Modelling the Impact Parameter Dependence of the nPDFs With EKS98 and EPS09 Parametrizations

Spaatind 2012

Ilkka Helenius

In collaboration with
Kari J. Eskola, Heli Honkanen, and Carlos Salgado

University of Jyväskylä
Department of Physics

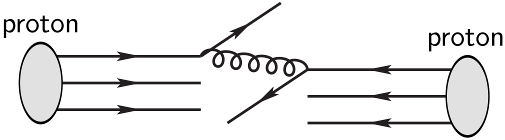
4.1.2012

Outline

1. Introduction and Motivation
   - Parton Distribution Functions
   - Nuclear Geometry in Heavy Ion Collisions
2. Model
   - Assumptions
   - Fitting Procedure
   - Outcome
3. Application
   - Nuclear Modification Factor R_{AA}
   - Central-to-Peripheral Ratio R_{CP}
4. Summary & Outlook

Parton Distribution Functions

- Hard interactions in hadronic collisions happens between partons (quarks and gluons)



$\Rightarrow$ Requires parton distribution functions (PDFs) $f_{i/N}(x, Q^2)$
  - Determined from experimental data+DGLAP (e.g. CTEQ)
- Heavy ion collisions: protons (and neutrons) bound to nucleus
  $\Rightarrow$ Nuclear PDFs (nPDFs)

$$f_{i/A}(x, Q^2) = R_{i/A}(x, Q^2) \cdot f_{i/N}(x, Q^2)$$

- Nuclear modification $R_{i/A}(x, Q^2)$ from global analysis
  - EKS98 (LO DGLAP evolution) [*Eur.Phys.J.*, C9:61-68, 1999]
  - EPS09 (LO, NLO DGLAP evolution, with uncertainties) [*JHEP*, 04:065, 2009]

Hard Processes in Heavy Ion Collisions

The hard cross section for given centrality class in $A+B$ collisions

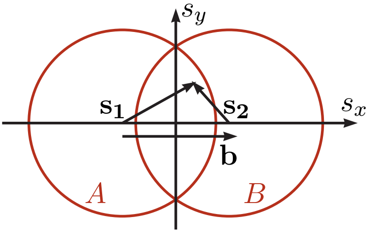
$$\mathrm{d}\sigma^{AB\to k+X} = \sum_{i,j} \int_{b_1}^{b_2} \mathrm{d}^2\mathbf{b}\, T_{AB}(\mathbf{b})\, f_{i/A} \otimes f_{j/B} \otimes \mathrm{d}\hat{\sigma}^{ij\to k+X} \quad (1)$$

Nuclear overlap function

Amount of the interacting matter at impact parameter $\mathbf{b}$.

$$T_{AB}(\mathbf{b}) = \int \mathrm{d}^2\mathbf{s}\, T_A(\mathbf{s_1}) T_B(\mathbf{s_2}),$$

where $\mathbf{s_1} = \mathbf{s} + \mathbf{b}/2$ and $\mathbf{s_2} = \mathbf{s} - \mathbf{b}/2$.



Nuclear Thickness Function

Amount of nuclear matter in beam direction

Thickness function

Woods-Saxon density profile:

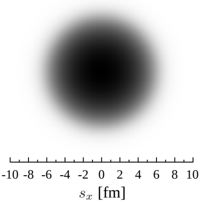
$$T_A(\mathbf{s}) = \int_{-\infty}^{\infty} \mathrm{d}z \frac{n_0}{1+\exp\left[\frac{\sqrt{\mathbf{s}^2+z^2}-R_A}{d}\right]}$$

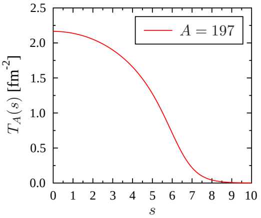
$$d = 0.54 \text{ fm}$$

$$R_A = 1.12 A^{1/3} - 0.86 A^{-1/3} \text{ fm}$$

$$n_0 = \frac{3}{4}\frac{A}{\pi R_A^3}\frac{1}{(1+(\frac{\pi d}{R_A})^2)}$$

$$A = \int \mathrm{d}^2\mathbf{s}\, T_A(\mathbf{s})$$





Framework

Nuclear modification with spatial dependence

- We replace

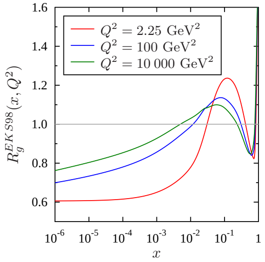
$$R_{i/A}(x, Q^2) \to r_{i/A}(x, Q^2, \mathbf{s}),$$

where s the transverse position of the nucleon

- Definition

$$R_A(x, Q^2) = \frac{1}{A} \int d^2\mathbf{s}\, T_A(\mathbf{s}) r_A(x, Q^2, \mathbf{s}),$$

where $R_A(x, Q^2)$ from EKS98 or EPS09



Fitting Procedure

Assumption: spatial dependence of the form

$$r_A(x,Q^2,s) = 1 + c_1(x,Q^2)[T_A(s)] + c_2(x,Q^2)[T_A(s)]^2 + c_3(x,Q^2)[T_A(s)]^3 + c_4(x,Q^2)[T_A(s)]^4$$

Important: no A dependence in fit parameters $c_i(x,Q^2)$!

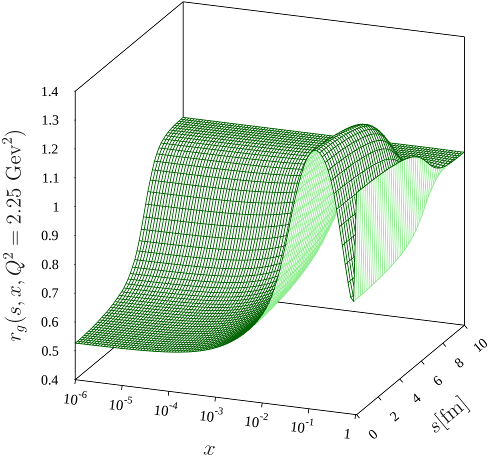
Parameters $c_i(x,Q^2)$ obtained by minimizing the χ^2. For EKS98s:

$$\chi^2(x,Q^2) = \sum_A \left[\frac{R_A(x,Q^2) - \frac{1}{A}\int d^2s\, T_A(s) r_A(x,Q^2,s)}{R_A(x,Q^2) - 1} \right]^2,$$

where $A = 16, 20, 24, \ldots, 300$.

Spatial Dependence of Nuclear Modification for Au

$$r^{EKS98s}(x, Q^2, s) = 1 + \sum_{i=1}^{4} c_i(x, Q^2)[T_A(s)]^i$$



Observations

- The shape in x is similar to EKS98
- Effects are slightly stronger in small s compared to EKS98
- Nuclear effects die out when $s > R_A$

Nuclear Modification Factor R_{AA}

Nuclear Modification Factor

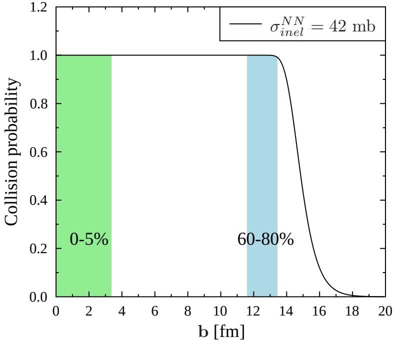
$$R_{AA} = \frac{\left\langle \frac{\mathrm{d}^2 N_{AA}}{\mathrm{d}p_T \mathrm{d}y} \right\rangle_{b_1,b_2}}{\frac{\langle N_{bin} \rangle_{b_1,b_2}}{\sigma_{inel}^{NN}} \frac{\mathrm{d}^2 \sigma_{pp}}{\mathrm{d}p_T \mathrm{d}y}}$$

The central-to-peripheral ratio

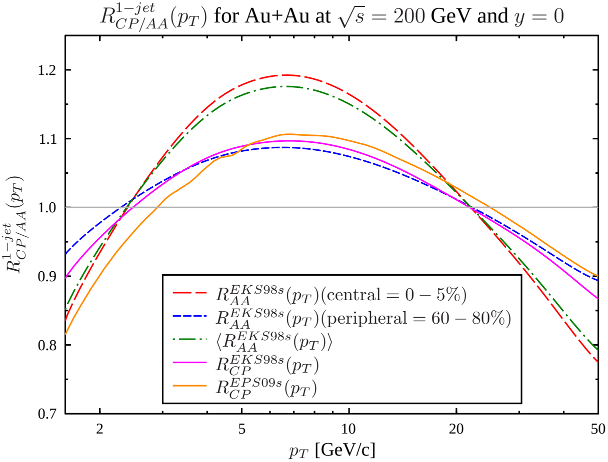
$$R_{CP} = \frac{\left\langle \frac{\mathrm{d}^2 N_{AA}}{\mathrm{d}p_T \mathrm{d}y} \right\rangle \frac{1}{\langle N_{bin} \rangle} (central)}{\left\langle \frac{\mathrm{d}^2 N_{AA}}{\mathrm{d}p_T \mathrm{d}y} \right\rangle \frac{1}{\langle N_{bin} \rangle} (peripheral)}$$

- Centrality classes from optical glauber model

$$p_{AA}^{inel}(b) = 1 - e^{-T_{AA}(\mathbf{b})\sigma_{inel}^{NN}}$$



1-jet Central-to-Peripheral Ratio for RHIC



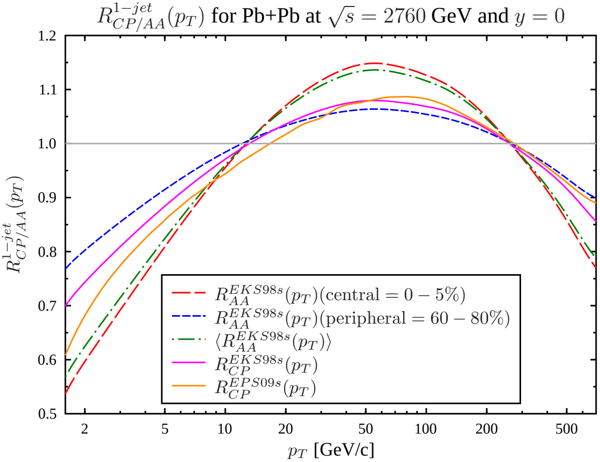
Observations

$R_{AA}(central) \approx \langle R_{AA} \rangle$

$R_{AA}(peripheral) \neq 1$

$R_{CP} \neq \langle R_{AA} \rangle$

1-jet Central-to-Peripheral Ratio for LHC



Observations

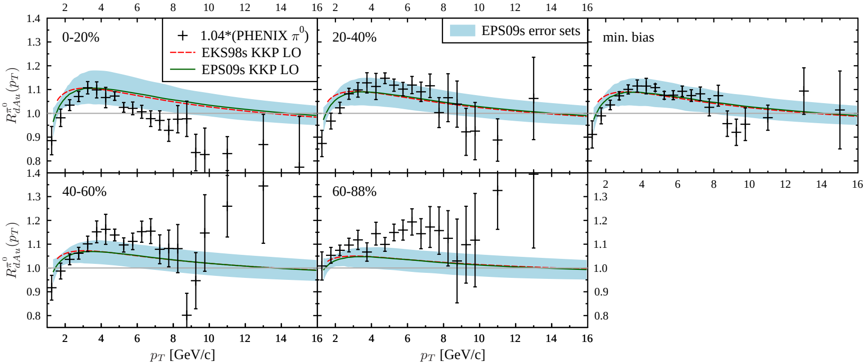
$R_{AA}(central) \approx \langle R_{AA}\rangle$

$R_{AA}(peripheral) \neq 1$

$R_{CP} \neq \langle R_{AA}\rangle$

Pions in d+Au collisions at RHIC

R_{dAu} for π^0's in different centrality classes at $\sqrt{s} = 200$ GeV, $\eta = 0$
Data: PHENIX ($|\eta| < 0.5$) [*Phys. Rev. Lett. 98*, 172302, 2007]



More centrality dependent data is needed (p+Pb at LHC?)

Summary

We have

- Developed a model for spatial dependence of nuclear modification based on
  - the A dependence of the EKS98/EPS09 (= data!)
  - the nuclear thickness function $T_A(s)$
- Program to calculate $r_A(x, Q^2, \mathbf{s})$
- Calculated R_{AA}^{1-jet}, R_{CP}^{1-jet} and $R_{dAu}^{\pi^0}$ in LO

We will

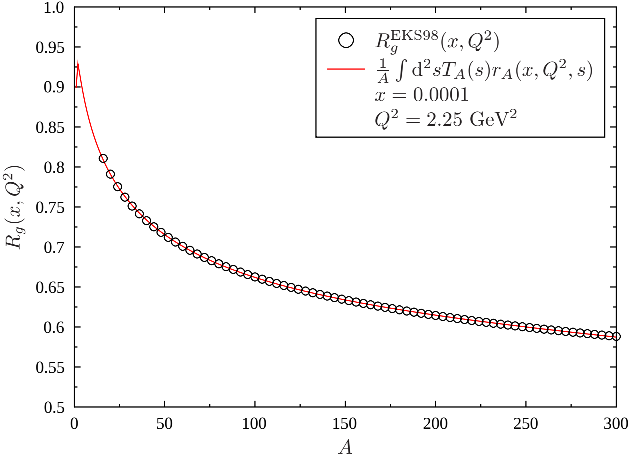
- Calculate also NLO ratios
- Make the codes for $r_A(x, Q^2, \mathbf{s})$ calculation public (EKS98s and EPS09s)

  $\Rightarrow$ Nuclear modifications of any hard process in different centrality classes can now be computed consistently with EKS98/EPS09!

Backup

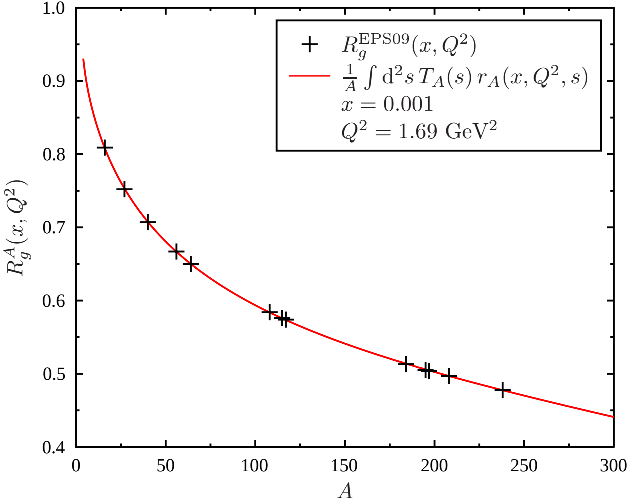
Fit Outcome

Example fit: gluon modification from EKS98



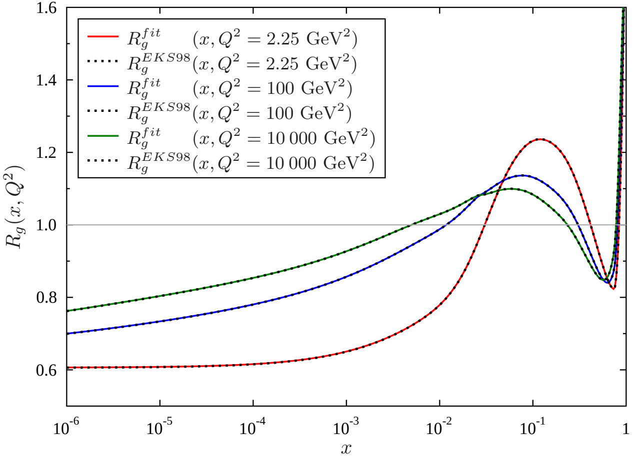
Fit Outcome

Example fit: gluon modification from EPS09

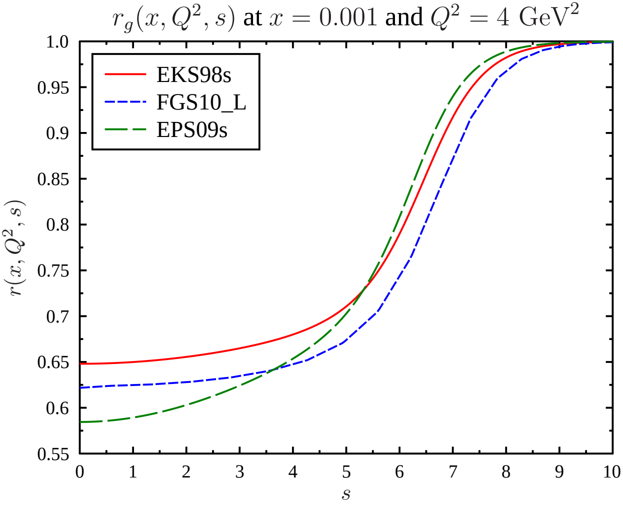


Fitted $R(x,Q^2)$ vs. old $R(x,Q^2)$

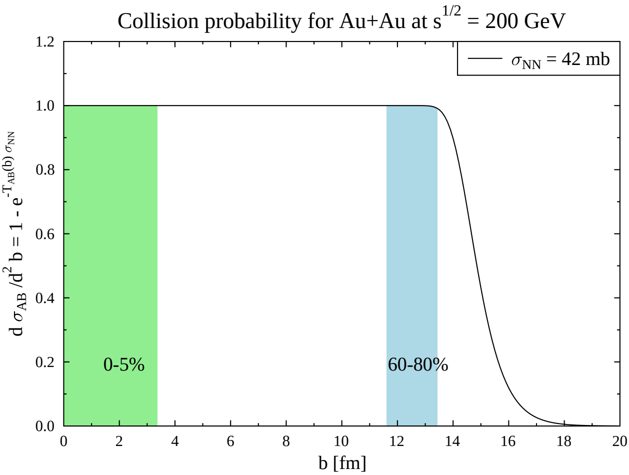
$$R^{fit}(x,Q^2) = \frac{1}{A}\int \mathrm{d}^2\mathbf{s}\, T_A(s)\left[1+\sum_{i=1}^{4} c_i(x,Q^2)[T_A(s)]^i\right]$$



Comparision of the spatial dependence



Centrality Classes for RHIC



Numerical Calculation of $T_A(s)$

Thickness function

- Woods-Saxon density profile:

$$T_A(\mathbf{s}) = \int_0^\infty dz \frac{2\,n_0}{1+\exp[\frac{\sqrt{\mathbf{s}^2+z^2}-R_A}{d}]}$$

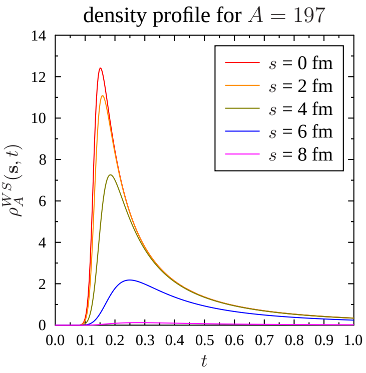
Needs numerical integration

- Change of variable as $z = \frac{1-t}{t}$ gives

$$T_A(\mathbf{s}) = \int_0^1 dt \frac{2\,n_0}{t^2\left\{1+\exp\left[\frac{\sqrt{\mathbf{s}^2+\left(\frac{1-t}{t}\right)^2}-R_A}{d}\right]\right\}}$$

- Singularity at t = 0 is ok, because

$$\lim_{t\to 0} \rho^{WS}(t) = 0$$



A-dependent modification

Thickness function

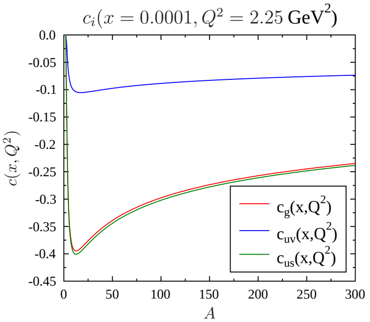
- If the Modification of the form

$$r_A(x, Q^2, s) = 1 + c(x, Q^2)[T_A(s)]$$

[*Phys.Rev.*, C61:044904, 2000]

- The parameter $c(x, Q^2)$ from the normalization condition

$$c(x, Q^2) = \frac{A(R_i^A(x, Q^2) - 1)}{\int \mathrm{d}^2\mathbf{s}\,[T_A(\mathbf{s})]^2}$$



$$\frac{c_g^{208}(x,Q^2)}{c_g^{12}(x,Q^2)} = 0.65$$

⇒ Strong A dependence of $c(x, Q^2)$!

The s dependence not entirely decomposed from $c(x, Q^2)$.

Central-to-Peripheral Ratio R_{CP}^{1-jet}

- The 1-jet distribution for a centrality class with $b \in [b_1, b_2]$ can be calculated from

$$\left\langle \frac{\mathrm{d}^2 N_{AA}^{1-jet}}{\mathrm{d}p_T \mathrm{d}y} \right\rangle_{b_1,b_2} = \frac{\int_{b_1}^{b_2} \mathrm{d}^2 b \frac{\mathrm{d}^2 N_{AA}^{1-jet}(b)}{\mathrm{d}p_T \mathrm{d}y}}{\int_{b_1}^{b_2} \mathrm{d}^2 b \, p_{AA}^{inel}(b)}$$

- $p_{AA}^{inel}(b) = 1 - e^{-T_{AA}(\mathbf{b})\sigma_{inel}^{NN}}$ (optical Glauber model)

Parameters from Optical Glauber Model

	$central = 0 - 5\%$			$peripheral = 60 - 80\%$		
	b_1 [fm]	b_2 [fm]	$\langle N_{bin} \rangle$	b_1 [fm]	b_2 [fm]	$\langle N_{bin} \rangle$
RHIC	0.0	3.355	1083	11.62	13.42	15.11
LHC	0.0	3.478	1772	12.05	13.91	19.08

- RHIC: $\sigma_{inel}^{NN} = 42$ mb
- LHC: $\sigma_{inel}^{NN} = 64$ mb