Diffractive excitation in pp and pA scattering at high energies

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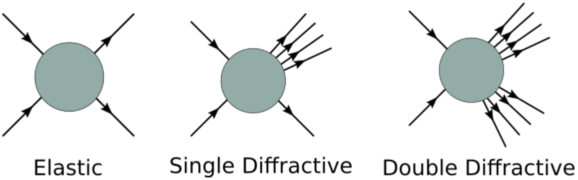
Introduction

- Hadronic soft scattering is a challenge for QCD
- Elastic, Single and Double diff. are dominated by non-perturbative effects



- Dissociation $\rightarrow \begin{cases} \text{hadron has internal structure} \\ \text{fluctuations in proton's wave function} \end{cases}$

Good-Walker Approach [Phys.Rev. (1960)]

- Particle states written in terms of **interaction eigenstates**, $|\psi_k\rangle$
- Eigenstates of scattering matrix S

$$S|\psi_k\rangle = t_k|\psi_k\rangle$$

- Cross sections are given by

$$\frac{d\sigma_{\rm tot}}{d^2\mathbf{b}} = \langle t\rangle$$

$$\frac{d\sigma_{\rm el}}{d^2\mathbf{b}} = \langle t\rangle^2$$

$$\frac{d\sigma_{\rm diff}}{d^2\mathbf{b}} = \langle t^2\rangle - \langle t\rangle^2$$

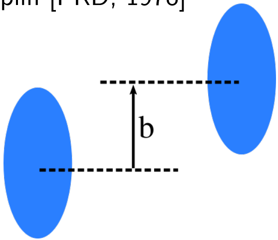
In this talk

- Dissociation in pp and pA scattering
- Predicitons for LHC energies and beyond
- $pp \rightarrow$ Miettinen-Pumplin Model
  - Energy dependence of parameters
  - Amplitudes in b-space
- $pA \rightarrow$ Glauber + fluctuations
  - Estimate diffraction cross sections in pA for several nuclei

pp scattering

Miettinen-Pumplin Model

- Eingestates for pp scattering using Miettinen-Pumplin [PRD, 1978]
- Amplitudes in impact parameter $\mathbf{b}$ space



- Only partons with small fraction of proton's momentum contribute
- Eingenstate can have $N(=1, 2, \dots)$ partons, each with y_i and $\mathbf{b}_i$

$$|H\rangle = \sum_N \int \prod_{i=1}^{N} d^2\mathbf{b}_i dy_i C_N(\{\mathbf{b}_i\};\{y_i\})\,|\mathbf{b}_1,\dots,\mathbf{b}_N;y_1,\dots,y_N\rangle$$

Miettinen-Pumplin Model

- **Uncorrelated** partons

$$|C_N(\mathbf{b}_1,\ldots,\mathbf{b}_N;y_1,\ldots,y_N)|^2 = e^{-G^2}\left(\frac{G^{2N}}{N!}\right)\prod_{i=1}^{N}|C_i(\mathbf{b}_i,y_i)|^2$$

- G^2: mean number of partons in the eigenstate

- Probability density of i-th parton in the eigenstate

$$|C_i(\mathbf{b}_i,y_i)|^2 = \frac{1}{2\pi\beta\lambda}\exp\left(-\frac{|y_i|}{\lambda}-\frac{|\mathbf{b}_i|^2}{\beta}\right)$$

Miettinen-Pumplin Model

- Partons interact in an **independent** way
- Total probability of interaction

$$t(\mathbf{b}_1,\ldots,\mathbf{b}_N;y_1,\ldots,y_N;\mathbf{b}) = 1-\prod_{i=1}^{N}(1-\tau(\mathbf{b}_i-\mathbf{b},y_i))$$

- With

$$\tau(\mathbf{b},y) = A\exp\left(-\frac{|y|}{\alpha}-\frac{|\mathbf{b}|^2}{\gamma}\right)$$

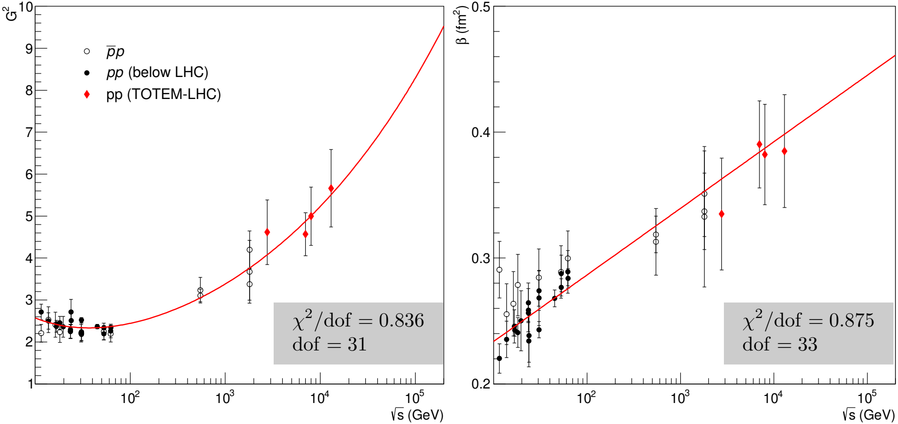
Miettinen-Pumplin Model

$$\frac{d\sigma_{\rm tot}}{d^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{4}{9}G^2 e^{-b^2/(3\beta)}\right)\right]$$

$$\frac{d\sigma_{\rm el}}{d^2\mathbf{b}} = \left[1 - \exp\left(-\frac{4}{9}G^2 e^{-b^2/(3\beta)}\right)\right]^2$$

- G^2 e β are determined from experimental values of $\sigma_{\rm tot}$ and $\sigma_{\rm el}$
- Strategy used in MP paper and also in Sapeta, Golec-Biernat, PLB (2005)
- Data in the range 10 GeV $\leq \sqrt{s} \leq$ 13 TeV

G^2 and β parameters

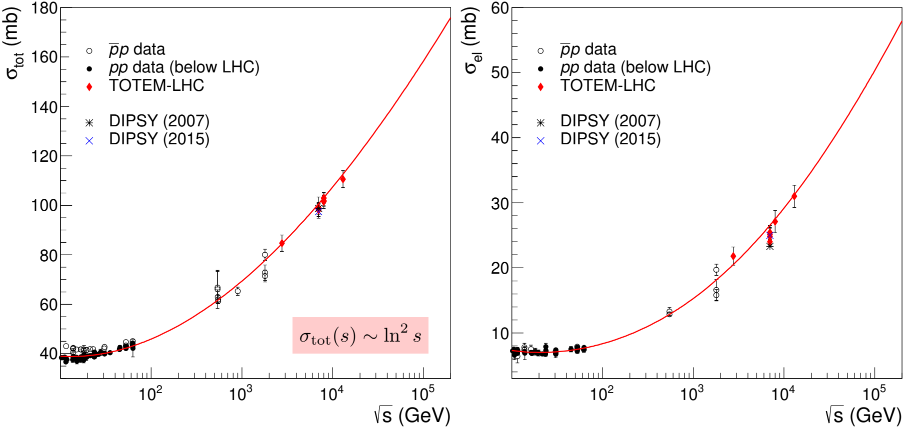


$$G^2(s) = 4.1\left(\frac{s}{s_0}\right)^{-0.25} + 0.8\left(\frac{s}{s_0}\right)^{0.101}$$

$$\beta(s) = 0.1809 + 0.0115\ln\left(\frac{s}{s_0}\right)$$

Cross sections

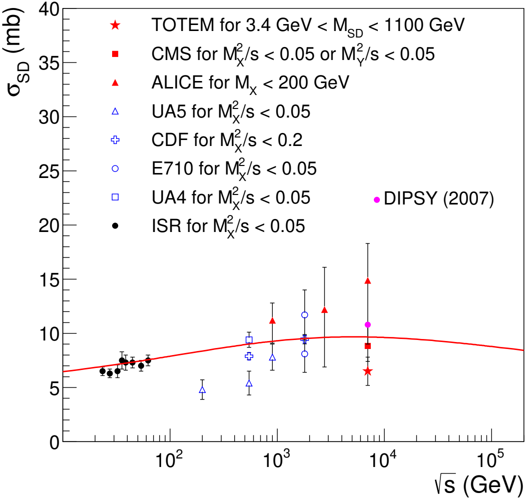
Cross sections as a function of energy



Cross sections

Parameter-free description of σ_{SD}

$$\frac{d\sigma_{\mathrm{diff}}}{d^2\mathbf{b}} = \exp\left(-\frac{8}{9}G^2 e^{-b^2/(3\beta)}\right)\left[\exp\left(\frac{1}{4}G^2 e^{-b^2/(2\beta)}\right) - 1\right]$$



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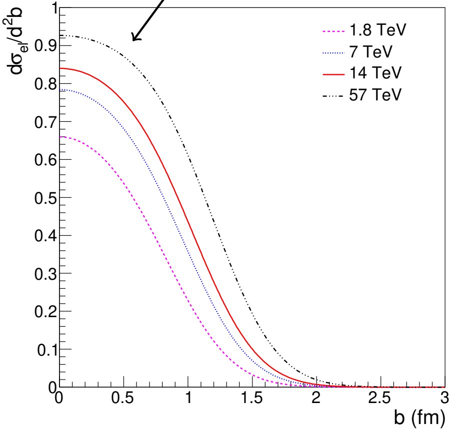
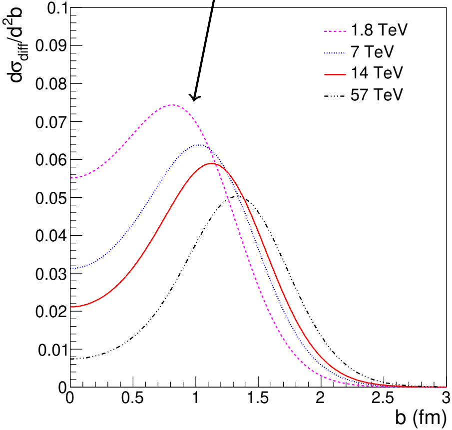
Distributions in b-space

- **Central** contribution
- Increases with energy

- **Peripheral** contribution
- Decreases with energy





pA scattering

pA Scattering

- proton-Nucleus collisions $\rightarrow$ Glauber model $\rightarrow$ $\sigma_{\rm tot}$ and $\sigma_{\rm el}$
- We use model by Blättel *et al* (1993): Good-Walker + Glauber
- p-nucleon cross section is not fixed. It fluctuates accordingly to a probability distribution

$$P(\sigma,s) = N(s)\frac{\sigma}{\sigma+\sigma_0(s)}\exp\left(-\frac{(\sigma/\sigma_0(s)-1)^2}{\Omega^2(s)}\right)$$

$$\int P(\sigma,s)d\sigma = 1$$
$$\int \sigma P(\sigma,s)d\sigma = \sigma_{\rm tot}(s)$$
$$\int \sigma^2 P(\sigma,s)d\sigma = \sigma_{\rm tot}^2(1+\omega_\sigma(s))$$

$\sigma_{\rm tot}$ and $\omega_\sigma = \left.\frac{d\sigma_{\rm diff}/dq^2}{d\sigma_{\rm el}/dq^2}\right|_{q^2=0}$

of pp scattering from MP model

pA Cross Sections

$$\frac{d\sigma_{\text{tot}}^{pA}}{d^2\mathbf{b}} = 2\langle\Gamma_A(\mathbf{b},\sigma)\rangle$$

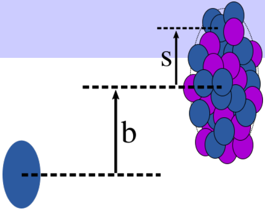
$$\frac{d\sigma_{\text{el}}^{pA}}{d^2\mathbf{b}} = \langle\Gamma_A(\mathbf{b},\sigma)\rangle$$

$$\frac{d\sigma_{\text{diff}}^{pA}}{d^2\mathbf{b}} = \langle\Gamma_A^2(\mathbf{b},\sigma)\rangle - \langle\Gamma_A(\mathbf{b},\sigma)\rangle^2$$

$$\langle f(\sigma)\rangle = \int d\sigma P(\sigma) f(\sigma)$$

- Limit of no-fluctuations: $P(\sigma) \to \delta(\sigma - \sigma_{\text{tot}})$
- Recover of "standard" Glauber model

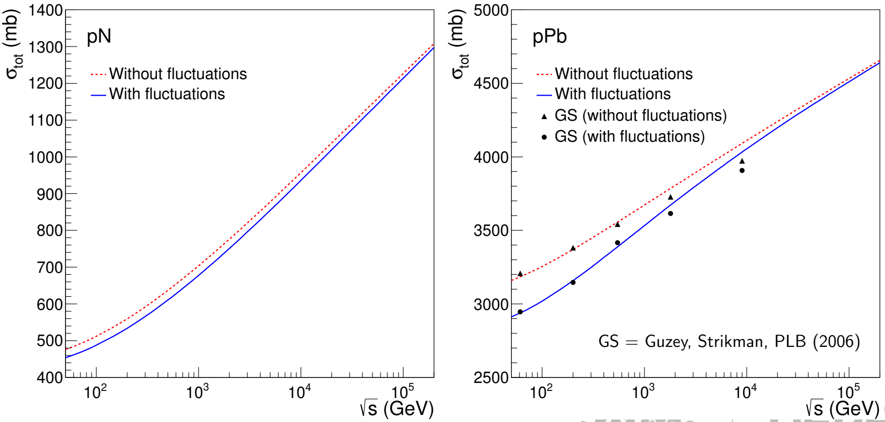
pA Cross Sections



- pA profile function: $\Gamma_A(\mathbf{b},\sigma) = 1 - \exp\left(-\frac{A}{2}\sigma T(\mathbf{b})\right)$
- $T(\mathbf{b}) = \frac{1}{2\pi B(s)} \int dz d^2\mathbf{s}\, e^{-(\mathbf{b}-\mathbf{s})^2/(2B(s))} \rho_A(\sqrt{|\mathbf{s}|^2 + z^2})$
- $\rho_A(r) = \frac{\rho_0}{1 + \exp((r - R_0)/a)}$ → Wood-Saxon distribution

Results

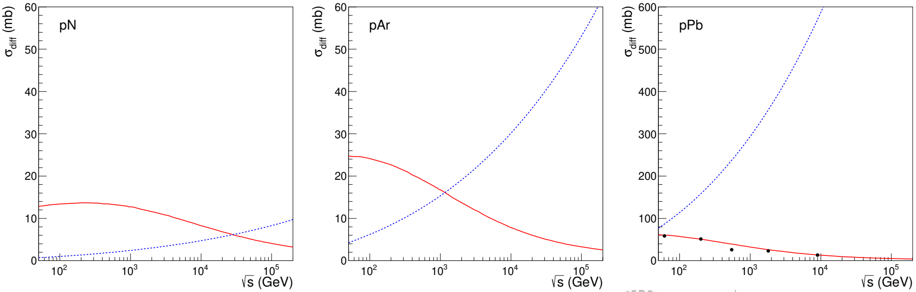
- Fluctuations: affect more at low energies and for heavy nucleus



- Same behavior for σ_{el}

pA diffractive cross section

- Hadronic contribution: cross section fluctuations
- EM contrib.: equivalent photon flux $\sigma^{pA}_{\text{e.m.}} = \int \frac{d\omega}{\omega} n_A(\omega)\, \sigma_{\gamma p \to X}(\omega)$



- Dominance of EM contribution for large Z

Summary and Conclusions

- Diffractive scattering in pp and pA scattering $\rightarrow$ Good-Walker
- $pp \rightarrow$ model by Miettinen and Pumplin
  - Energy evolution of model parameters (constrained by data)
  - Consistent description of $\sigma_{\rm tot}$, $\sigma_{\rm el}$ and $\sigma_{\rm SD}$
  - $\sigma_{\rm SD} \sim$ constant at LHC
  - Structure in b-space (elastic central and dissociation peripheral)
- $pA \rightarrow$ model based on fluctuations of p-nucleon cross section
  - Parameters constrained by pp scattering
  - Effects of fluctuations in cross sections (fluctuation *vs* Glauber)
  - Comparison between dissociation from hadronic and electromagnetic components
- Further discussions: PRD **100** (2019) 014019; arXiv:1905.00806[hep-ph]

Thank you!!

Backup Slides

Miettinen-Pumplin Model

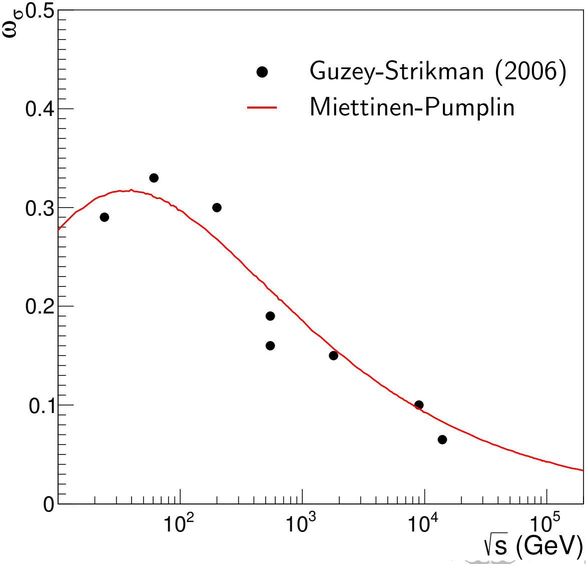
- Cross sections:

$$\frac{d\sigma_{\rm tot}}{d^2\mathbf{b}} = 2\langle t\rangle = 2\left[1 - \exp\left(-\frac{G^2A}{\beta\xi}\left(\frac{\alpha/\lambda}{1+\alpha/\lambda}\right)e^{-b^2/(\gamma+\beta)}\right)\right]$$

$$\frac{d\sigma_{\rm el}}{d^2\mathbf{b}} = \langle t\rangle^2 = \left[1 - \exp\left(-\frac{G^2A}{\beta\xi}\left(\frac{\alpha/\lambda}{1+\alpha/\lambda}\right)e^{-b^2/(\gamma+\beta)}\right)\right]^2$$

- $\xi = \beta^{-1} + \gamma^{-1}$
- $A = 1$ fixed
- $\alpha/\lambda = 2$ e $\gamma/\beta = 2$ fixos
- Two free parameters: G^2 e β

$\omega_\sigma(s)$ - MP model



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MP model: Cross section in q^2-space