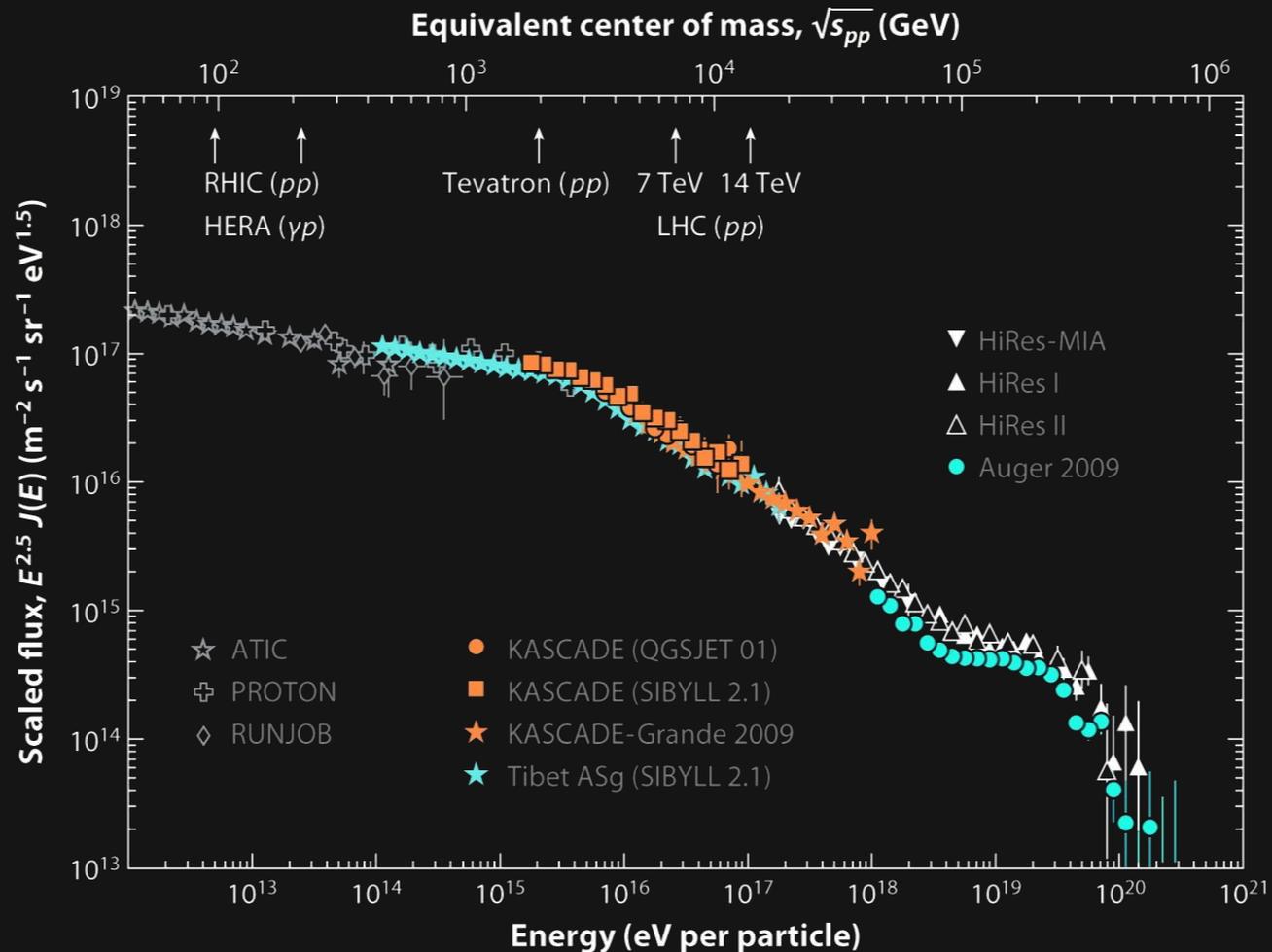


# SIMULAÇÃO E ANÁLISE DE DADOS EM FÍSICA DE ASTROPARTÍCULAS

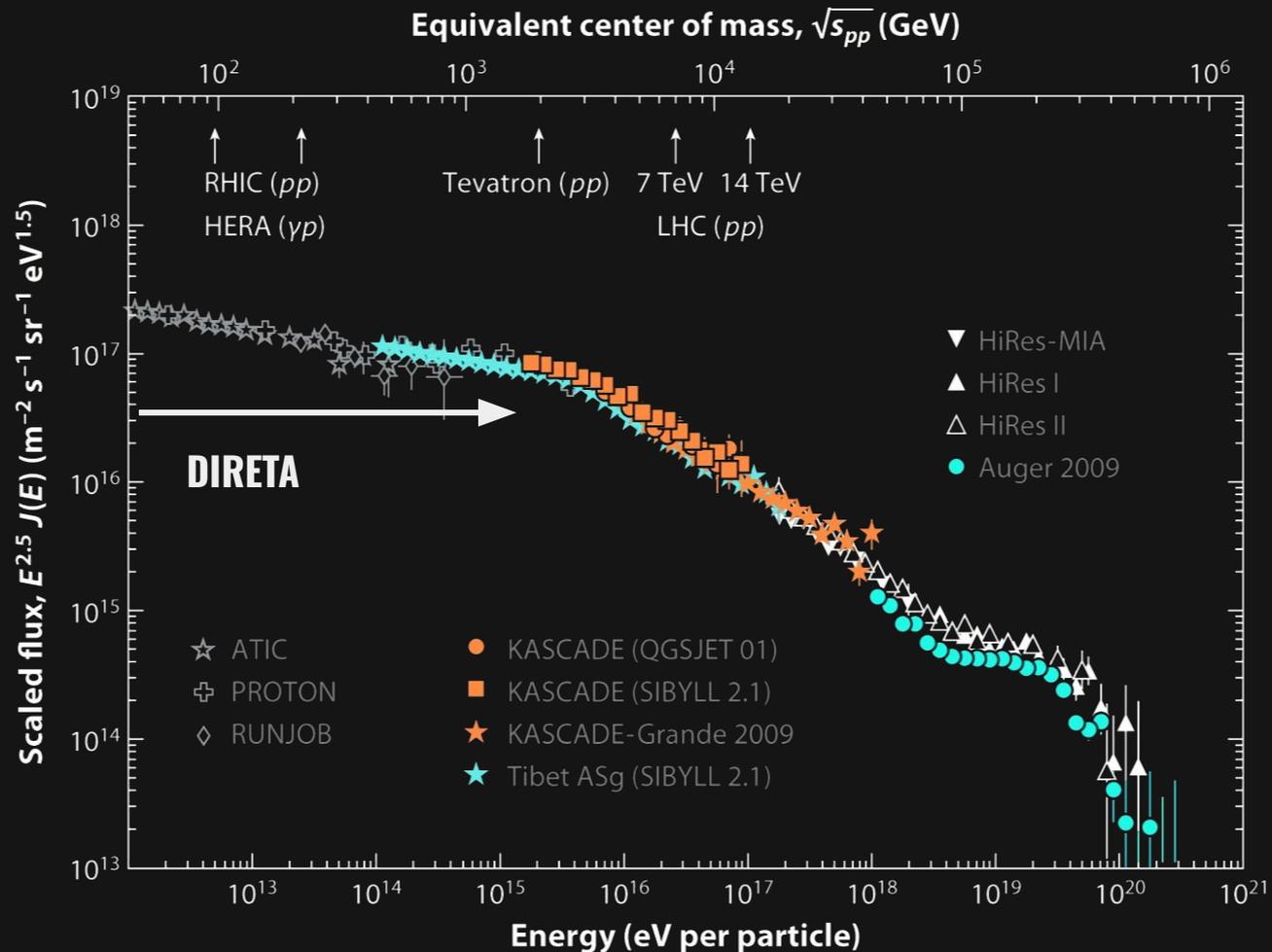
**LUAN BONNEAU ARBELETCHÉ**

luan.arbeletche@gmail.com

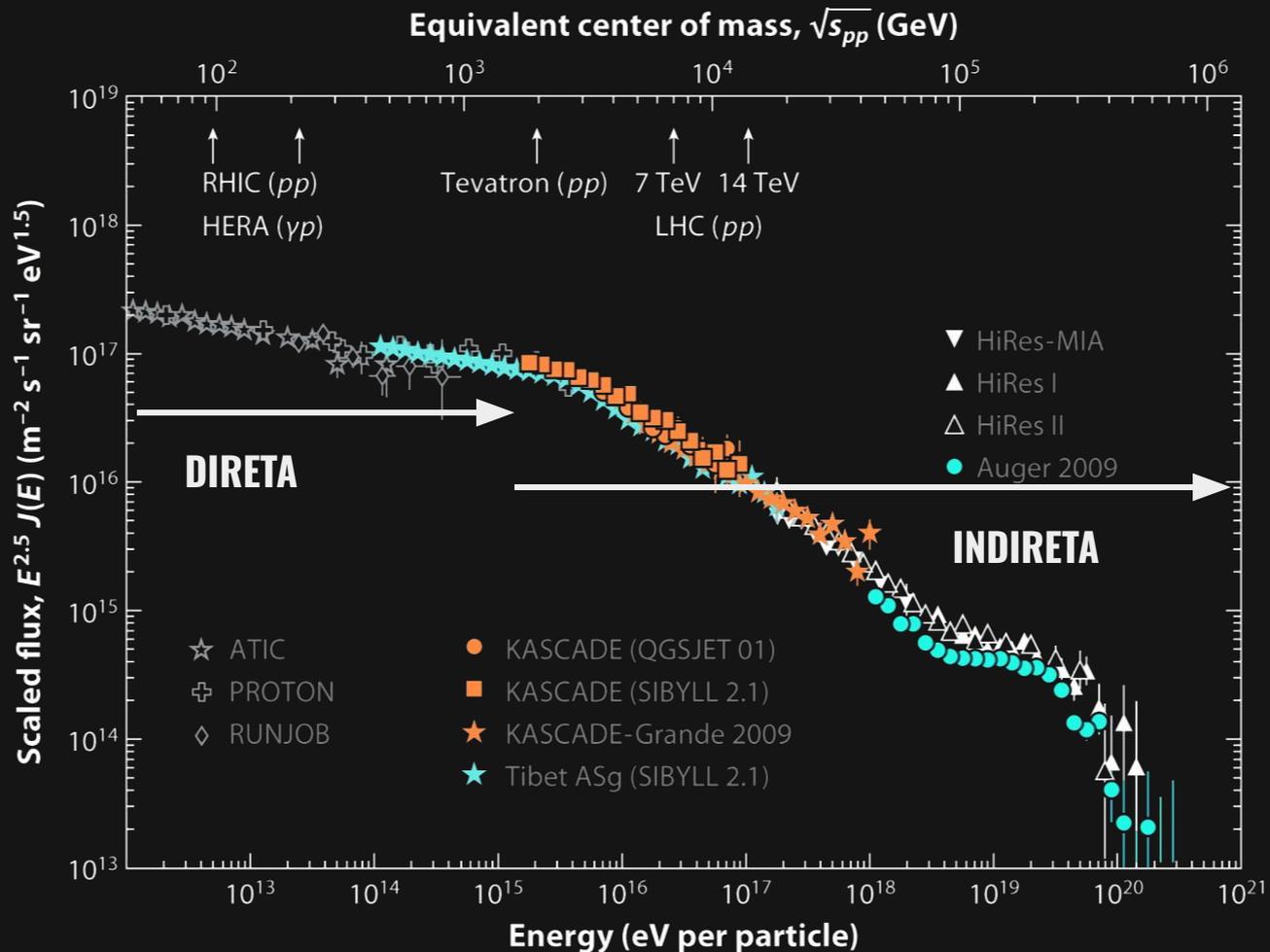
# REGIMES DE DETEÇÃO



# REGIMES DE DETEÇÃO



# REGIMES DE DETEÇÃO



# CHUVEIROS ATMOSFÉRICOS EXTENSOS



# CHUVEIROS ATMOSFÉRICOS EXTENSOS

FONTE



# CHUVEIROS ATMOSFÉRICOS EXTENSOS

FONTE

PARTÍCULA  
PRIMÁRIA



# CHUVEIROS ATMOSFÉRICOS EXTENSOS

FONTE

PARTÍCULA  
PRIMÁRIA

PARTÍCULAS  
SECUNDÁRIAS



# CHUVEIROS ATMOSFÉRICOS EXTENSOS

FONTE

PARTÍCULA  
PRIMÁRIA

PARTÍCULAS  
SECUNDÁRIAS

RADIAÇÃO

- fluorescência
- Cherenkov
- rádio



# CHUVEIROS ATMOSFÉRICOS EXTENSOS

FONTE

PARTÍCULA  
PRIMÁRIA

PARTÍCULAS  
SECUNDÁRIAS

RADIAÇÃO  
- fluorescência  
- Cherenkov  
- rádio

PARTÍCULAS NO SOLO



# FERRAMENTAS DE SIMULAÇÃO

## **i. CORSIKA**

Monte Carlo  
completo

## **ii. CONEX**

Monte Carlo +  
eq. de cascata

# FERRAMENTAS DE SIMULAÇÃO

## i. CORSIKA

Monte Carlo  
completo



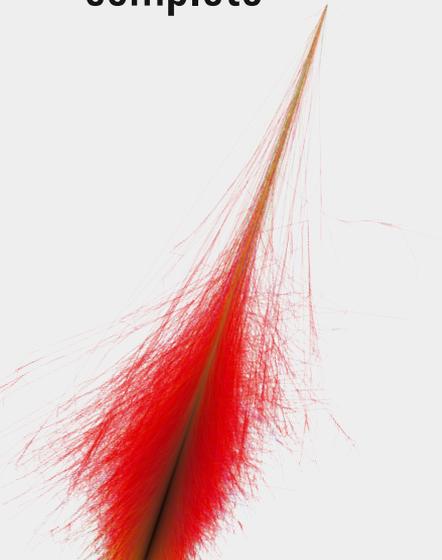
## ii. CONEX

Monte Carlo +  
eq. de cascata

# FERRAMENTAS DE SIMULAÇÃO

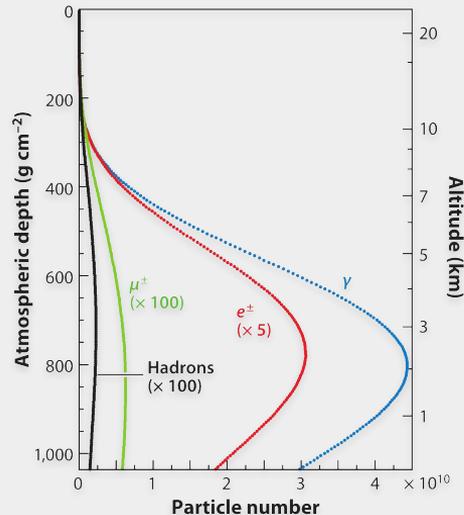
## i. CORSIKA

Monte Carlo  
completo



## ii. CONEX

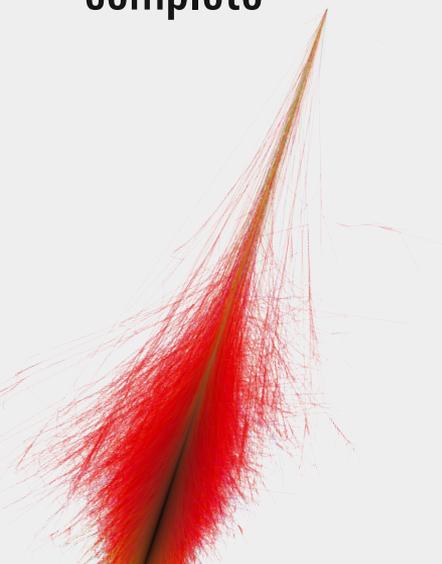
Monte Carlo +  
eq. de cascata



# FERRAMENTAS DE SIMULAÇÃO

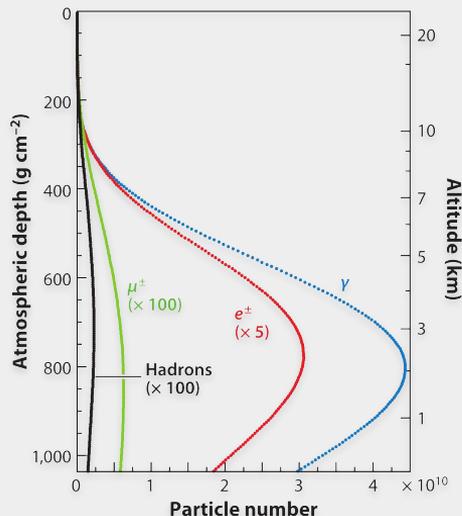
## i. CORSIKA

Monte Carlo  
completo



## ii. CONEX

Monte Carlo +  
eq. de cascata



## MODELOS DE INTERAÇÃO

- cascata eletromagnética
- interações hadrônicas

# FERRAMENTAS DE SIMULAÇÃO

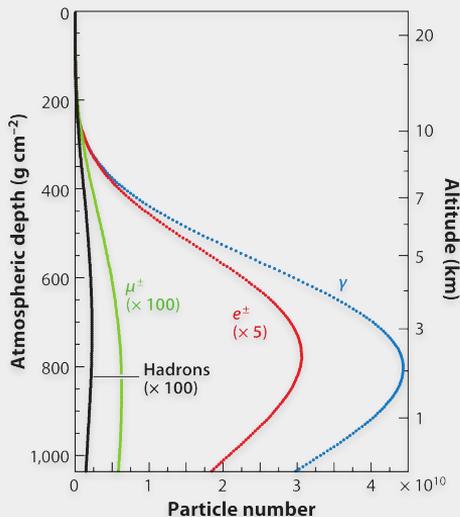
## i. CORSIKA

Monte Carlo  
completo



## ii. CONEX

Monte Carlo +  
eq. de cascata

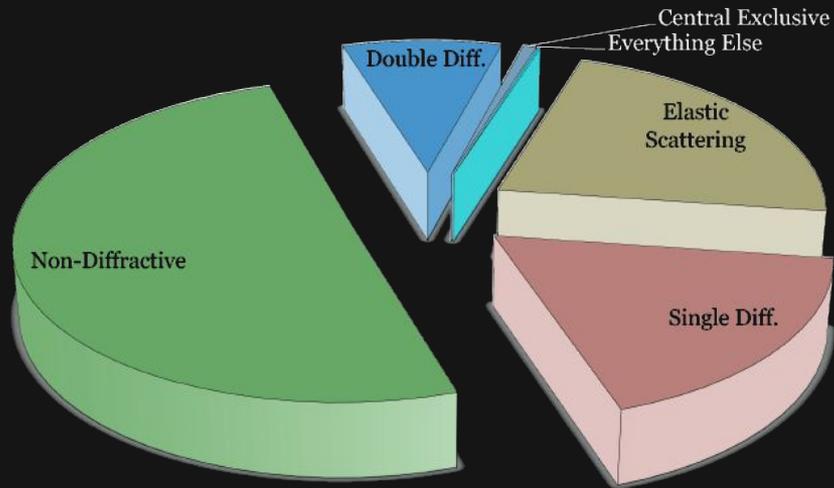


## MODELOS DE INTERAÇÃO

- cascata eletromagnética
- interações hadrônicas

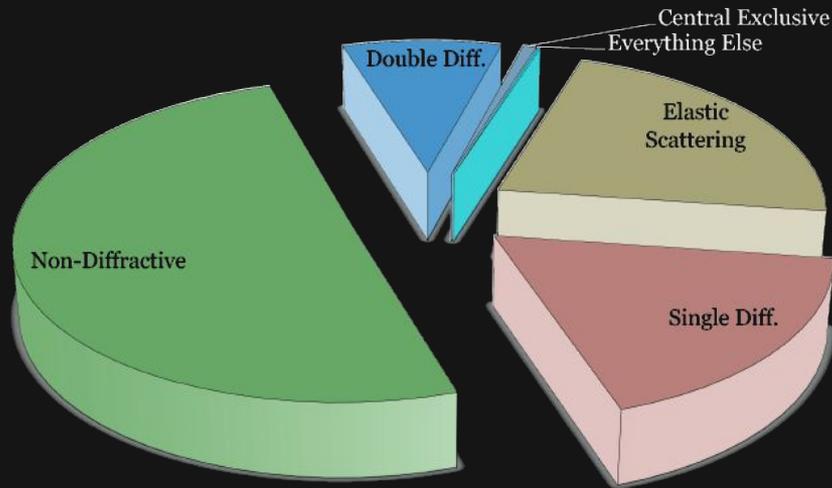
**EPOS, Sibyll, QGSJet,  
VENUS, Pythia, DPMJet,  
etc**

# INTERAÇÕES HADRÔNICAS



seção de choque hádron-hádron

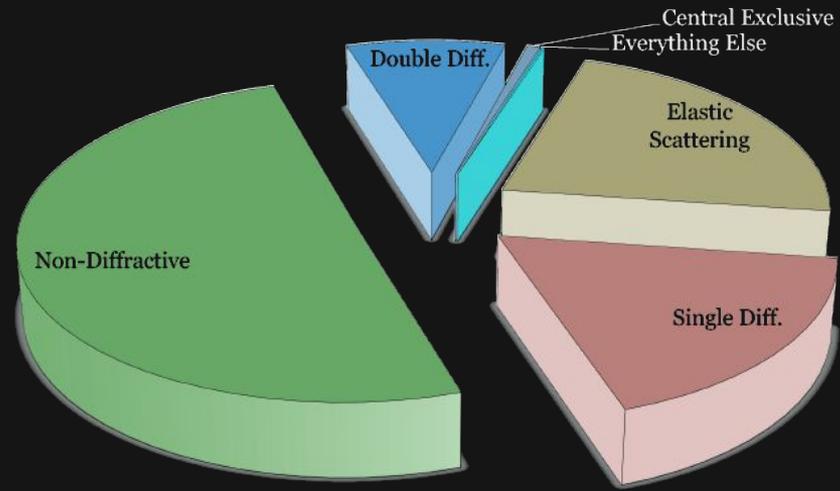
# INTERAÇÕES HADRÔNICAS



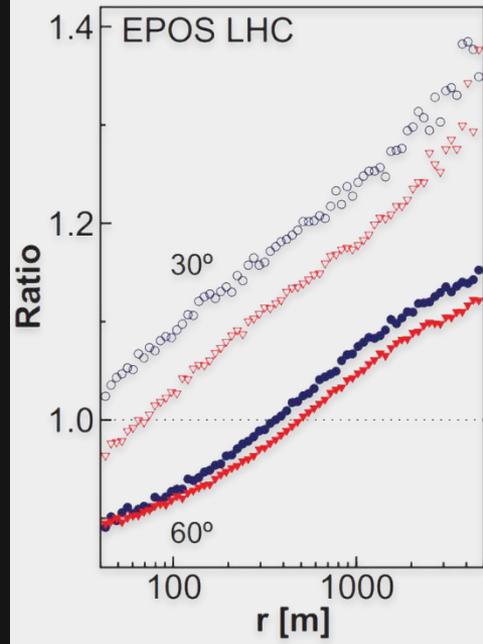
seção de choque hádron-hádron

**DIFRAÇÃO  
VS  
NÃO-DIFRAÇÃO**

# INTERAÇÕES HADRÔNICAS



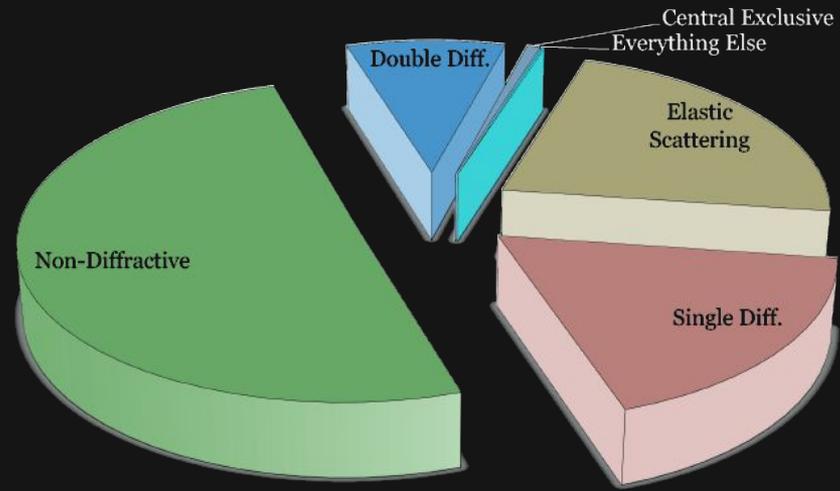
seção de choque hádron-hádron



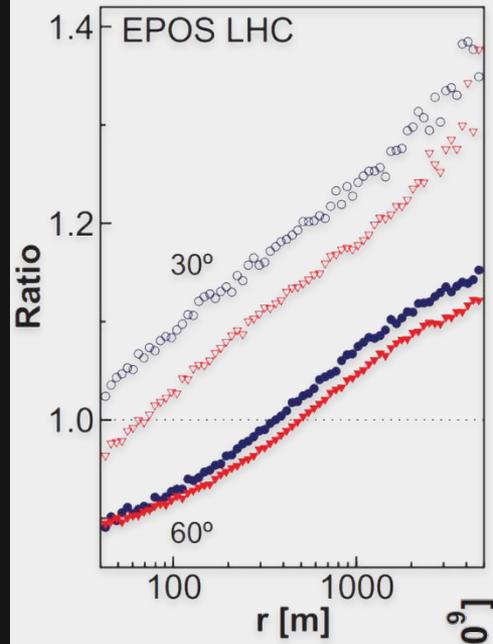
distribuição lateral de múons

## DIFRAÇÃO VS NÃO-DIFRAÇÃO

# INTERAÇÕES HADRÔNICAS



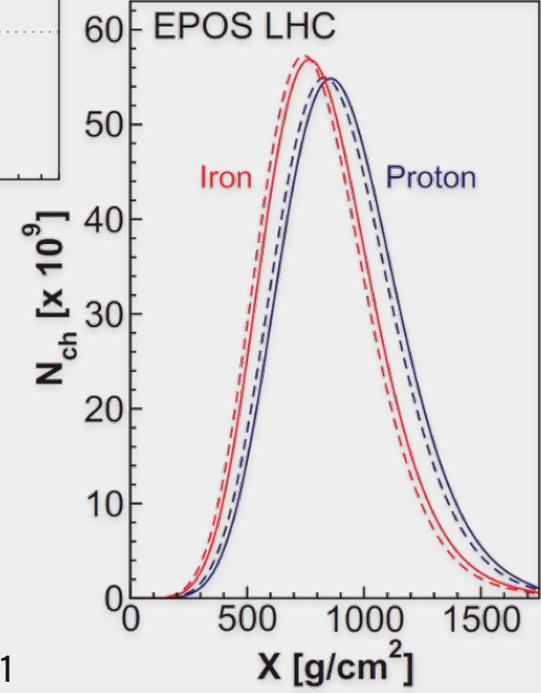
seção de choque hádron-hádron



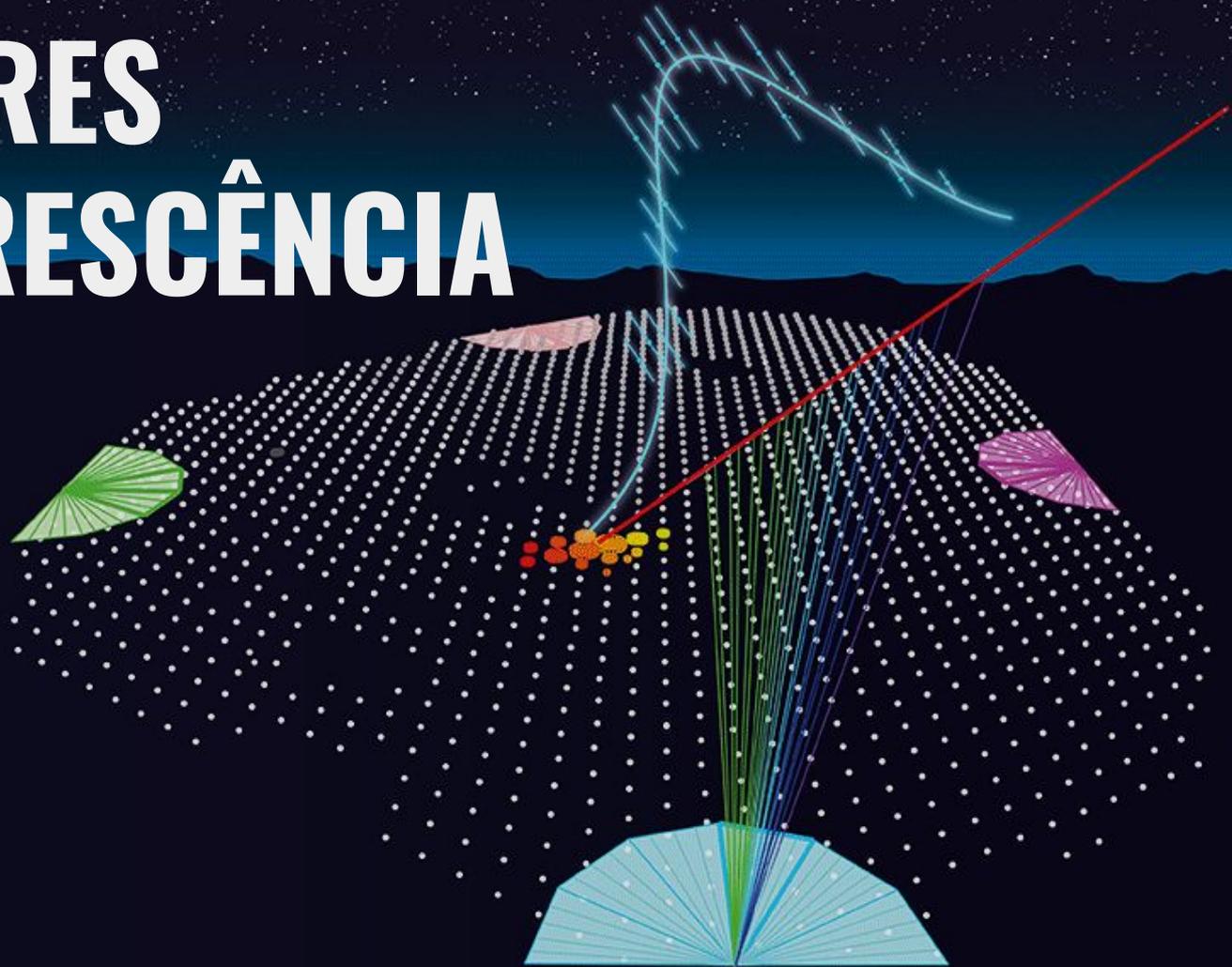
distribuição lateral de múons

## DIFRAÇÃO VS NÃO-DIFRAÇÃO

perfil longitudinal:  $\sim 20 \text{ g/cm}^2$

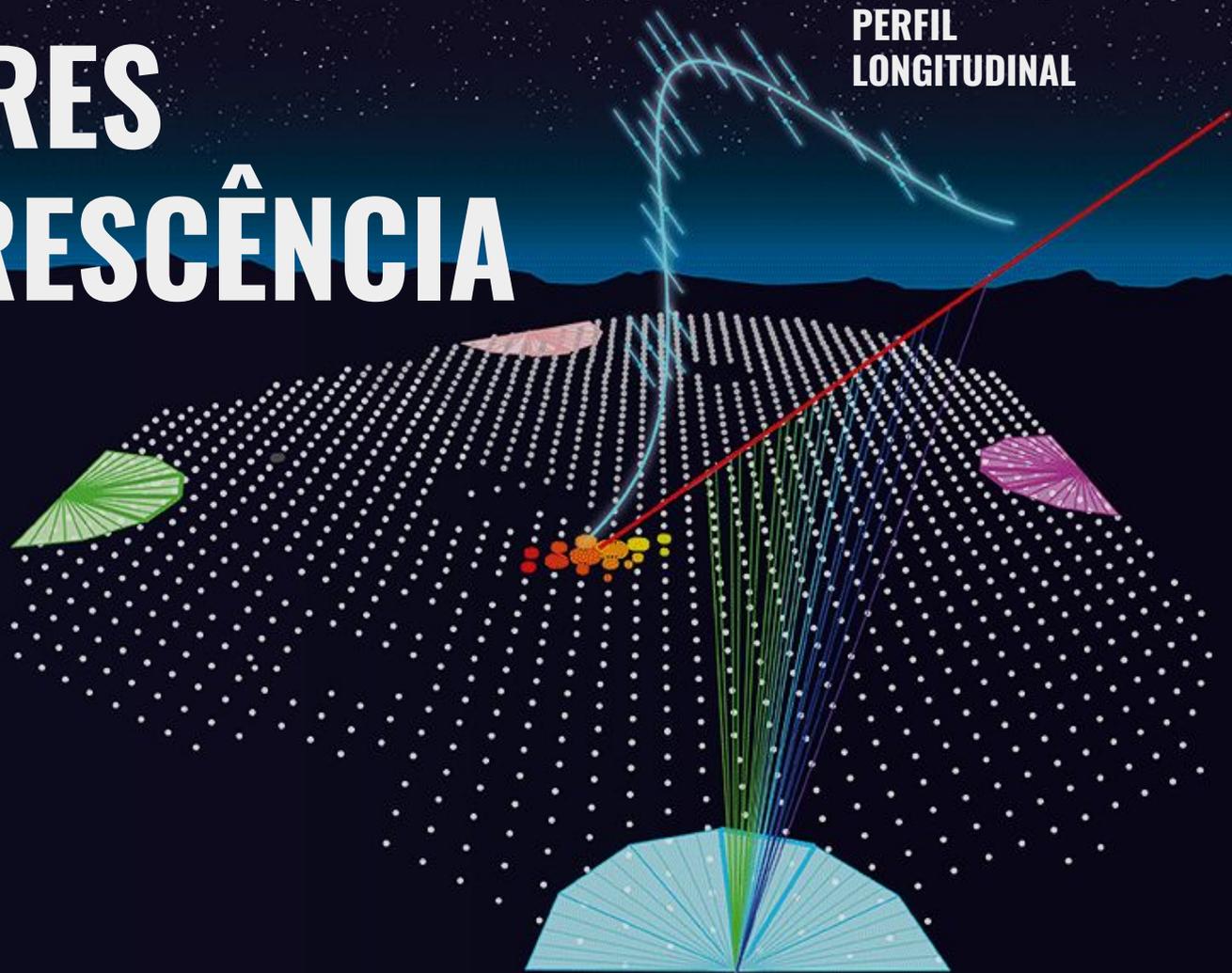


# DETECTORES DE FLUORESCÊNCIA

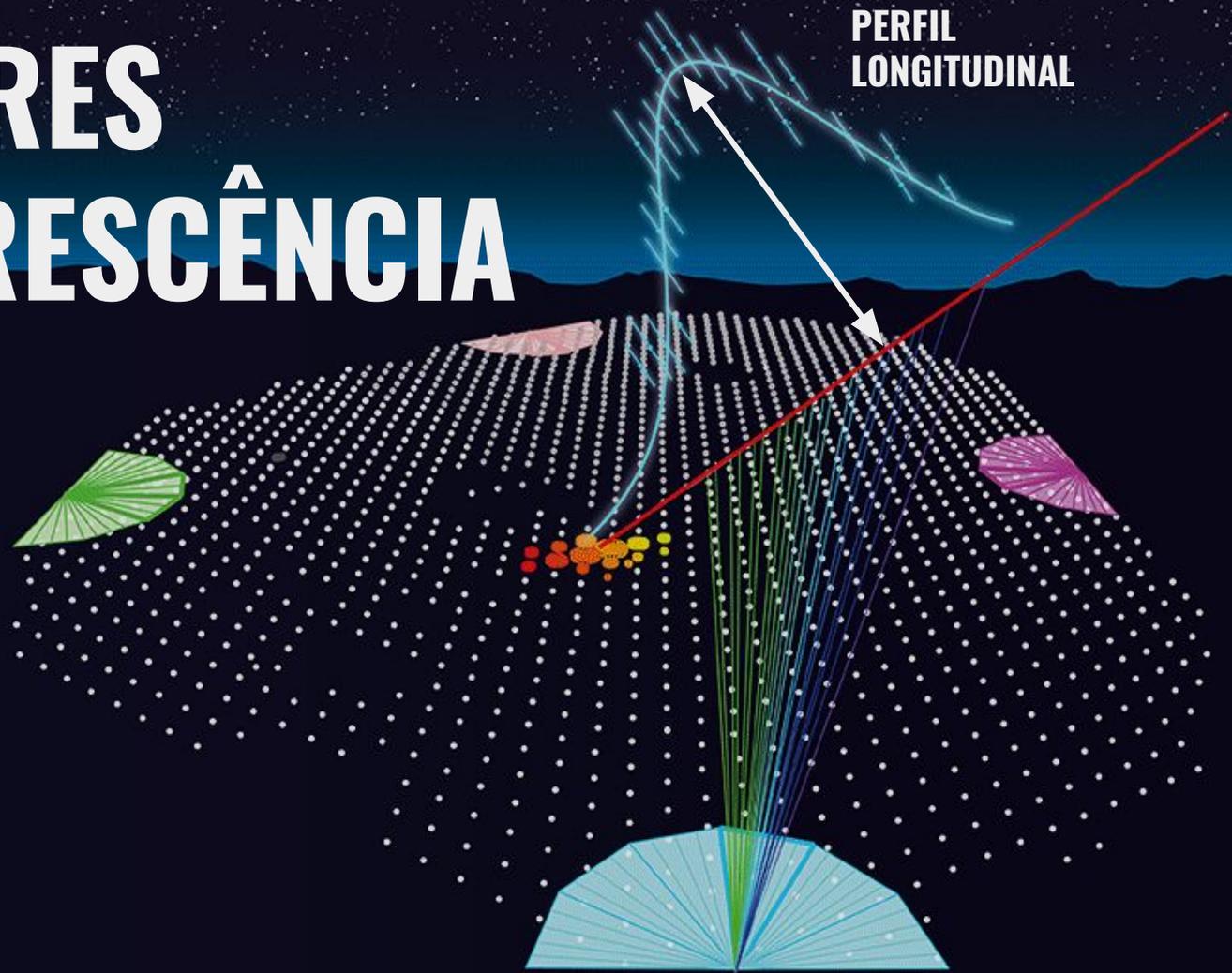


# DETECTORES DE FLUORESCÊNCIA

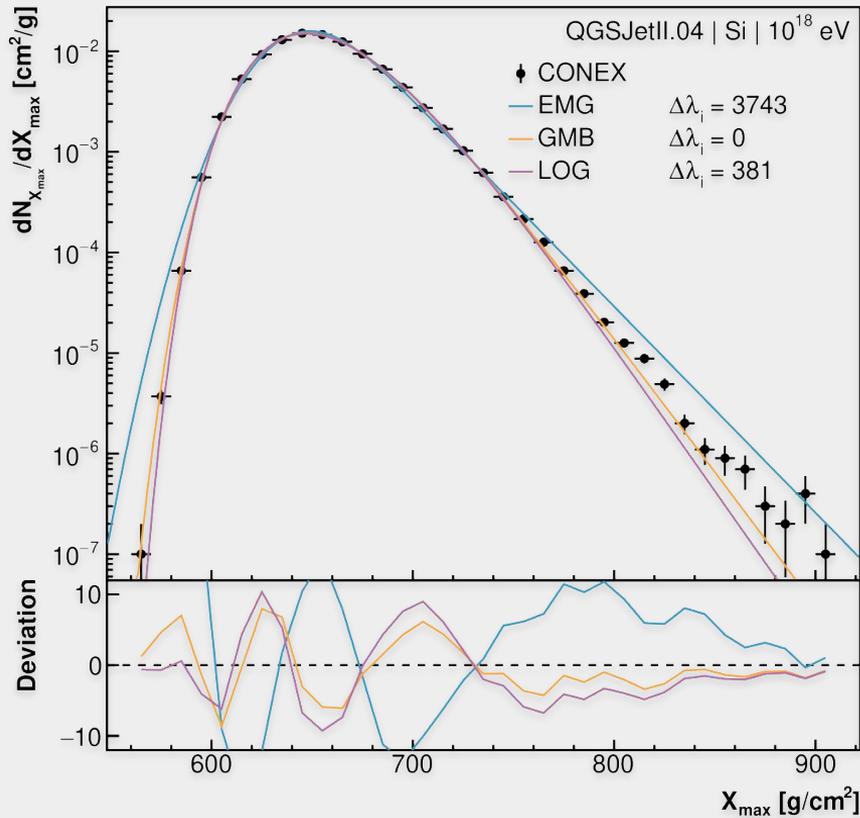
PERFIL  
LONGITUDINAL



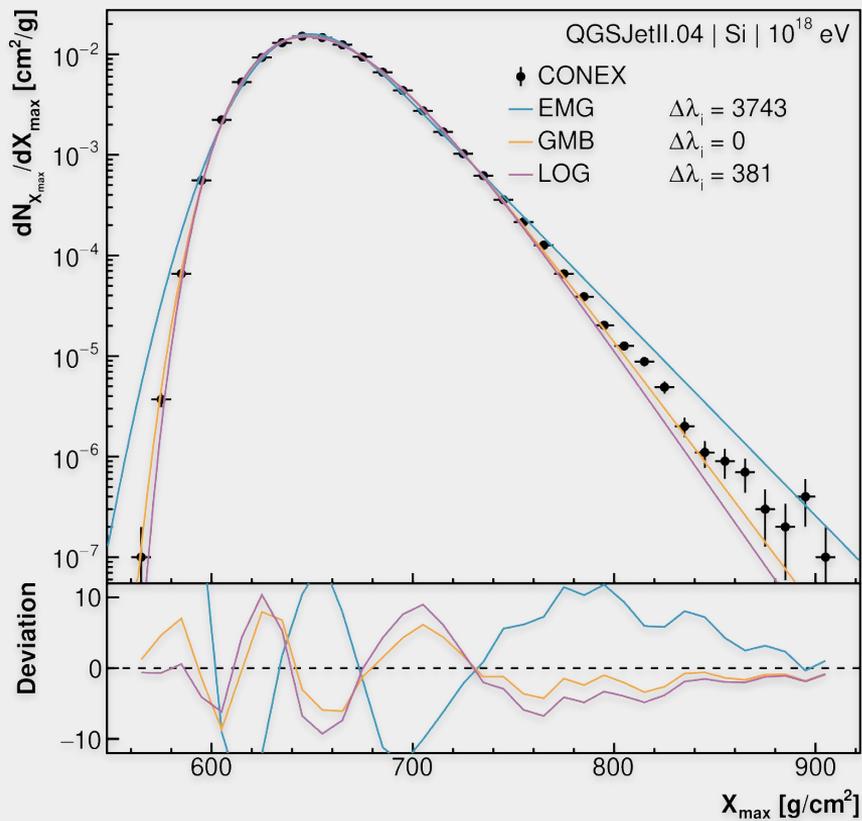
# DETECTORES DE FLUORESCÊNCIA



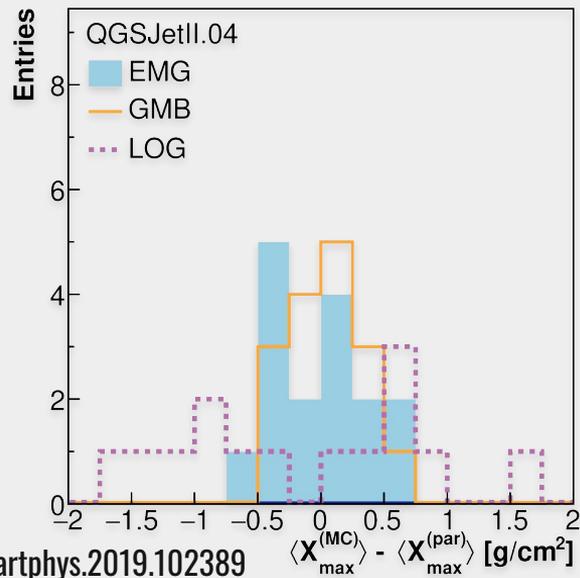
# DISTRIBUIÇÕES DE $X_{\text{MAX}}$



# DISTRIBUIÇÕES DE $X_{\text{MAX}}$



**PARAMETRIÇÃO EM ENERGIA E MASSA PRIMÁRIA**  
desvio da média  $< 2 \text{ g}/\text{cm}^2$



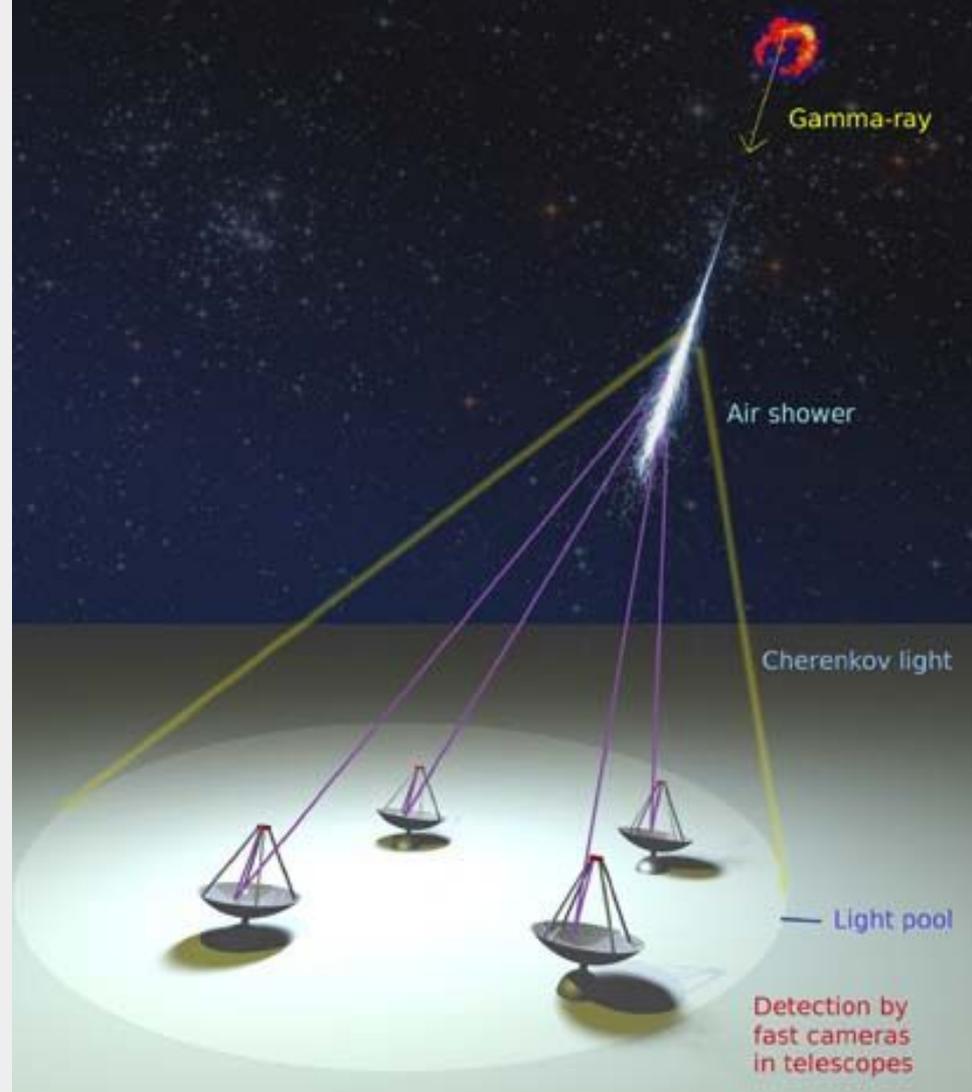
doi:10.1016/j.astropartphys.2019.102389

# TELESCÓPIOS DE IMAGEM CHERENKOV

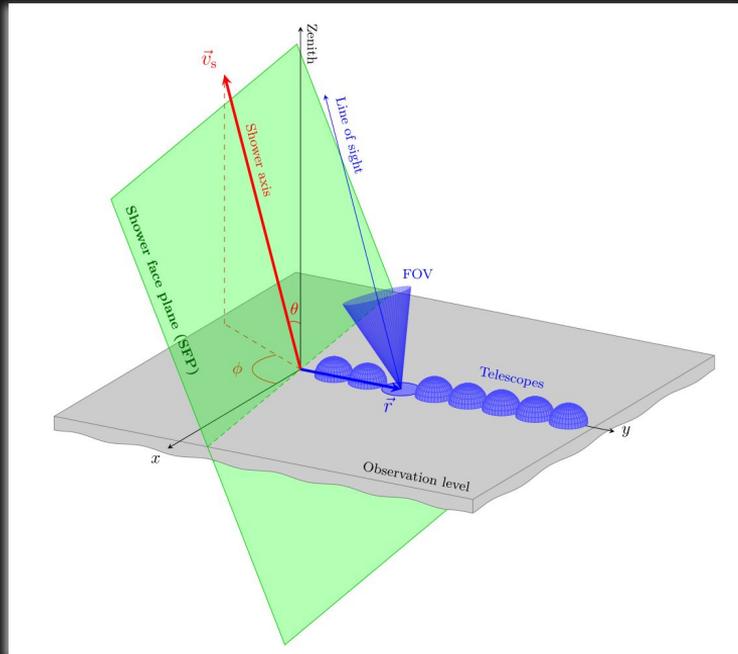
**sinal dominado por luz Cherenkov**

**energias ~10 GeV a ~300 TeV**

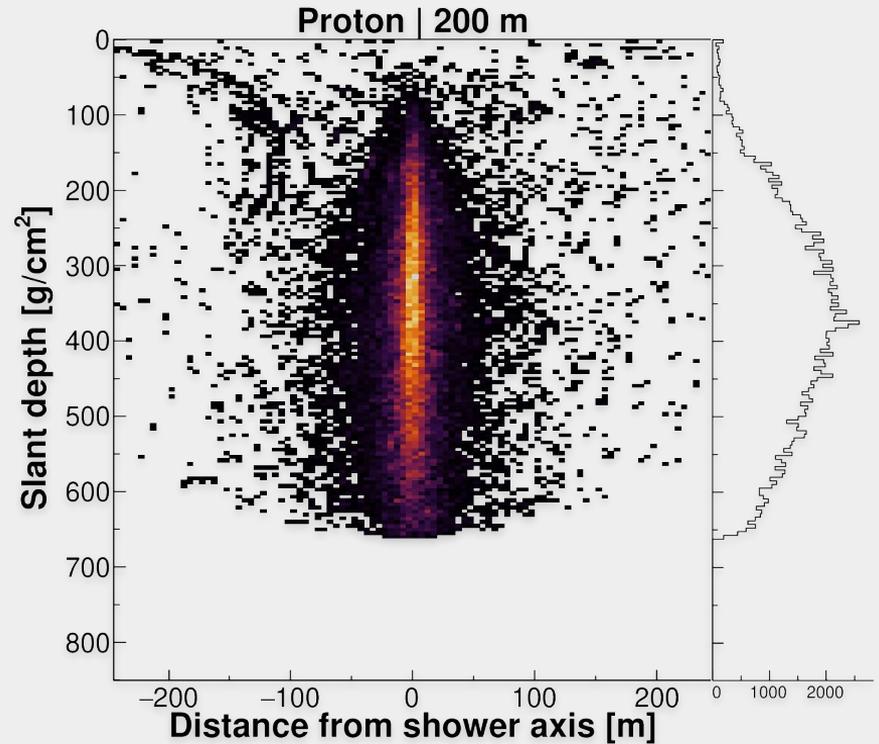
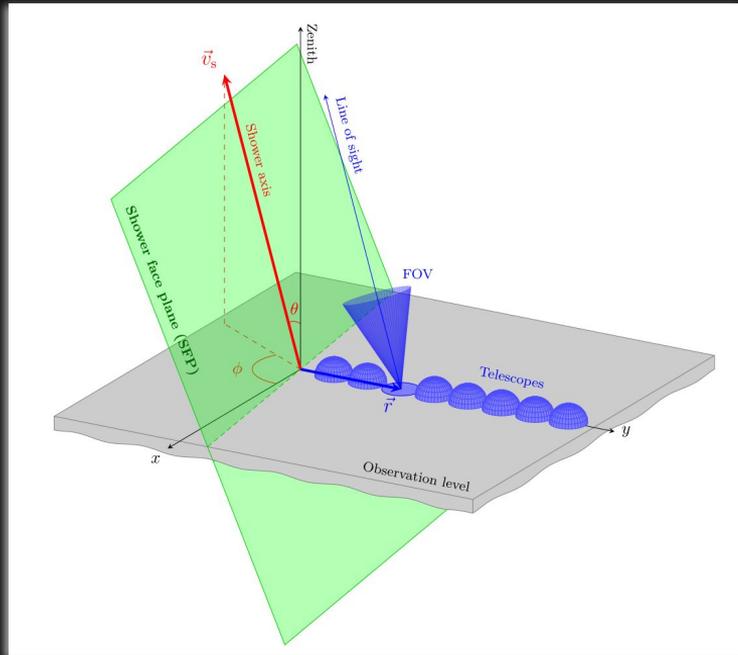
**raios gamma + background hadrônico**



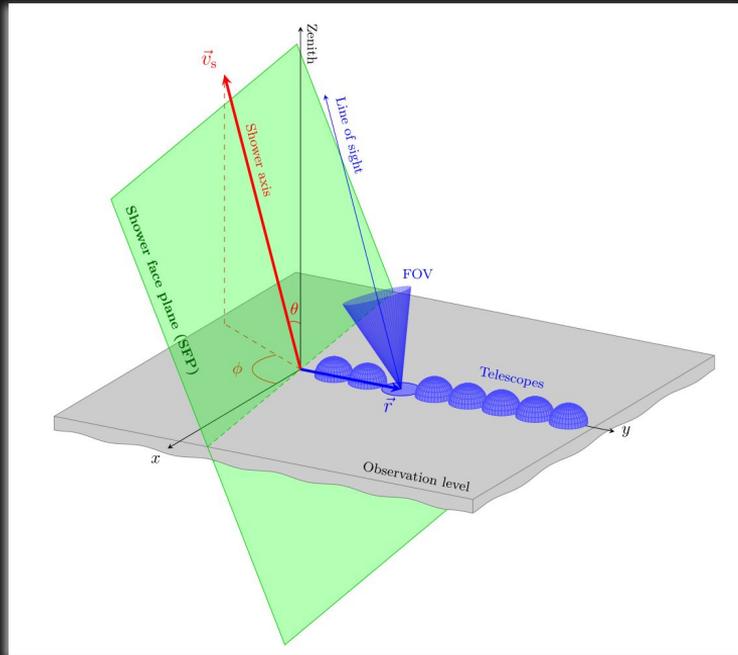
# MEDIDA DE $X_{\text{MAX}}$ USANDO IACTs



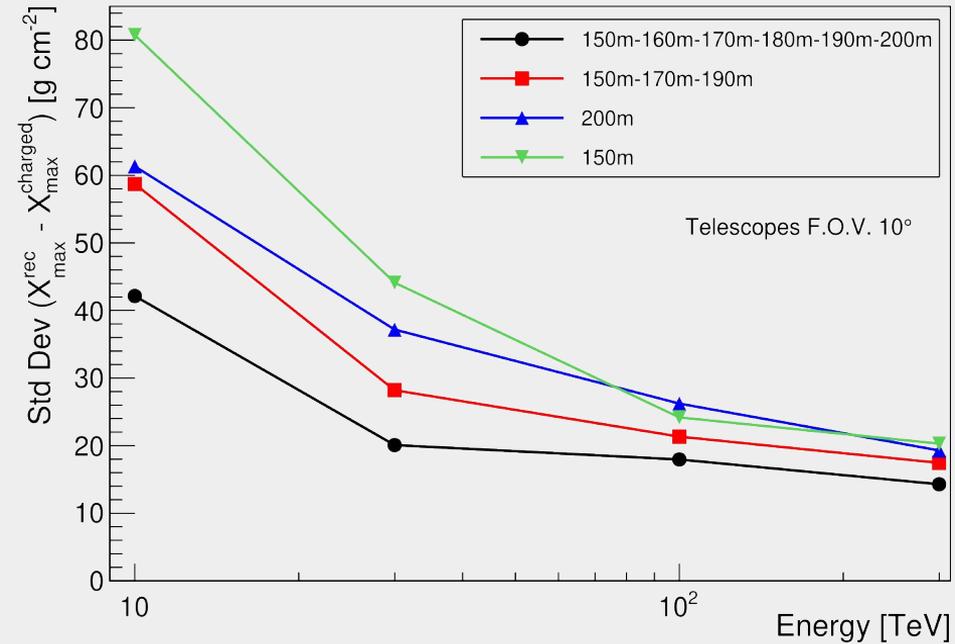
# MEDIDA DE $X_{\text{MAX}}$ USANDO IACTs



# MEDIDA DE $X_{\text{MAX}}$ USANDO IACTs



## RESOLUÇÃO COMPARÁVEL A DETECTORES DE FLUORESCÊNCIA



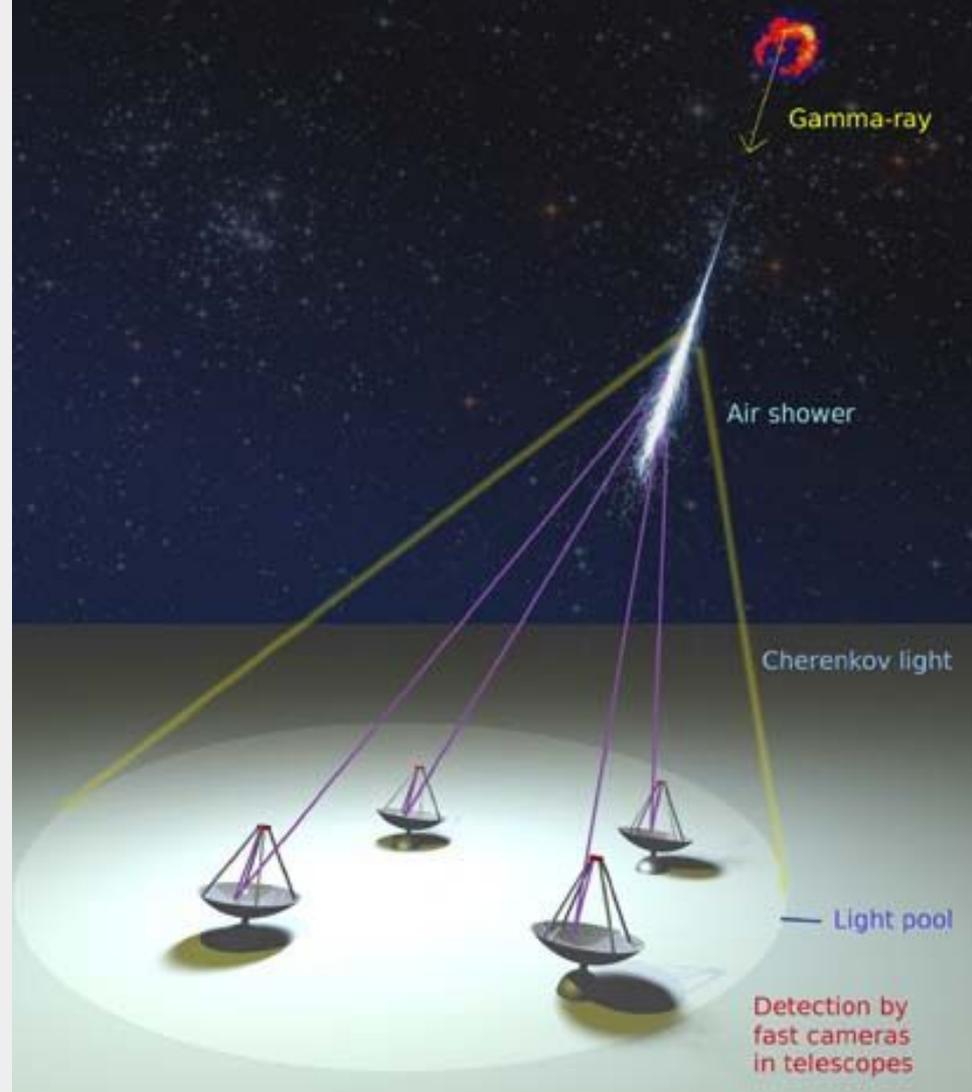
# TELESCÓPIOS DE IMAGEM CHERENKOV

sinal dominado por luz Cherenkov

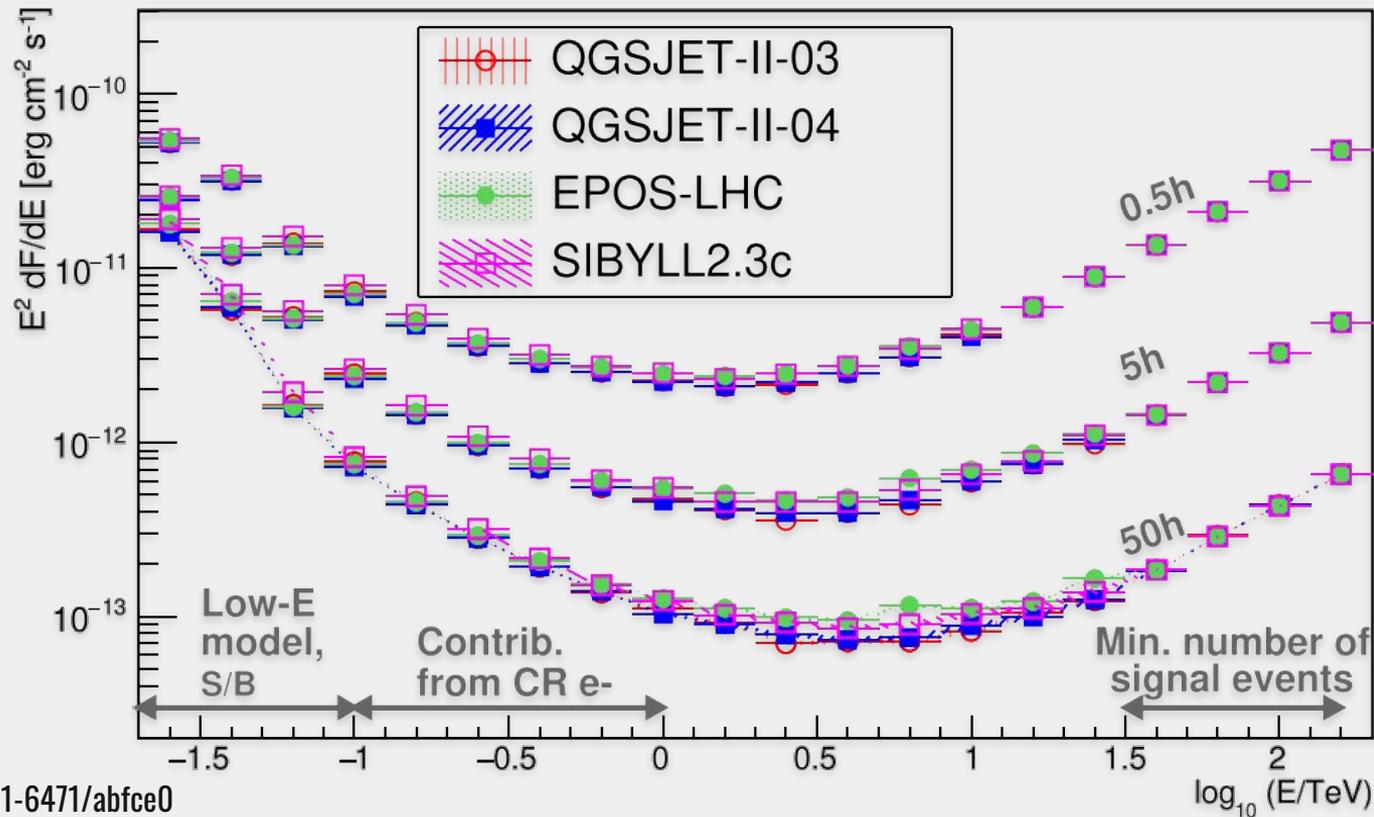
energias  $\sim 10$  GeV a  $\sim 300$  TeV

raios gamma + background hadrônico

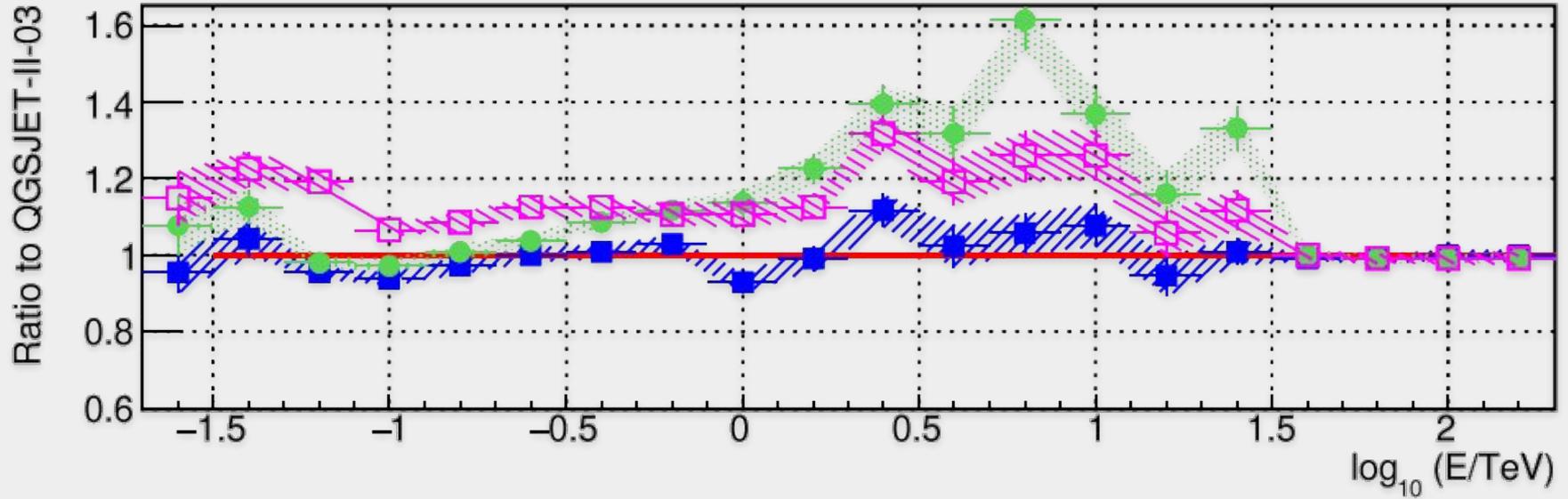
**sensibilidade do experimento**



# SENSIBILIDADE DO CTA



# SENSIBILIDADE DO CTA



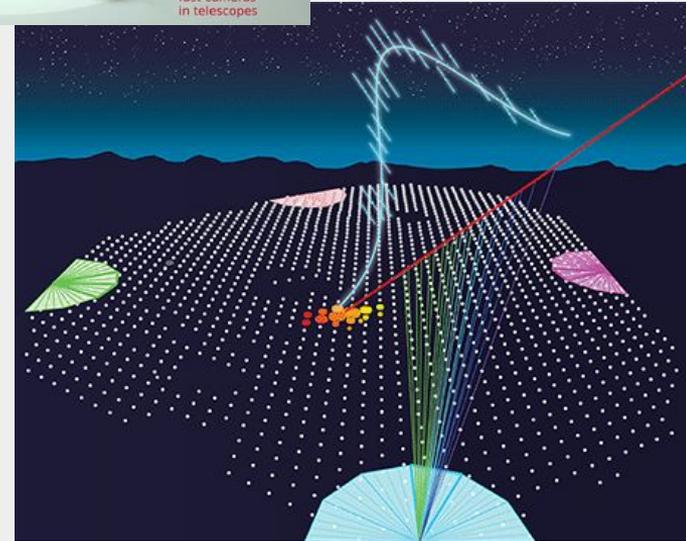
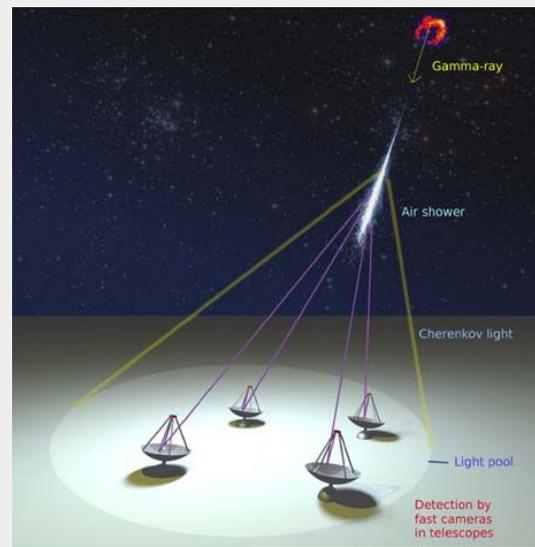
# TELESCÓPIOS ÓTICOS

$$y_i = y_i^{\text{Fl}} + y_i^{\text{Cd}} + y_i^{\text{Cs}}$$

(Fl) luz de fluorescência

(Cd) luz Cherenkov direta

(Cs) luz Cherenkov espalhada



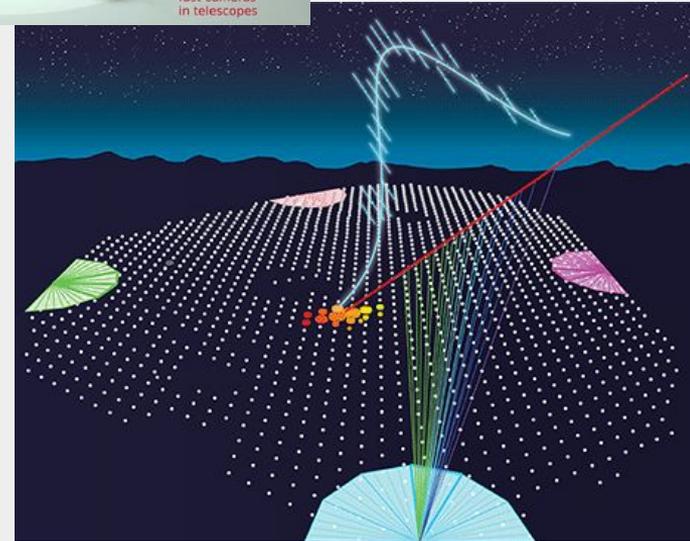
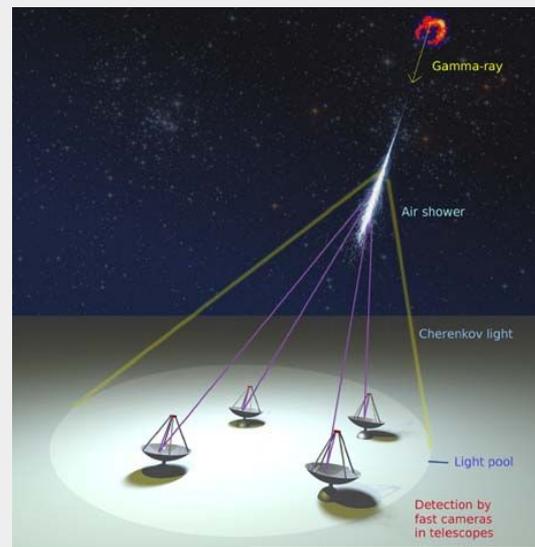
# TELESCÓPIOS ÓTICOS

$$y_i = y_i^{\text{Fl}} + y_i^{\text{Cd}} + y_i^{\text{Cs}}$$

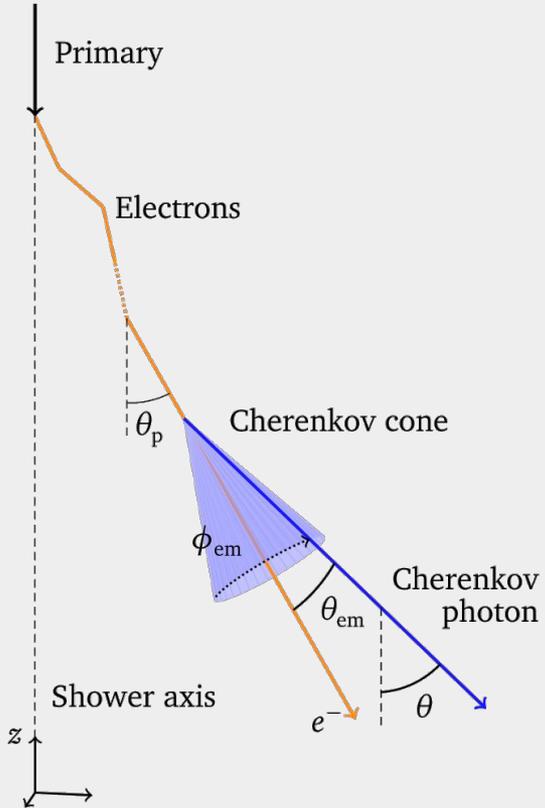
(Fl) luz de fluorescência

(Cd) luz Cherenkov direta

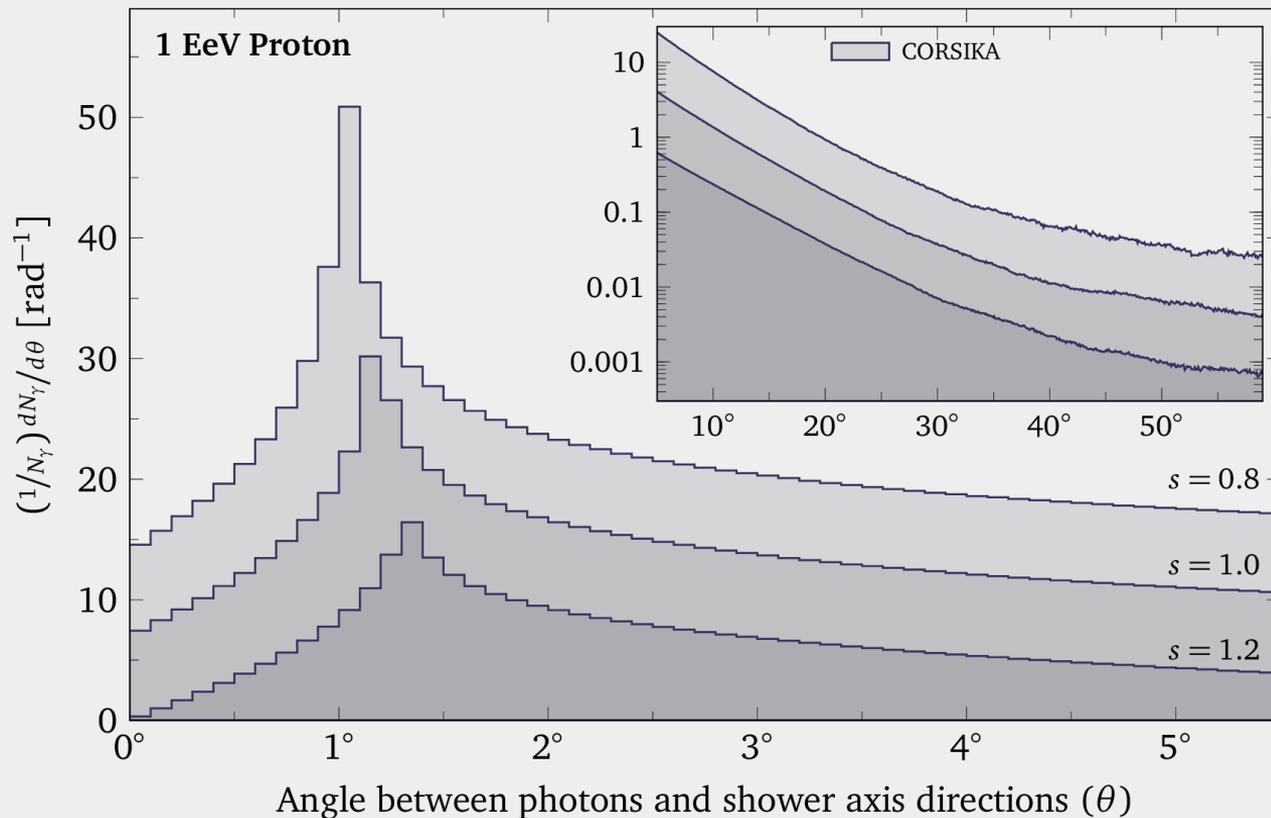
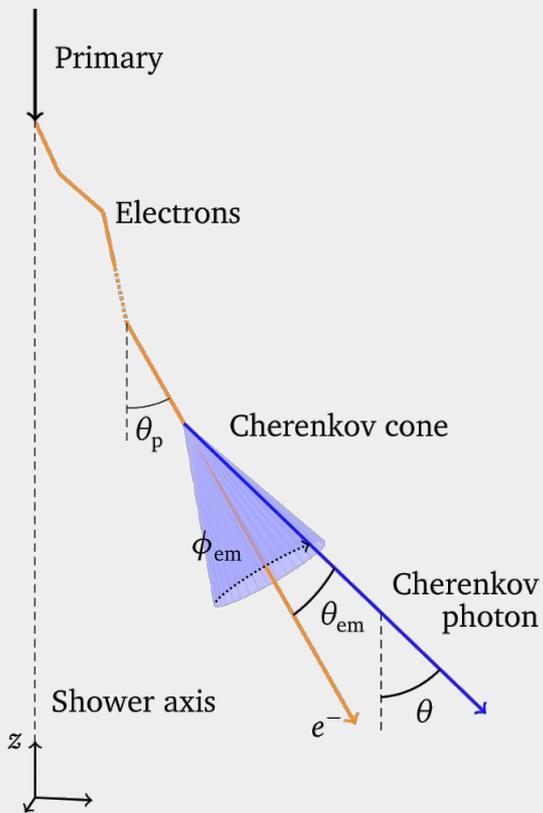
(Cs) luz Cherenkov espalhada



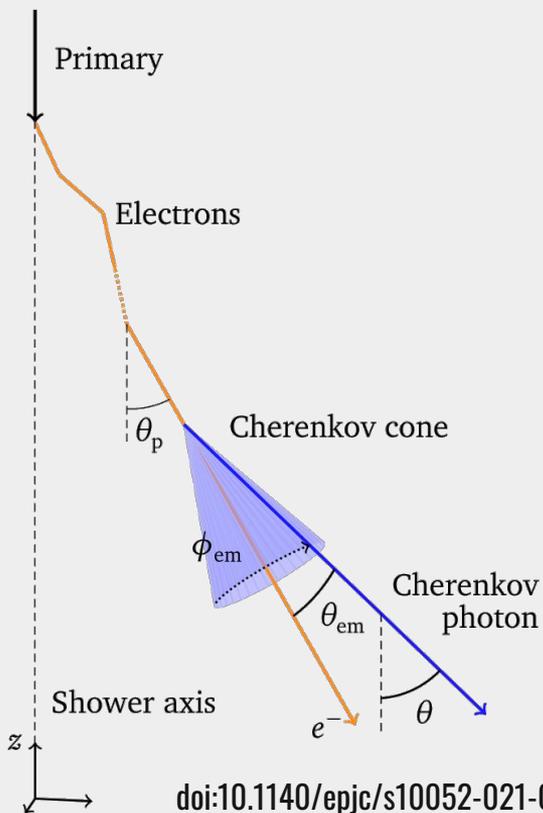
# LUZ CHERENKOV DIRETA



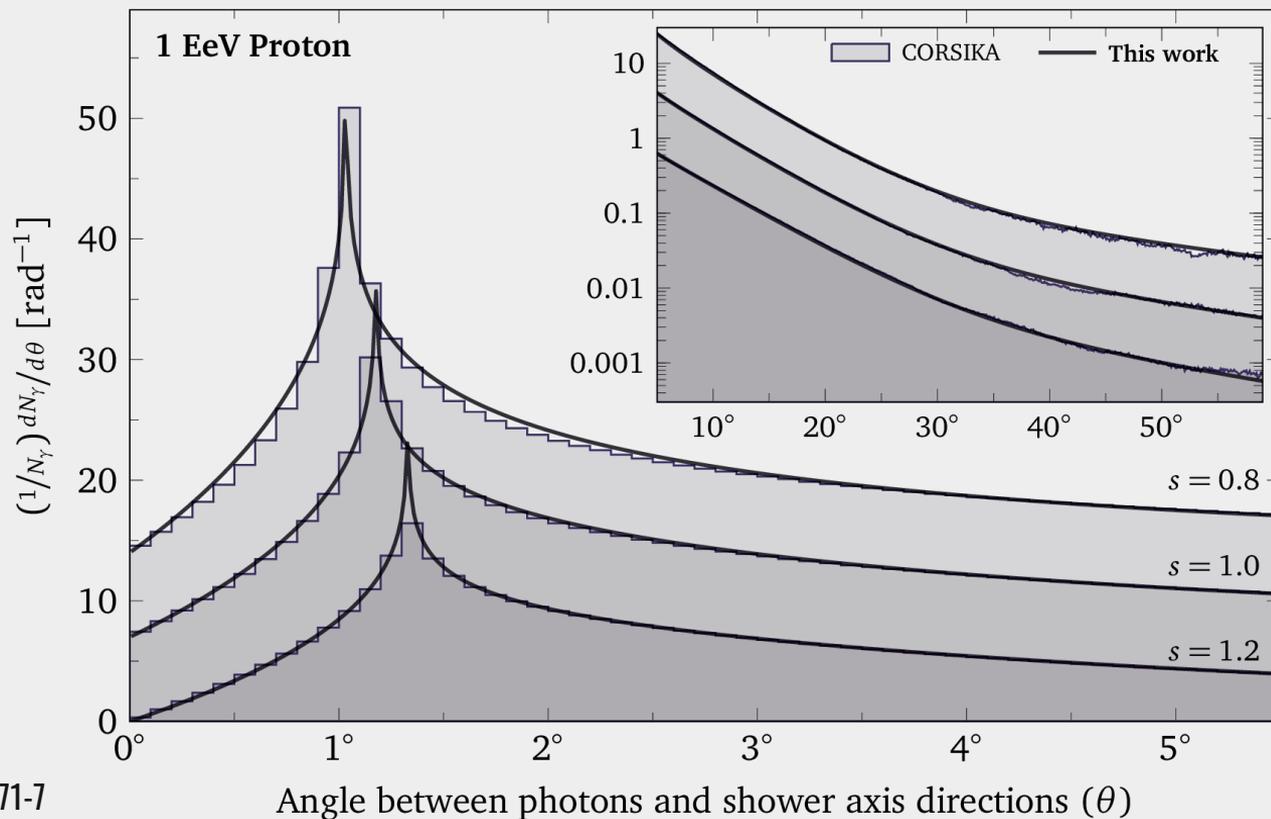
# LUZ CHERENKOV DIRETA



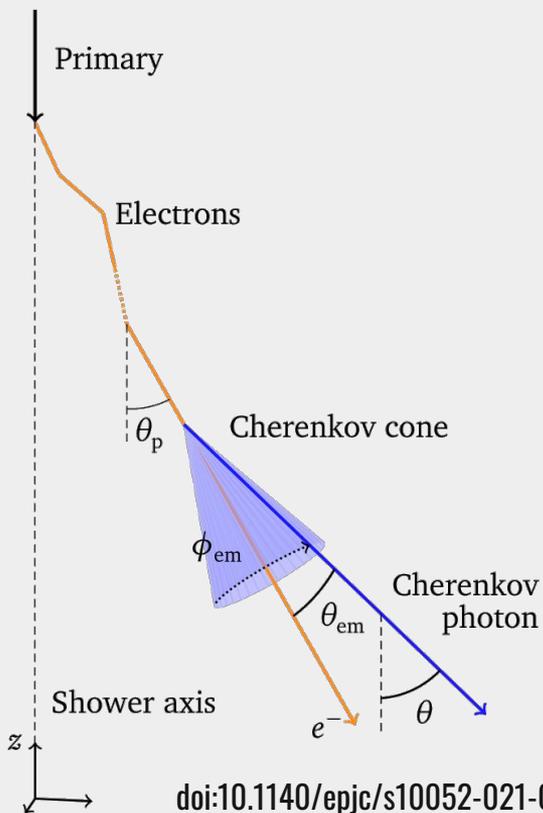
# LUZ CHERENKOV DIRETA



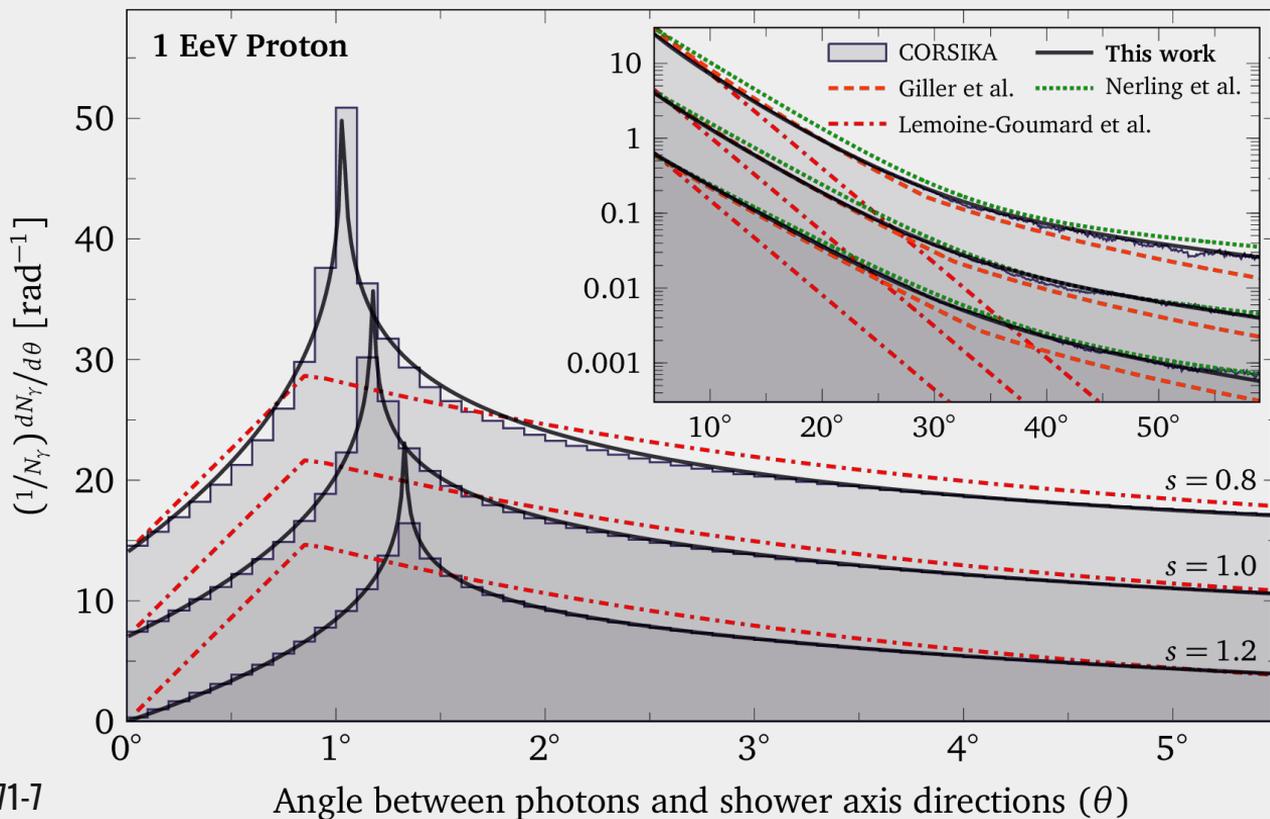
doi:10.1140/epjc/s10052-021-08971-7



# LUZ CHERENKOV DIRETA



doi:10.1140/epjc/s10052-021-08971-7



# CONSIDERAÇÕES FINAIS

## DETECÇÃO INDIRETA

observáveis de chuveiros  $\Rightarrow$  partícula primária

## DESCRIÇÃO DE CHUVEIROS $\leftrightarrow$ INTERAÇÕES HADRÔNICAS

## SIMULAÇÕES

interações hadrônicas em diferentes regimes  
profundidade de máximo: composição  
sinal de luz Cherenkov

**OBRIGADO!**

