP, Brazil



Método geral para criar moléculas hadrônicas em colisões fóton-fóton

Nova posdoc: Celsina Azevedo !

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 visitou o IFUSP por 6 meses

The $X(3872)$ to $\psi(2S)$ yield ratio in heavy-ion collisions #1
L.M. Abreu, F.S. Navarra, H.P.L. Vieira (Jan 20, 2024)
e-Print: 2401.11320 [hep-ph]
pdf cite claim reference search 0 citations

Can femtoscopic correlation function shed light on the nature of the lightest, charm, axial mesons? #2
K.P. Khemchandani, Luciano M. Abreu, A. Martinez Torres, F.S. Navarra (Dec 18, 2023)
e-Print: 2312.11811 [hep-ph]
pdf cite claim reference search 0 citations

Interaction of exotic states in a hadronic medium: the $Z_c(3900)$ case #3
L.M. Abreu, R.O. Magalhães, F.S. Navarra, H.P.L. Vieira (Oct 28, 2023)
e-Print: 2310.18747 [hep-ph]
pdf cite claim reference search 1 citation

Teoria efetiva para as interações do Psi(2S)

Femtoscopia

The $X(3872)$ to $\psi(2S)$ yield ratio in heavy-ion collisions

L. M. Abreu[1,2,*] F. S. Navarra[2,†] and H. P. L. Vieira[1‡]
[1]Instituto de Física, Universidade Federal da Bahia,
Campus Universitário de Ondina, 40170-115, Bahia, Brazil and
[2]Instituto de Física, Universidade de São Paulo,
Rua do Matão, 1371, CEP 05508-090, São Paulo, SP, Brazil
(Dated: January 23, 2024)

In this work we evaluate the $X(3872)$ to $\psi(2S)$ yield ratio ($N_X/N_{\psi(2S)}$) in Pb Pb collisions, taking into account the interactions of the $\psi(2S)$ and $X(3872)$ states with light mesons in the hadron gas formed at the late stages of these collisions. We employ an effective Lagrangian approach to estimate the thermally-averaged cross sections for the production and absorption of the $\psi(2S)$ and use them in the rate equation to determine the time evolution of $N_{\psi(2S)}$. The multiplicity of these states at the end of mixed phase is obtained from the coalescence model. The multiplicity of $X(3872)$, treated as a bound state of ($D\bar{D}^* + c.c.$) and also as a compact tetraquark, was already calculated in previous works. Knowing these yields, we derive predictions for the ratio ($N_X/N_{\psi(2S)}$) as a function of the centrality, of the center-of-mass energy and of the charged hadron multiplicity measured at midrapidity [$dN_{ch}/d\eta\,(\eta < 0.5)$]. Finally, we make predictions for this ratio in Pb Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV to be measured by the ALICE Collaboration in the Run 3.

$$\frac{N_X}{N_{\psi(2S)}} \simeq 5 \qquad \text{for molecules}$$

$$\frac{N_X}{N_{\psi(2S)}} \simeq 0.1 \qquad \text{for tetraquarks}$$

Previsão para pequeno p_T !

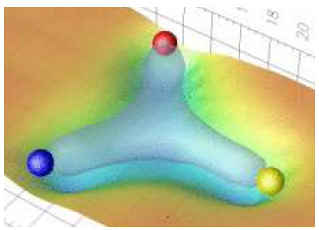
CMS: $R \sim 1$ para p_T grande !

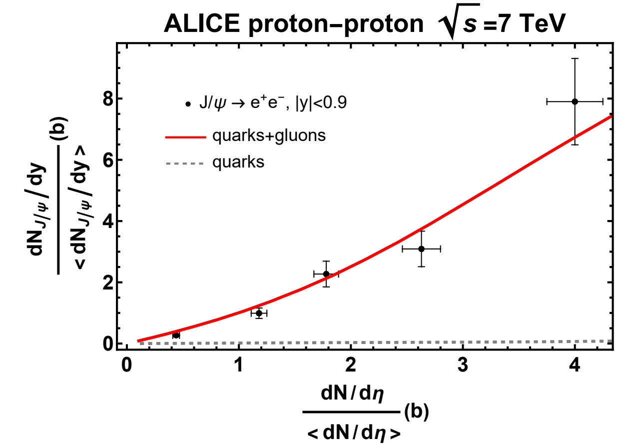
Produção de charmonium em colisões proton - proton

1 paper publicado sobre pp e um em conclusão sobre pPb

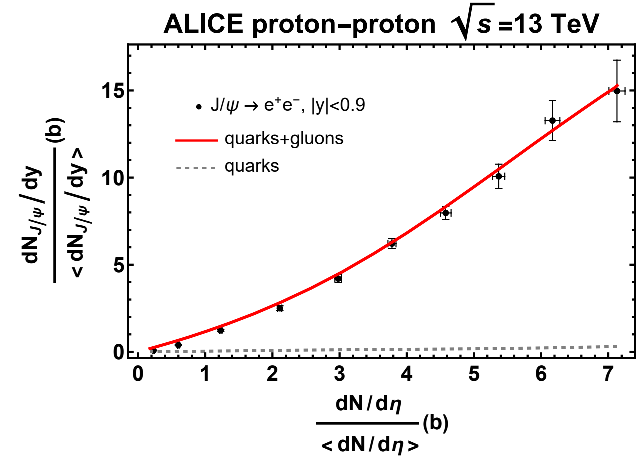
mestrado do Richard Terra

Estrutura do proton: core-corona





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

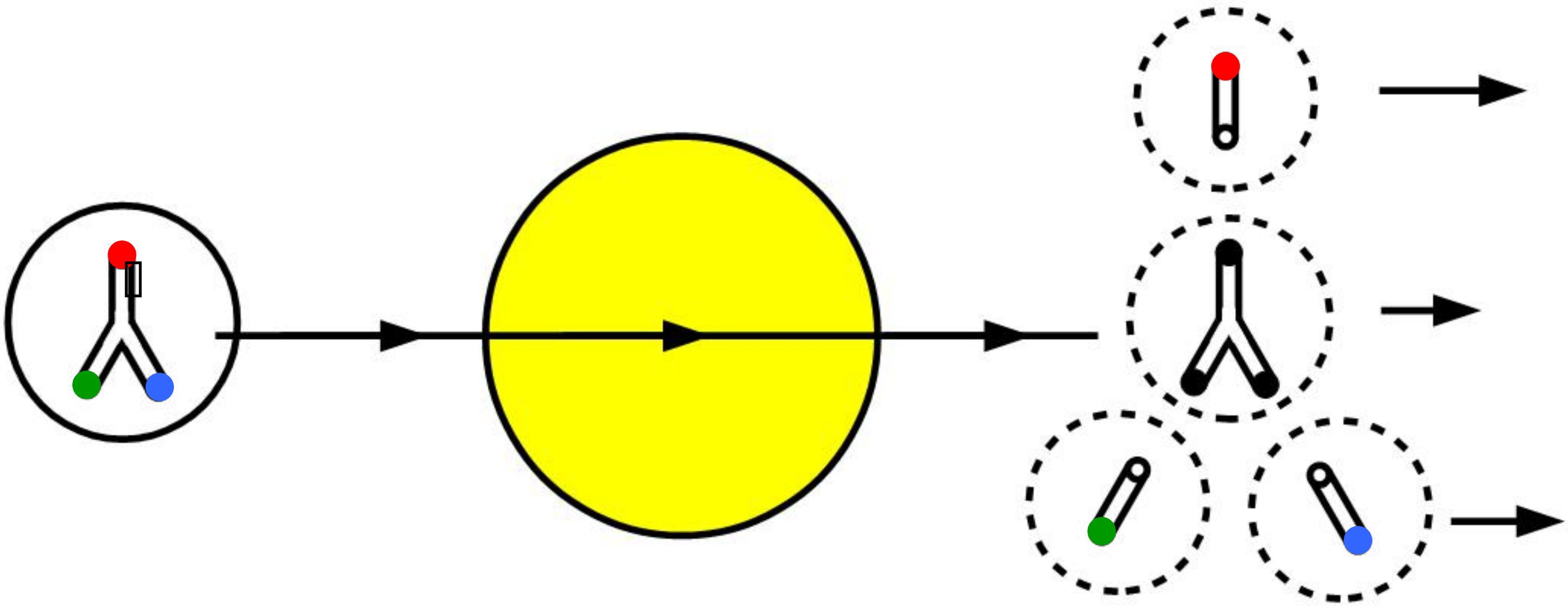


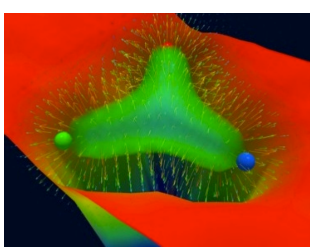
Busca experimental da junção bariônica !

1 Workshop on Baryon Dynamics from RHIC to EIC

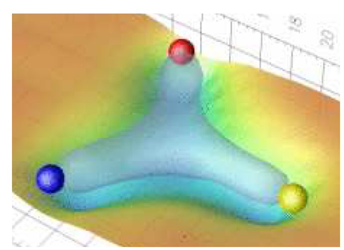
Baryon junction excitation

Kharzeev, PLB (1996)





Suganuma et. al
hep-lat/0006005
hep-lat/0204011

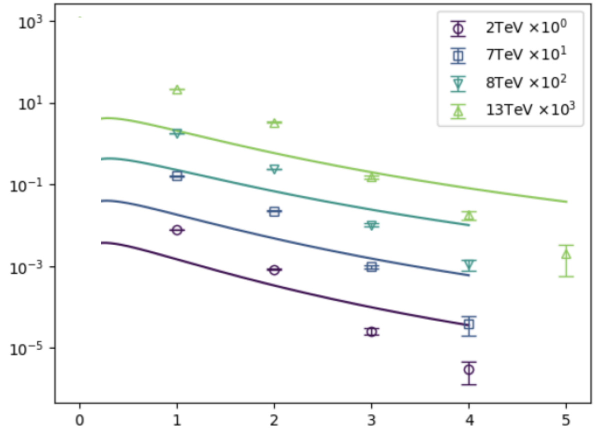


Leinweber et al.
hep-lat/0606016]

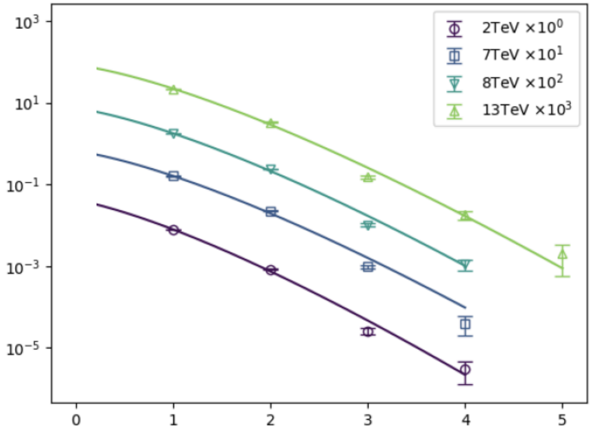
Distribuição de multiplicidade

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

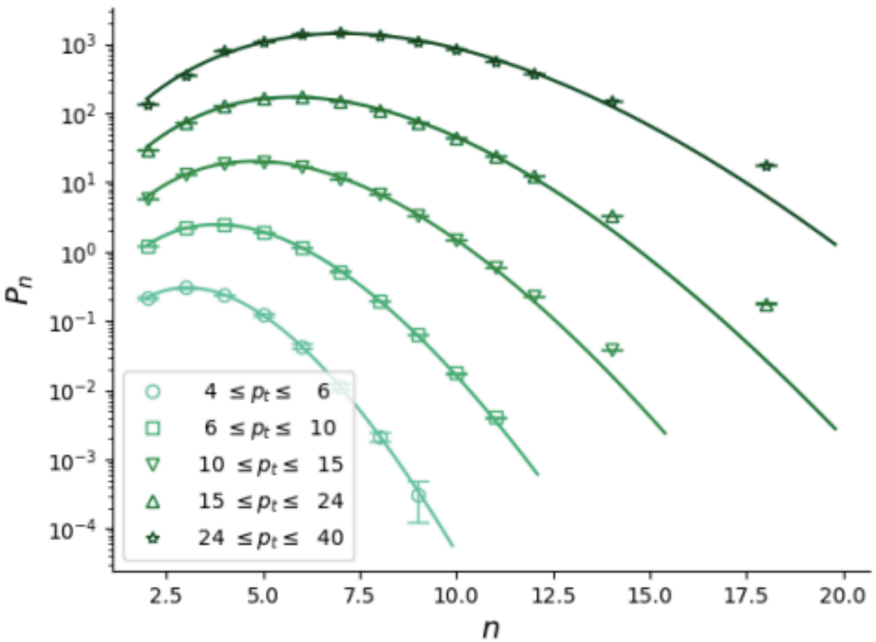
J. Arneiro, G. Germano, E. Marroquin, M. Munhoz, F.S. Navarra, A. Suaide
Instituto de Física, Universidade de São Paulo,
Rua do Matão 1371 - CEP 05508-090,
São Paulo, SP, Brazil

algum dia vai...

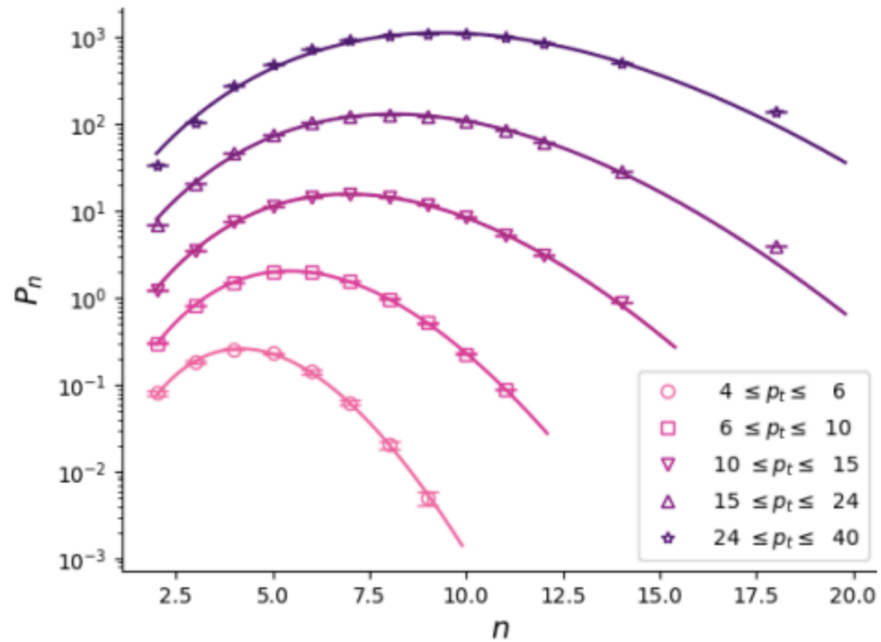
Distribuição de multiplicidade em jatos

Guilherme Germano

Sub Poisson funciona !



R = 0.4



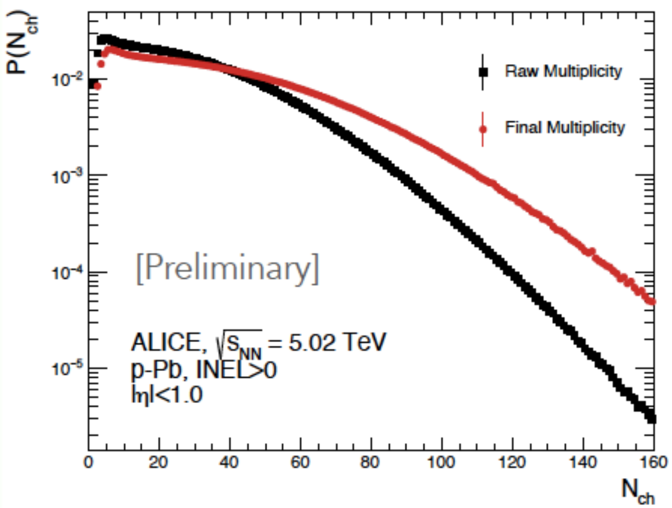
R = 0.6

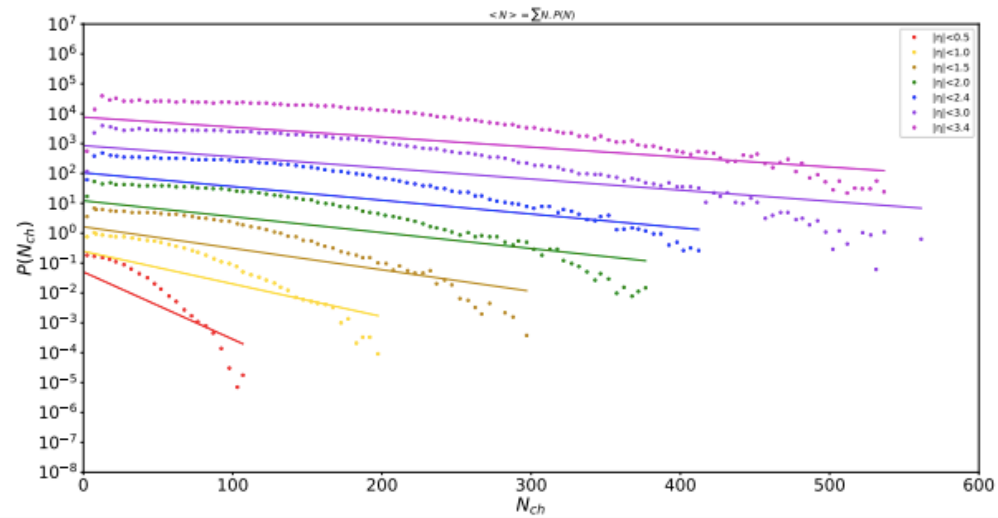
$$P(N) = c\frac{\alpha^N}{(N!)^{1+\delta}}$$

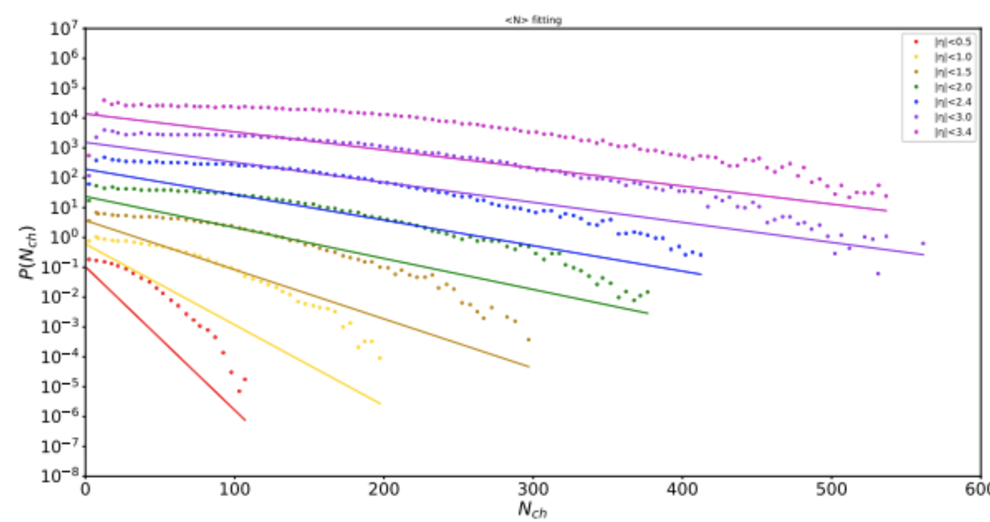
Distribuição de multiplicidade de mesons em colisões proton-chumbo

Mestrado da Eliana Marroquin

Mestrado do Henrique Martins Fontes







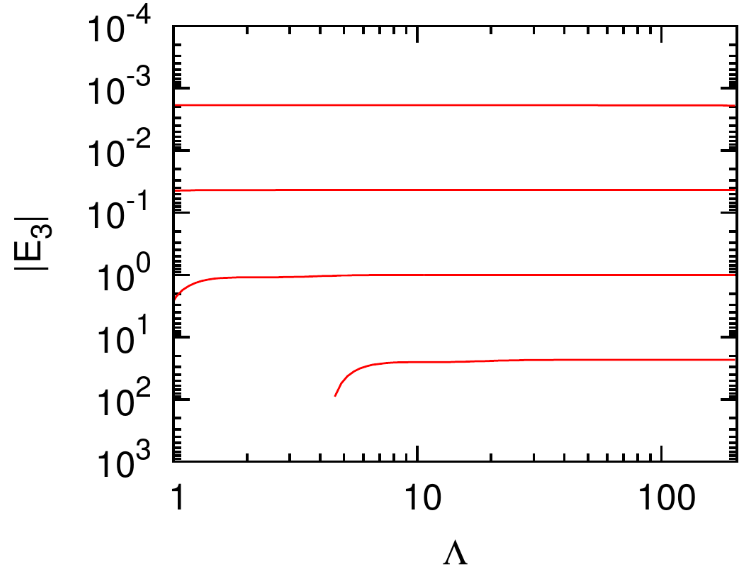
Ocorre termalização em p Pb ?

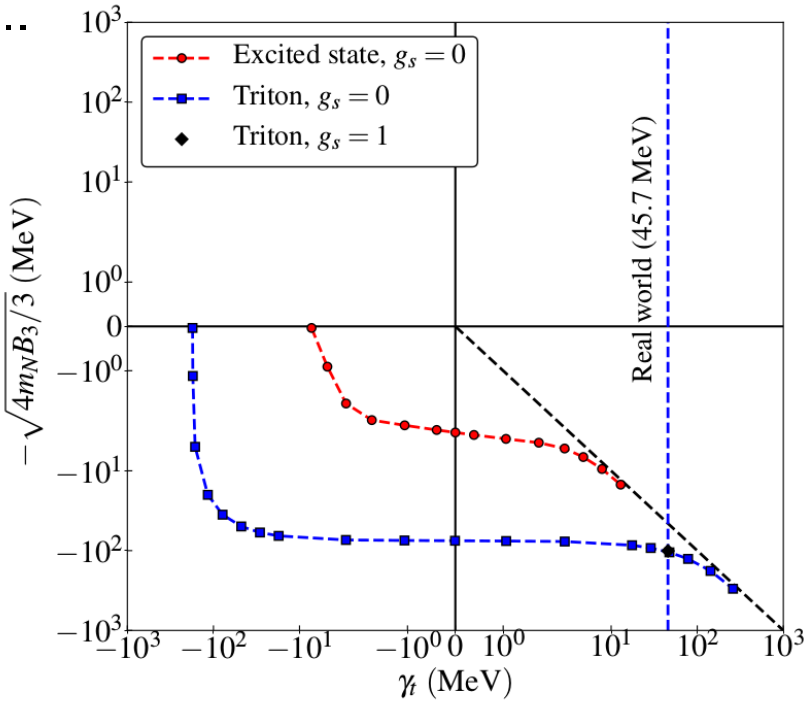
$$\frac{1}{\langle n\rangle+1}\left(1-\frac{1}{\langle n\rangle+1}\right)^{n} \equiv P_{F}(n,\langle n\rangle)$$

Renato Higa

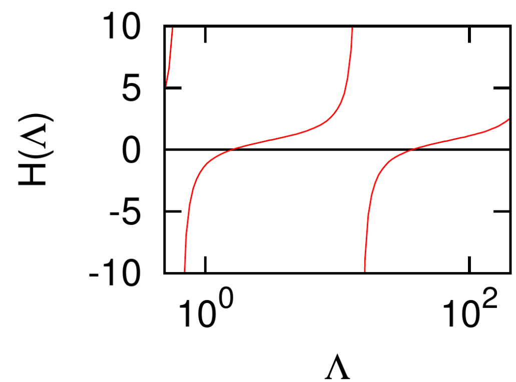
EFT and universality of SRI

- RG-flow towards a limit-cycle
- Efimov states: $E^{(n+1)}/E^{(n)}$ ~ 515
- V. Efimov, PLB33, 563 (1970)
- Ahrus group
- ITA-UNESP-UNICMP-UFF group
- Seattle group
- Purdue-Colorado group
- ...



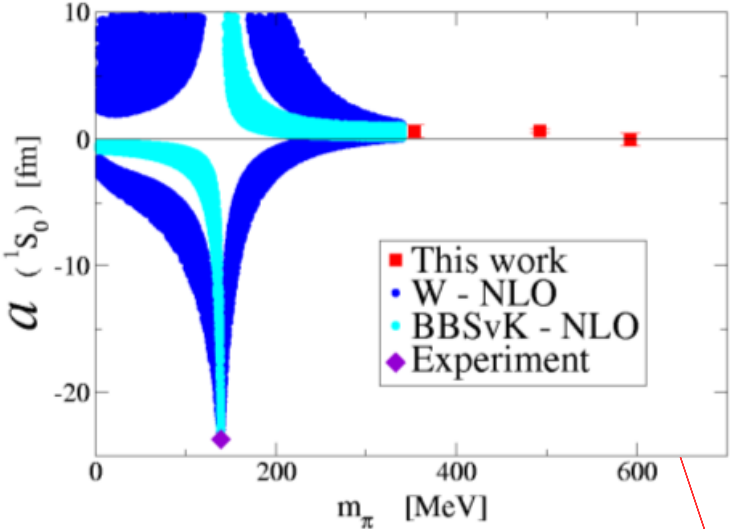


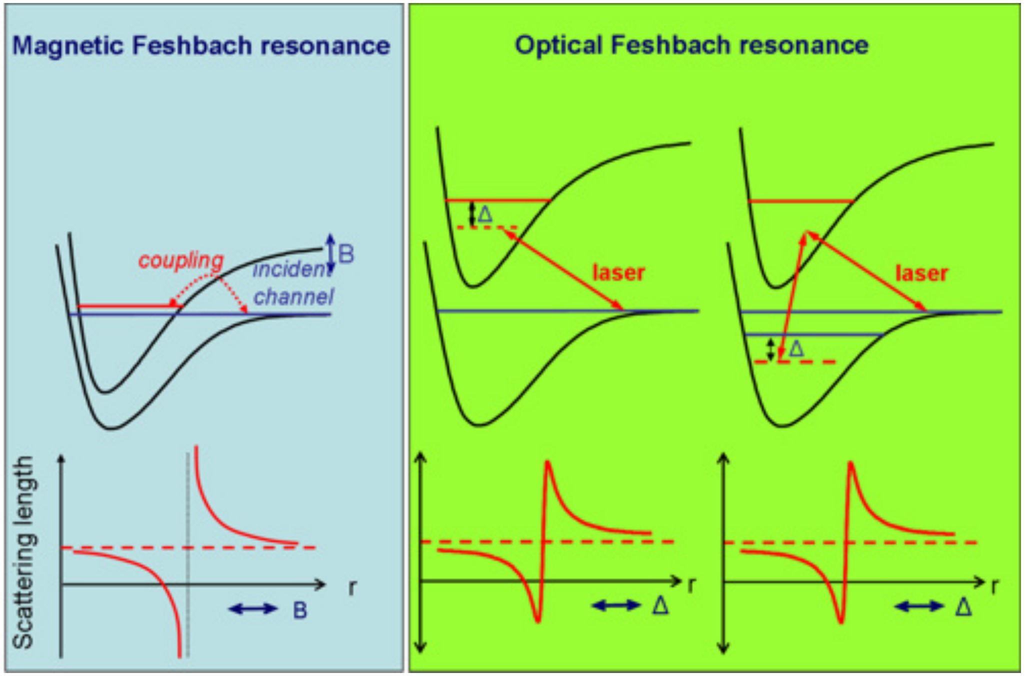
Hammer. RH

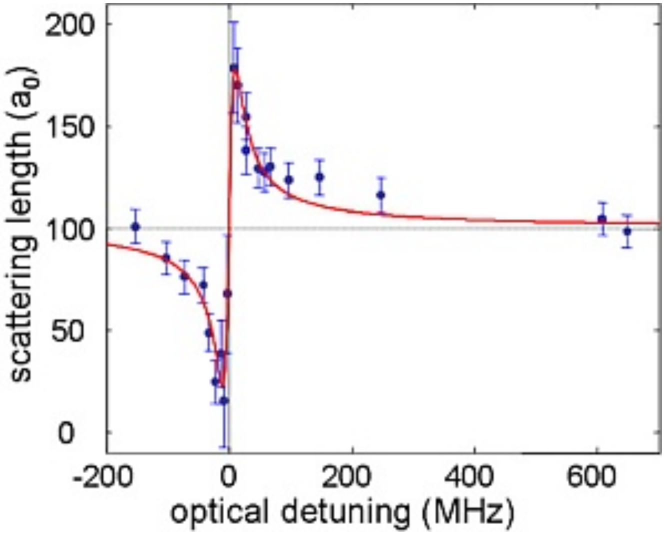


Rupak, Vaghani, RH, van Kolck (2019)

pion mass dependence of a_{NN}







NP around the unitary limit?

Konig et al. PRL 118, 202501 (2017

Strangeness sector: Λnn

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Search for evidence of ${}^3_\Lambda n$ by observing $d+\pi^-$ and $t+\pi^-$ final states in the reaction of ^{6}Li+^{12}C at $2A$ GeV

C. Rappold *et al.* (HypHI Collaboration)

Phys. Rev. C **88**, 041001(R) – Published 10 October 2013

Article | References | Citing Articles (67) | PDF | HTML | Export Citation

ABSTRACT

The experimental data obtained from the reaction of ^{6}Li projectiles at $2A$ GeV on a fixed graphite target were analyzed to study the invariant mass distributions of $d+\pi^-$ and $t+\pi^-$. Indications of a signal in the $d+\pi^-$ and $t+\pi^-$ invariant mass distributions were observed with significances of 5.3 σ and 5.0 σ, respectively, when including the production target, and 3.7 σ and 5.2 σ, respectively, when excluding the target. The estimated mean values of the invariant mass for $d+\pi^-$ and $t+\pi^-$ signal were 2059.3 $\pm$ 1.3 $\pm$ 1.7 MeV/c^2 and 2993.7 $\pm$ 1.3 $\pm$ 0.6 MeV/c^2 respectively. The lifetime estimation of the possible bound states yielding to $d+\pi^-$ and $t+\pi^-$ final states were deduced to be as $181^{+30}_{-24} \pm 25$ ps and $190^{+47}_{-35} \pm 36$ ps, respectively. Those final states may be interpreted as the two-body and three-body decay modes of a neutral bound state of two neutrons and a Λ hyperon, ${}^3_\Lambda n$.

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Letter

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Spectroscopic study of a possible Λnn resonance and a pair of ΣNN states using the $(e, e'K^+)$ reaction with a tritium target

B. Pandey *et al.* (Hall A Collaboration)

Phys. Rev. C **105**, L051001 – Published 20 May 2022

Article | References | No Citing Articles | PDF | HTML | Export Citation

ABSTRACT

A mass spectroscopy experiment with a pair of nearly identical high-resolution spectrometers and a tritium target was performed in Hall A at Jefferson Lab. Utilizing the $(e, e'K^+)$ reaction, enhancements, which may correspond to a possible Λnn resonance and a pair of ΣNN states, were observed with an energy resolution of about 1.21 MeV (σ), although greater statistics are needed to make definitive identifications. An experimentally measured Λnn state may provide a unique constraint in determining the Λn interaction, for which no scattering data exist. In addition, although bound $A=3$ and 4 Σ hypernuclei have been predicted, only an $A=4$ Σ hypernucleus (${}^4_\Sigma$He) was found, utilizing the (K^-, π^-) reaction on a ^{4}He target. The possible bound ΣNN state is likely a $\Sigma^0 nn$ state, although this has to be confirmed by future experiments.

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Perspective | Published: 14 September 2021

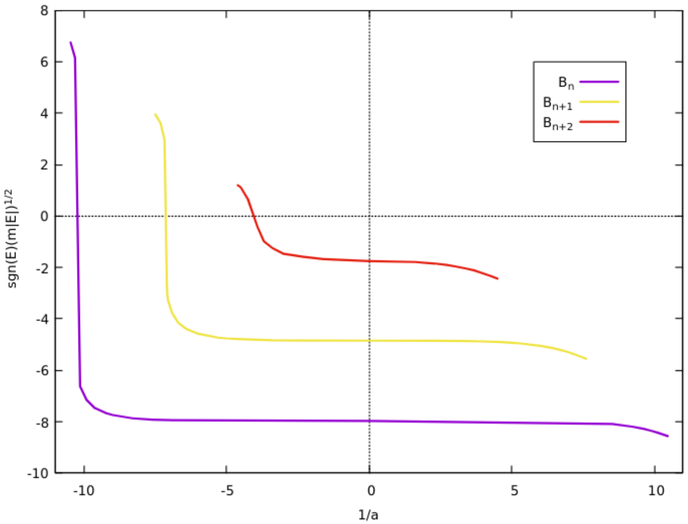
New directions in hypernuclear physics

Takehiko R. Saito, Wenbou Dou, Vasyl Drozd, Hiroyuki Ekawa, Samuel Escrig, Yan He, Nasser Kalantar-Nayestanaki, Ayumi Kasagi, Myroslav Kavatsyuk, Enqiang Liu, Yue Ma, Shizu Minami, Abdul Muneem, Manami Nakagawa, Kazuma Nakazawa, Christophe Rappold, Nami Saito, Christoph Scheidenberger, Masato Taki, Yoshiki K. Tanaka, Junya Yoshida, Masahiro Yoshimoto, He Wang & Xiaohon

Nature Reviews Physics 3, 803–813 (2021) | Cite this article

Breno A. Garcia MSc. project

Strangeness sector: Λnn



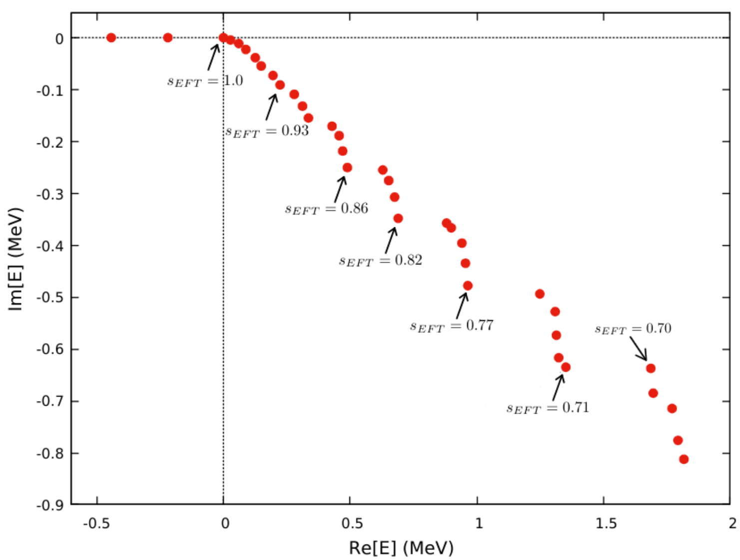


Figure 5.3: Pole trajectory as a function of the scattering length a_2.

Breno A. Garcia MSc. project, Sep2023

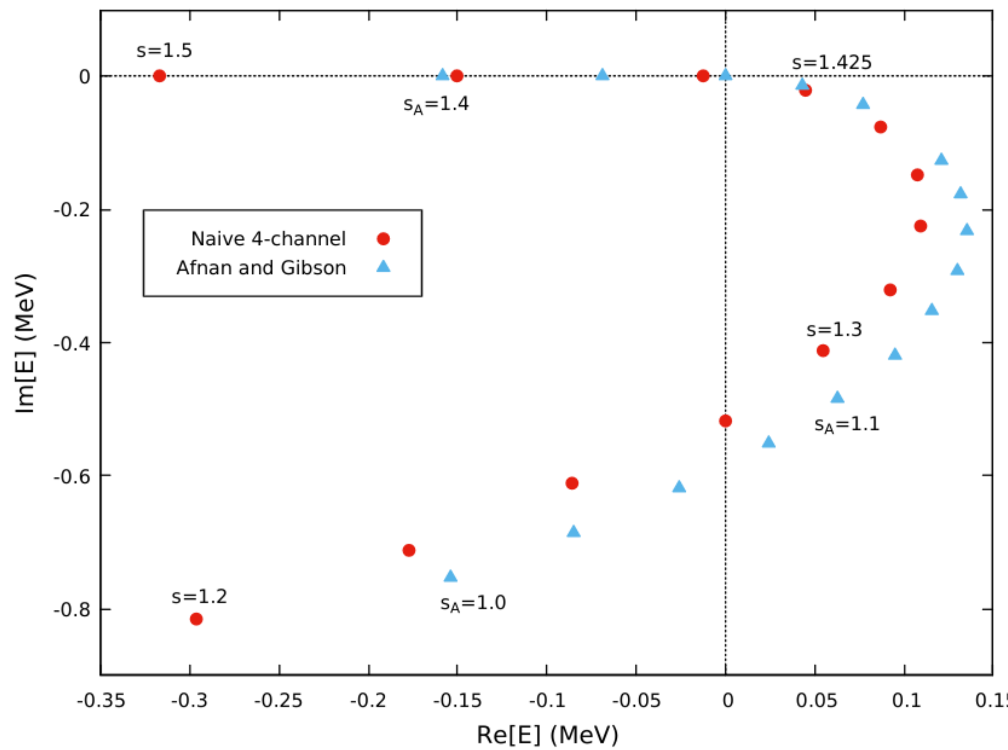
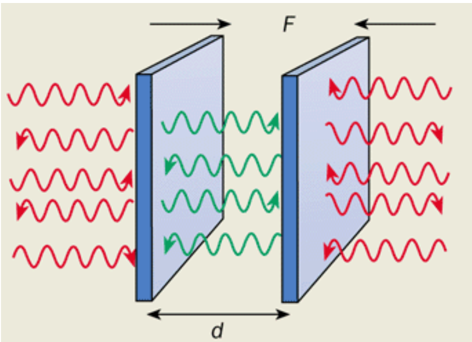
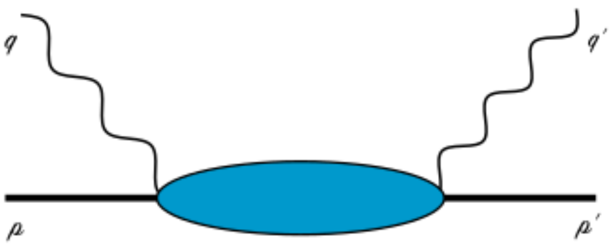


Figure 5.9: Combined plot of Figure 5.8 and reference [34].

Casimir-Polder forces btw two neutrons





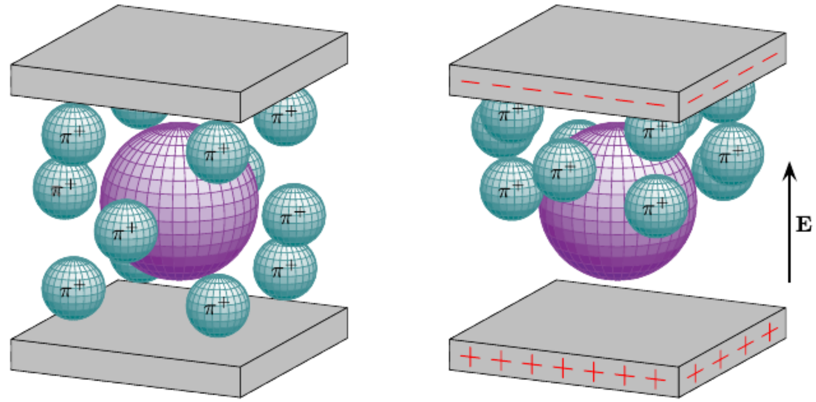


Fig. 2.1. Naive view of the proton, consisting of a pion cloud and a quark core, placed between the plates of a parallel plate capacitor. The left (right) figure shows the capacitor discharged (charged).
Source: Plot courtesy of Phil Martel.

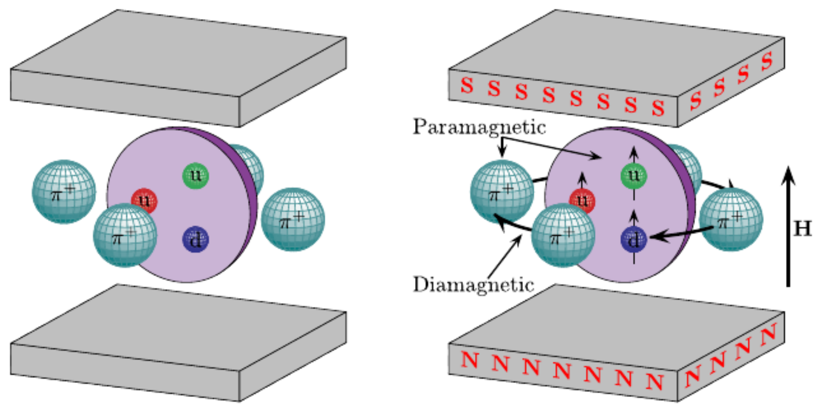
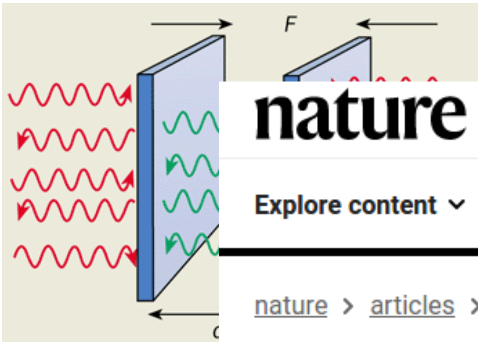


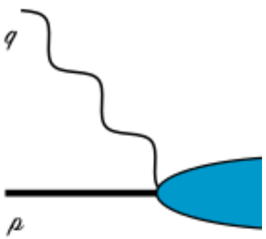
Fig. 2.2. Naive view of the proton, consisting of a pion cloud and a quark core, placed between the poles of a magnet. The left (right) figure shows the external magnetic field turned off (on).
Source: Plot courtesy of Phil Martel.

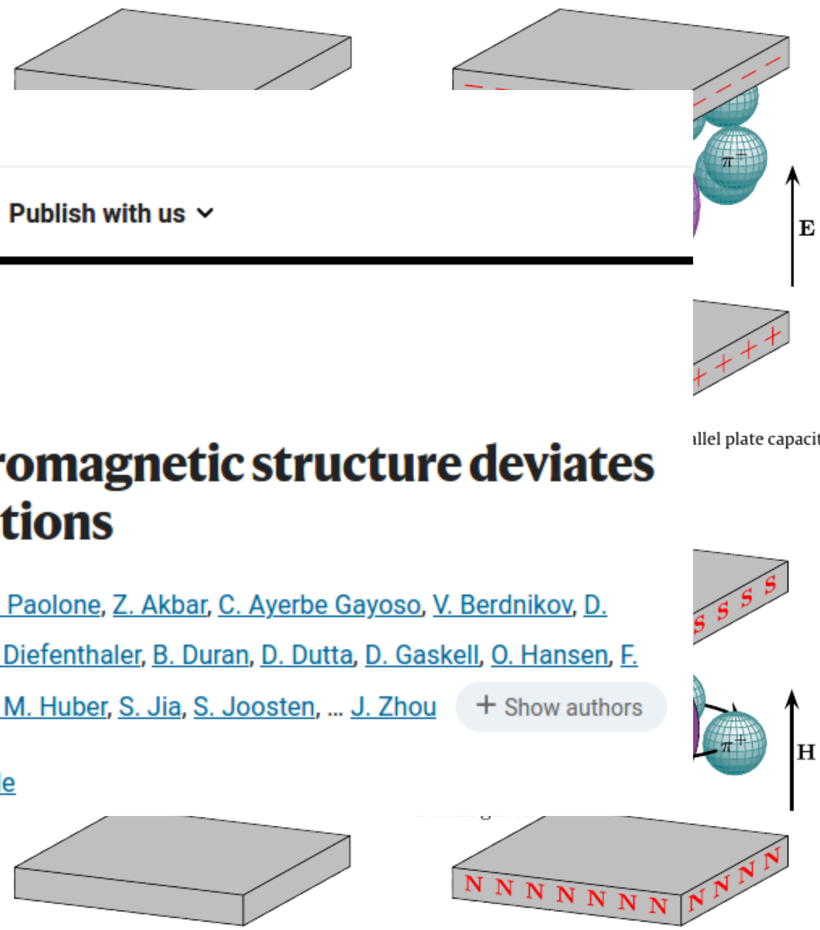
Hagelstein, et al., Prog.Part.Nucl.Phys. 88, 29 (2016)

Casimir-Polder forces btw two neutrons

F. Hagelstein et al. / Progress in Particle and Nuclear Physics 88 (2016) 29–97 33







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Article | Published: 19 October 2022

Measured proton electromagnetic structure deviates from theoretical predictions

R. Li, N. Sparveris, H. Atac, M. K. Jones, M. Paolone, Z. Akbar, C. Ayerbe Gayoso, V. Berdnikov, D. Biswas, M. Boer, A. Camsonne, J.-P. Chen, M. Diefenthaler, B. Duran, D. Dutta, D. Gaskell, O. Hansen, F. Hauenstein, N. Heinrich, W. Henry, T. Horn, G. M. Huber, S. Jia, S. Joosten, ... J. Zhou + Show authors

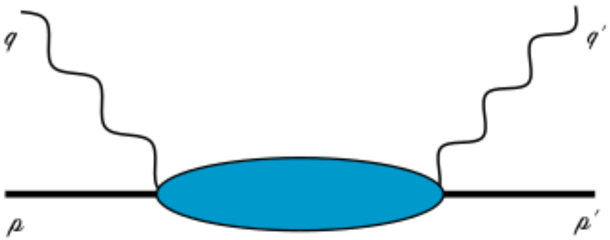
Nature **611**, 265–270 (2022) | Cite this article

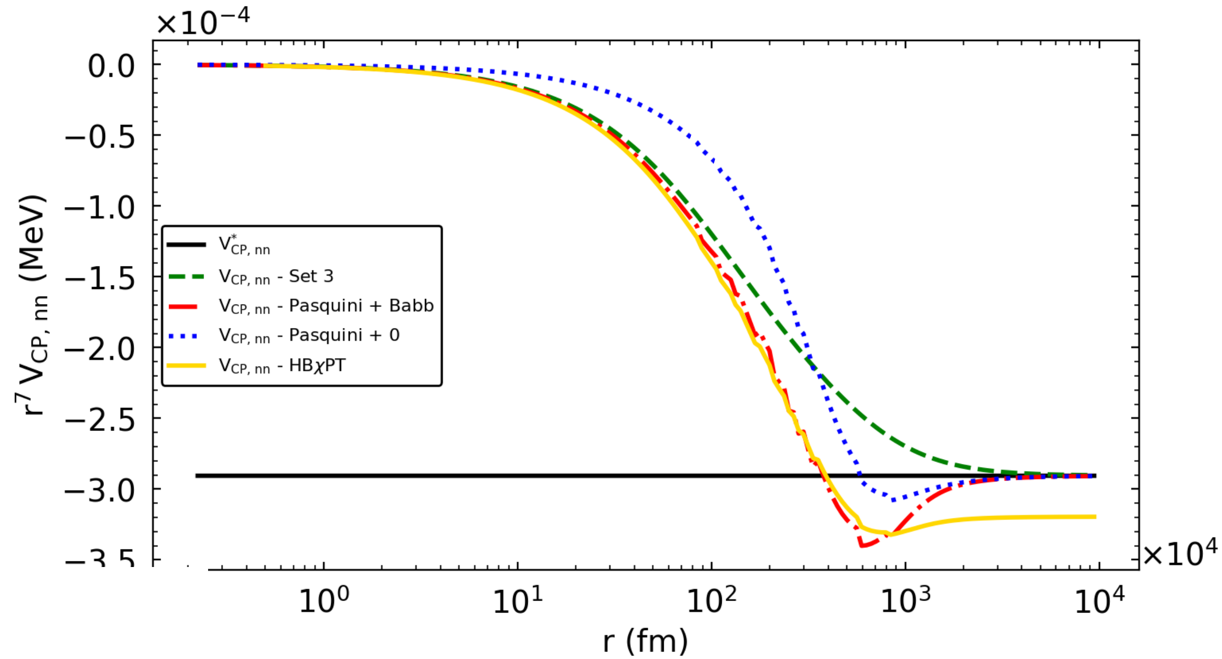
...llel plate capacitor. The left (right) figure

Fig. 2.2. Naive view of the proton, consisting of a pion cloud and a quark core, placed between the poles of a magnet. The left (right) figure shows the external magnetic field turned off (on).
Source: Plot courtesy of Phil Martel.

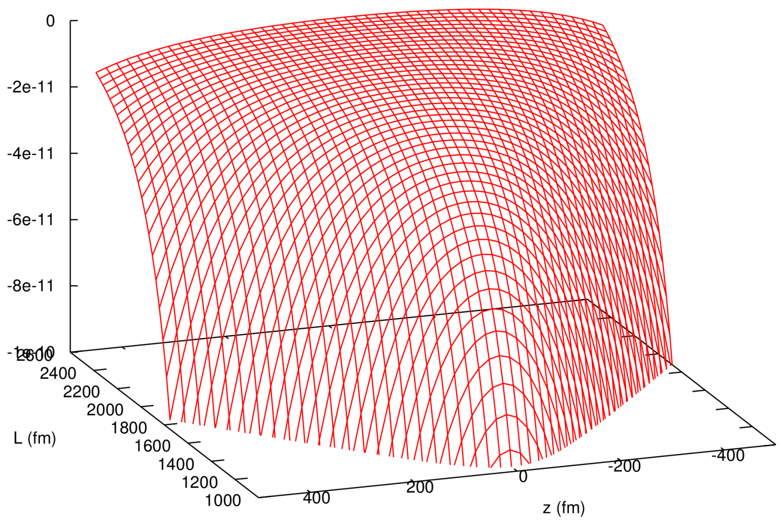
Hagelstein, et al., Prog.Part.Nucl.Phys. 88, 29 (2016)

Casimir-Polder forces btw two neutrons





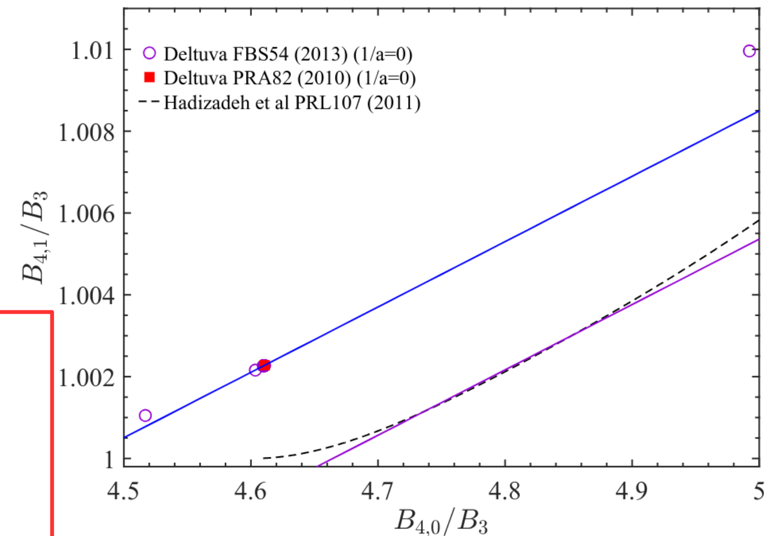
Relevance to UCN physics
M. S. Godoy's MSc. project

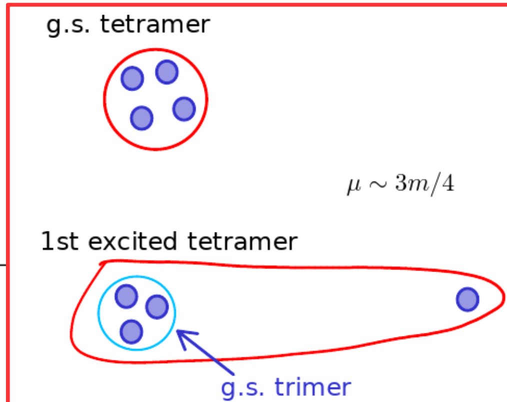


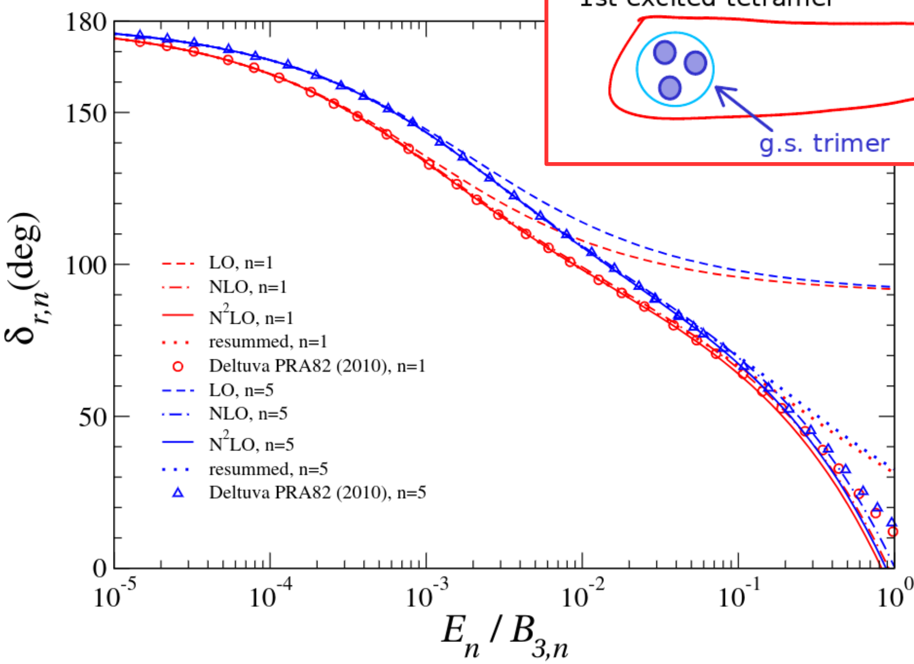
Babb, RH, Hussein, EPJA 53, 126 (2017)

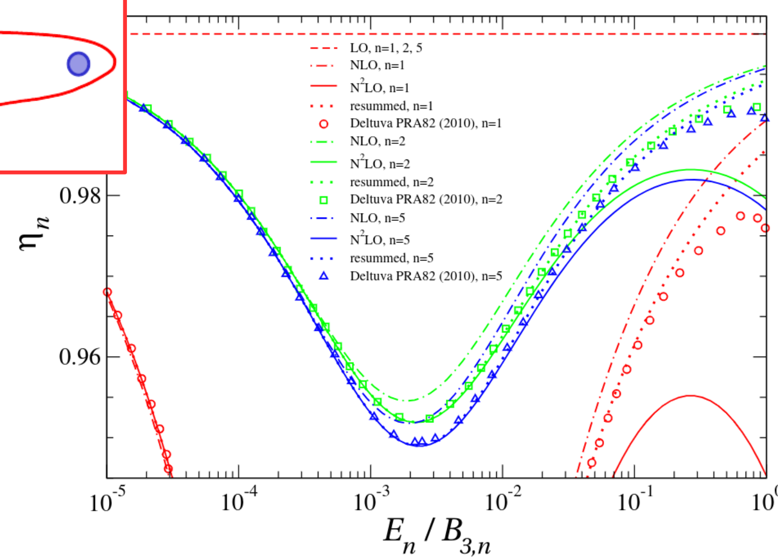
EFT and universality of SRI

- Importance of 4BF: NLO
- Excited 4Bsyst: halo structure
- Predictions for boson-trimer obs.
- F. Wu, T.Frederico, RH, U.van Kolck
- (PRA, accepted)





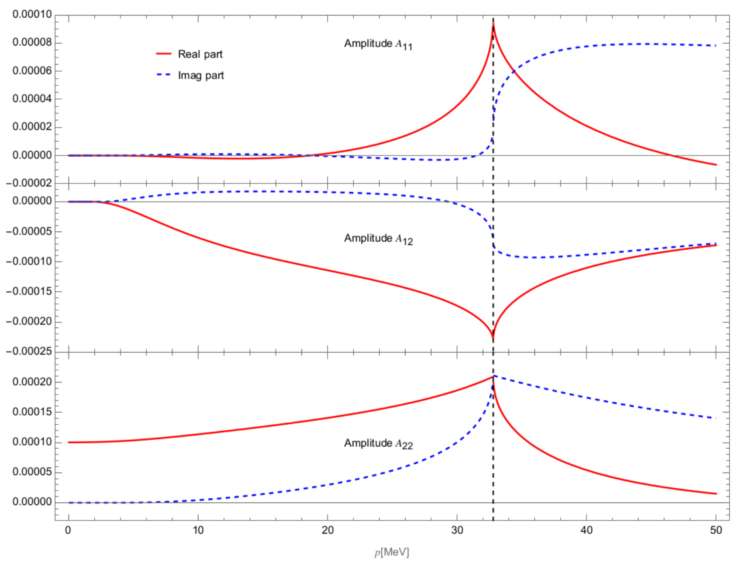


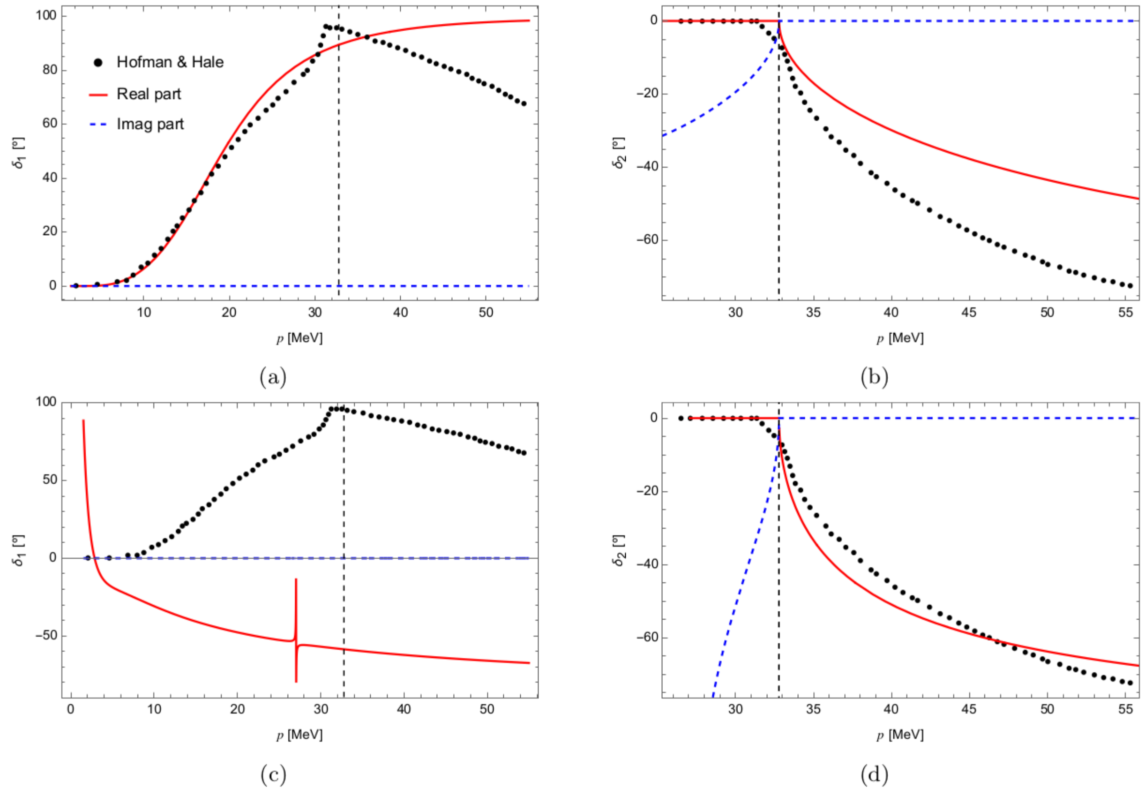


Excited ^{4}He state

Vinícius B. Ader MSc. project

- Between p-^{3}H and n-^{3}He thresholds
- ATOMKI anomaly: 5th force?
- coupled-channel problem
- [Matheus' IC project - X(3872)]





FIM

Wed 15/11

09:00	**Exotic charmonium production in ultra-peripheral heavy ion collisions**	*Fernando Silveira Navarra*
	KMI Science Symposia (ES635), E & S Building, Nagoya University	09:00 - 09:30

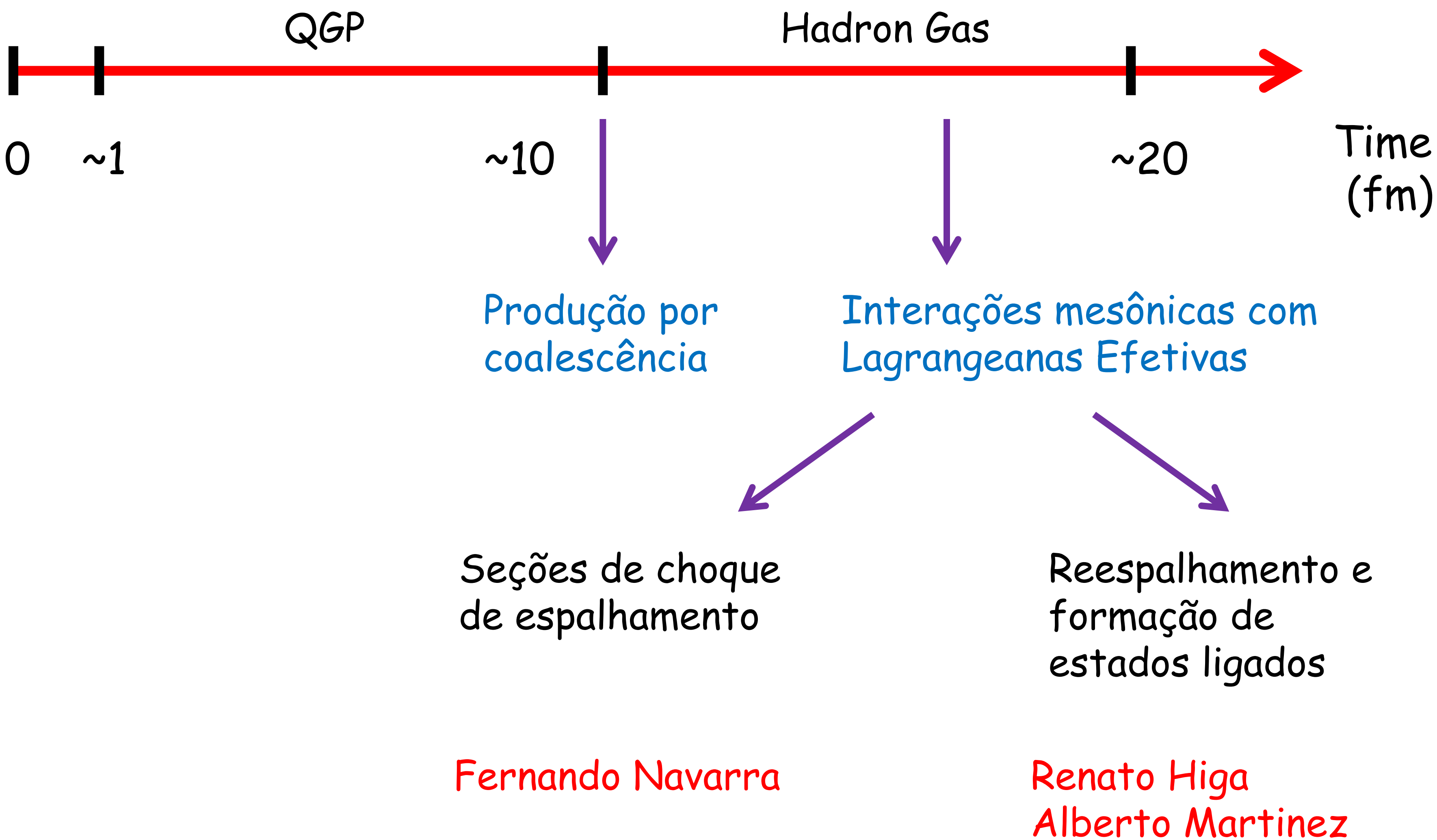
Fri 15/12

10:00	**Novel aspects of particle production in UPCs**	*Dr. Fernando Navarra*
	Playa del Carmen	10:00 - 10:30

Wed 24/01

	C120, CFNS	13:30 - 14:00
14:00	**Baryon structure and charmonium production in high multiplicity proton-proton collisions**	*Fernando Navarra*
	C120, CFNS	14:00 - 14:30

Linha do tempo de uma colisão de ions pesados

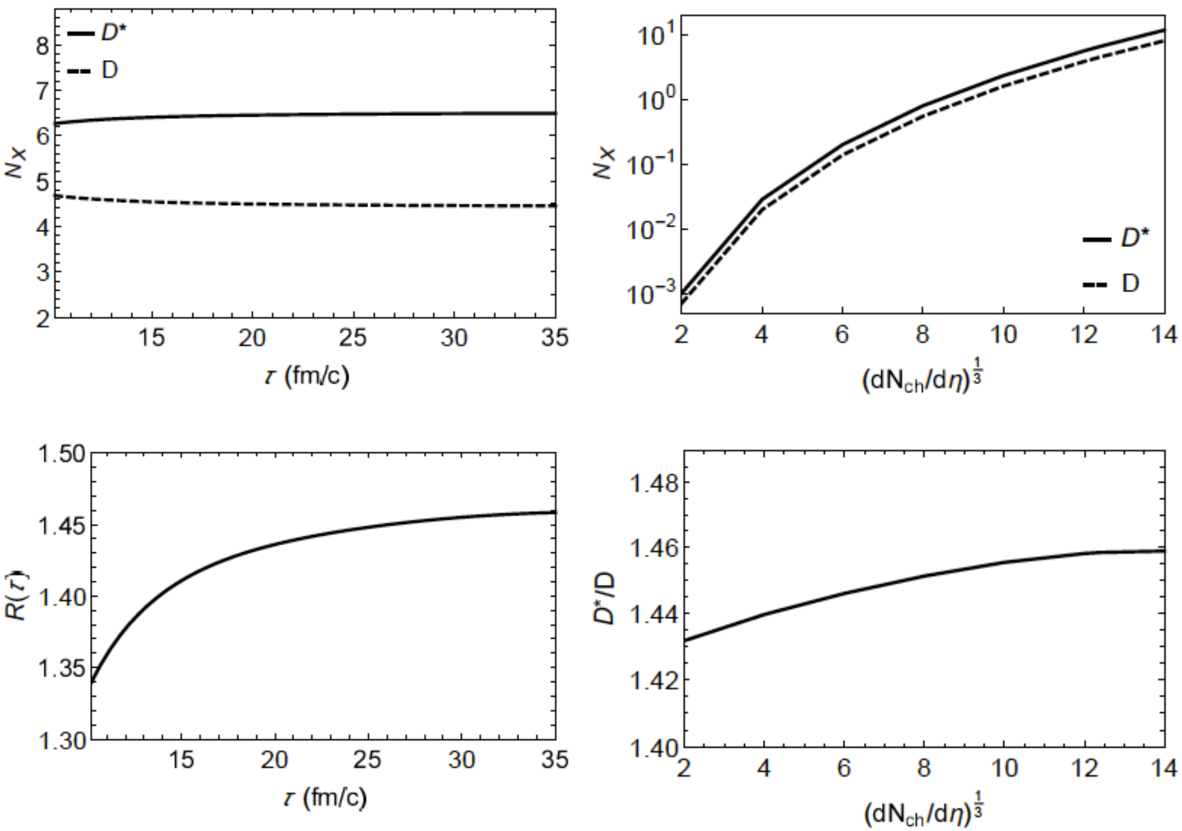


Fernando Navarra

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

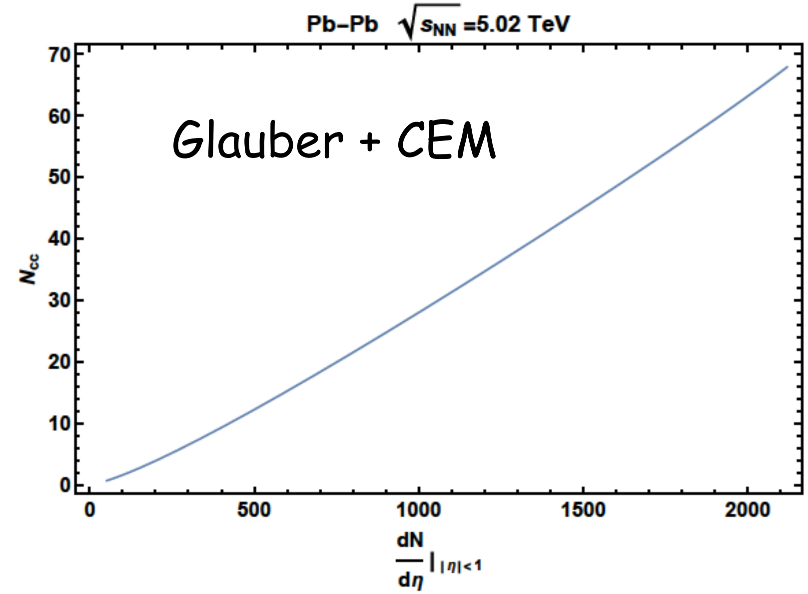
Abreu, FSN and Vieira,
Phys. Rev. D 106, 074028 (2022)

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



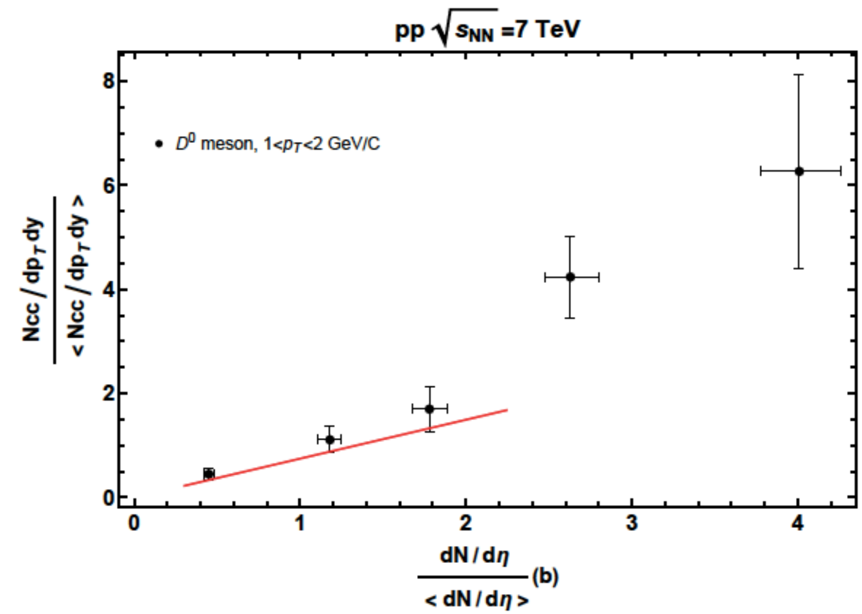
Produção de charme em proton - proton

Crescimento mais rápido do que o esperado

Color Glass Condensate?

Hidrodinâmica?

Multiple parton scattering?



Distribuição de multiplicidade de mesons com charme em proton-proton

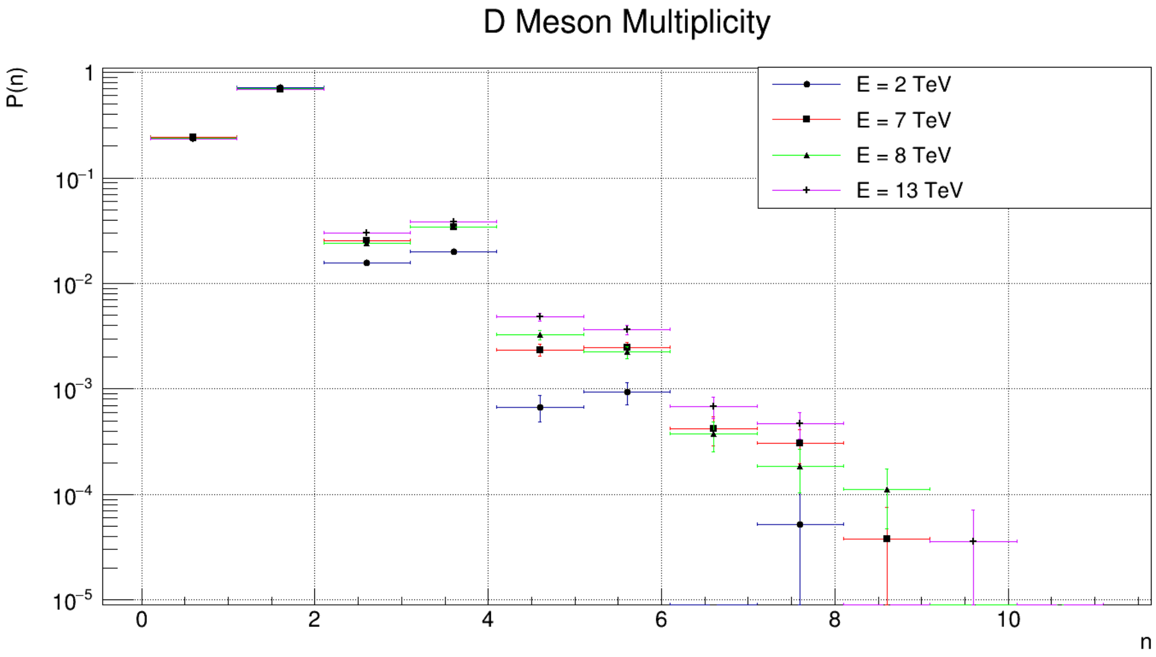
Trabalho de Jhoão Arneiro (doutorando do Suaide)

Simulação com PYTHIA

Comparação com NBD

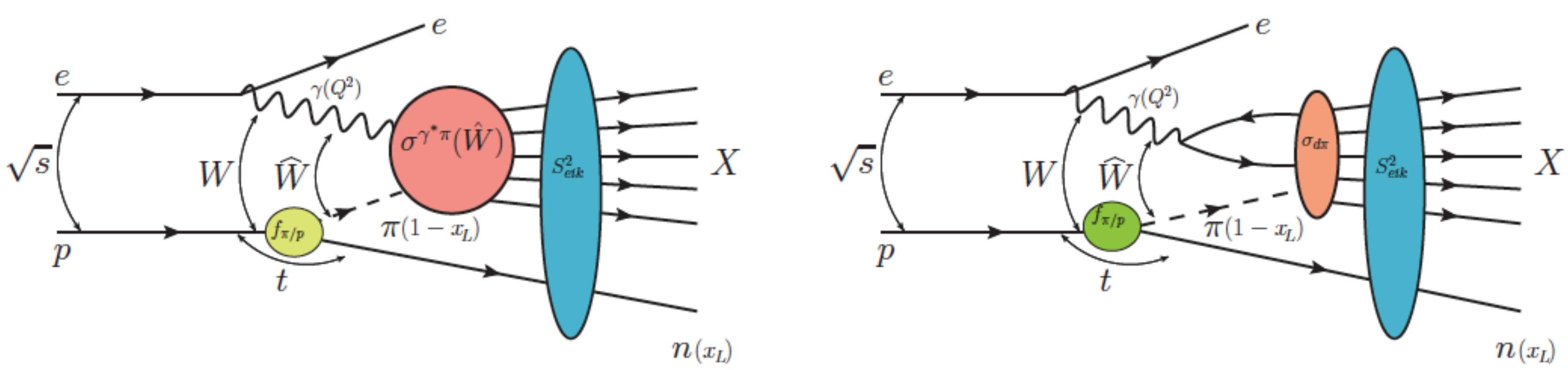
Altas densidades ?

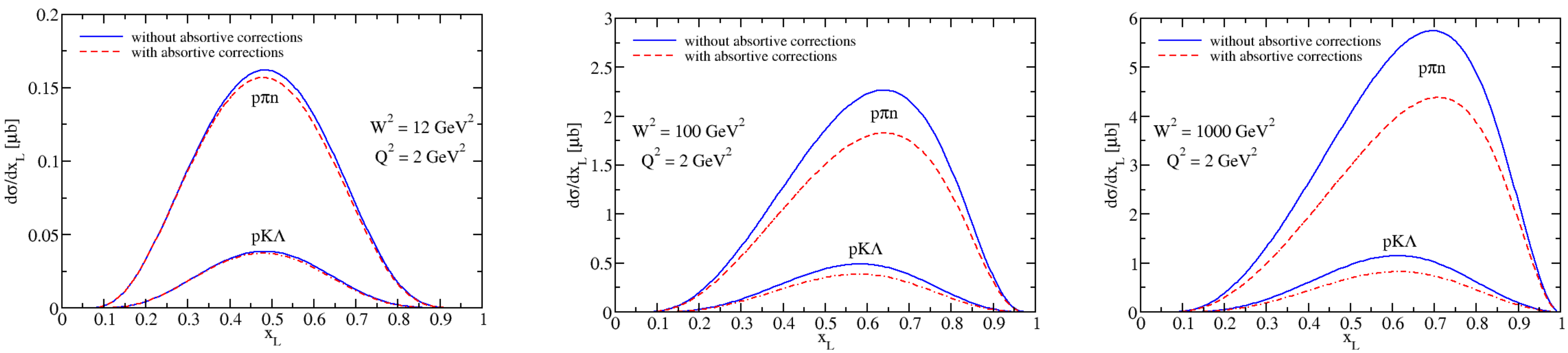
Multiple parton scattering ?



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

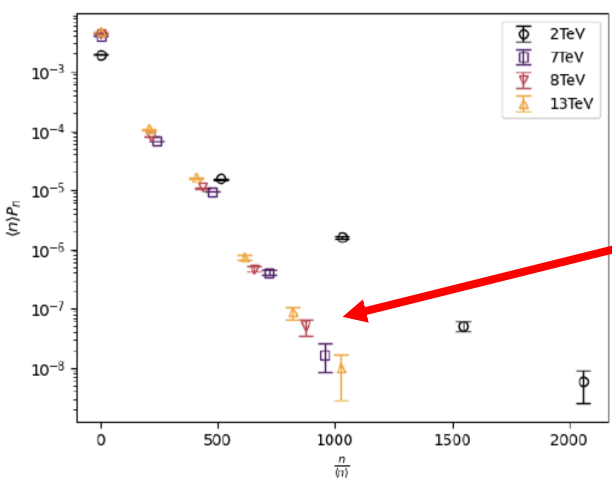
Victor Roberto Soares da Silva, iniciação científica

Novo projeto

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

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

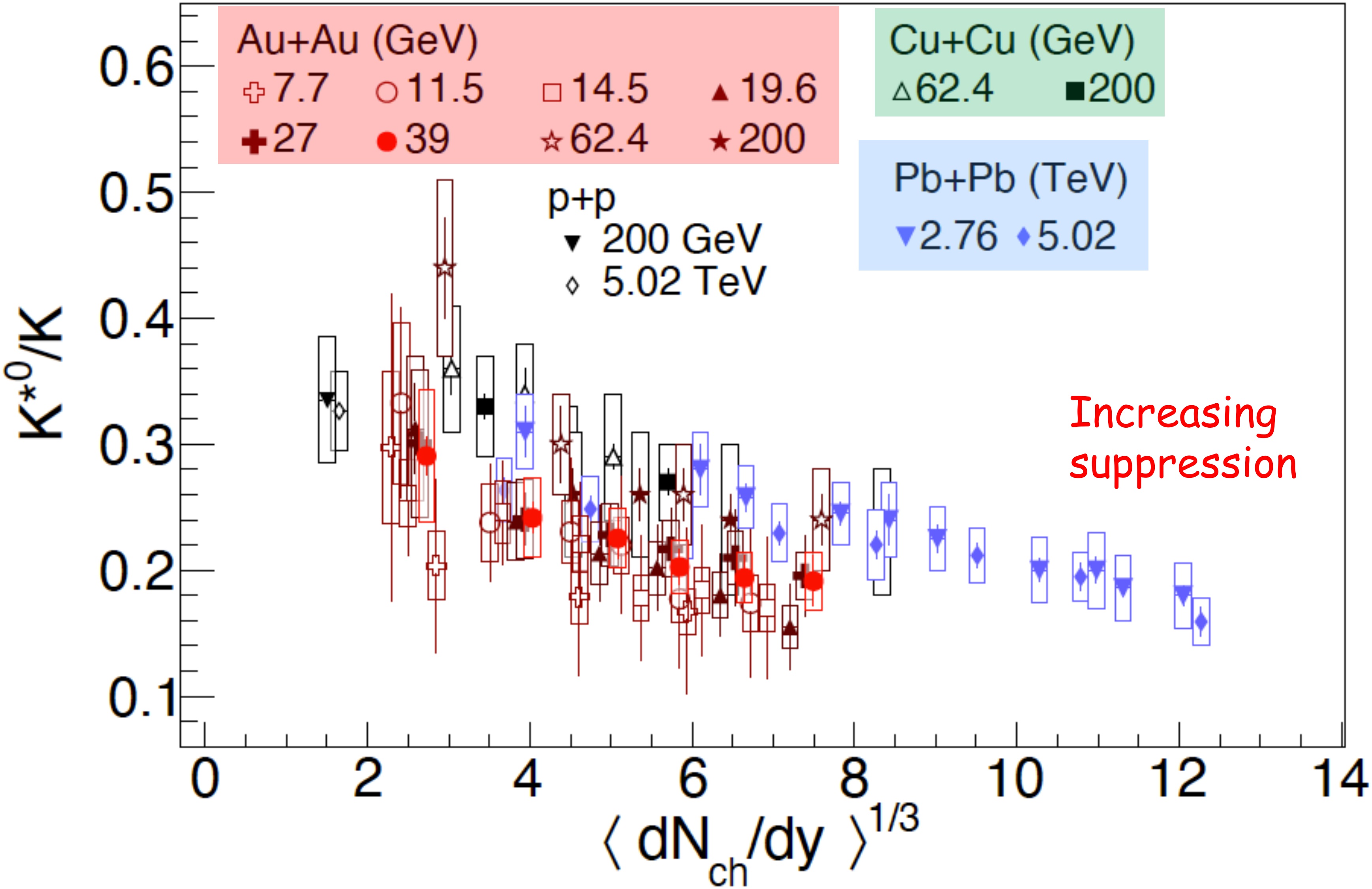
Estudo do decaimento de $\phi(2170)$ a $\phi\eta$ e $\phi\eta^\prime$. Recentemente, as colaborações Belle e BESIII tem medido o decaimento de $\phi(2170)$ a $\phi\eta$ e $\phi\eta^\prime$ como um jeito de obter informação da natureza do estado $\phi(2170)$. Os dados obtidos mostram que o estado $\phi(2170)$ 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 $\eta\eta^\prime$.



Scaling
de KNO

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

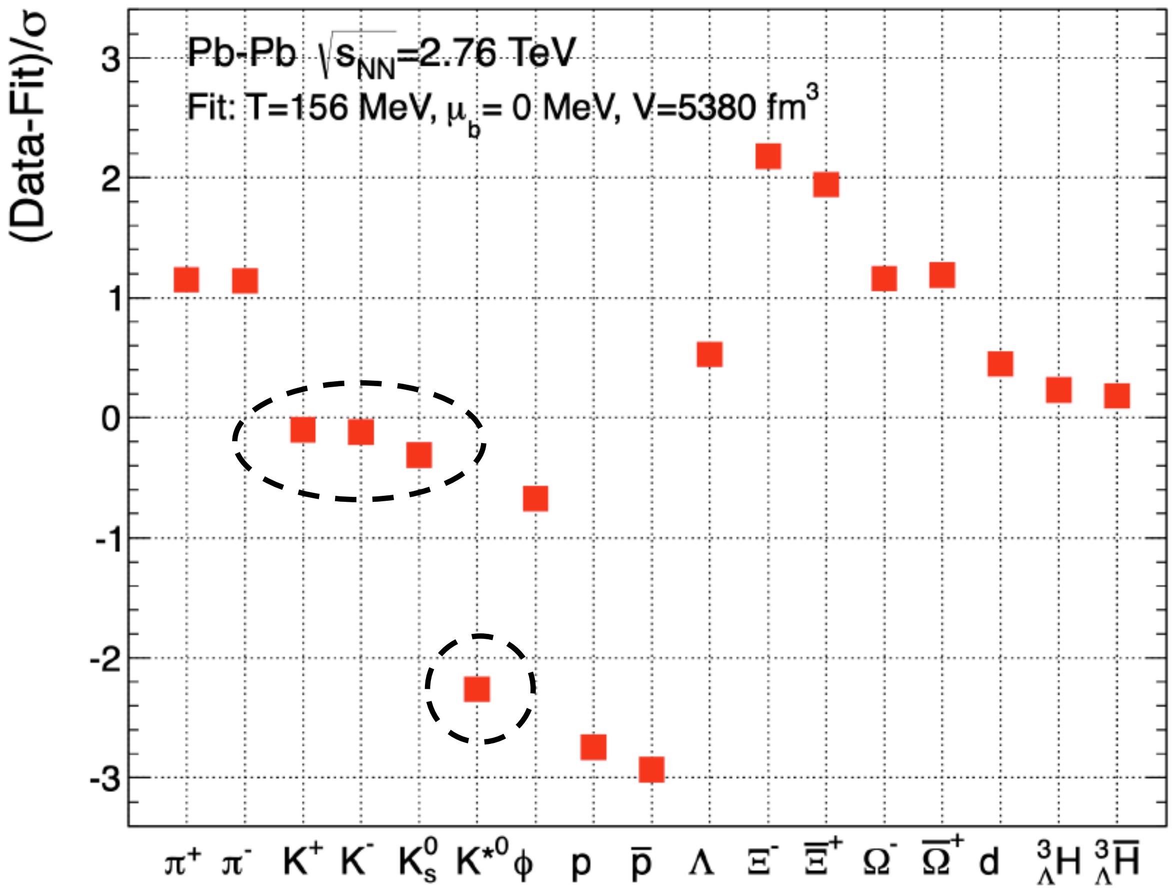
Emergence of chemical equilibrium (freeze-out)

Kinetic freeze-out: lifetime of the hadron gas phase

Confirm the existence of a hot hadron gas

Do we have a good theory ?

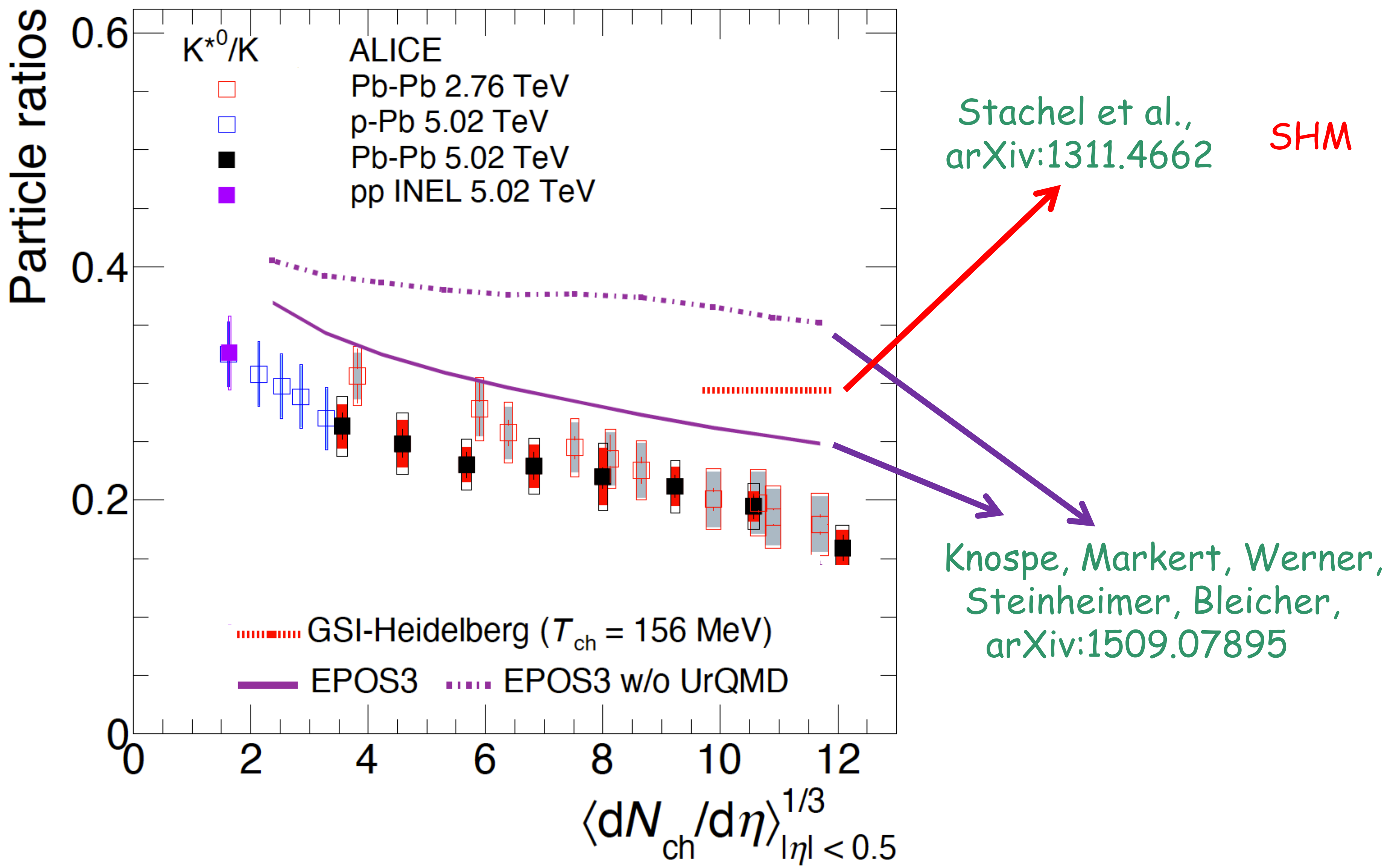
Statistical Hadronization Model fails...



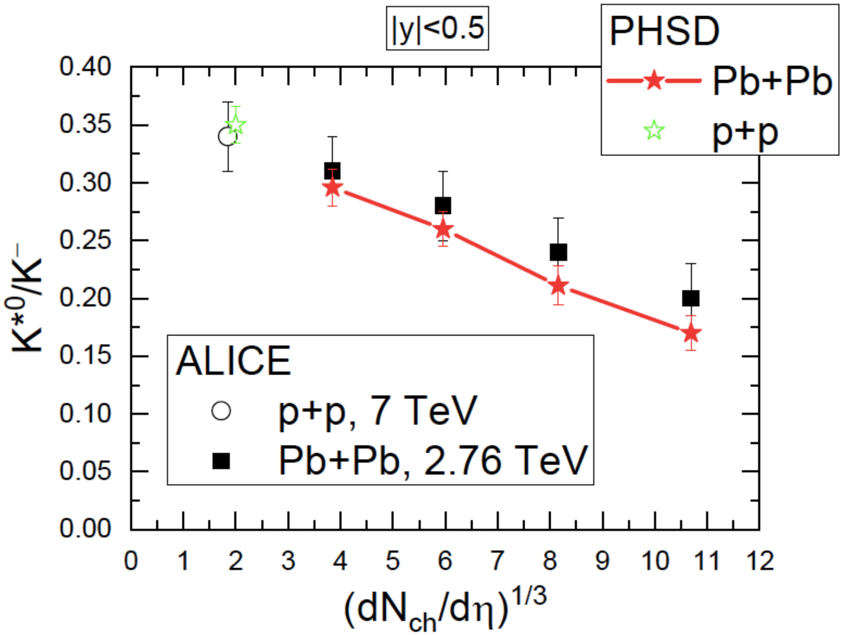
Stachel et al., arXiv:1311.4662

We must include rescattering and/or decay !

ALICE, arXiv:1910.14419

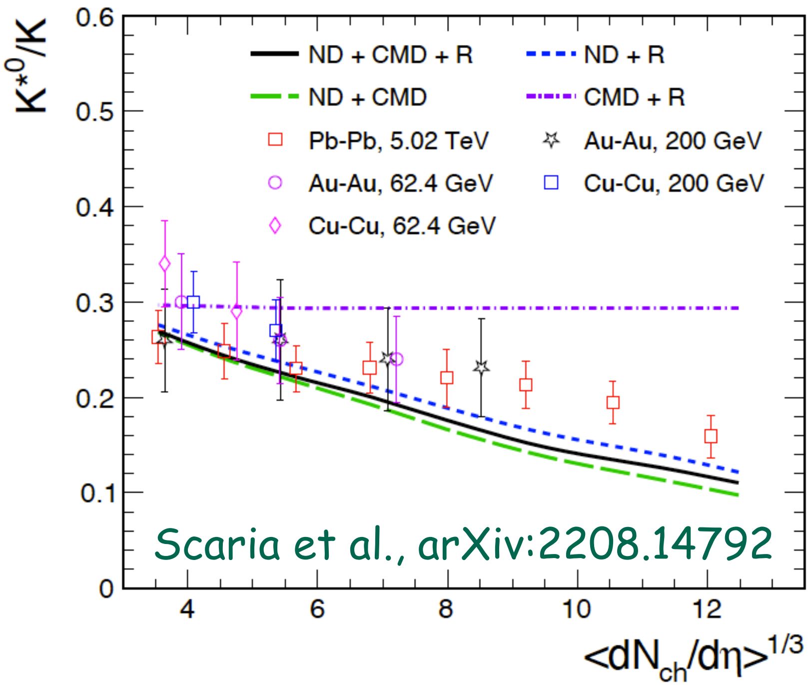


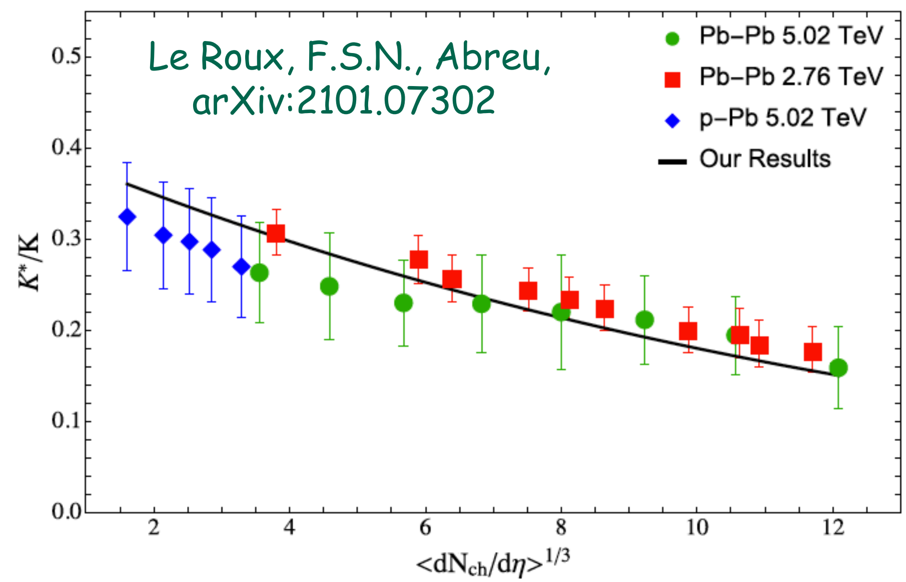
Interactions with the hadron gas improve agreement with data !



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

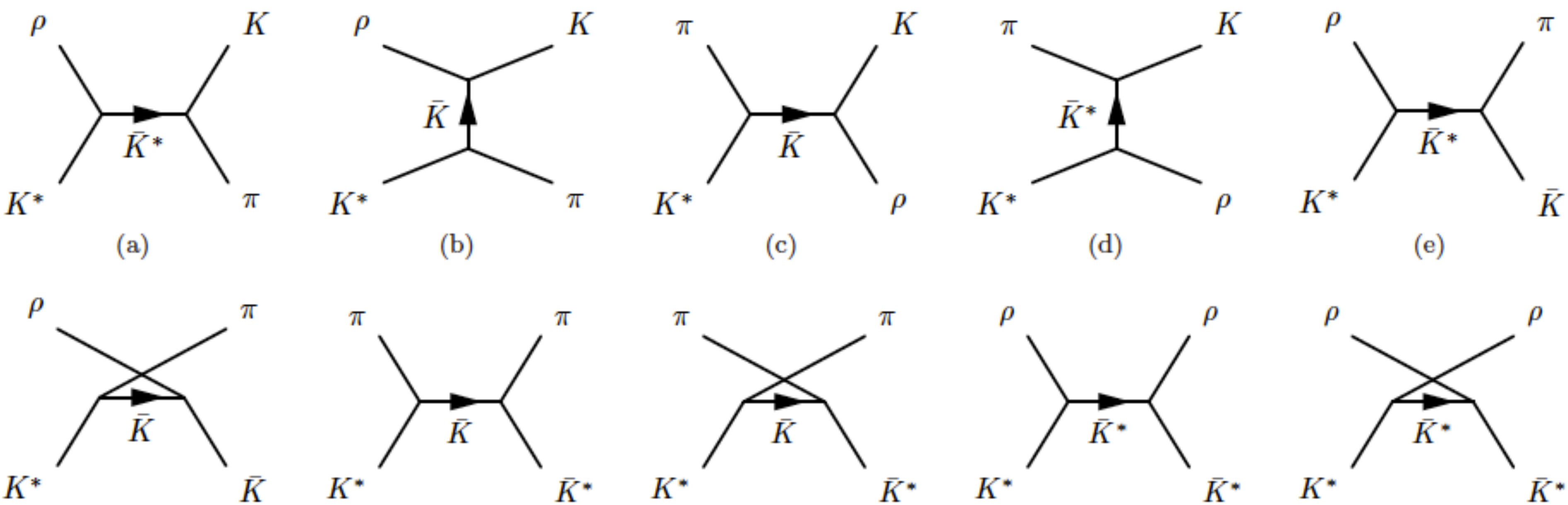
Lagrangians -> Amplitudes -> Cross Sections -> Thermal Cross Sections

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 :

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

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 :

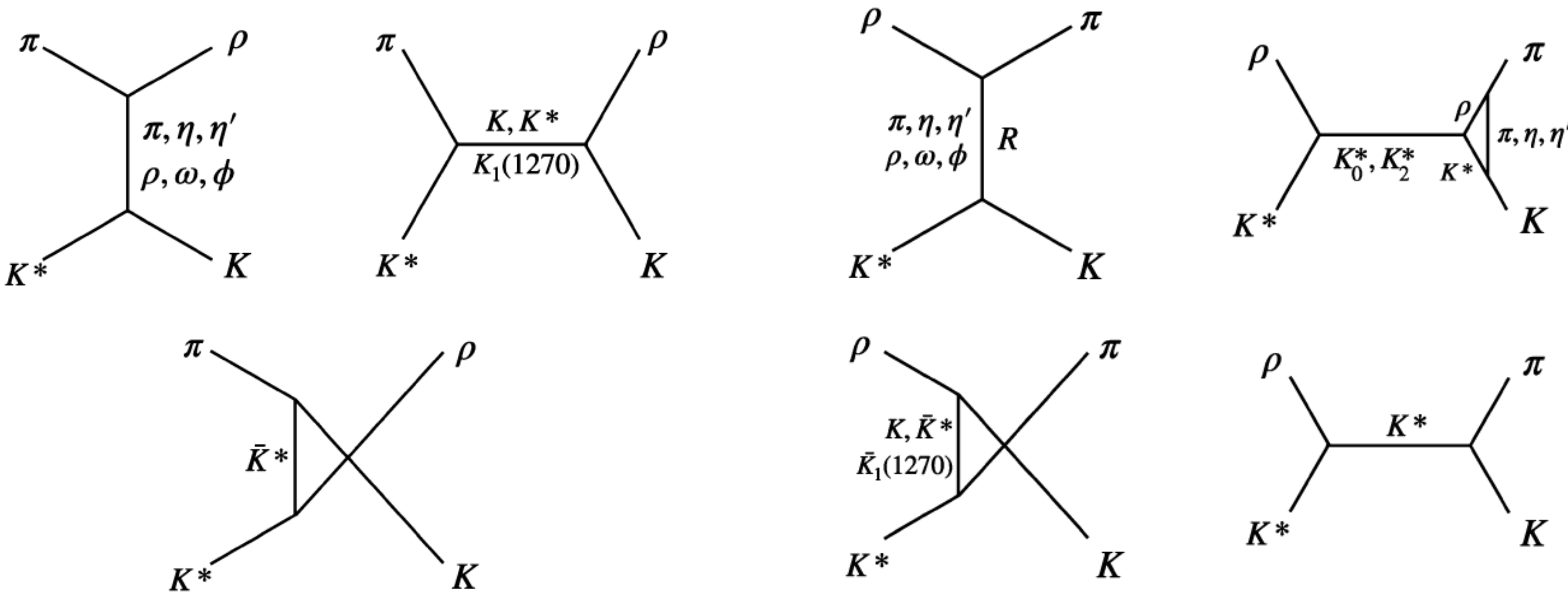
$$\begin{cases} V(\tau) = \pi[R_c + v_c(\tau-\tau_c) + a_c/2(\tau-\tau_c)^2]^2 \tau c, \\ T(\tau) = T_c - (T_h - T_f)\left(\dfrac{\tau-\tau_h}{\tau_f-\tau_h}\right)^{4/5}, \end{cases}$$

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

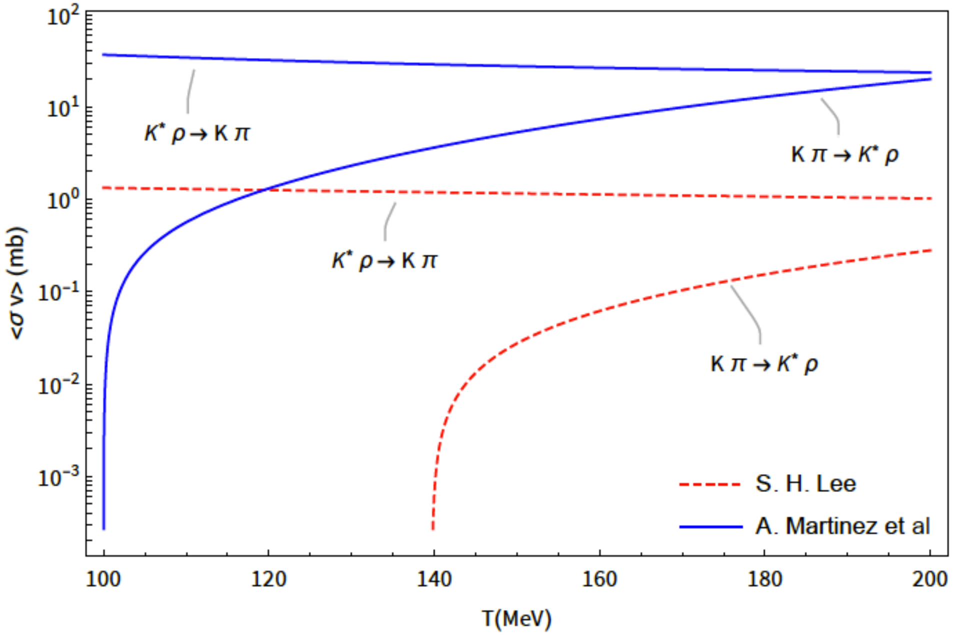
Exchange of axial resonances



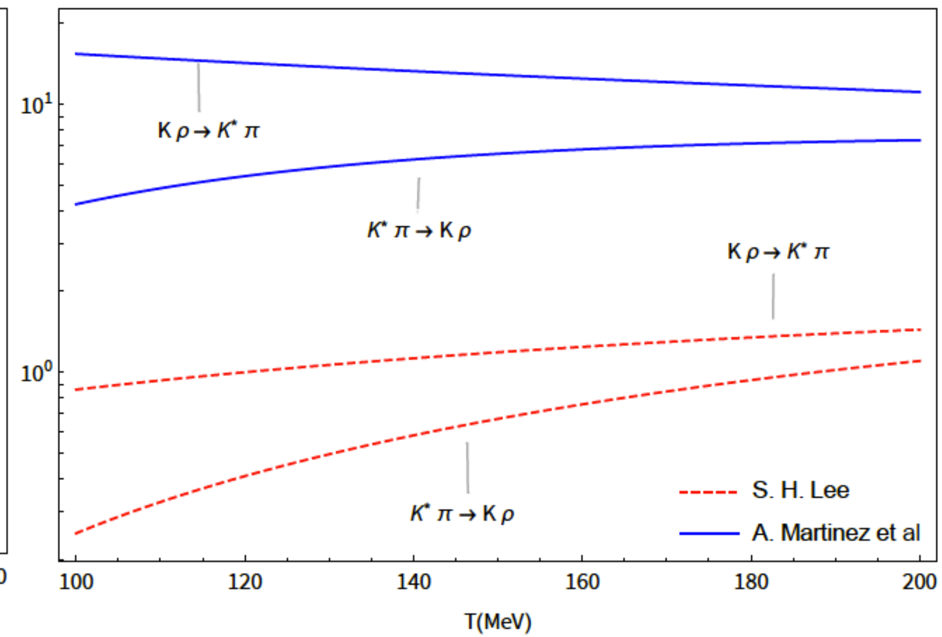
Many processes but only 3 are really important:

$$\left\{ \begin{array}{l} K^* \rho \leftrightarrow K \pi \\ K^* \pi \leftrightarrow K \rho \\ K^* \leftrightarrow K + \pi \end{array} \right.$$

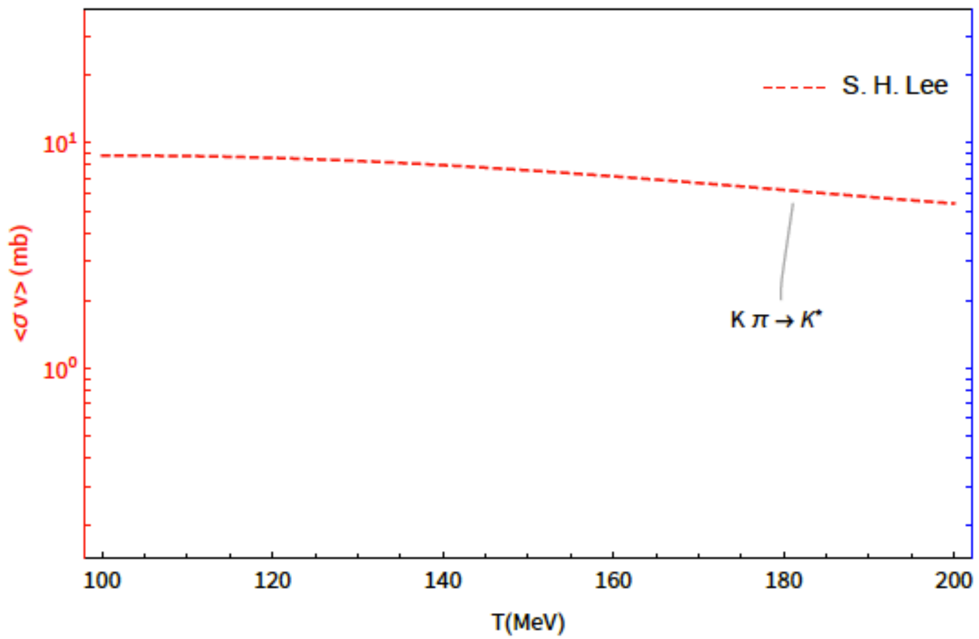
$K^* \rho \leftrightarrow K \pi$



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



$K^* \leftrightarrow K + \pi$



Simplified evolution equations :

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

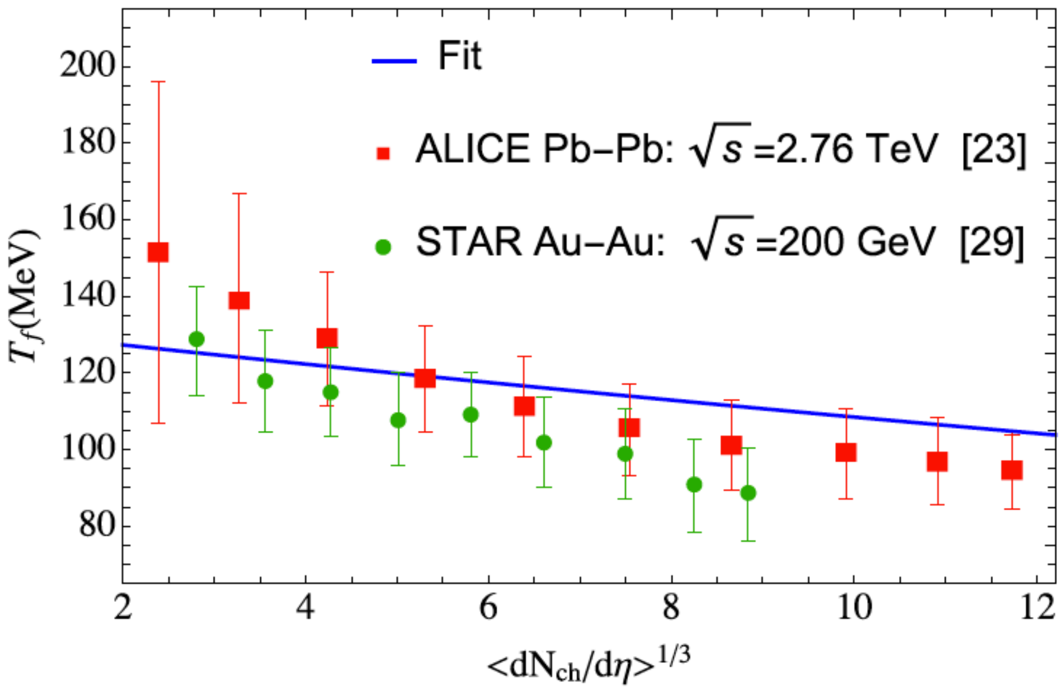
$$\gamma_K = \langle \sigma_{K\pi \to K^*\rho} v_{K\pi} \rangle n_\pi + \langle \sigma_{K\rho \to K^*\pi} v_{K\rho} \rangle n_\rho + \langle \sigma_{K\pi \to K^*} v_{K\pi} \rangle n_\pi ,$$

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

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

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

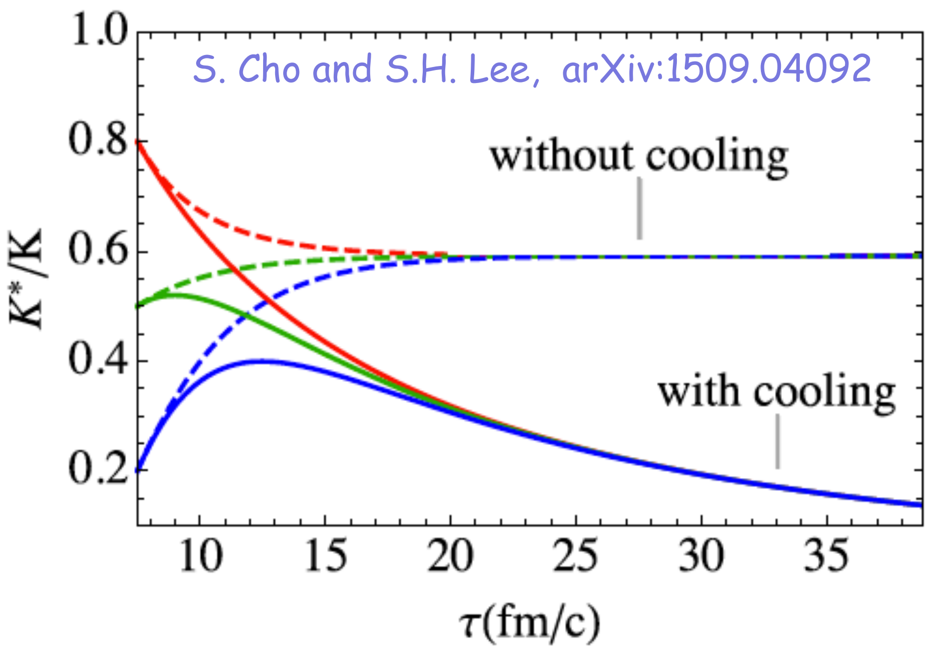
System size dependent freeze-out temperature

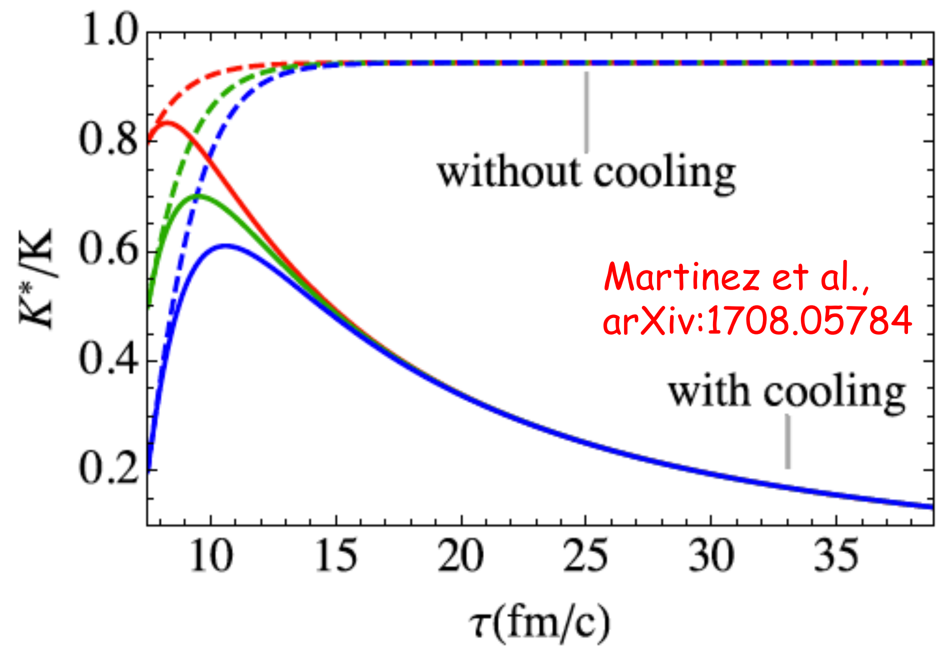


ALICE, arXiv:1303.0737

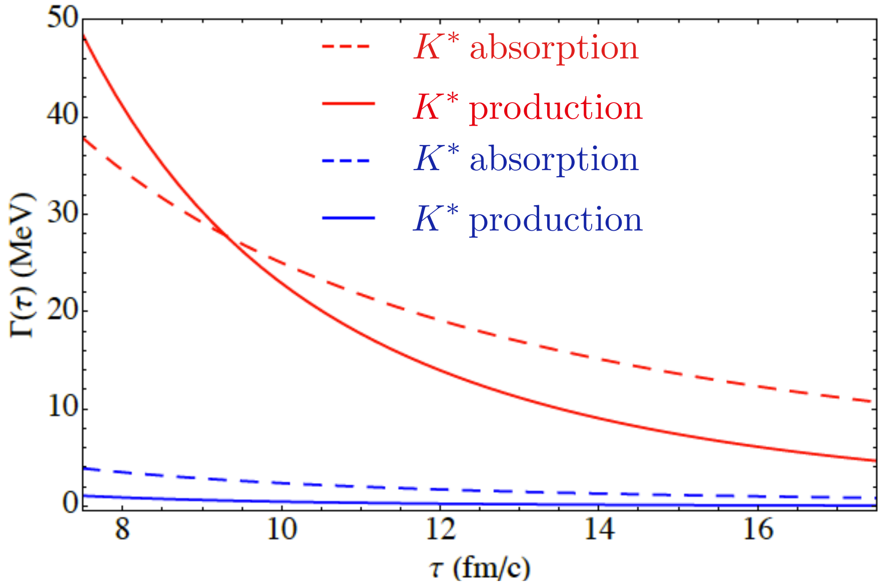
$$T_f = T_{f0}\, e^{-b\mathcal{N}}$$

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





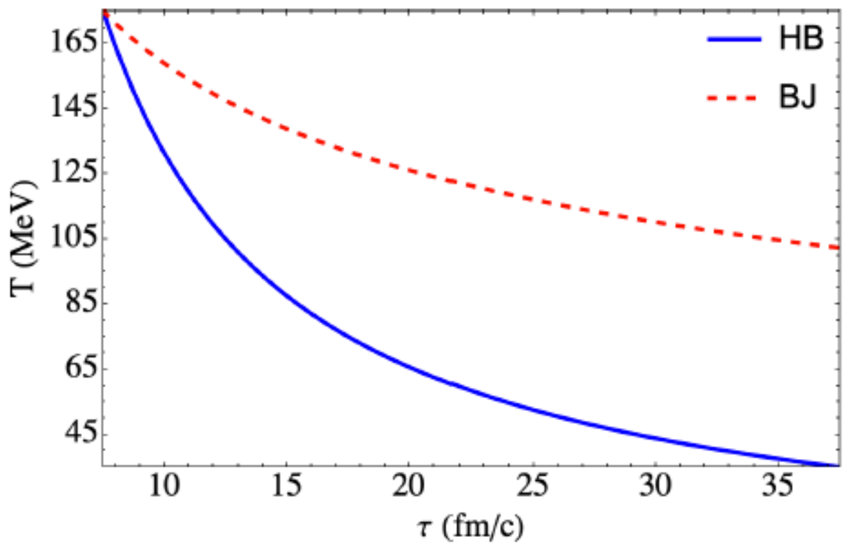
Reaction Rate



Martinez et al., arXiv:1708.05784

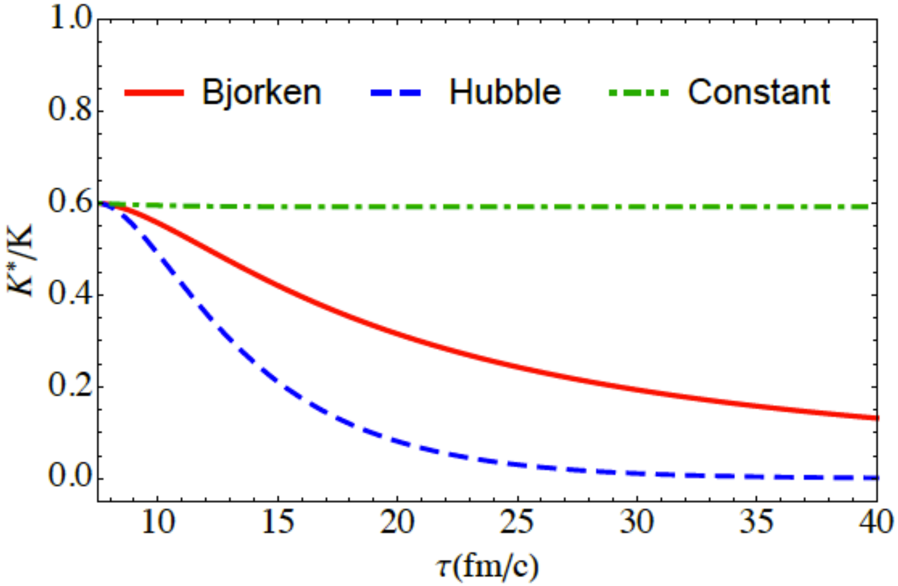
S. Cho,S.H. Lee, arXiv:1509.04092

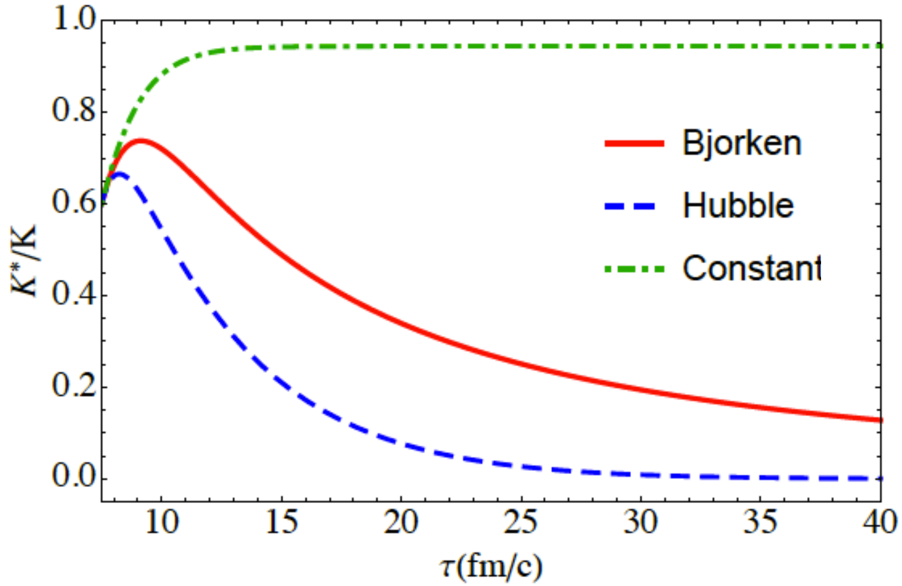
Effect of cooling



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

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



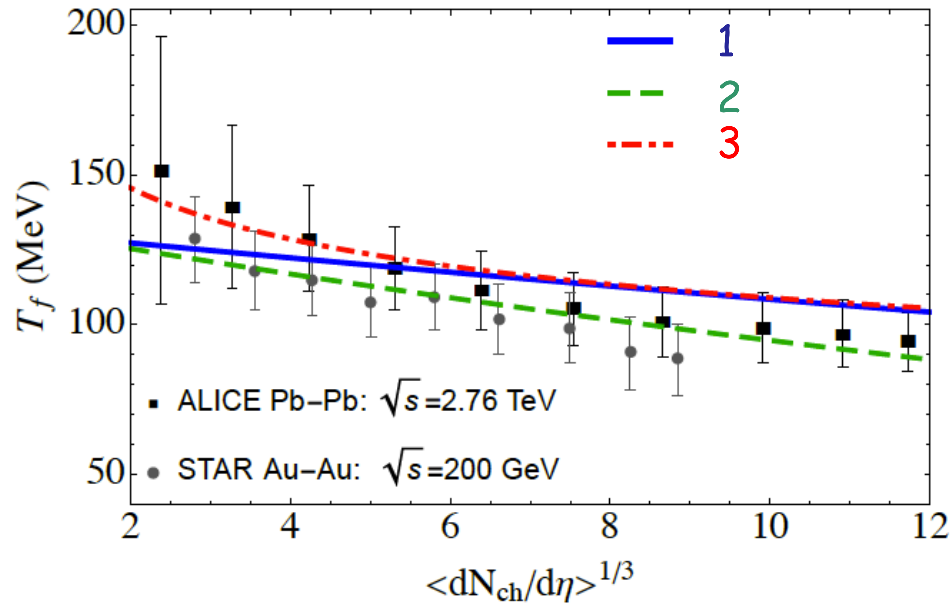


Effect of the parametrization of T_f

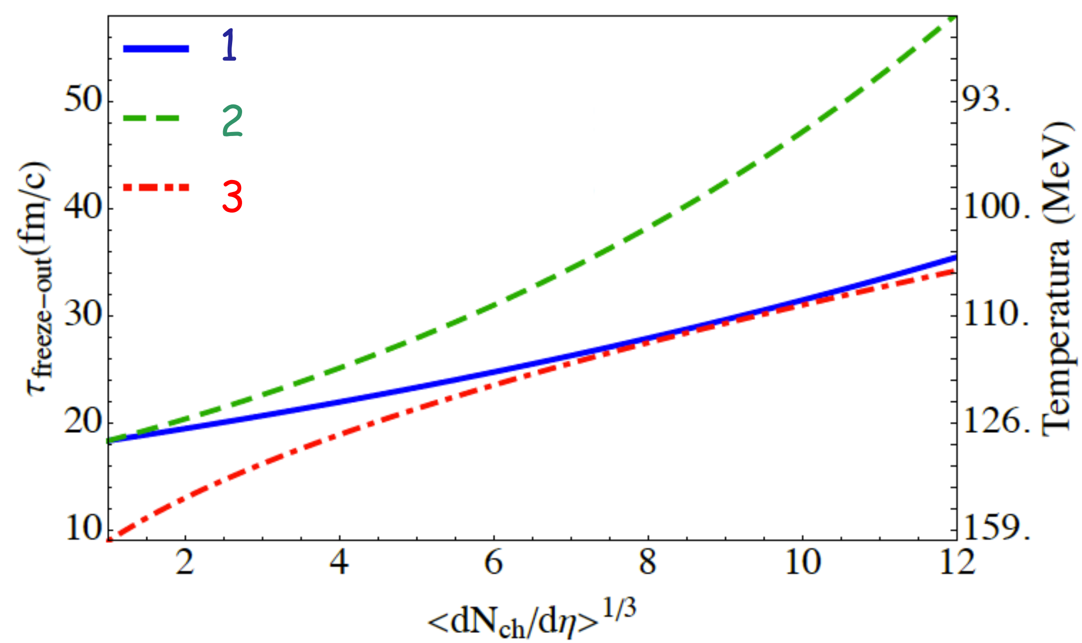
1 $T_f = 132\, e^{-0.02\,\mathcal{N}}$

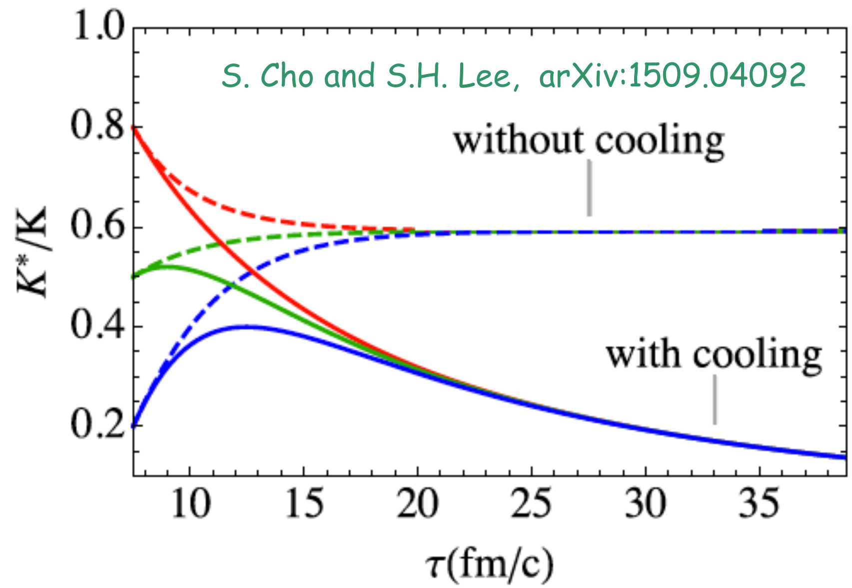
2 $T_f = 134\, e^{-0.035\,\mathcal{N}}$

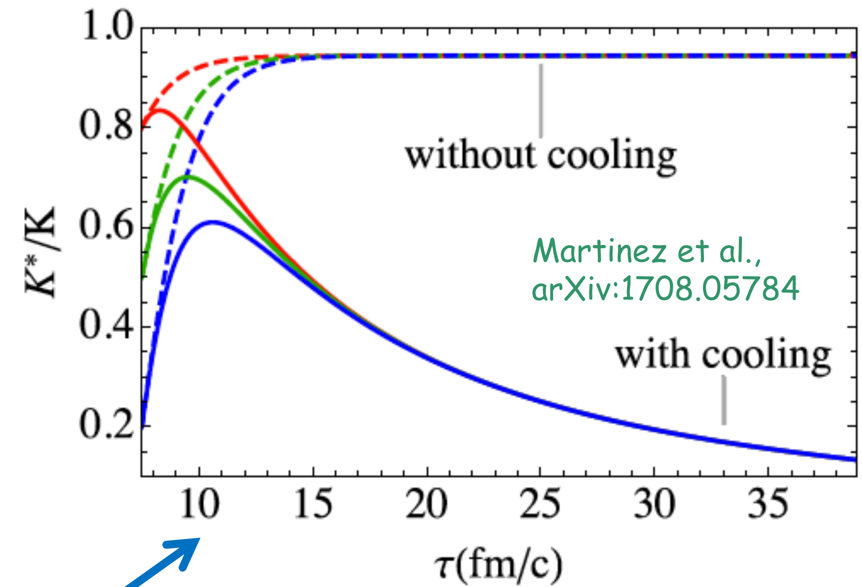
3 $T_f = 165\, e^{-0.18\,\mathcal{N}}$



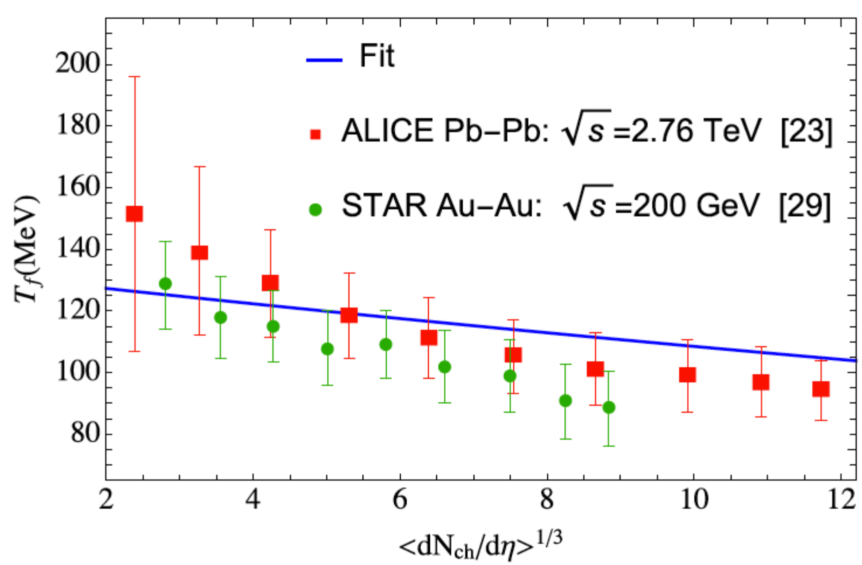
$$\tau_f = \tau_h \left(\frac{T_h}{T_f}\right)^3$$

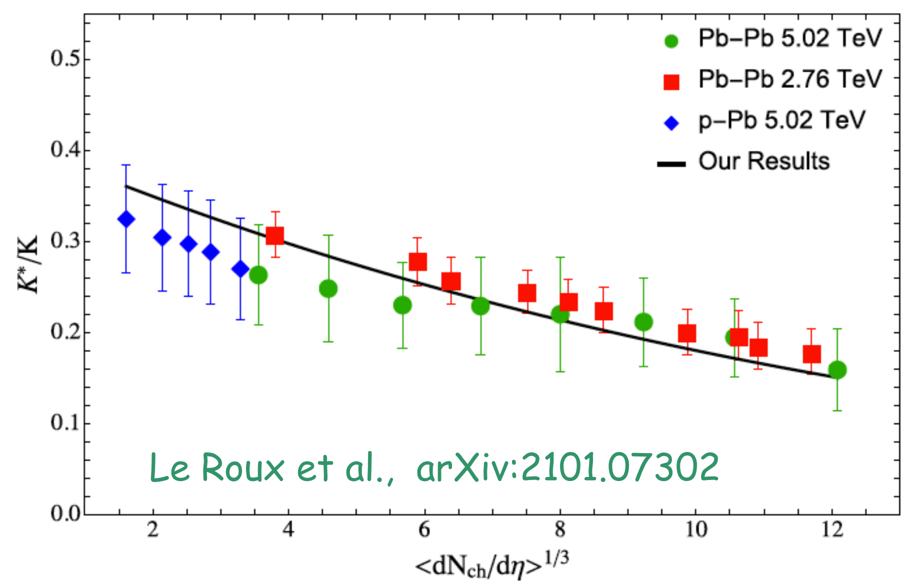






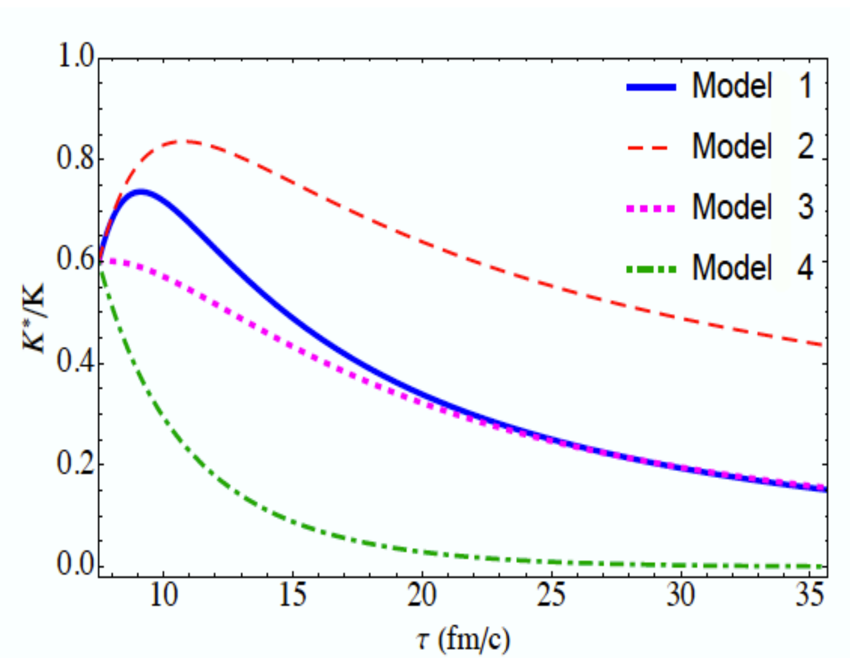
$$\tau_f = \tau_h \left(\frac{T_h}{T_f}\right)^3$$

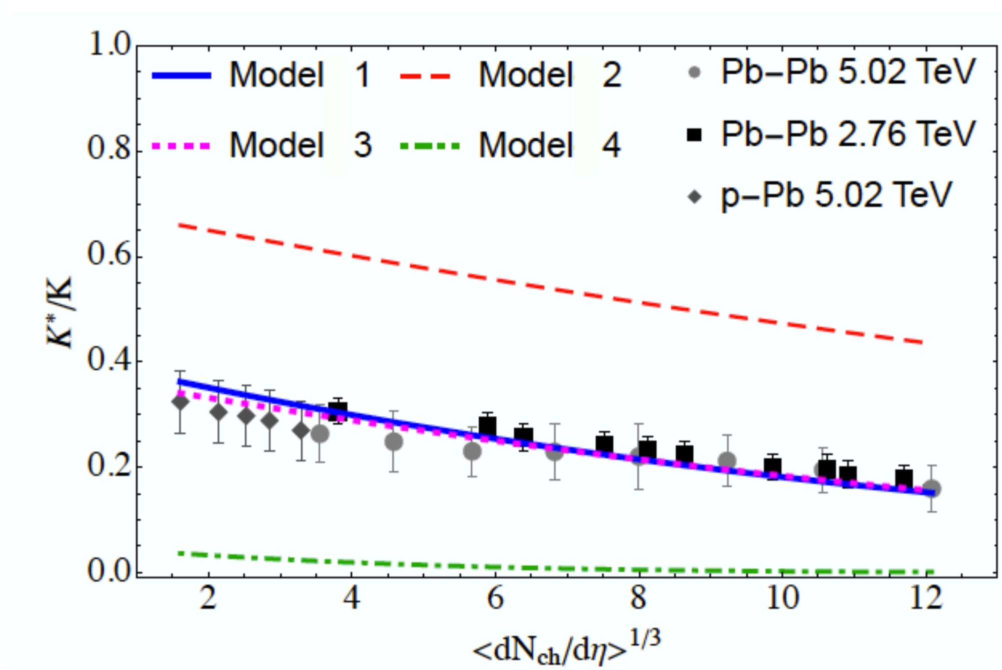




Which reaction is more important?

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

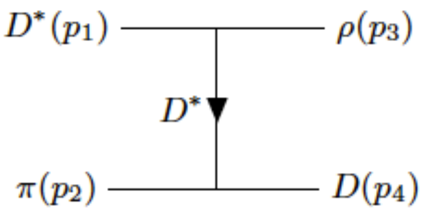
Interactions with rhos and pions

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

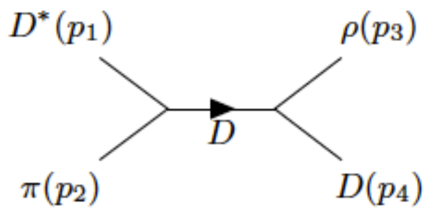
All couplings and form factors calculated with QCD sum rules!

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

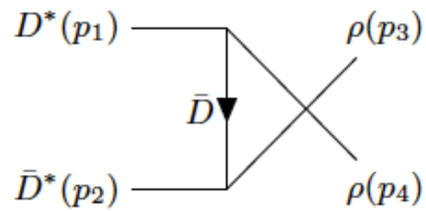
Amplitudes



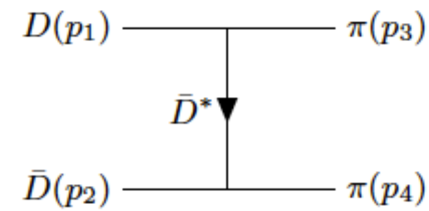
(1.a)



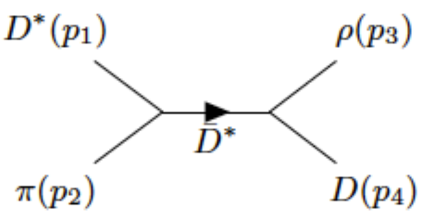
(1.b)



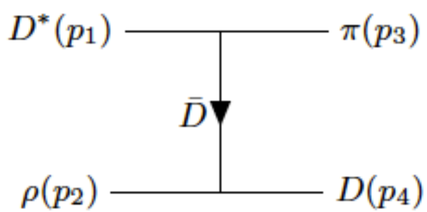
(5.d)



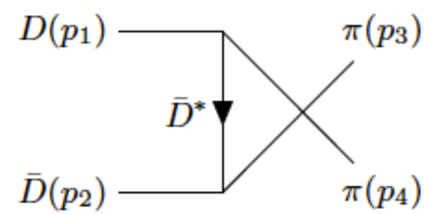
(6.a)



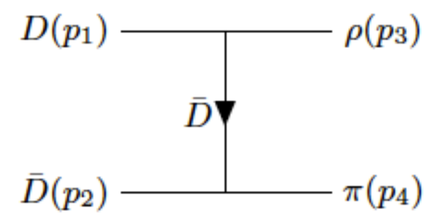
(1.c)



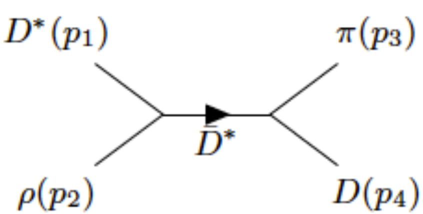
(2.a)

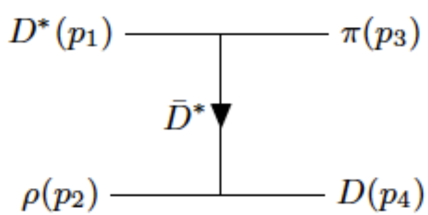


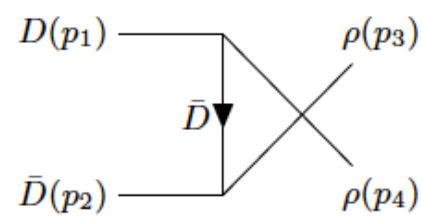
(6.b)

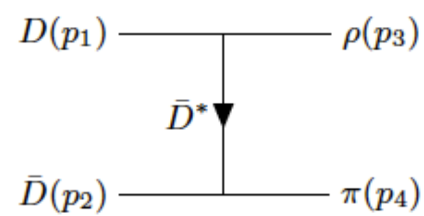


(7.a)









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

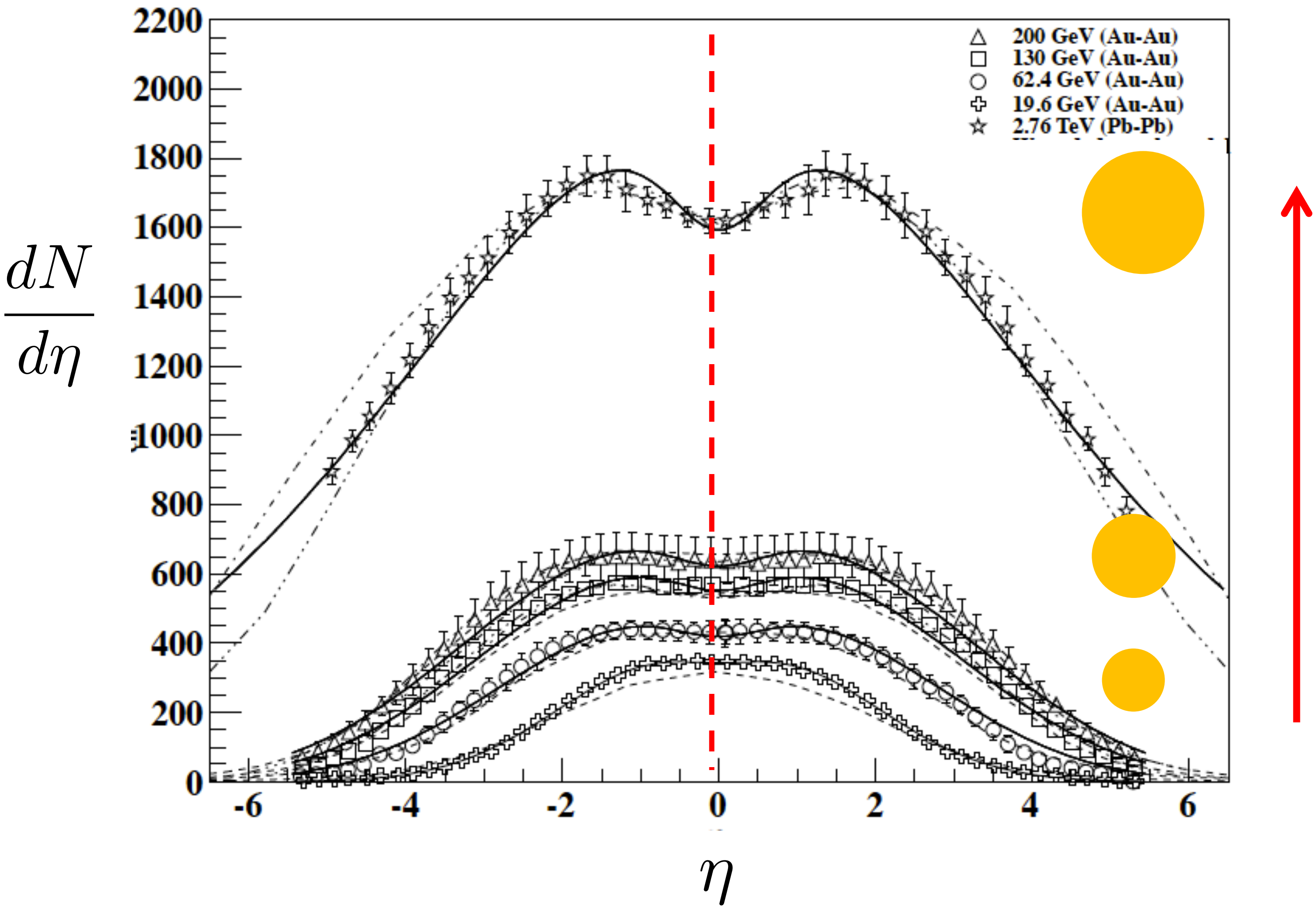
Predictions for the D* / D ratio

Thank you very much !!!

Back-ups

System Size

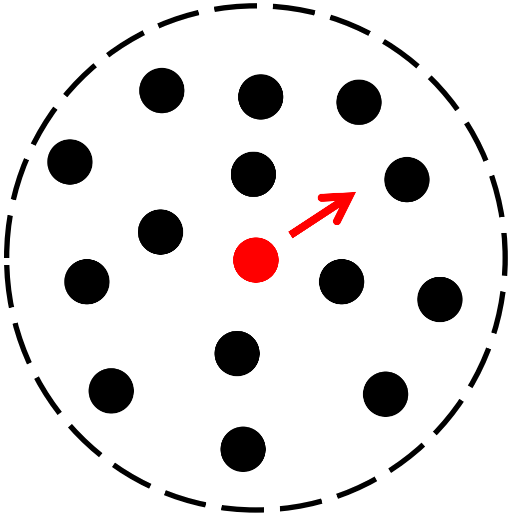
$$\left(\frac{dN}{d\eta}\right)_{\eta=0} \qquad \mathcal{N} = \left[\left(\frac{dN}{d\eta}\right)_{\eta=0}\right]^{1/3}$$



More mesons produced

Larger volume

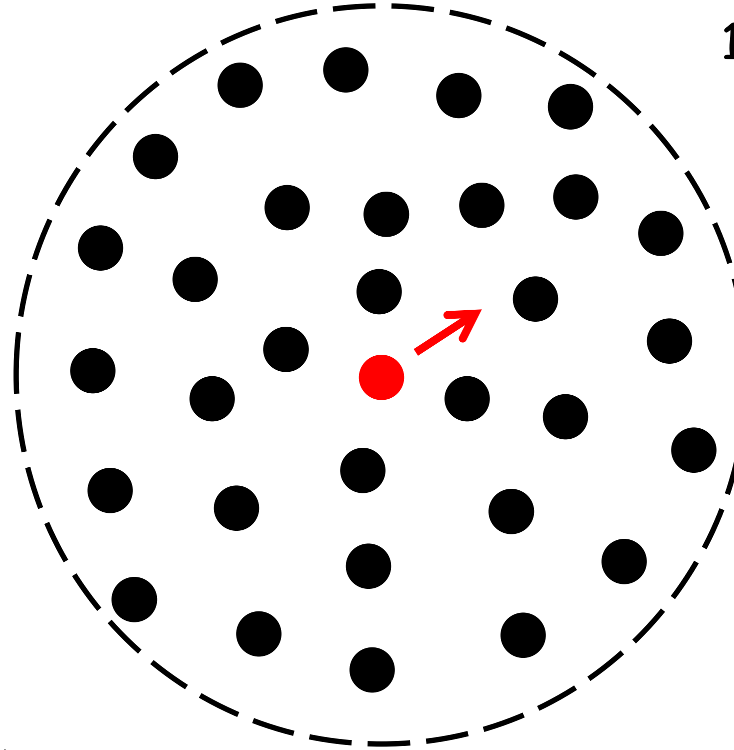
Lives longer



larger volume

same density

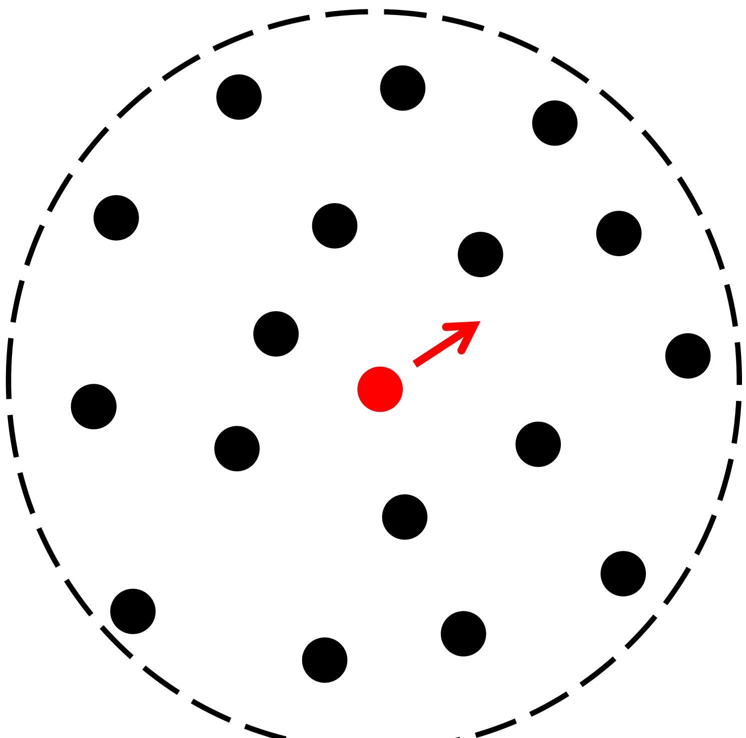
same temperature



same volume

lower density

lower temperature



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

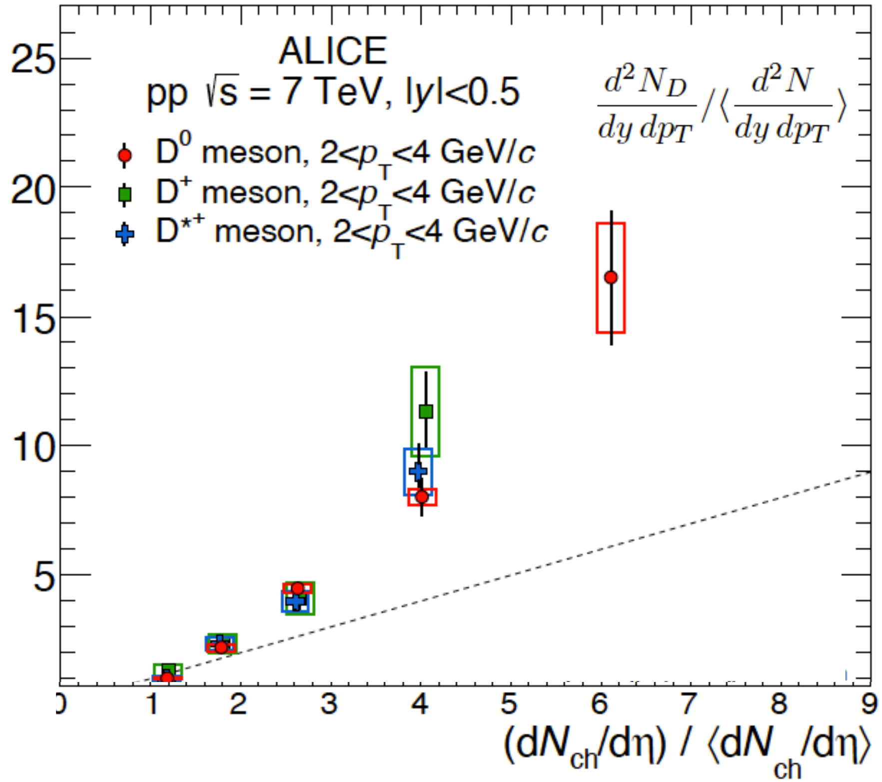
Freeze-out e tamanho

SU(4)

Gamma térmico = loops

System size and number of charm quarks

$$\frac{\frac{d^2 N_D}{dy\, dp_T}}{\langle \frac{d^2 N}{dy\, dp_T} \rangle}$$



ALICE, JHEP (2015), arXiv:1505.00664

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

$$\beta = 1.6$$

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