Forward hadron productions at high energy colliders in CGC framework

H. Fujii[1], K. Itakura[2], Y. Nara[3]

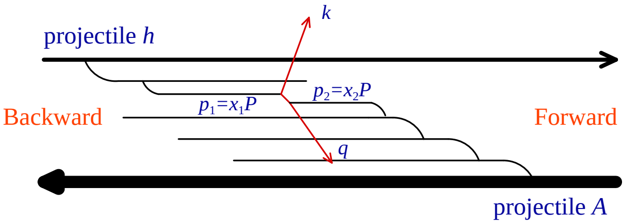
([1]U Tokyo, [2]KEK, [3]Akita Int'l U)

27-Sep-2011, ISMD2011, Miyajima island, Hiroshima

1. **Introduction**
   - small x
2. **Framework**
   - rcBK eqn
   - DHJ
   - MC
3. **Results**
4. **Summary**

Motivation

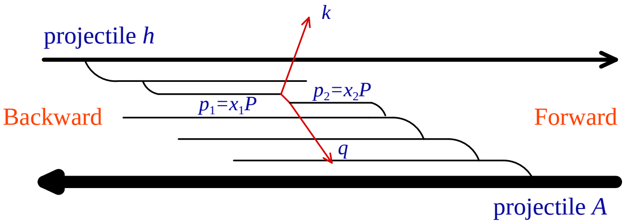
- Collider energies $\sqrt{s} \gg k_\perp$ in forward region $y > 0$,
  $=$ kinematic regime of $x_2 = \frac{|k_\perp|e^{-y_k} + |q_\perp|e^{-y_q}}{\sqrt{s}} \ll 1$



- many gluons emerge due to BFKL cascade
- atomic number $A > 1$ enhances the gluon density

Motivation

- Collider energies $\sqrt{s} \gg k_\perp$ in forward region $y > 0$,
  $=$ kinematic regime of $x_2 = \frac{|k_\perp|e^{-y_k} + |q_\perp|e^{-y_q}}{\sqrt{s}} \ll 1$



- many gluons emerge due to BFKL cascade
- atomic number $A > 1$ enhances the gluon density
- system becomes nonlinear, leading to a universal state: Color Glass Condensate (CGC) with $Q_s^2(x)$ $(\gg \Lambda_{\rm QCD}^2)$
- universal in any high-energy processes such as cosmic ray

Aim

- To describe high-energy particle productions by incorporating the universal CGC aspects
- This is a status report of our group

Small-x evolution: running coupling BK

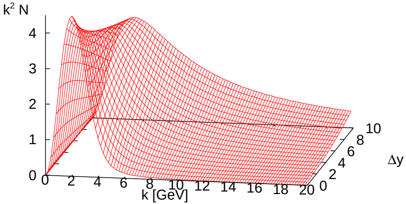
Kovchegov-Weigert, Balitsky

rcBK eqn in Balitsky's prescription:

$$\frac{\partial \mathcal{N}(r,y)}{\partial y} = \int d^2\boldsymbol{r}_1\, K^{\text{run}} \left[\mathcal{N}(r_1,y) + \mathcal{N}(r_2,y) - \mathcal{N}(r,y) - \mathcal{N}(r_1,y)\mathcal{N}(r_2,y) \right]$$

- needs an initial condition at $x = x_0$
- describes BFKL cascade (growing) and non-linear effects (saturation)
- running coupling effects leads to $Q_s^2 \propto (x_0/x)^{0.3} = e^{0.3y}$ Albacete

  $\Rightarrow$ *practical tool to phenomenology* (Cf. geometric scaling at HERA)

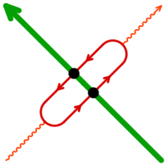


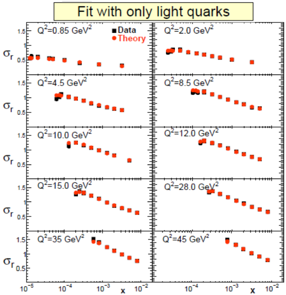
DIS: AAMQS

DIS cross section

$$\sigma_{T,L}(x,Q^2) = \sigma_0 \int dz d^2r |\Psi_{T,L}(z,Q^2,r)|^2 \mathcal{N}(r,x)$$

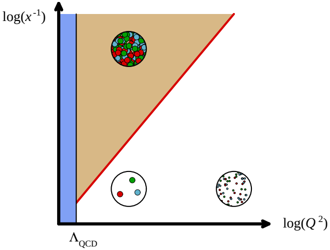
- successful description for the compiled HERA data
- stringent constraint on fixing $\mathcal{N}(r,x)$ for the proton
- $\mathcal{N}(r,x)$ can be used in other processes





Albacete et al.(2010)

rcBK as a tool for QCD phenomenology



Eqn.	DGLAP	(rc)BK
(u)pdf	$f(Q,x)$	$\mathcal{N}(k,x)$
global fit	CTEQ, ...	AAMQS
evolution in	Q^2	x
initial cond	some model	MV$^\gamma$, rcMV, ...
system becomes	more dilute	more dense/non-linear scale $Q_s^2(x)$
produced hadron	$k_\perp^2$	x_F

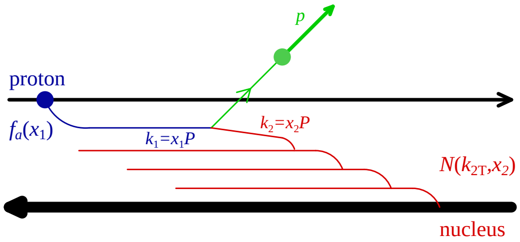
Forward particle production

"Large-x – small-x" reactions: Dumitru-Hayashigaki-Jalilian-Marian (DHJ)

DHJ factorization form

$$\frac{dN}{dy_h d^2 p_T} = \frac{K}{(2\pi)^2} \sum_{ijk} \int_{x_F}^{1} \frac{dz}{z^2}\, x_1 f_{i/p}(x_1, p_T^2)\, \tilde{\mathcal{N}}_j(\frac{p_T}{z}, x_2)\, D_{h/k}(z, p_T^2)\ ,$$

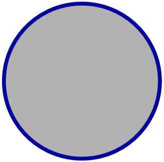
- $f_{i/p}$ for large-x partons (CTEQ6 NLO)
- $D_{h/k}$ high-p_T fragmentation (DSS NLO)
- $\mathcal{N}_i$ for small-x gluons in the proton (rcBK) $\rightarrow$ nuclear target?



Nuclear target

MC modeling for a nucleus:

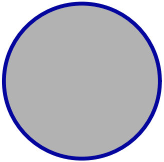
- The simplest will be a homogeneous disk
  no impact parameter dependence
  an additional parameter Q^2_{s0A} needed



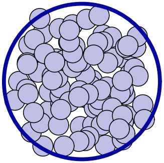
Nuclear target

MC modeling for a nucleus:

- The simplest will be a homogeneous disk
  no impact parameter dependence
  an additional parameter Q^2_{s0A} needed

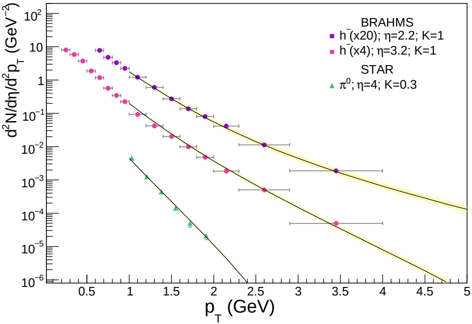


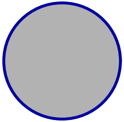
- Random nucleons w/ Woods-Saxon dist.
  fluctuating density $\Rightarrow$ b-dependence
  $Q^2_{s0A} = Q^2_{s0p} \times N$ w/o additional parameter
  Drescher-Nara



Single particle spectra in dA at RHIC

homogeneous nucleus with an effective scale Q_{sA}^2 (DHJ/rcBK)
Albacete-Marquet

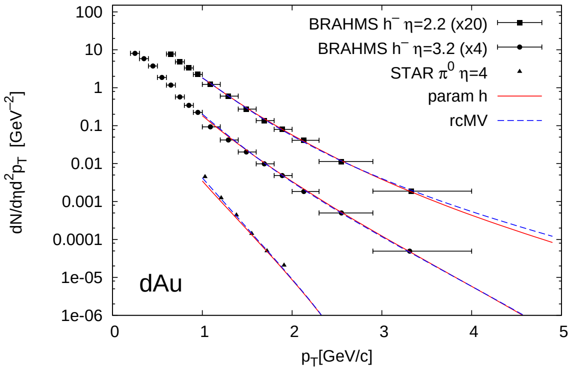


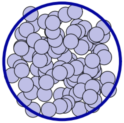


- reproduce the data nicely

Single particle spectra in dA at RHIC

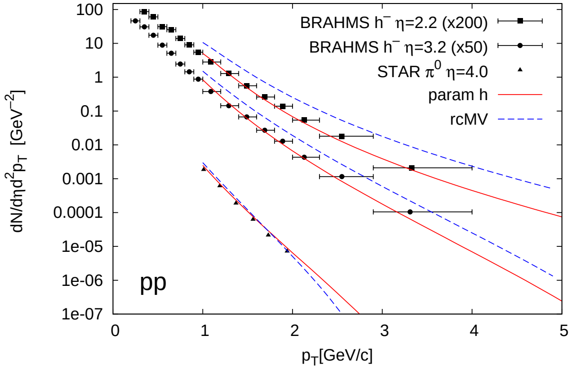
MC modeling (MC-DHJ/rcBK)   HF-Itakura-Kitadono-Nara





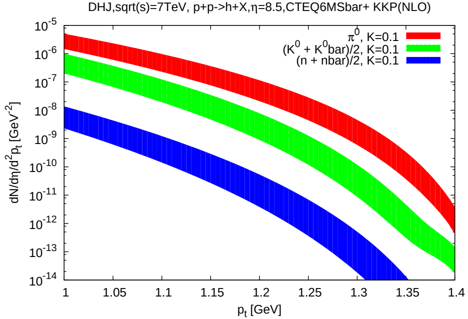
- reproduce the data nicely
- AAMQS set h and rcMV for $\mathcal{N}(r, y)$
- Q_{s0A}^2 fixed by MC; no additional parameter besides K

Attempt: pp at $\sqrt{s} = 200$ GeV



- set h works reasonably even for proton at $\sqrt{s} = 200$ GeV
- rcMV is a model which is not yet tuned to DIS

Test calculation for forward physics at LHC



- Hadron productions (π^0, K^0 and n) at $\eta = 8.5$ at 7 TeV (LHCf) is being studied in this framework

Summary

- **The rcBK eqn is a QCD-based practical tool for phenomenology**

  global fit of compiled DIS data gives a stringent constraint

- **We optimized our description for p(d)A, combining the state-of-the-art pdf's for large-x and small-x partons, and the MC modeling for the nucleus:**

  MC-DHJ/rc-BK

- **MC-DHJ/rcBK fits the forward data very nicely**

Summary

- **The rcBK eqn is a QCD-based practical tool for phenomenology**

  global fit of compiled DIS data gives a stringent constraint

- **We optimized our description for p(d)A, combining the state-of-the-art pdf's for large-x and small-x partons, and the MC modeling for the nucleus:**

  MC-DHJ/rc-BK

- **MC-DHJ/rcBK fits the forward data very nicely**

- Outlook for MC-DHJ/rcBK:
  - More systematic analyses: R_{cp}, two-particle correlations, ...
    Albacete-Marquet
  - Applications to forward physics at LHC and in cosmic ray
    Cf. for LHC Albacete-Dumitru
  - more complete NLO extension...

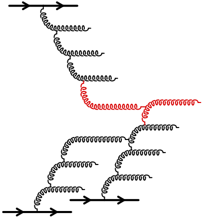
back-up

Framework II: hadronic collisions

k_t factorization form

$$\frac{d\sigma^{A+B\to g}}{dyd^2p_Td^2X} \sim K\,\frac{\alpha_s}{p_T^2}\,\phi(k_1,x_1,b)\otimes\phi(k_2,x_2,X-b)$$

- is proved for pp, pA at LO, but is a working assumption for AA BGV
- $\phi(k,x) \propto k^2\ \mathrm{F.T.}\ \mathcal{N}_G(\boldsymbol{r},x)$ is the unintegrated gluon dist in the hadron.
- $\mathcal{N}_G = 2\mathcal{N} - \mathcal{N}^2$, with $\mathcal{N}$ constrained by DIS
- **$\mathcal{N}$ in a nucleus requires a modeling for a nucleus**

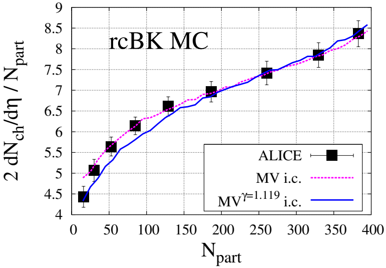


MC-KT model

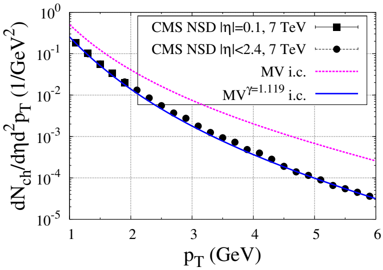
Albacete-Dumitru

- **MC-KT/rcBK** $= k_T$ factorization formalism with ϕ obtained from rcBK evolution locally on transverse plane of a Monte-Carlo-generated nucleus
- applied at LHC

AA



pp



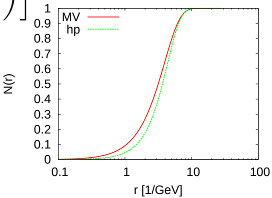
Initial condition for rcBK

- Adopted I.C. at $x_0 = 0.01$:

$$\mathcal{N}(r, x_0) = 1 - \exp\left[-\frac{(r^2 Q_{s0}^2)^\gamma}{4} \ln\left(\frac{1}{\Lambda r} + e\right)\right]$$

	γ	Q_{s0A}^2	C	Λ
MV	1.0	0.2	1.0	0.2
h'	1.119	0.168	1.715	0.241

N.B.: for a larger γ $\mathcal{N}(k)$ has negative values.



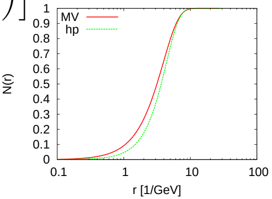
Initial condition for rcBK

- Adopted I.C. at $x_0 = 0.01$:

$$\mathcal{N}(r, x_0) = 1 - \exp\left[-\frac{(r^2 Q_{s0}^2)^\gamma}{4} \ln\left(\frac{1}{\Lambda r} + e\right)\right]$$

	γ	Q_{s0A}^2	C	Λ
MV	1.0	0.2	1.0	0.2
h'	1.119	0.168	1.715	0.241

N.B.: for a larger γ $\mathcal{N}(k)$ has negative values.



- Another possible I.C.: running coupling (rc) MV

$$\mathcal{N}(r, x_0) = \frac{\alpha_s(\mu)}{\alpha_s(r)}\left(1 - \exp\left[-\frac{r^2 Q_A^2}{4}\right]\right)$$

N.B. Q_A^2 is not tuned, but fixed $Q_s^2 = Q_A^2 \ln(Q_s^2/\Lambda^2)$

IIT