

Planos do grupo de trabalho de teoria



É titular! Parabéns!



Working Group 3

Alberto Martinez Torres

Fernando Silveira Navarra

Renato Higa

Marina Nielsen (senior)

Hadrons exóticos : estrutura e reações

Estudo do gás de hadrons

Distribuição de multiplicidades

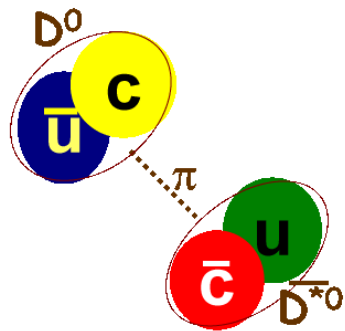
Campo magnético em colisões de ions pesados

Hadrons exóticos : estrutura e reações

$$X(3872) = (c \bar{c} q \bar{q}) \quad J^P = 1^+$$

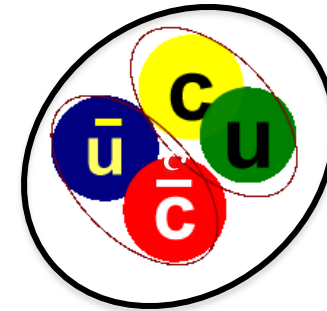
BELLE (2003)

Molécula mesônica



extenso
~ 10 fm

Tetraquark



compacto
~ 1 fm

Porque ions pesados ?

Número grande de quarks charme

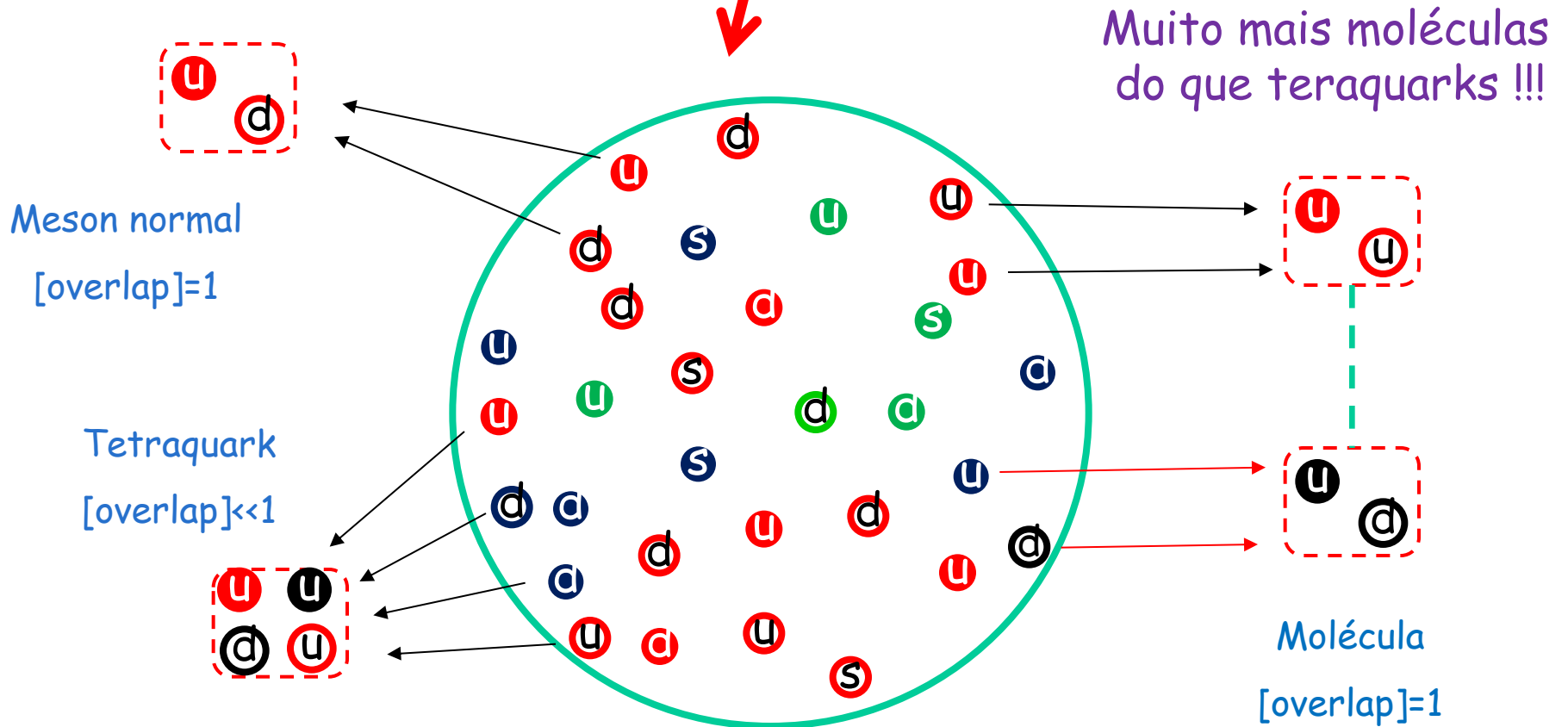
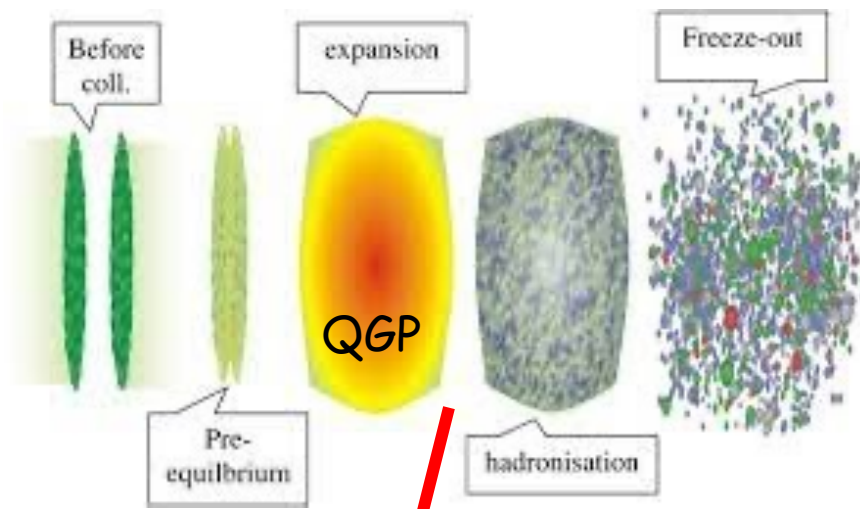
É possível observar :

Evidence for X(3872) in Pb-Pb Collisions and Studies of its Prompt Production at $\sqrt{s_{NN}}=5.02$ TeV

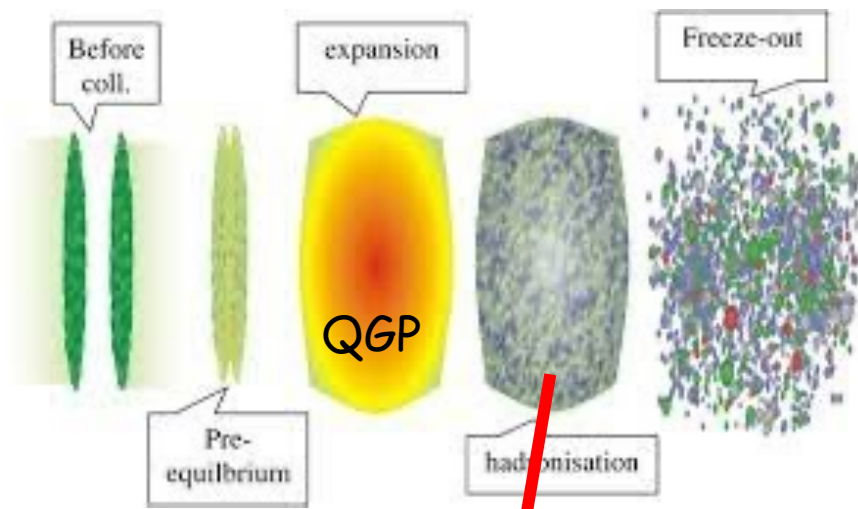
CMS Collaboration • Albert M. Sirunyan (Yerevan Phys. Inst.) et al. (Feb 25, 2021)

Published in: *Phys.Rev.Lett.* 128 (2022) 3, 032001 • e-Print: [2102.13048](https://arxiv.org/abs/2102.13048) [hep-ex]

Produção :



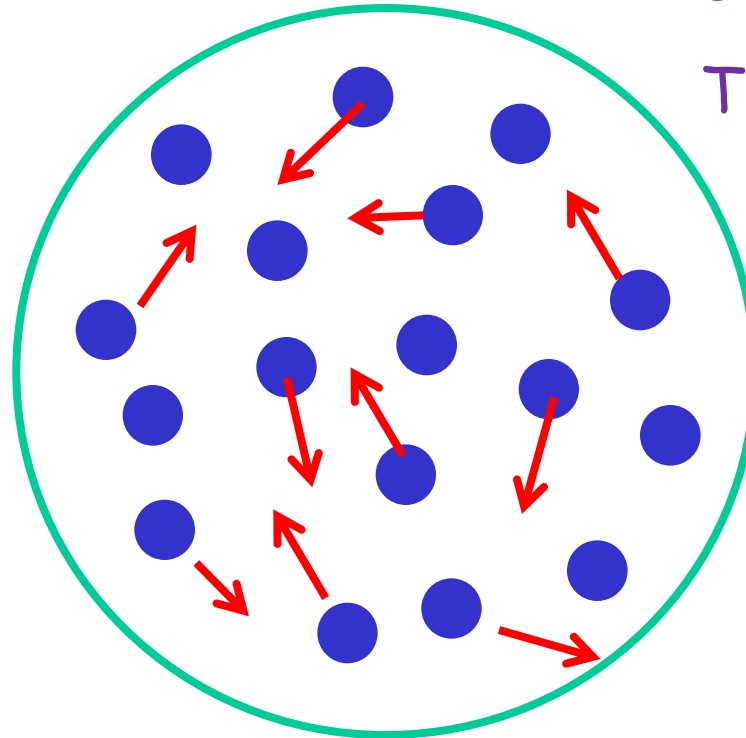
Produção :



Gás de Hadrons

$T \sim 100 - 200 \text{ MeV}$

Formação e
destruição de
hadrons exóticos



O tetraquark interage com os mesons do gás de hadrons

Abreu, Navarra, Nielsen, Vieira, EPJC (2022), arXiv:2110.11145

Muitas interações são conhecidas :

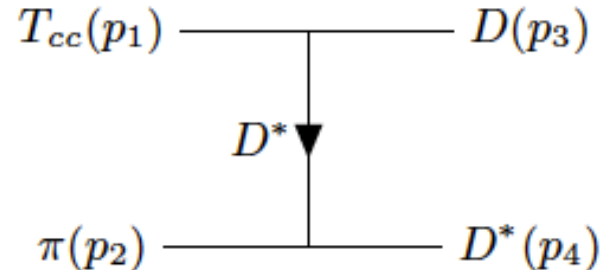
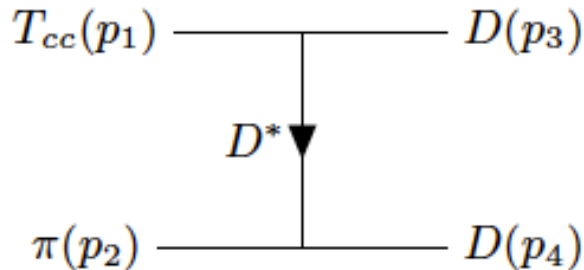
$$\mathcal{L}_{\pi DD^*} = ig_{\pi DD^*} D_{\mu}^* \vec{\tau} \cdot (\bar{D} \partial^{\mu} \vec{\pi} - \partial^{\mu} \bar{D} \vec{\pi})$$

$$\mathcal{L}_{\rho DD} = ig_{\rho DD} (D \vec{\tau} \partial_{\mu} \bar{D} - \partial_{\mu} D \vec{\tau} \bar{D}) \cdot \vec{\rho}^{\mu},$$

e muitas outras...

Interação nova: $\mathcal{L}_{T_{cc}} = ig_{T_{cc} DD^*} T_{cc}^{\mu} D_{\mu}^* D.$

O tetraquark é destruído pelos mesons leves:



e recriado nos processos inversos

Nossa "expertise" :

Constante de acoplamento e fatores de forma com regras de soma da QCD

Variáveis dos hadrons em termos das variáveis dos quarks

$$\mathcal{L}_{T_{cc}} = ig_{T_{cc}DD^*} T_{cc}^\mu D_\mu^* D.$$

$$\Pi_{\alpha\mu}(p, p', q) = \int d^4x d^4y e^{ip' \cdot x} e^{iq \cdot y} \langle 0 | T [j_\alpha^{D^*}(x) j_5^D(y) j_\mu^\dagger(0)] | 0 \rangle$$

$$j_\mu = i(c_a^T C \gamma_\mu c_b) (\bar{u}_a \gamma_5 C \bar{d}_b^T) \quad j_5^D = i\bar{u}_a \gamma_5 c_a \quad j_\alpha^{D^*} = \bar{d}_a \gamma_\alpha c_a$$

$$g_{T_{cc}DD^*}(Q^2) = g_{T_{cc}DD^*} e^{-g(Q^2 + m_D^2)}$$

$$g_{T_{cc}DD^*} = g_{T_{cc}DD^*}(-m_D^2) = (1.7 \pm 0.2) \text{ GeV}$$

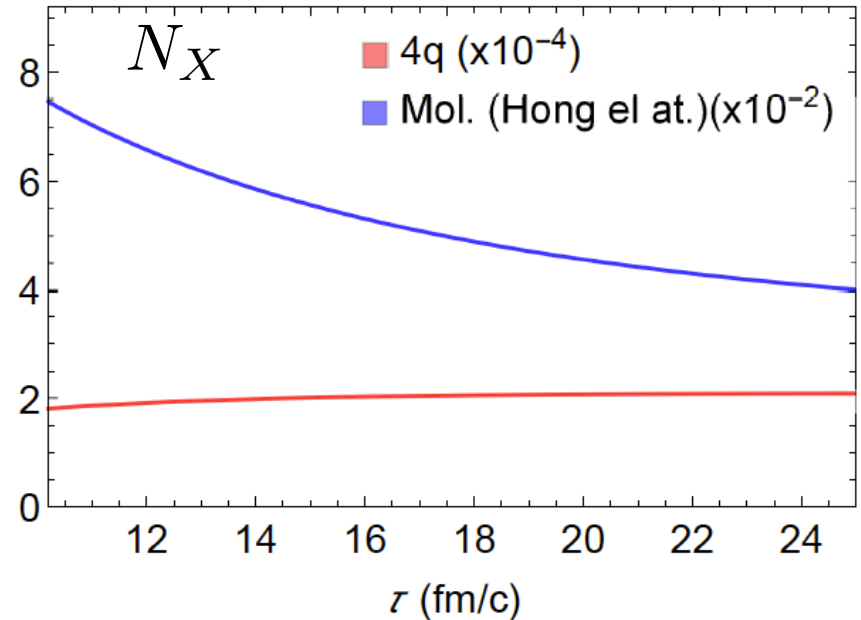
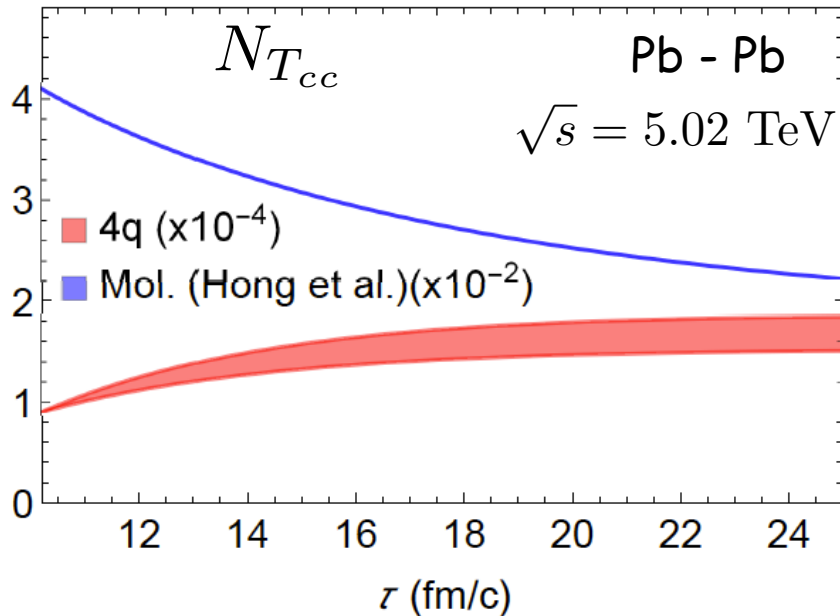
Multiplicidades

Abreu, Navarra, Vieira, PRD (2022), arXiv:2202.10882

$$\frac{dN_X}{d\tau} = N_a N_b \sigma_{ab \rightarrow cX} - N_c N_X \sigma_{cX \rightarrow ab}$$

ganho

perda



Diferença de multiplicidades diminui mas continua grande !

O que nós vamos fazer:

Com Lagr. Efetivas e QCDSR fazer o cálculo de multiplicidades de:

$$Z_c, Z_{cs}, T_{4c}, \dots$$

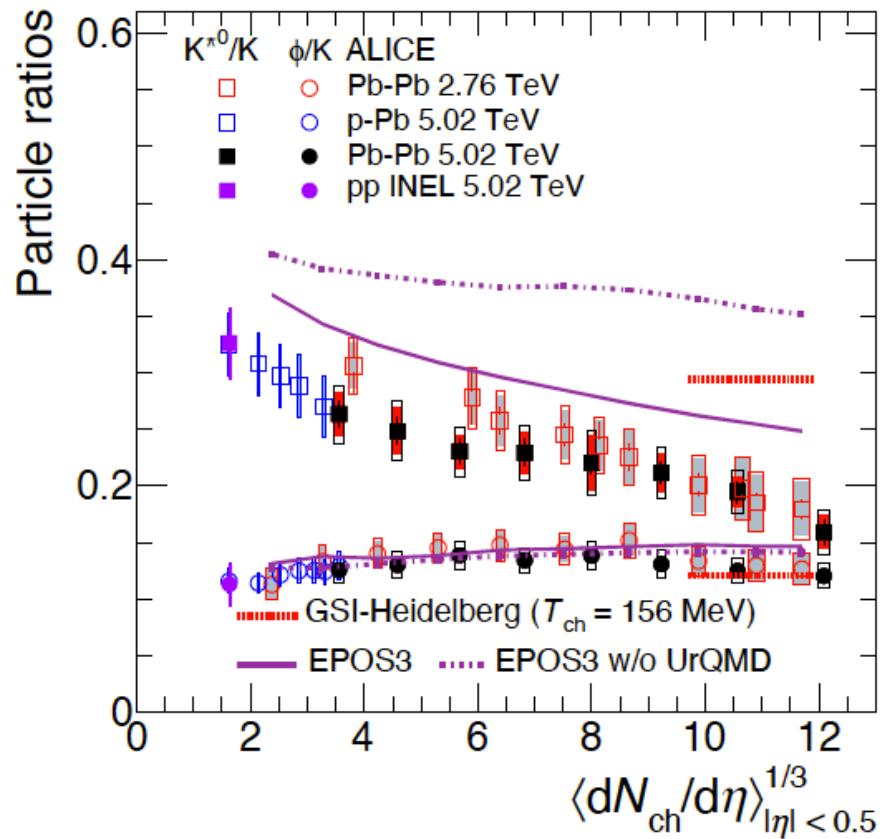
Fernando, Marina, Luciano Abreu (UFBA), Richard Terra (mestrado IF)

Estudo do gás de hádrons

Evidence of rescattering effect in Pb-Pb collisions at the LHC through production of $K^*(892)^0$ and $\phi(1020)$ mesons

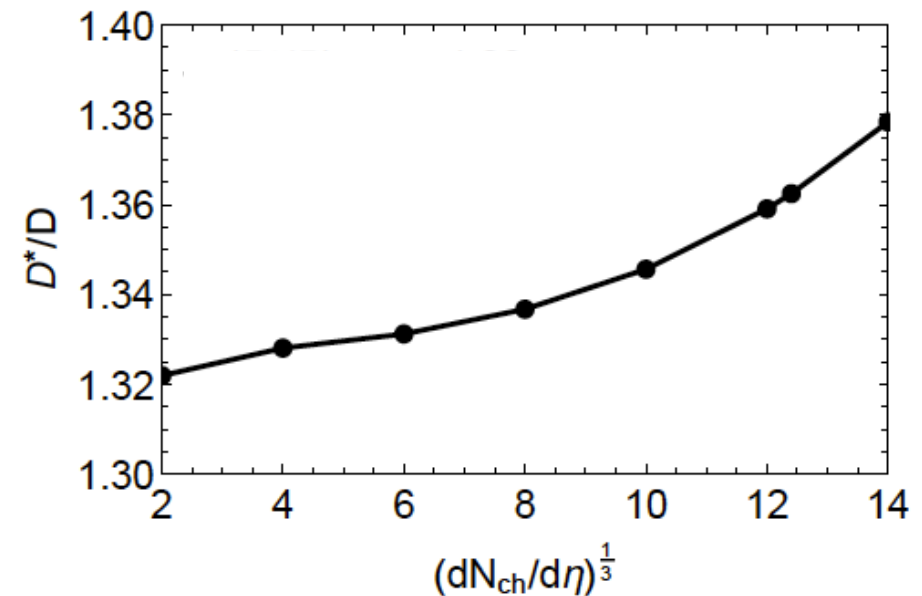
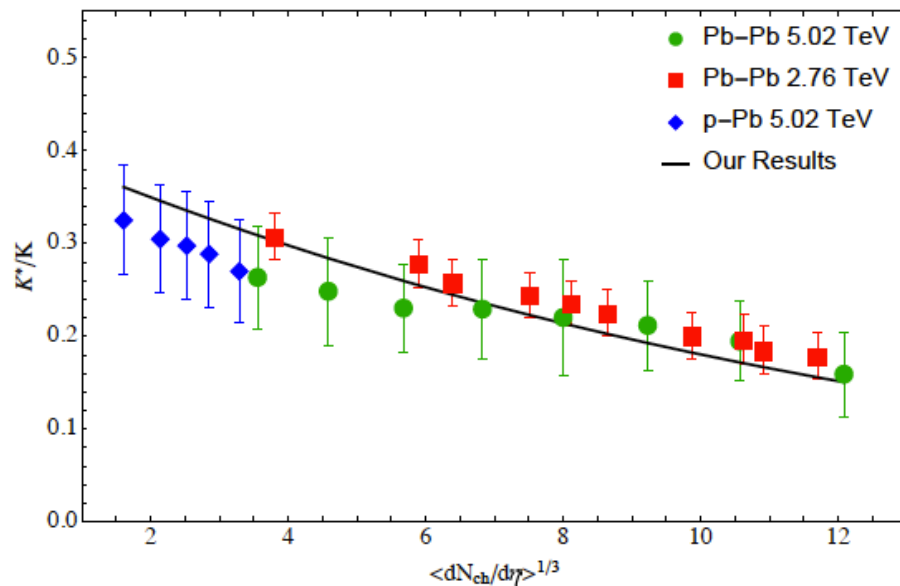
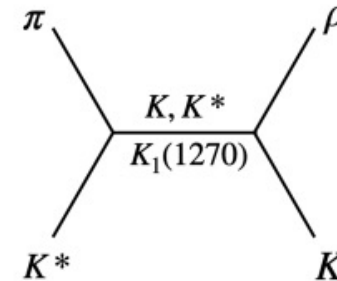
ALICE Collaboration • Shreyasi Acharya (Calcutta, VECC) et al. (Oct 31, 2019)

Published in: *Phys.Lett.B* 802 (2020) 135225 • e-Print: [1910.14419](https://arxiv.org/abs/1910.14419) [nucl-ex]



Efeitos do gás de hadrons na produção de charme e estranheza

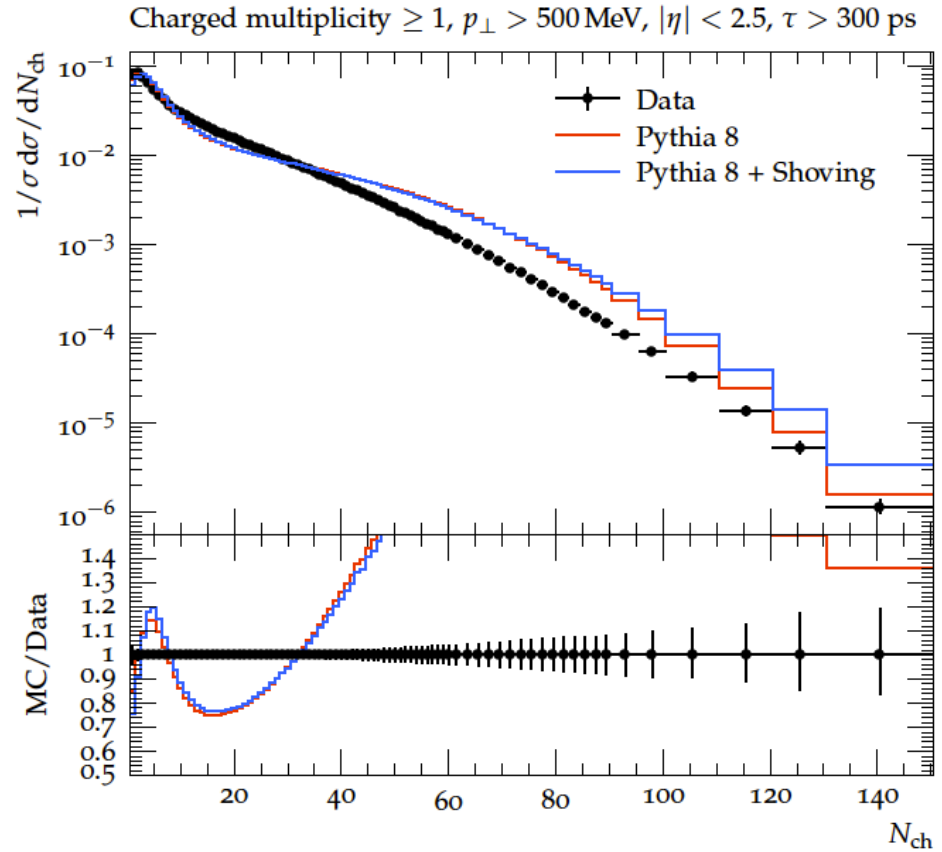
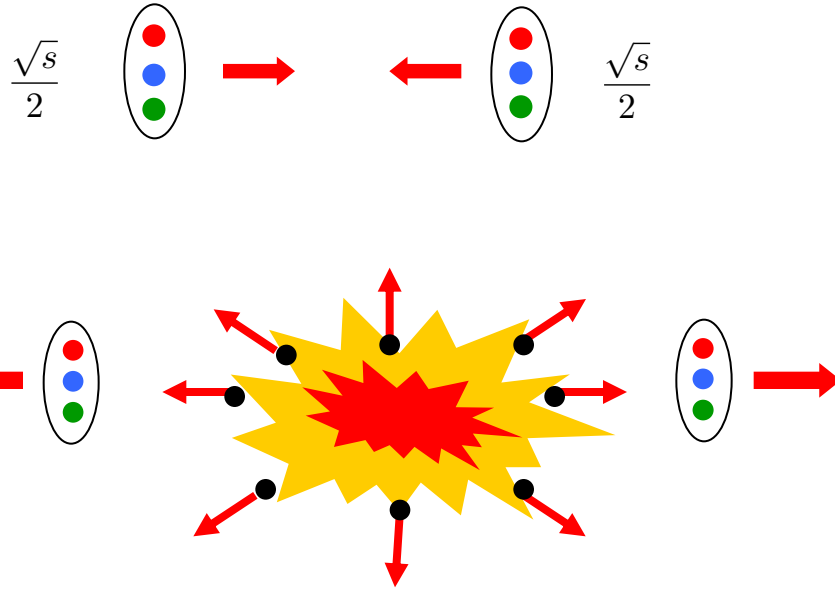
Novas ressonâncias mudam a interação das partículas conhecidas:



Le Roux, Navarra, Abreu,
PLB (2021), arXiv:2202.10882

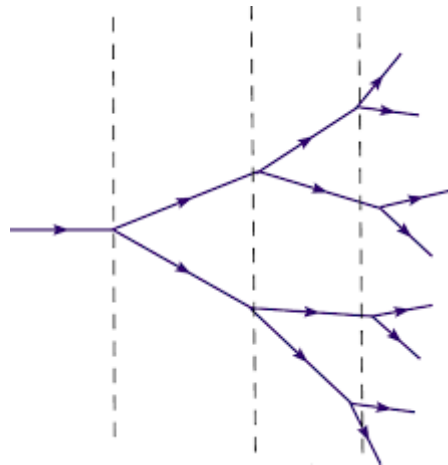
Fernando, Chiara Le Roux, Luciano Abreu

Distribuição de multiplicidades



arXiv:2010.07595

Parton branching
antes da colisão



O que podemos aprender com as MD ?

Mecanismo de produção: transição soft \rightarrow hard

Teste dos modelos de evolução da cascata de partons

Teste do Color Glass Condensate

Teste dos modelos de hadronização ("cordas")

Instantons ("vácuo em ação")

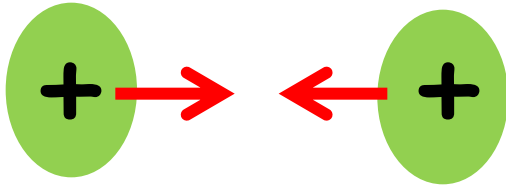
Estudar informação quântica em altas energias

Mais teoria: flutuações vindas do CGC, melhorar as equações de cascata

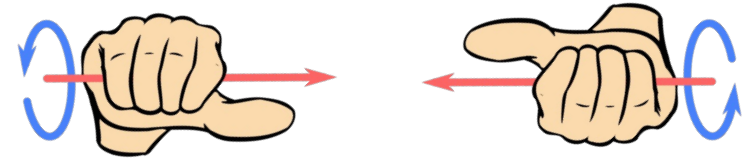
Estudar próton-núcleo

Usar o PYTHIA para simular DM de partículas com charme

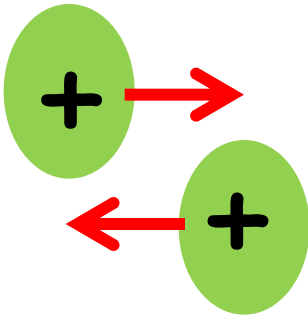
Campo magnético em colisões de íons pesados



central



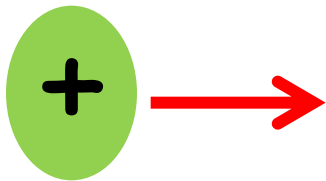
$$\vec{B} = 0$$



non-
central



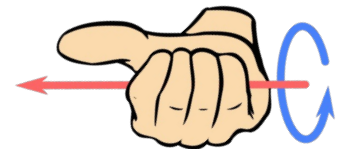
$$\vec{B} \neq 0$$

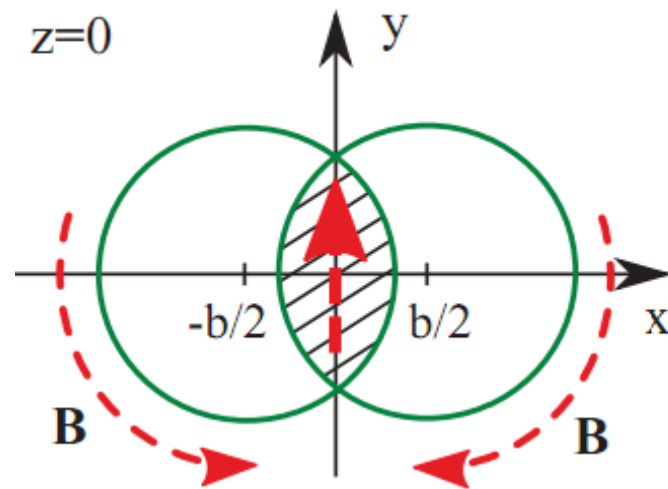
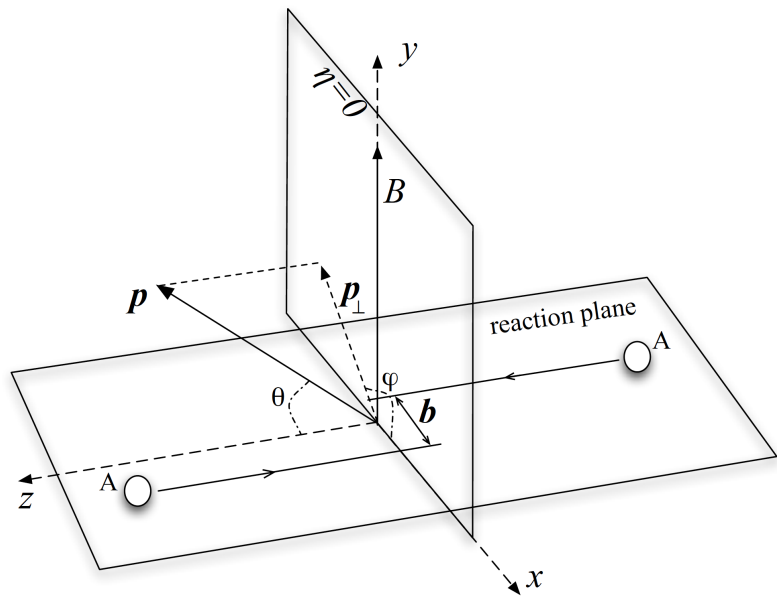


ultra
peripheral



$$\vec{B} \neq 0$$





$$B \propto \frac{\gamma Z e}{R^2}$$



$$eB \approx m_\pi^2 \sim 10^{18} \text{ G}$$

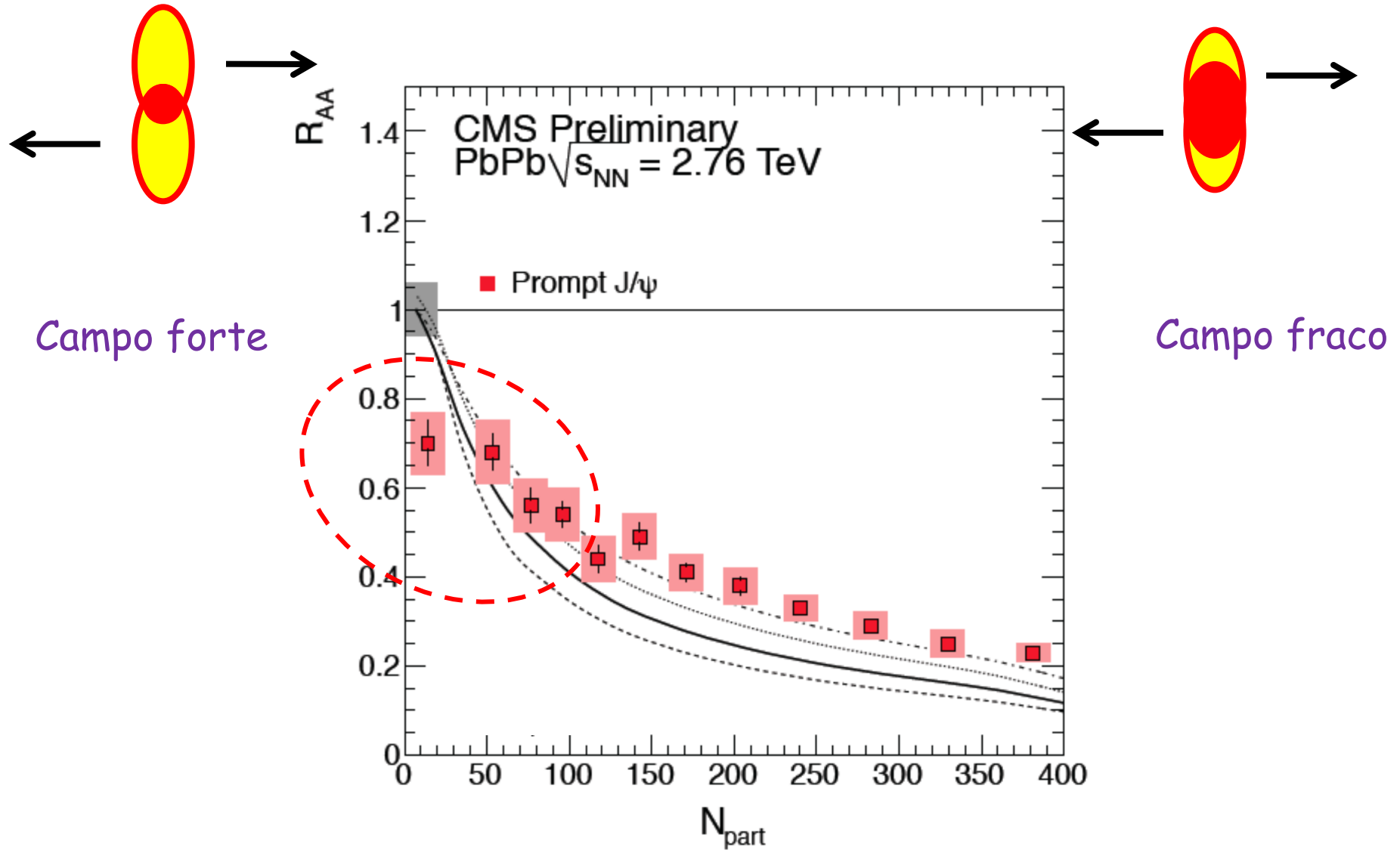
Neutron star : $eB = 10^{14} \text{ G}$

Magnetar: $eB = 10^{15} \text{ G}$

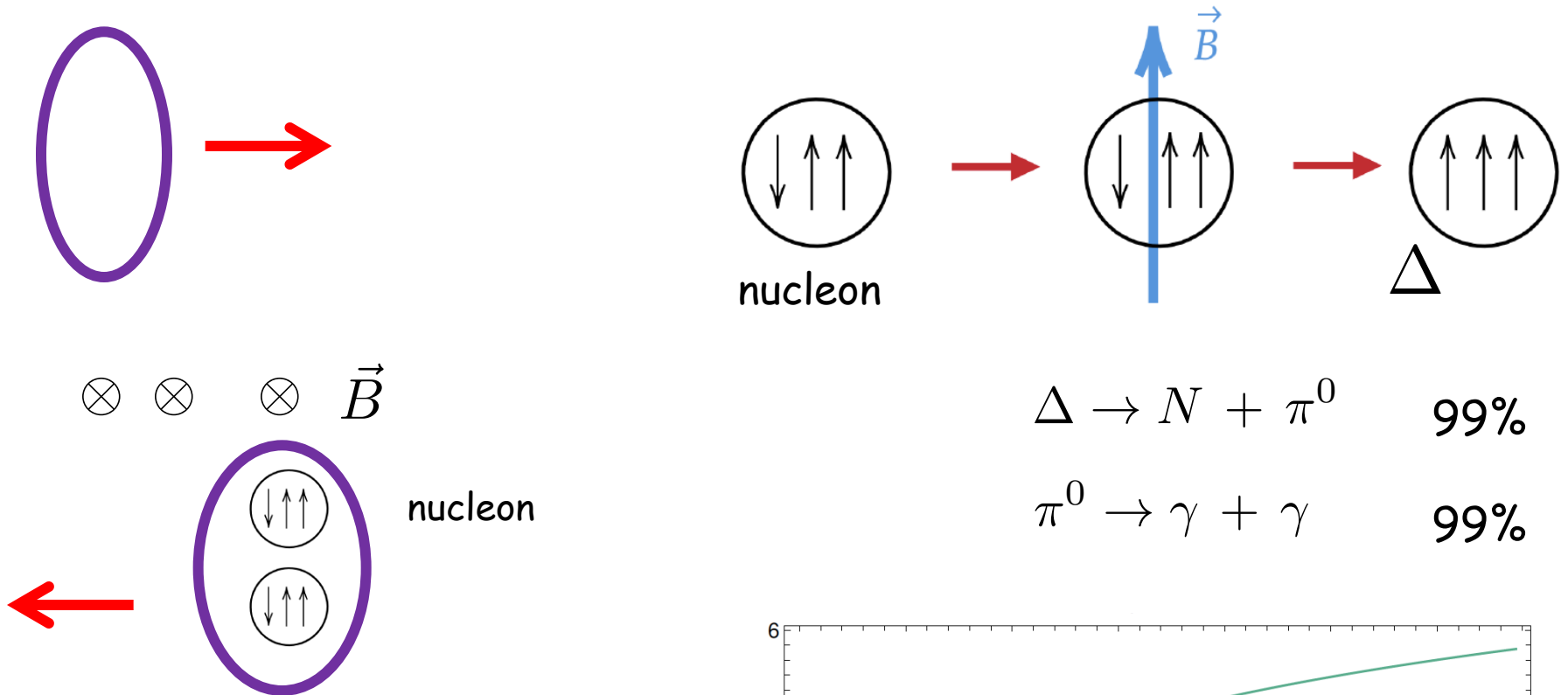
O mais intenso
da natureza!

Supressão de J/psi em colisões periféricas

Machado, Navarra, Noronha, Oliveira, Strickland, PRD (2013), arXiv:1305.3308



Transições magnéticas

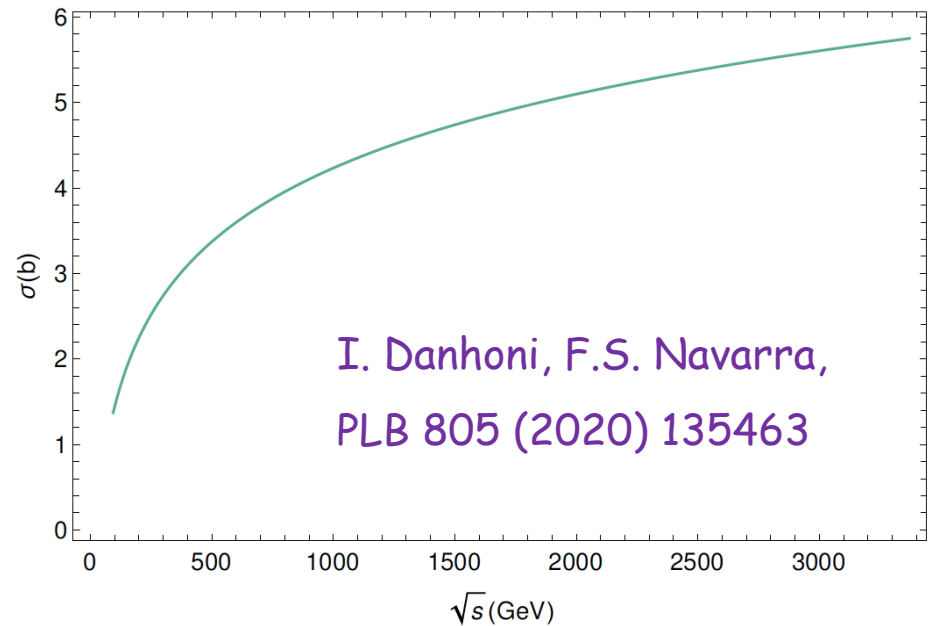


$$\Delta \rightarrow N + \pi^0 \quad 99\%$$

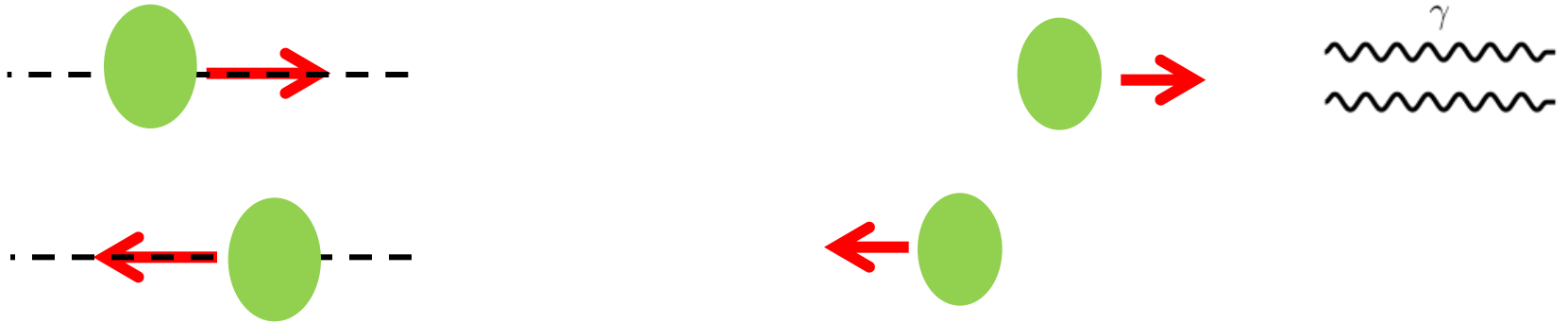
$$\pi^0 \rightarrow \gamma + \gamma \quad 99\%$$

Seção de choque enorme!

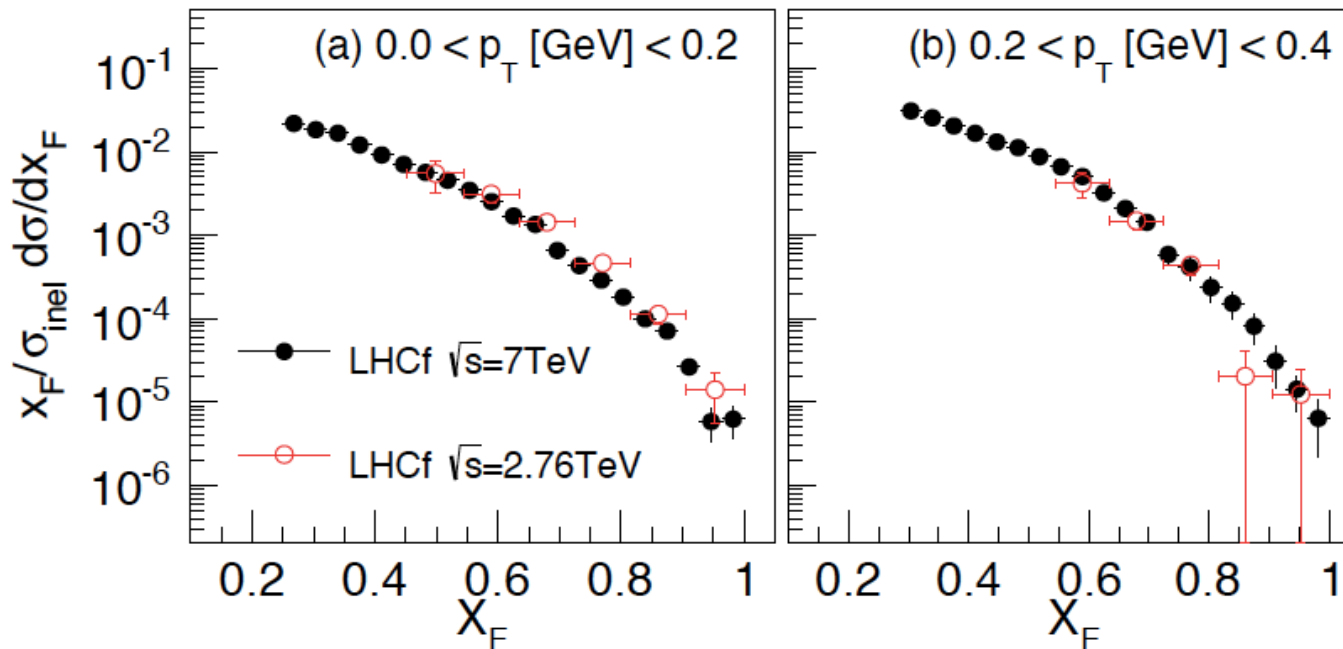
Pions super "forward"



Como medir?

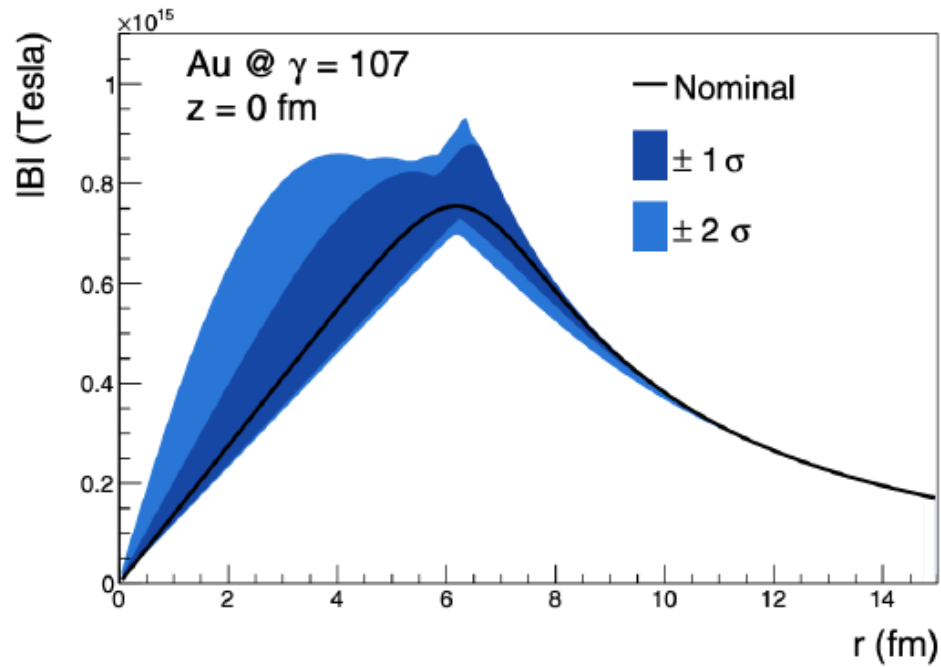


Usar os detetores do LHCf e RHICf em colisões **ultra-periféricas**



$$x_F = \frac{p_{\pi^0}}{p_{\text{beam}}}$$

Já tem um pessoal tentando medir B



D. Brandenburg et al. EPJA (2021)