How can we prove/disprove the relevance of Color Glass Condensate/saturation physics at the LHC?

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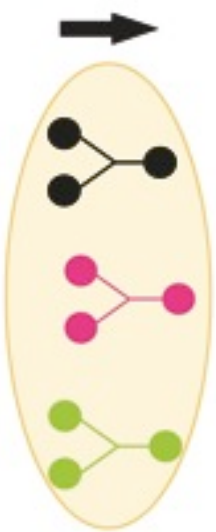
Hard Probes 2012, Cagliari, Italy, 27 May- 01 June 2012

What the CGC is about : coherence effects in high energy QCD (small-x)

High gluon densities in the projectile/target



Saturation: gluon self-interactions tame the growth of gluon densities towards small-x

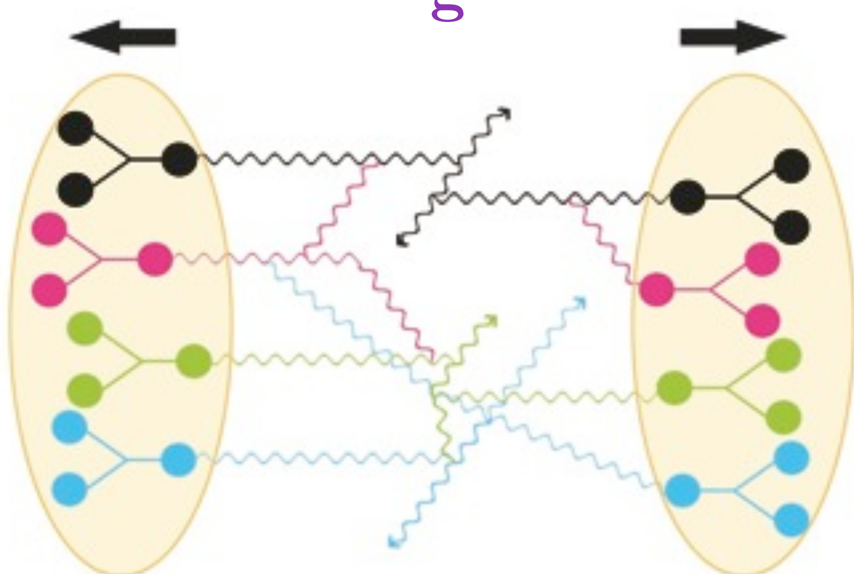
$$\frac{\partial \phi(\mathbf{x}, \mathbf{k_t})}{\partial \ln(\mathbf{x_0}/\mathbf{x})} \approx \mathcal{K} \otimes \phi(\mathbf{x}, \mathbf{k_t}) - \phi(\mathbf{x}, \mathbf{k_t})^{\mathbf{2}}$$

radiation   recombination

$$\mathbf{k_t} \lesssim \mathbf{Q_s}(\mathbf{x})$$

Breakdown of independent particle production

$$\mathcal{A}(\mathbf{k} \lesssim \mathbf{Q_s}) \sim \frac{\mathbf{1}}{\mathbf{g}} \qquad \mathbf{g}\mathcal{A} \sim \mathcal{O}(\mathbf{1})$$



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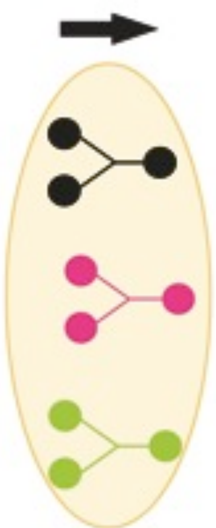

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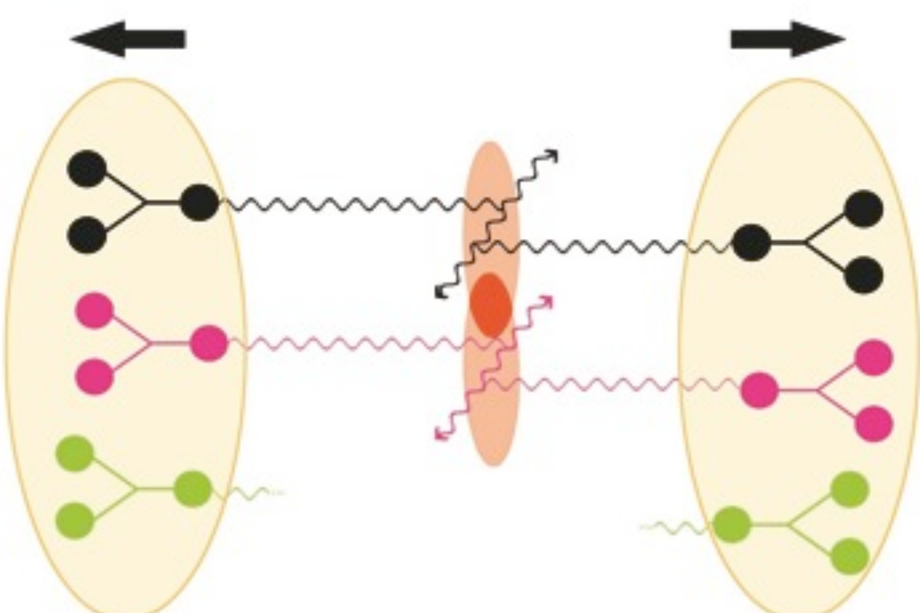
radiation — recombination

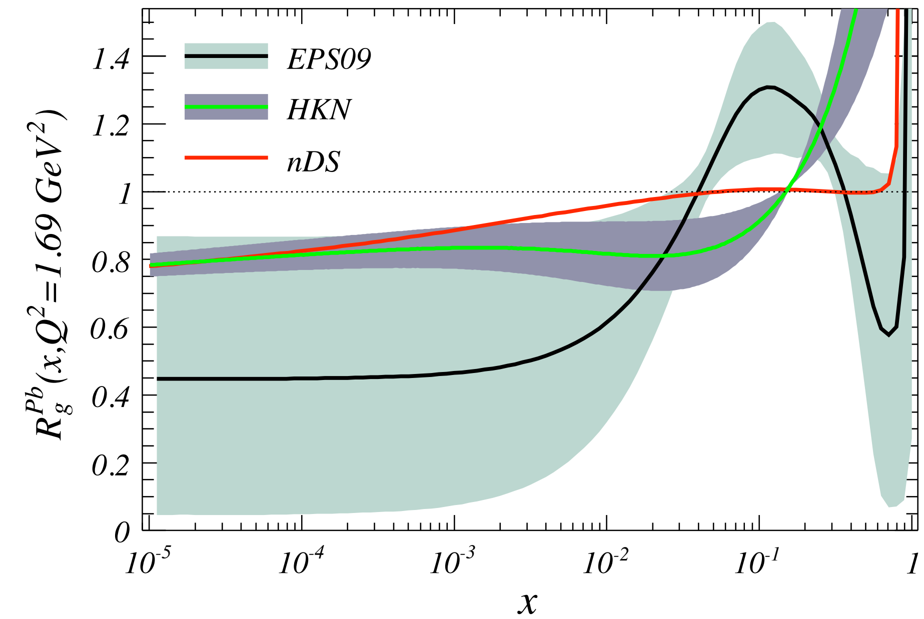
$$\mathbf{k_t} \lesssim \mathbf{Q_s}(\mathbf{x})$$

Breakdown of independent particle production

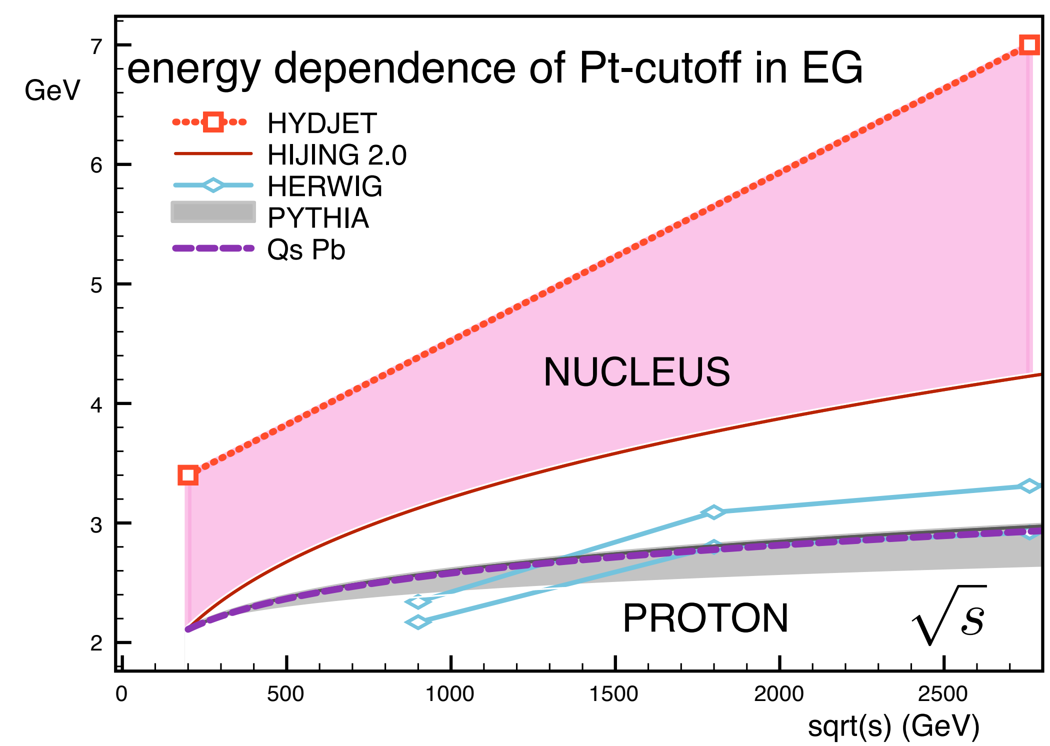


HIC phenomenology

•Nuclear shadowing, String fusion, percolation

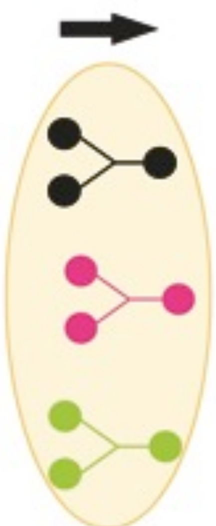


- Resummation of multiple scatterings
- kt-broadening
- Energy dependent cutoff in event generators



What the CGC is about : coherence effects

High gluon densities in the projectile/target



Saturation: gluon self-interactions tame the growth of gluon densities towards small-x

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radiation   recombination

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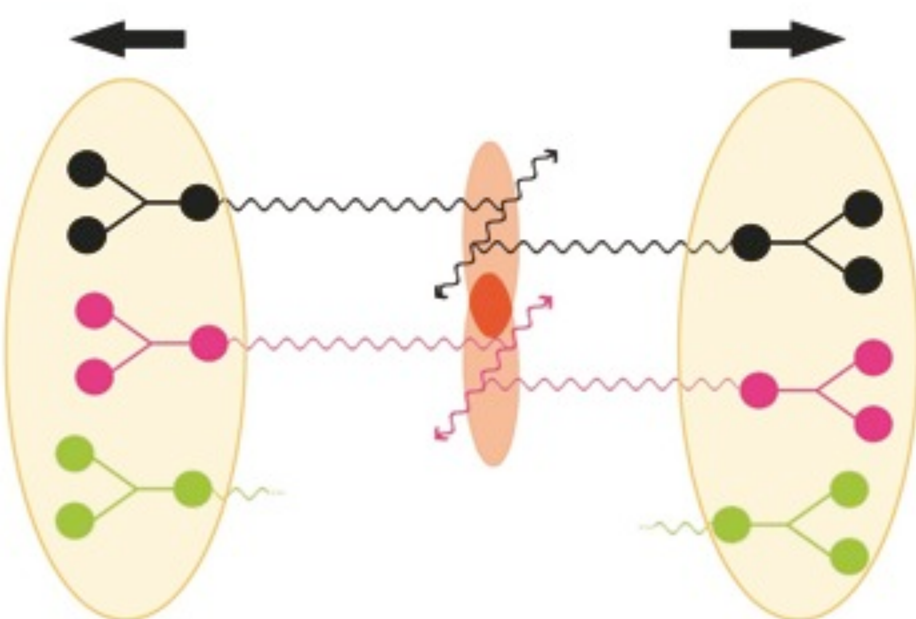
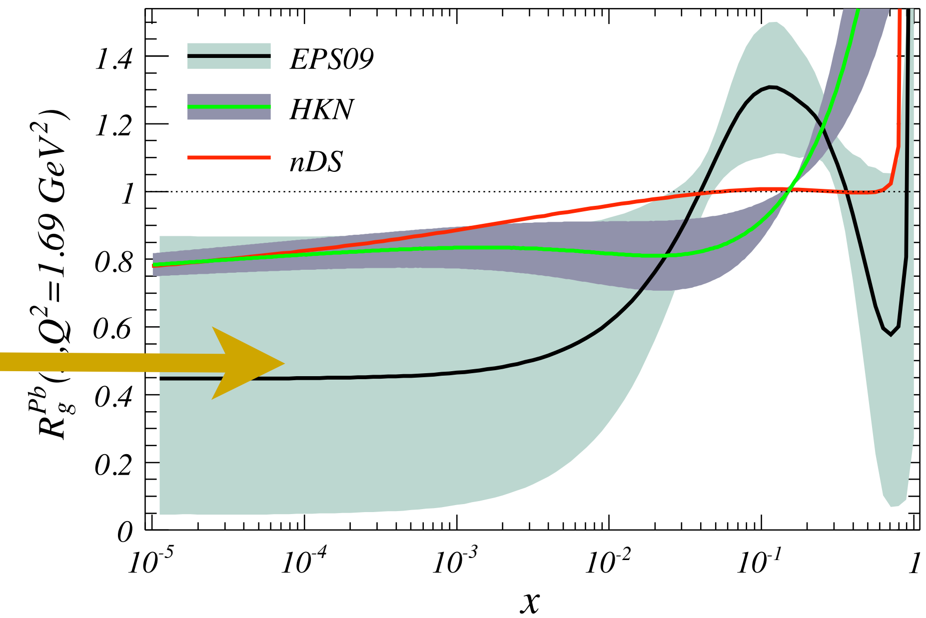
Breakdown of independent particle production



HIC phenomenology

- Nuclear shadowing, String fusion, percolation



- Resummation of multiple scatterings
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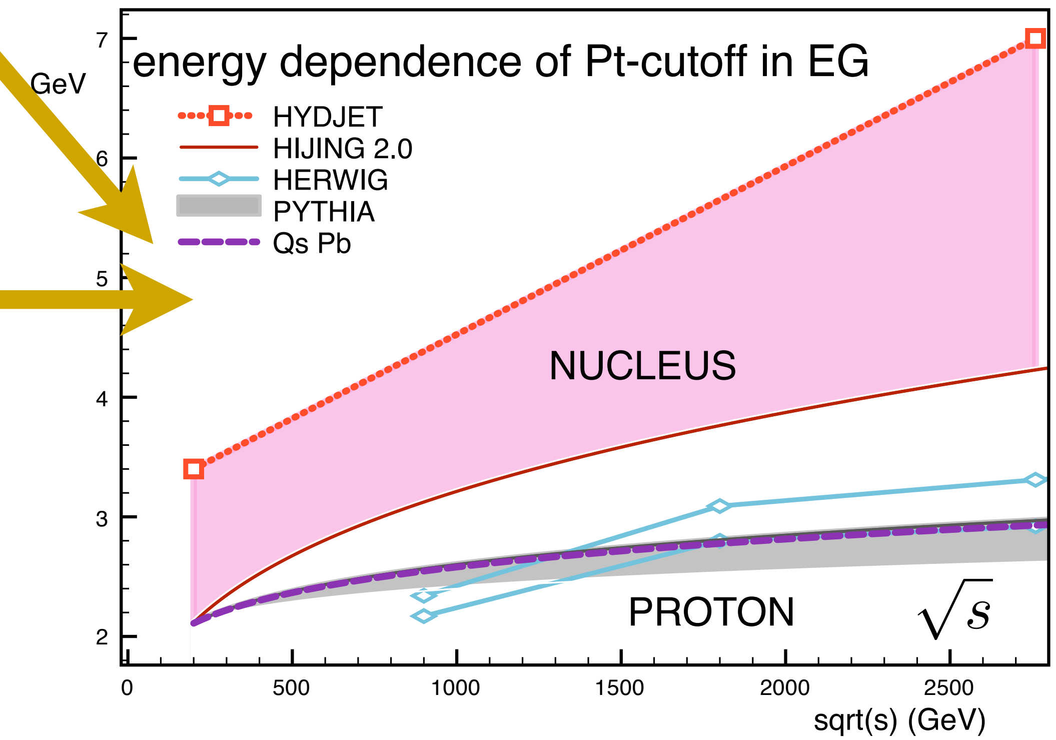


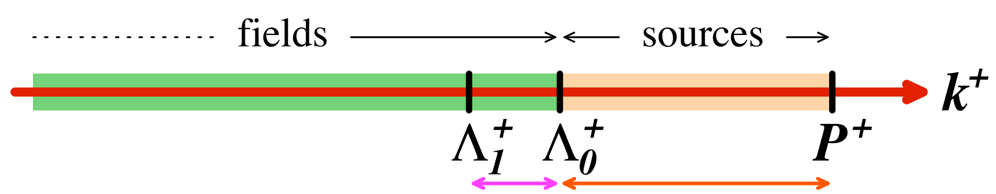
OUTLINE

- **Coherence effects are essential for the description of data in HIC collisions (RHIC, LHC)**

- **Is the CGC effective theory (at its present degree of accuracy) the best suited framework to quantify those coherence phenomena in LHC HI collisions?**

- **Pros and Cons:**
  - Derived from QCD within a controlled approximation -> Theory driven predictive power
  - Systematic unified description of different observables/collision systems
  - Limited degree of applicability: High-(x,Q2) effects not accounted for

small-x d.o.f (dynamical) **valence d.o.f (static)**



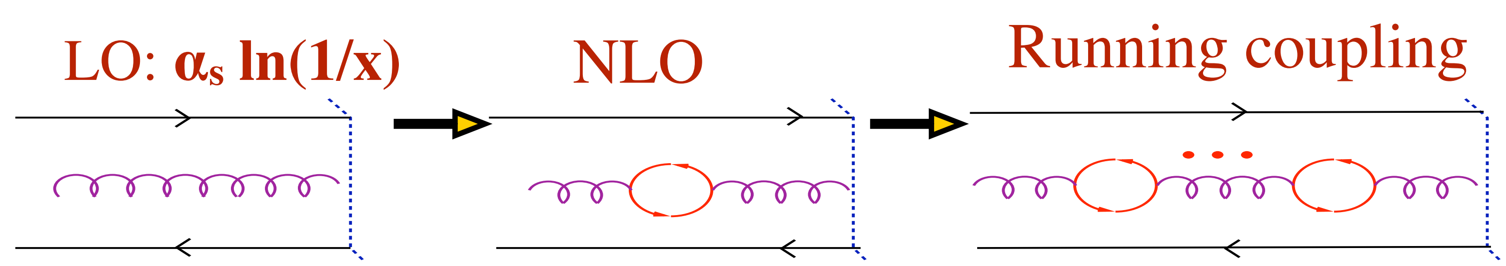
LHC **RHIC** **SPS**

- **Can you give us predictions for some observable that would allow to unambiguously distinguish the CGC approach from others?**

(brief and incomplete) CGC Theory Status: Entering the NLO era

Evolution Equations: $\frac{\partial\, \phi(x,k)}{\partial\, \ln(1/x)} = \mathcal{K} \otimes \phi(x,k) - \phi^2(x,k)$ $\qquad \frac{\partial\, W[\rho]}{\partial\, Y} = \dots$

- ✓ - Running coupling kernel in BK evolution for the 2-point function [Kovchegov Weigert Gardi Balitsky]
- ✗ - Full NLO kernel for BK-JIMWLK [Balitsky Chirilli]
- ✗ - Analytic [D. Triantafyllopoulos's talk] and numerical [T. Lappi's talk] solutions of full B-JIMWLK hierarchy for n-point functions
- - ...



Production processes $\frac{dN^{AB\to X}}{d^3p_1 \dots}\,[\phi(x,k); W_Y[\rho]]$

- ✗ - Running coupling and full NLO corrections to kt-factorization [Kovchegov, Horowitz, Balitsky, Chirilli]
- ✓ - Inelastic terms in the hybrid formalism [Rezaeian's talk]
- ✓ - Hadron-hadron, hadron-photon* correlations [Heikki's talk, Jalilian Marian's talk]
- ✗ - Factorization of multiparticle production processes at NLO [Lappi's talk]
- ✗ - DIS NLO photon impact factors [Chirilli]
- - ...

Used in phenomenological works? ✓ Yes ✗ No ✓A bit :)

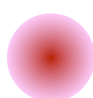
(brief and incomplete) CGC Phenomenology Status

Empiric information needed to constrain:

- Non-perturbative parameters: initial conditions for BK-JIMWLK evolution, impact parameter
- K-factors to account for higher order corrections (effectively also for missing high-(x,Q2) contributions, energy-conservation corrections etc)

:) **proton**

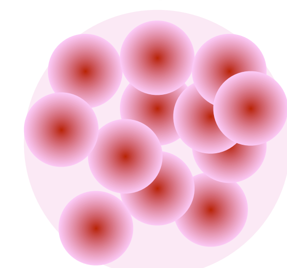
- Abundant high quality data at small-x
- Good simultaneous description of e+p and p+p data
- Global rcBK fits to constrain gluon distribution



modelling!

:(**nucleus**

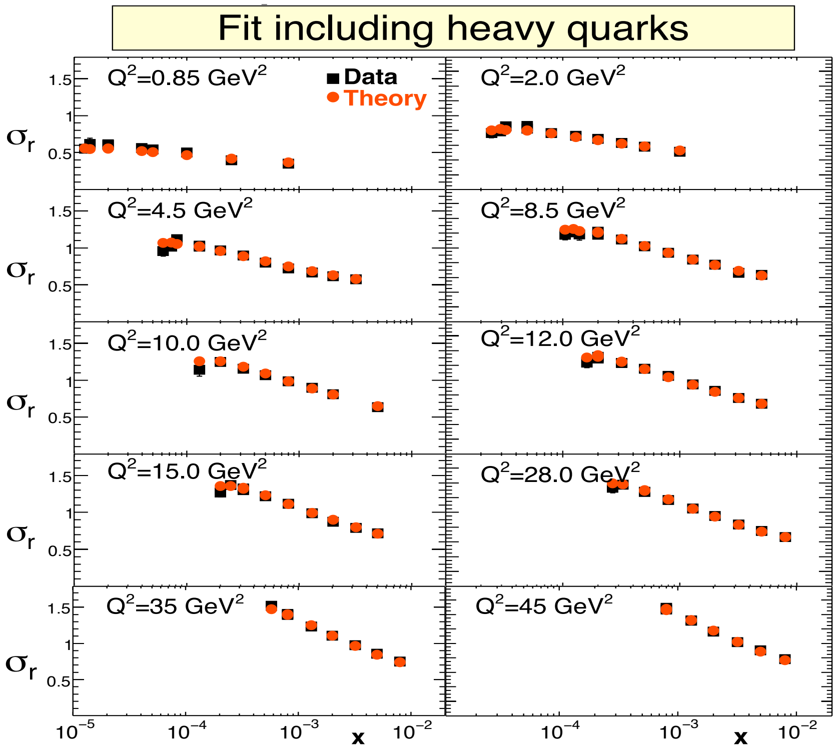
- Few data at small-x
- LHC Pb+Pb data and RHIC dAu forward data troublesome (more later)



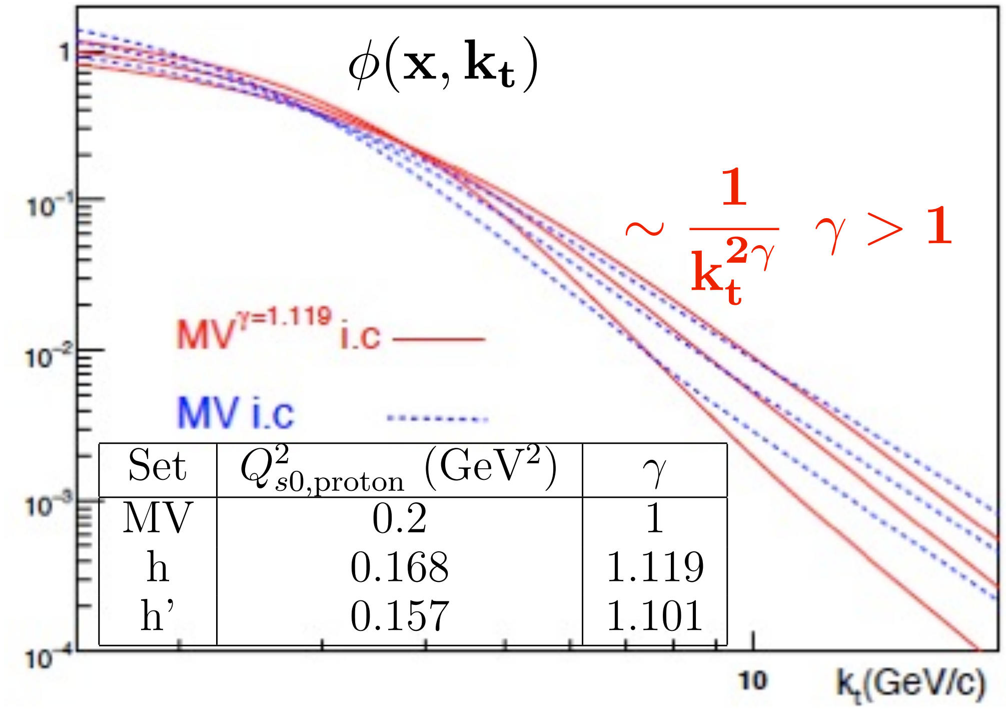
The baseline: proton collisions

Talk by P. Quiroga

1. Global fits to e+p data at small-x



2. Extract NP fit parameters



Set	$Q^2_{s0,\mathrm{proton}}$ (GeV^2)	γ
MV	0.2	1
h	0.168	1.119
h'	0.157	1.101

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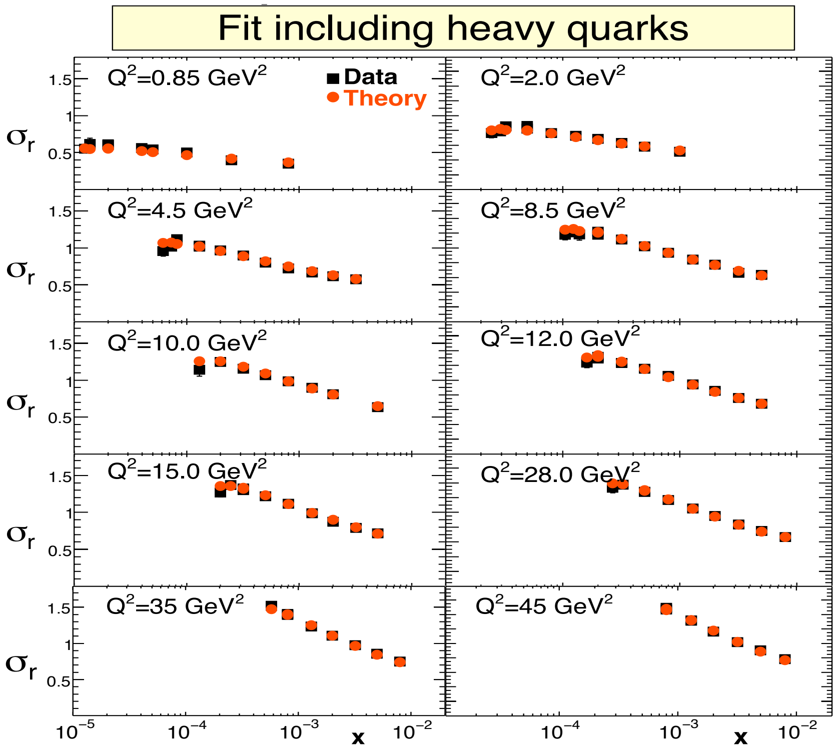

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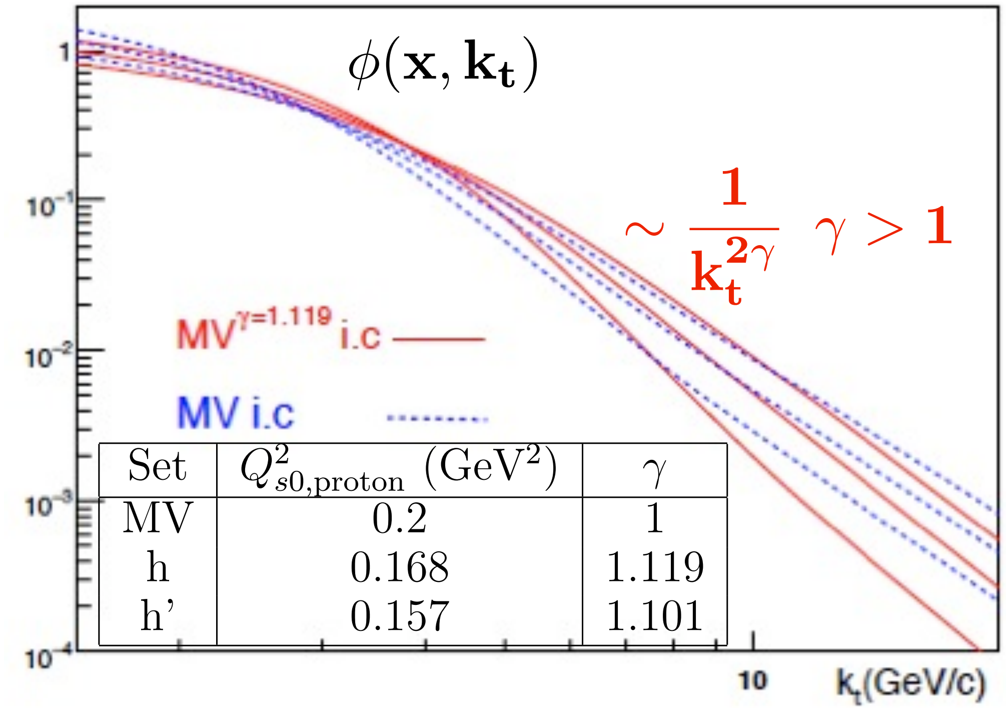
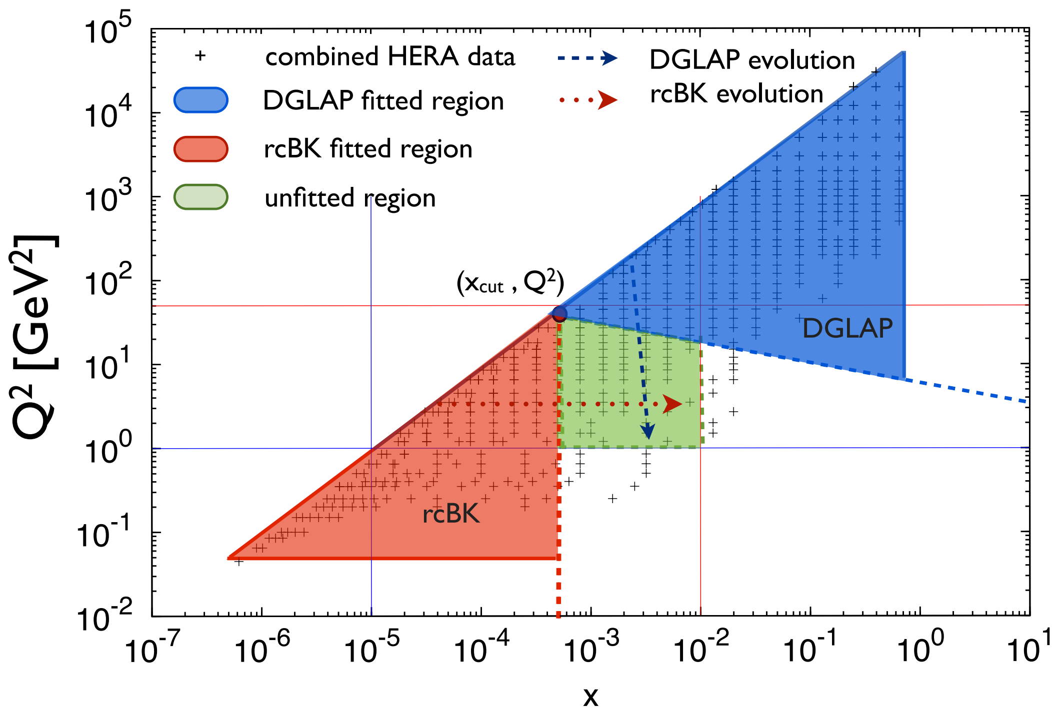
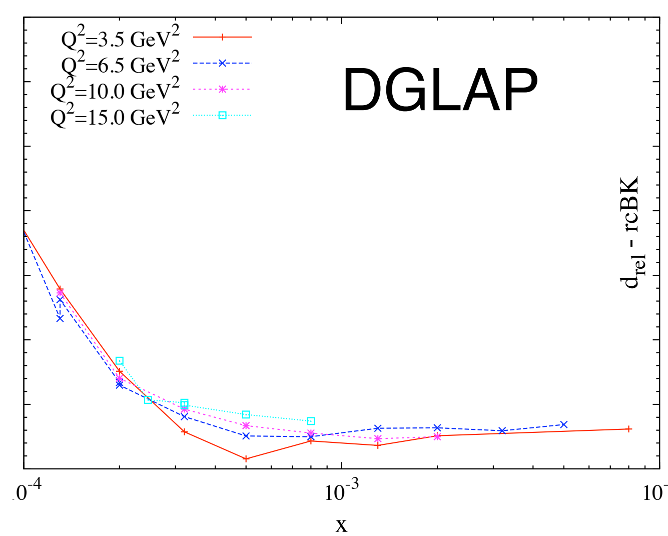
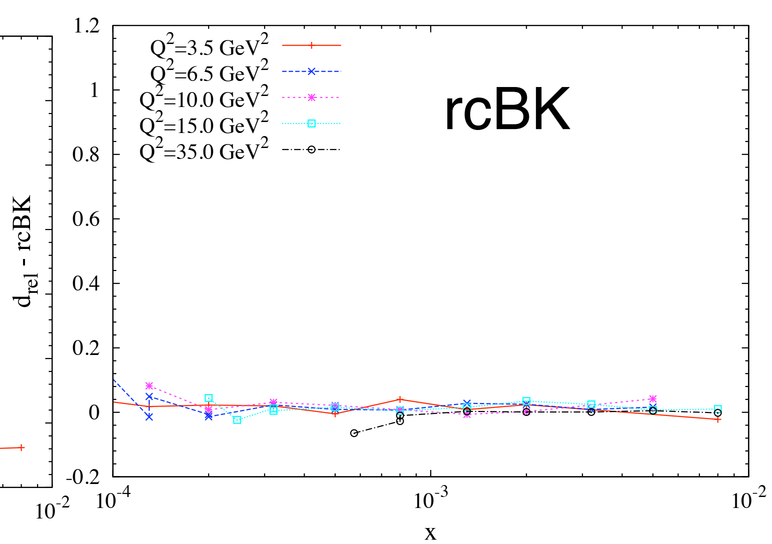


Set	$Q^2_{s0,\mathrm{proton}}$ (GeV^2)	γ
MV	0.2	1
h	0.168	1.119
h'	0.157	1.101

3. Run consistency and stability checks







rcBK fits more stable than DGLAP fits at small-x

The baseline: proton collisions

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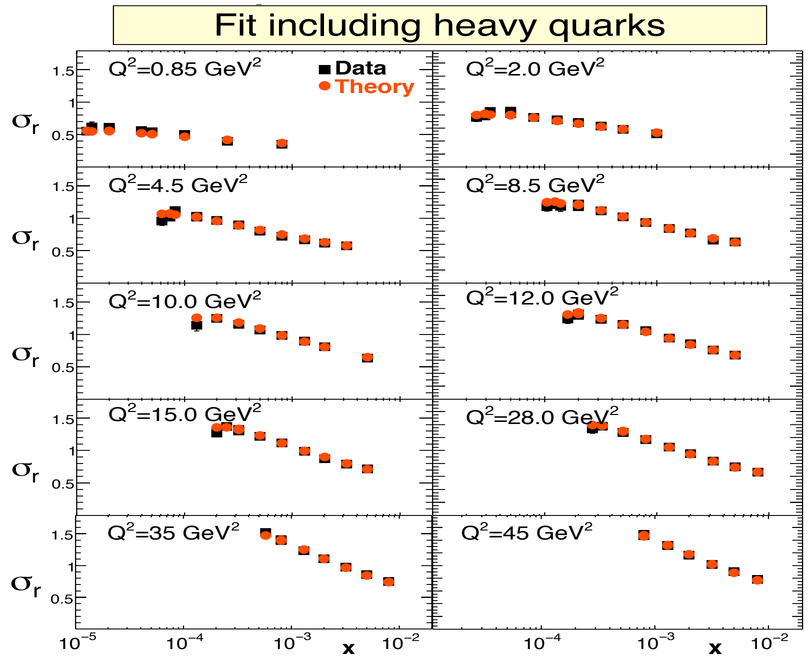

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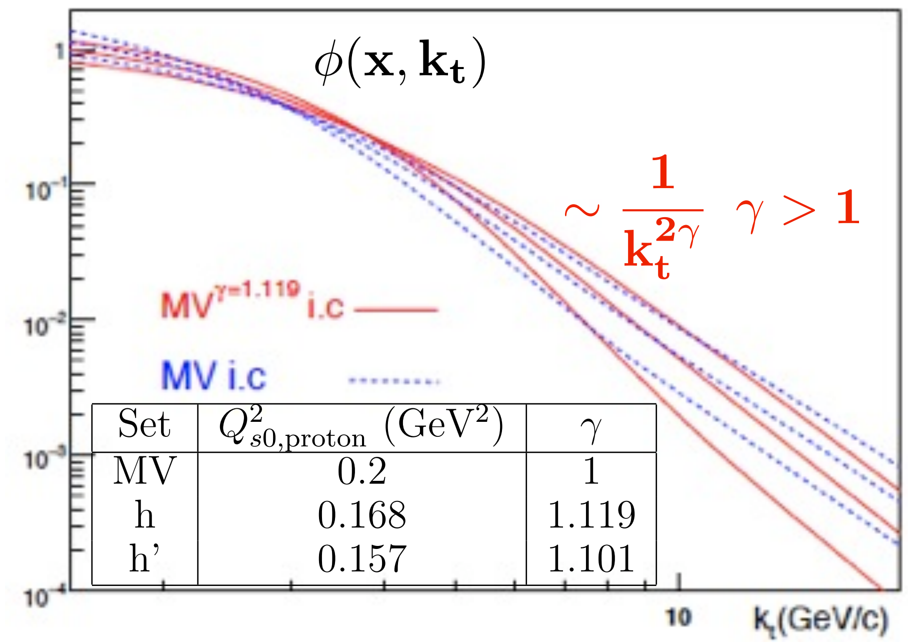
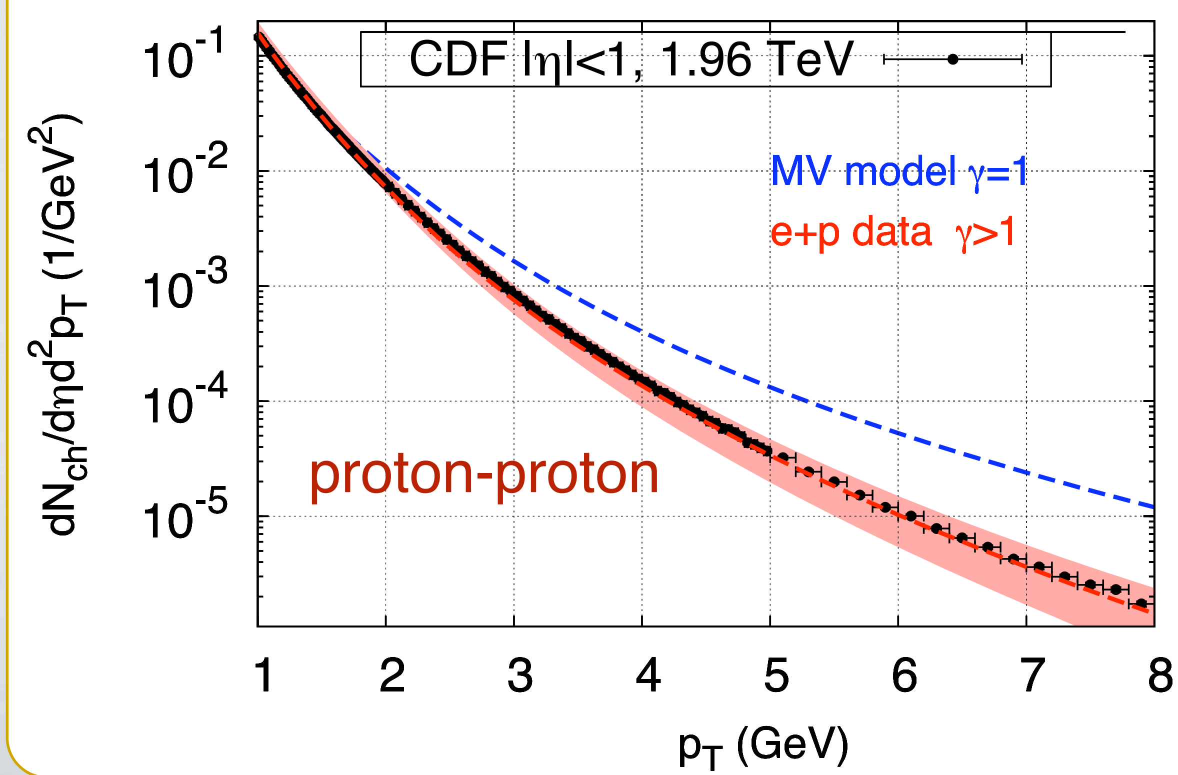
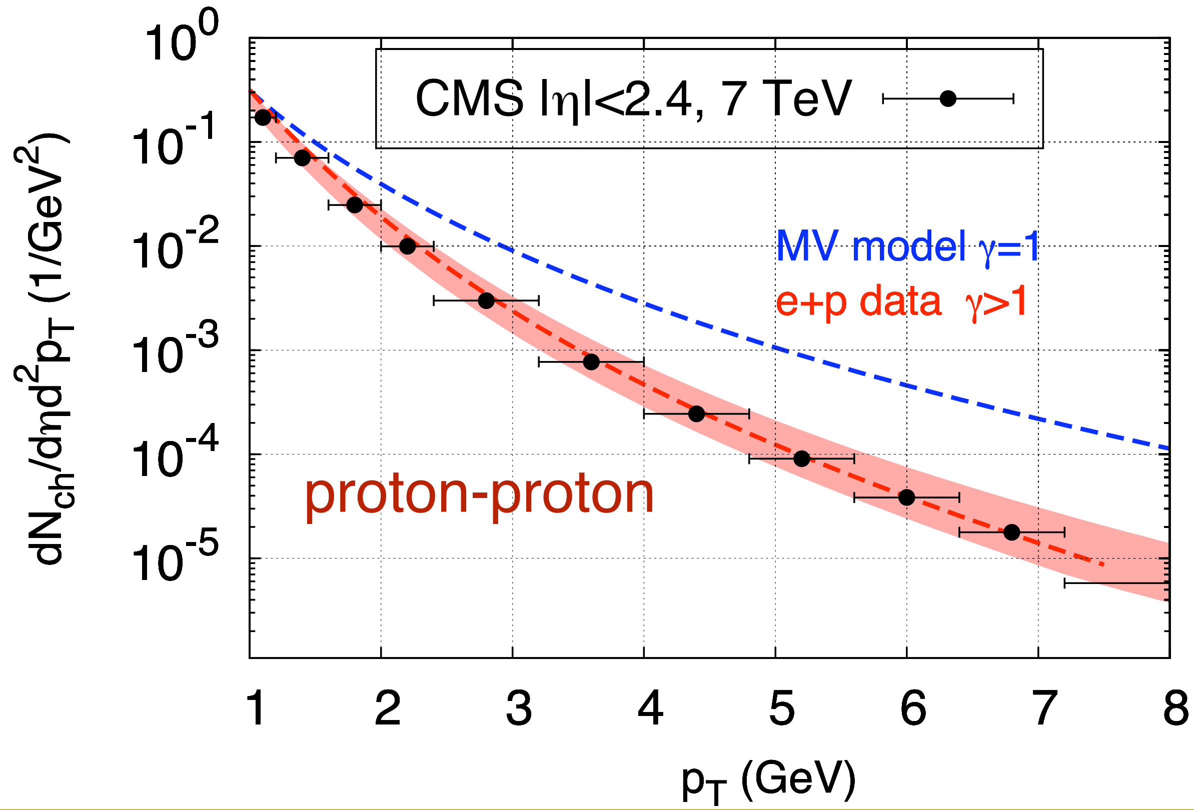


Set	$Q^2_{s0,\mathrm{proton}}$ (GeV^2)	γ
MV	0.2	1
h	0.168	1.119
h'	0.157	1.101

4. Apply gained knowledge in the study of other systems (theory driven extrapolation)

LO kt-factorization: $$\frac{dN^g}{d\eta d^2p_t} \sim K\, \alpha_s(Q_r^2)\, \phi(x_1, k_t) \otimes \phi(x_2, k_t - pt) \otimes FF(Q_f^2)$$





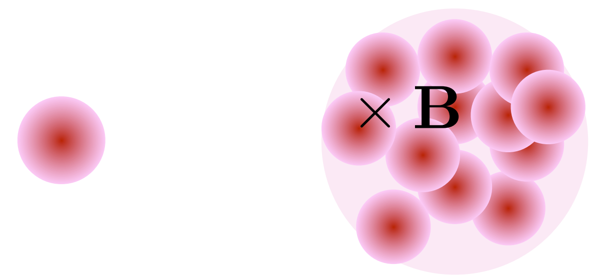
Nuclear ugd's and nuclear modification factors

Setting up the evolution

$$\phi^{\mathbf{Pb}}(\mathbf{x_0},\mathbf{k_t},\mathbf{B}) = \phi^{\mathbf{p}}(\mathbf{x_0},\mathbf{k_t};\{\mathbf{Q^2_{s0,p}} \to \mathbf{Q^2_{s0,Pb}}(\mathbf{B}));\gamma\}$$

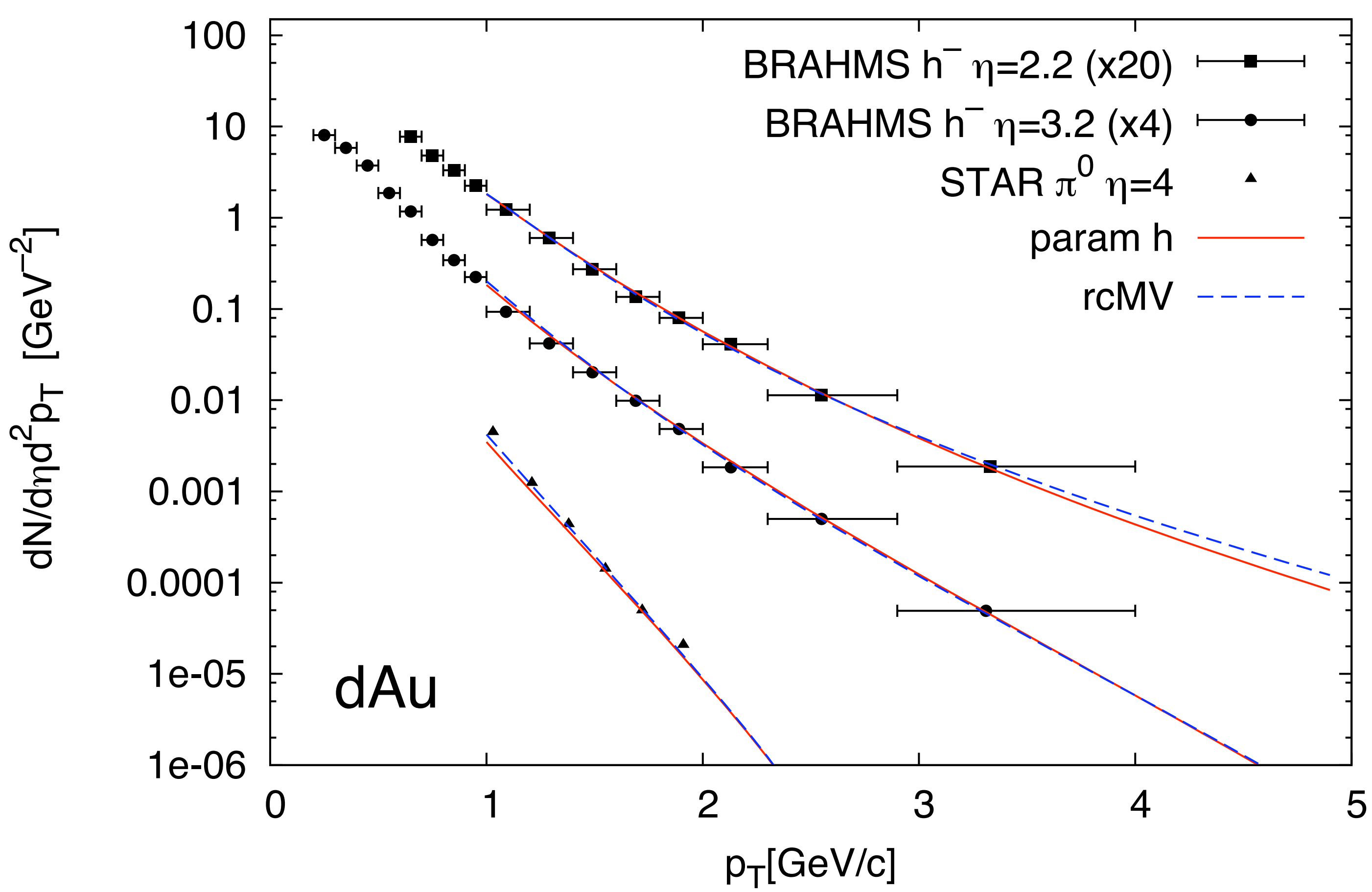
$$\downarrow$$

$$\phi^{\mathbf{Pb}}(\mathbf{x},\mathbf{k_t},\mathbf{B}) = \mathbf{rcBK}[\phi^{\mathbf{Pb}}(\mathbf{x_0},\mathbf{k_t},\mathbf{B})]$$



- RHIC forward data does not constraint the NP parameters for the initial condition
- Other approaches based on high-x energy loss effects also account for data
- Rapidity dependent K-factors

Fujii-Itakura-Nara



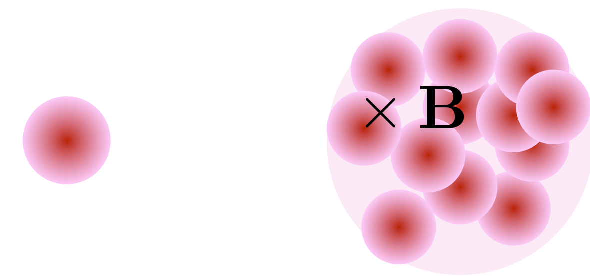
Nuclear ugd's and nuclear modification factors

Setting up the evolution

$$\phi^{Pb}(x_0, k_t, B) = \phi^{p}(x_0, k_t; \{Q^2_{s0,p} \to Q^2_{s0,Pb}(B)); \gamma\}$$

$$\downarrow$$

$$\phi^{Pb}(x, k_t, B) = \mathrm{rcBK}[\phi^{Pb}(x_0, k_t, B)]$$

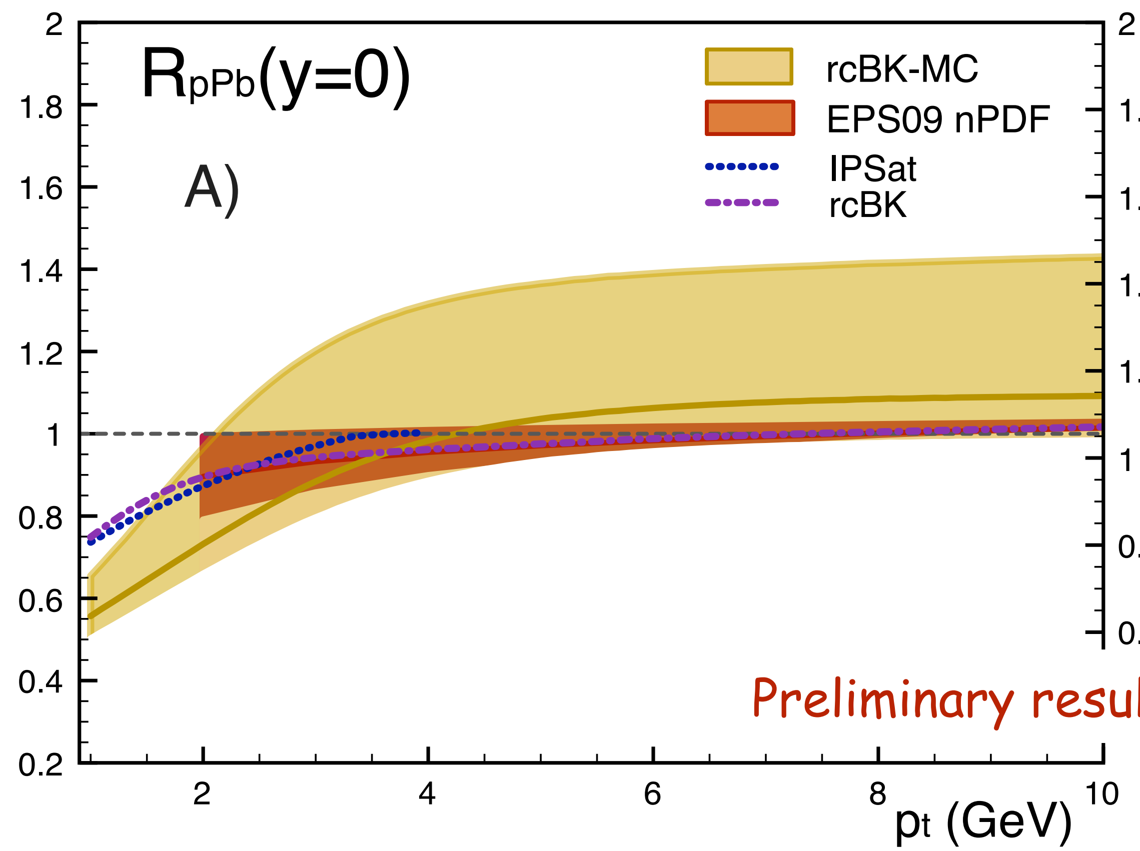


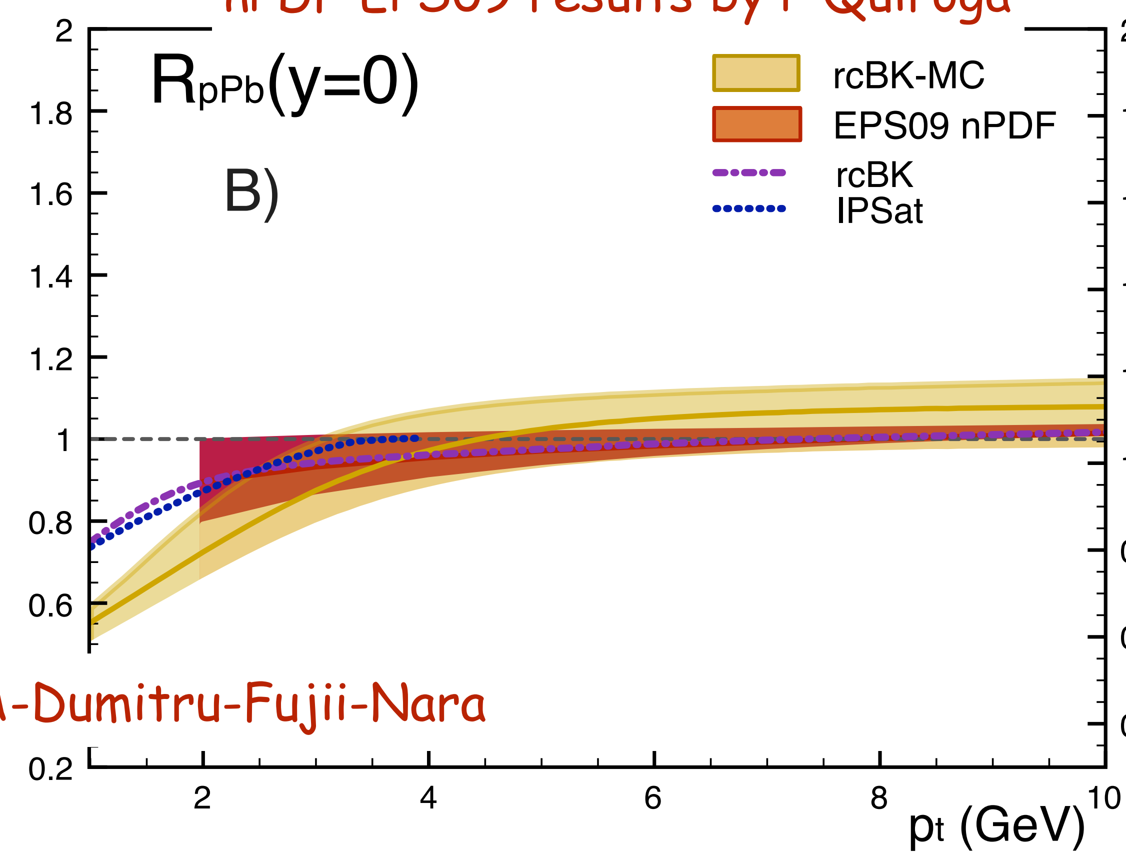
A) Most "natural" option: $Q^2_{s0,Pb}(B) = T_A(B)\, Q^2_{s0,p}$ $\quad \gamma^{Pb} = \gamma^{p} (> 1)$

PROBLEM: yields $R_{pPB} > 1$ at high transverse momentum

B) Possible solution $Q^2_{s0,Pb}(B) = T_A(B)^{1/\gamma}\, Q^2_{s0,p}$ and/or $\gamma^{Pb} = 1(MV) + \frac{\#}{\Lambda\, 2\, /2}$

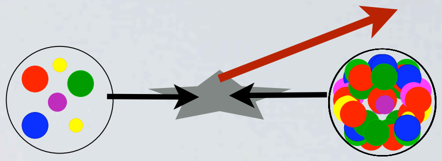
nPDF EPS09 results by P Quiroga





Preliminary results. JLA-Dumitru-Fujii-Nara

Moving forward



Yet another issue: Where to switch from kt-factorization to hybrid formalism? $x_{1(2)} \sim \frac{m_t}{\sqrt{s}} \exp(\pm y_h)$

Midrapidity: kt-factorization:

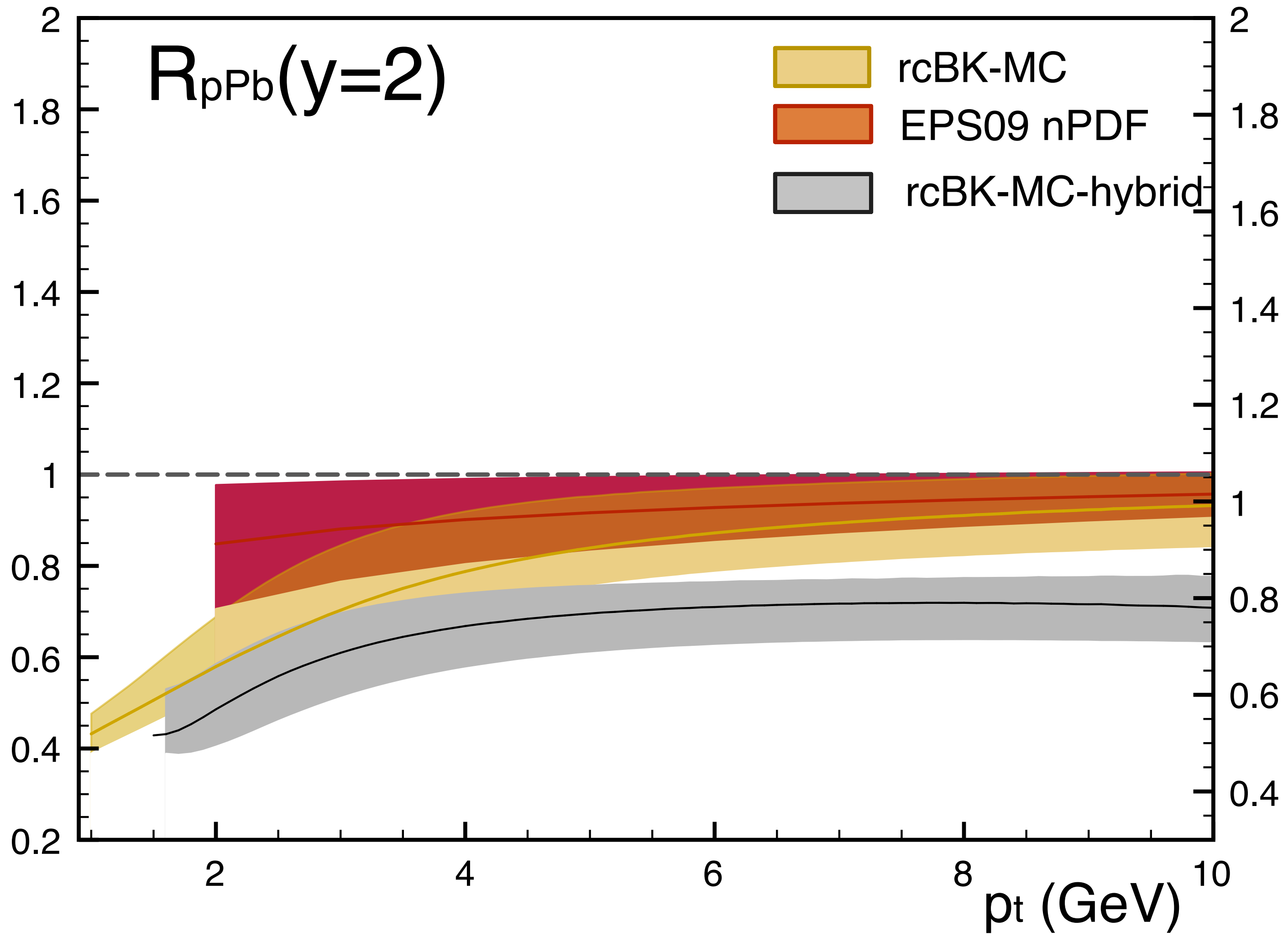
$$\frac{dN^g}{d\eta d^2p_t} \sim \phi^p(x_1) \otimes \phi^{Pb}(x_2)$$

Forward rapidity: hybrid formalism

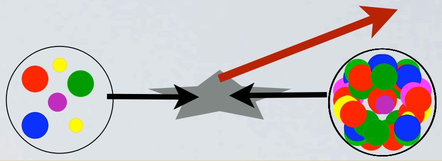
$$\frac{dN}{d\eta d^2p_t} \sim pdf^p(x_1) \otimes \phi^{Pb}(x_2)$$

nPDF EPS09 results by P Quiroga

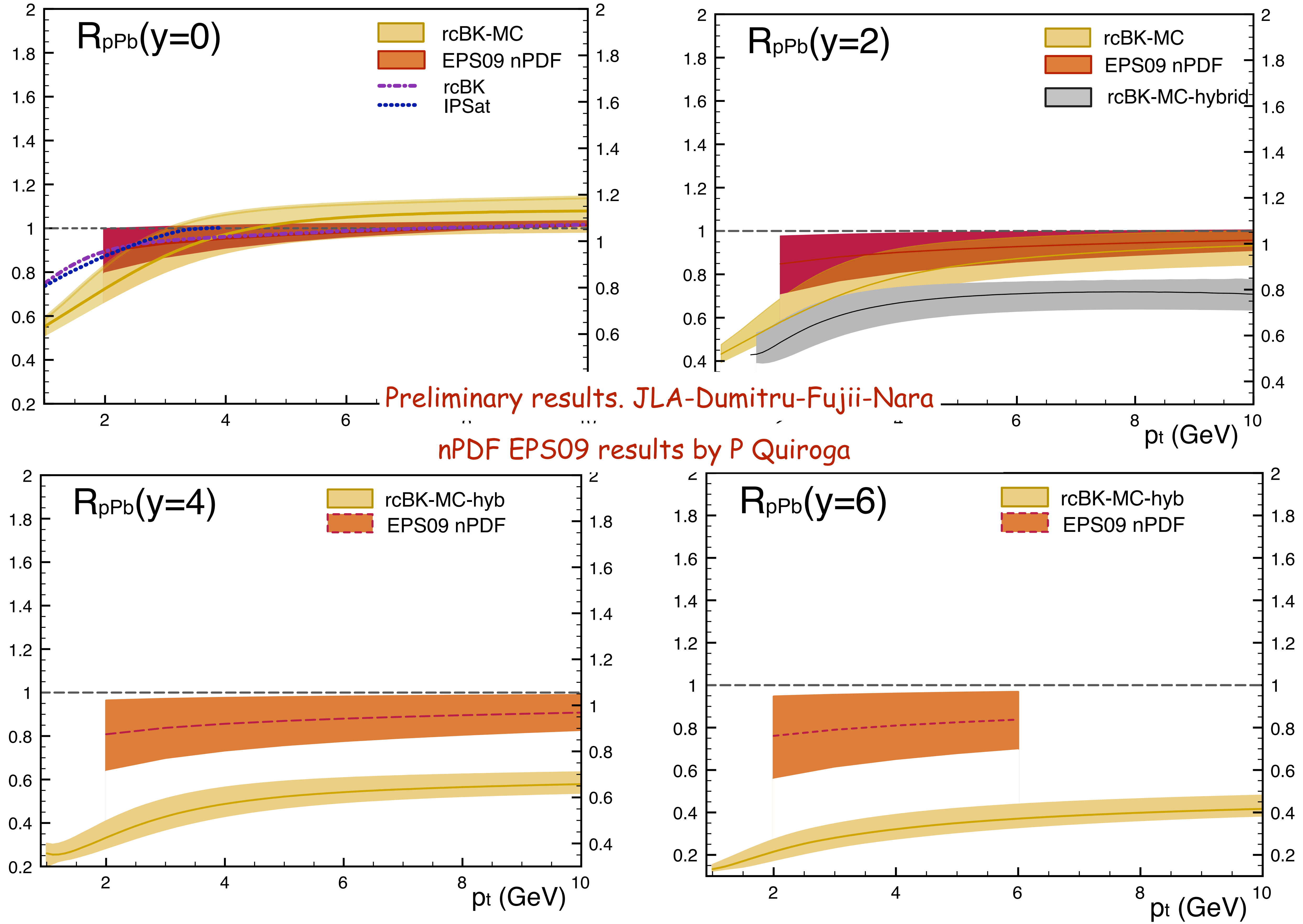
Preliminary results. JLA-Dumitru-Fujii-Nara



Moving forward: Testing the evolution



(p_t, y_h>>0)

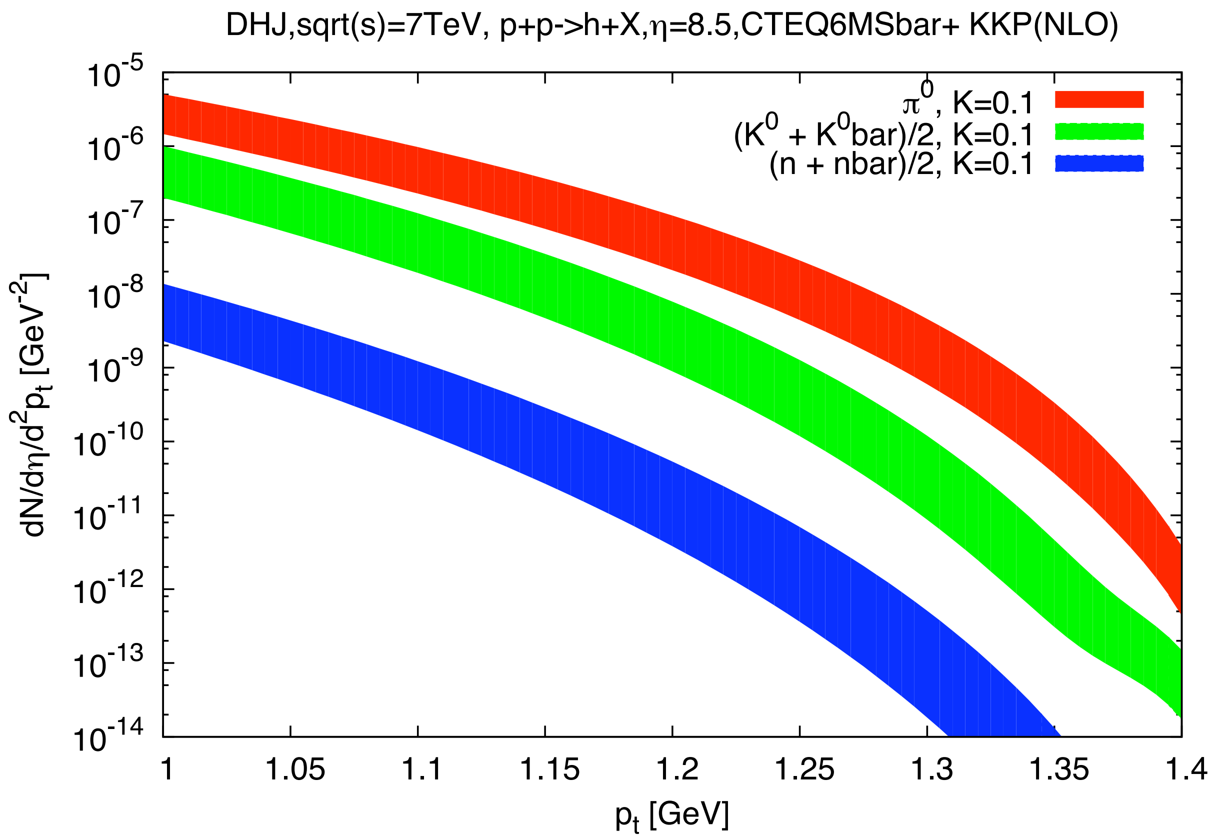


Preliminary results. JLA-Dumitru-Fujii-Nara

nPDF EPS09 results by P Quiroga

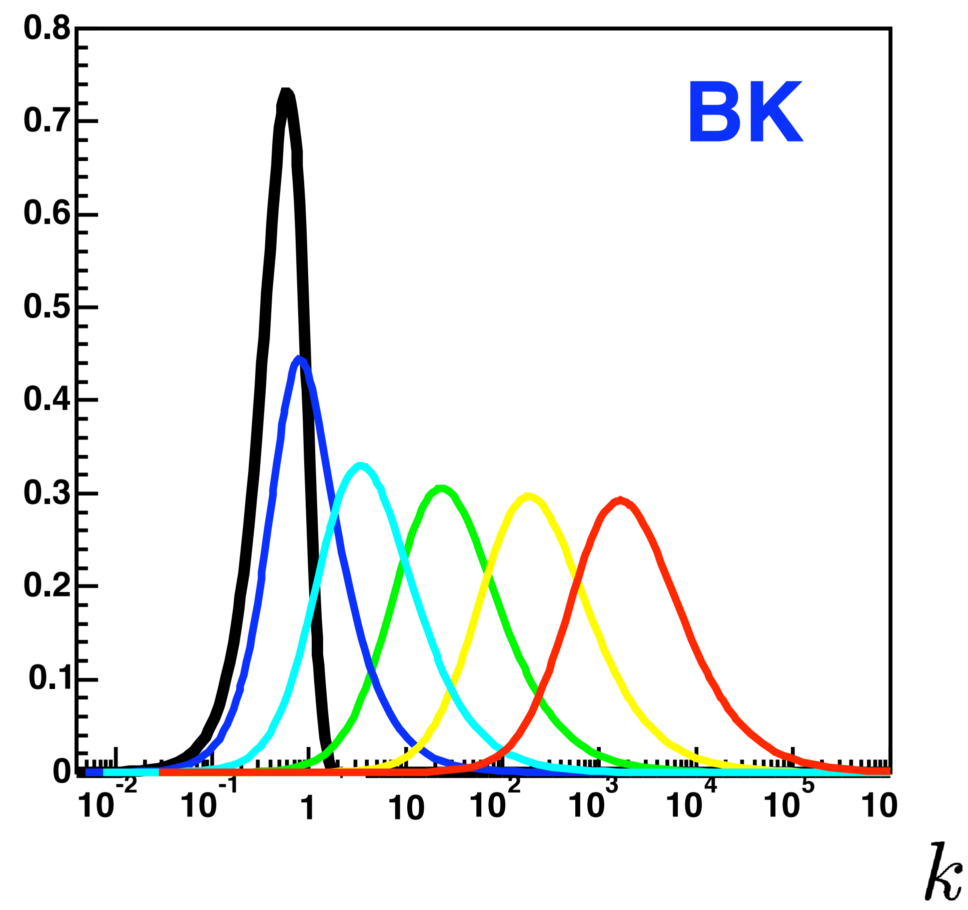
Moving even forward: LHCf (?)

At large rapidities (very small-x) the sensitivity to i.c is reduced (scaling regime)



RpPb should approach its universal limit at very forward rapidities. Scaling properties generated by evolution should be clearly visible in this region

$$\varphi(x, k_t, b) \rightarrow \varphi(k_t/Q_s(x, b))$$



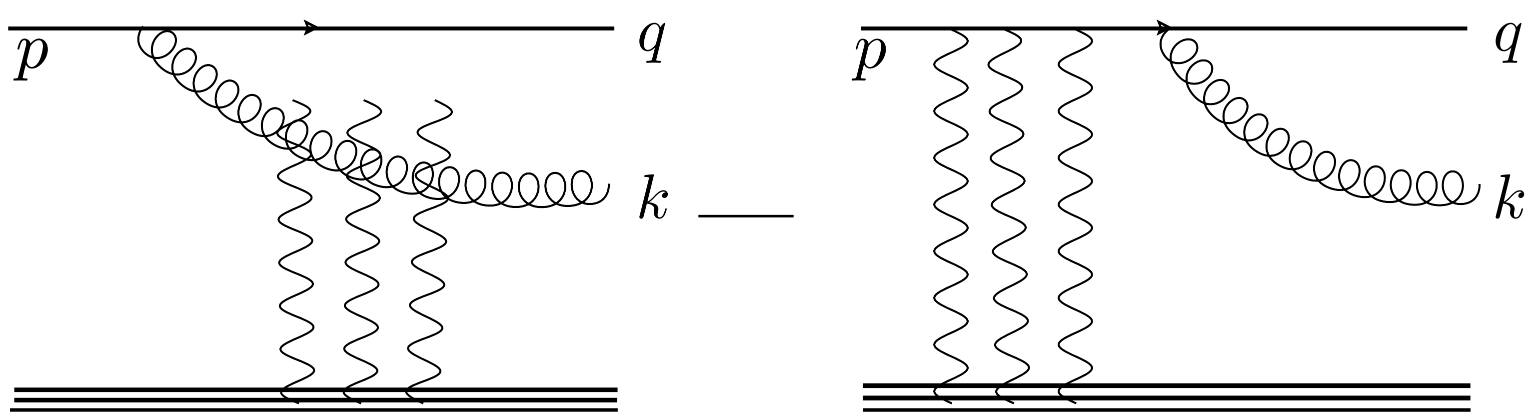
Hadron production (π^0 K^0 and n) at η =8.5 is being studied in this framework

Fujii-Itakura-Nara

Forward di-hadron angular correlations

Marquet '07, Dominguez et al

CGC description: A quark (gluon) emits a gluon. The pair scatters off the target

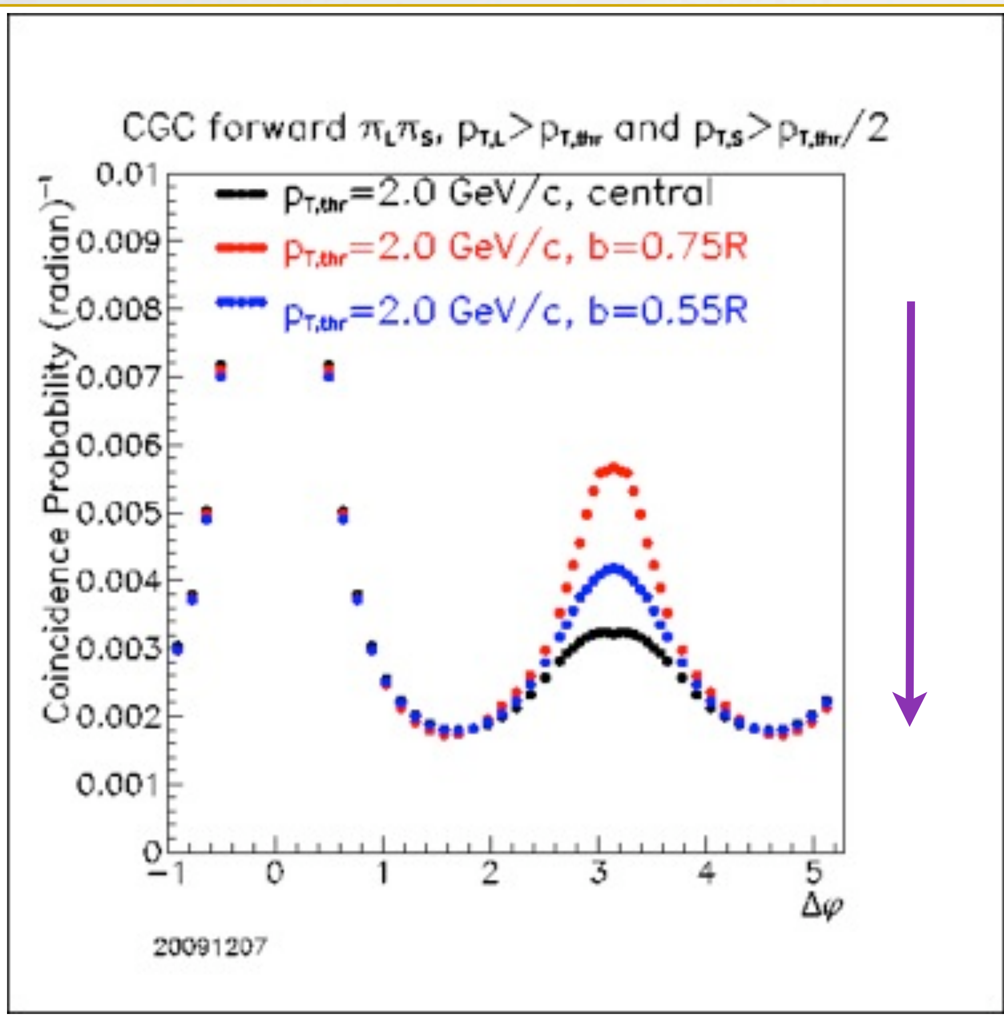


$$x_p = \frac{|k_1| e^{y_1} + |k_2| e^{y_2}}{\sqrt{s}}$$

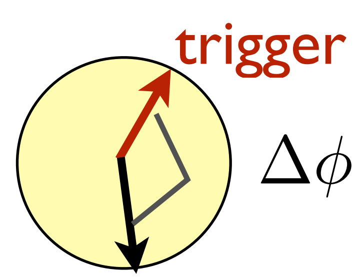
$$x_A = \frac{|k_1| e^{-y_1} + |k_2| e^{-y_2}}{\sqrt{s}}$$

At small-x, the transverse momentum transfer is controlled by the saturation scale

Angular decorrelation happens if $\mathbf{Q_s^{Pb}(x_A) \sim (k_1, k_2)}$



➡ Coincidence probability



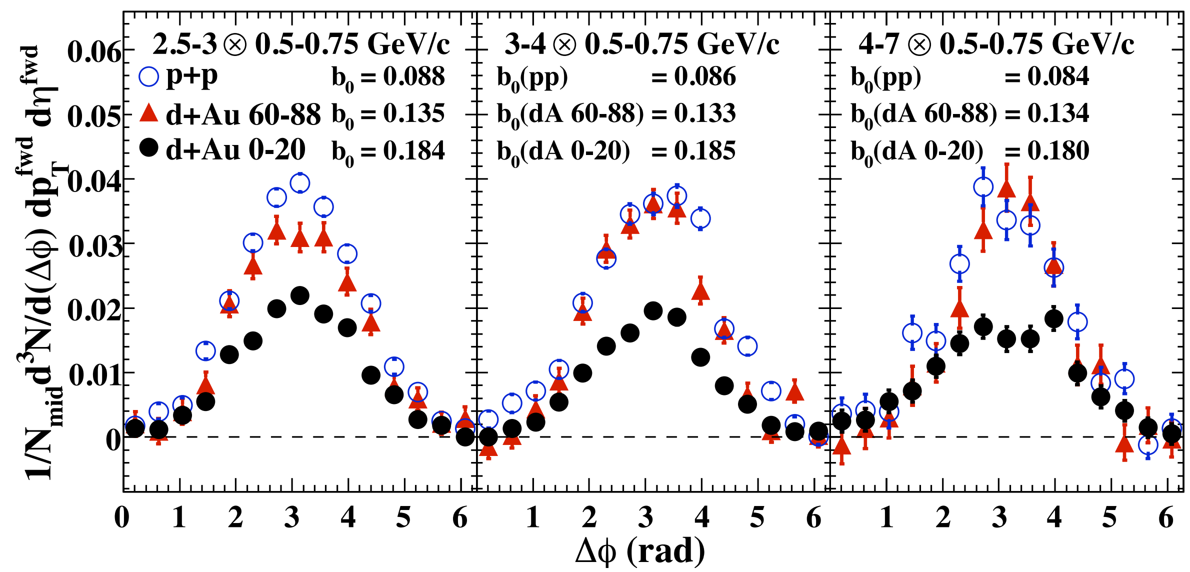
$$CP(\Delta\phi) = \frac{1}{N_{trig}} \frac{dN_{pair}}{d\Delta\phi}$$

Ergo, decorrelation should be stronger with

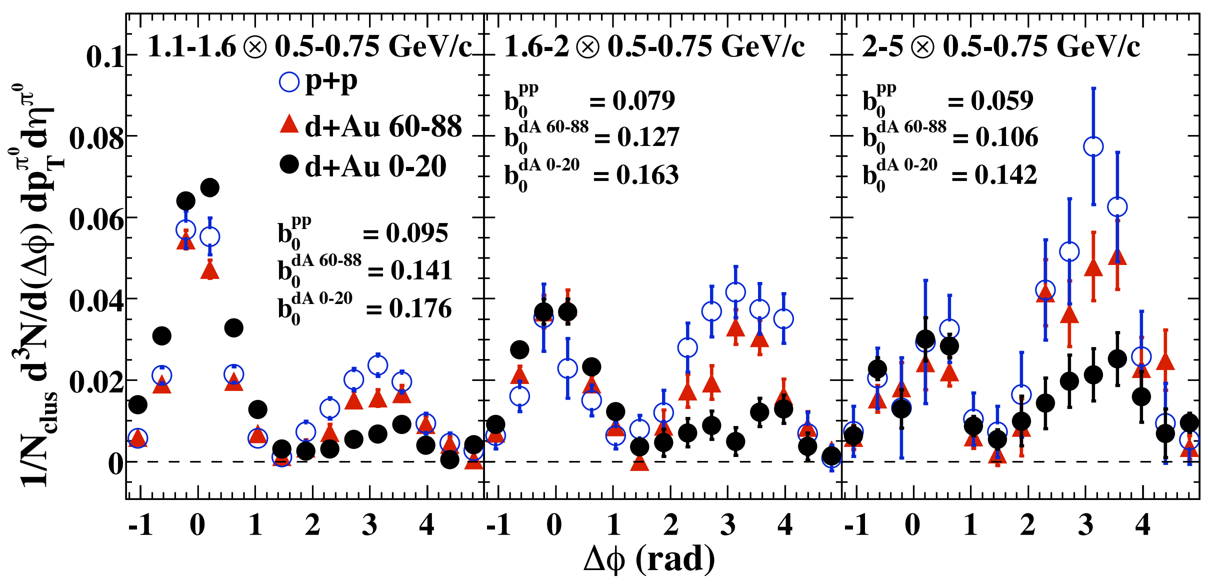
- Increasing rapidity of the pair
- Increasing collision centrality
- Decreasing hadron momentum

Forward di-hadron angular correlations in RHIC dAu data

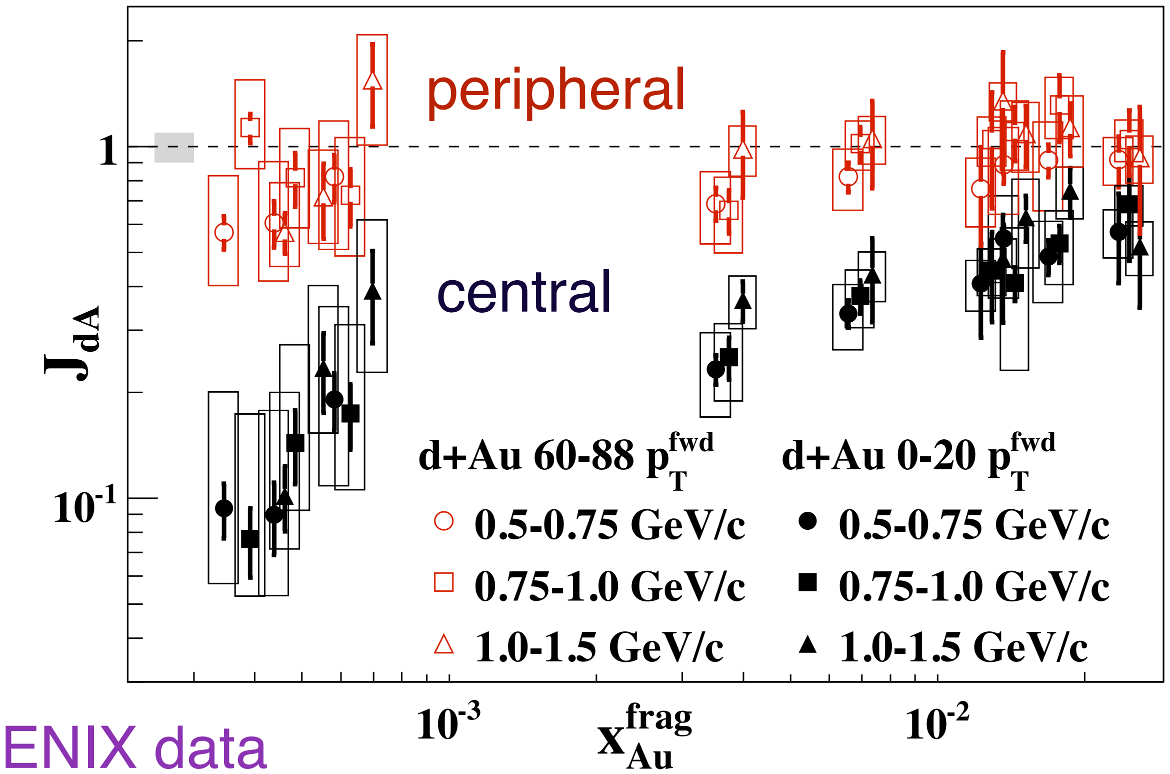
central-forward



forward-forward



$$J_{dA} = I_{dA} \times R^t_{dA} = \frac{1}{\langle N_{\rm coll}\rangle} \frac{\sigma^{\rm pair}_{dA}/\sigma_{dA}}{\sigma^{\rm pair}_{pp}/\sigma_{pp}}$$

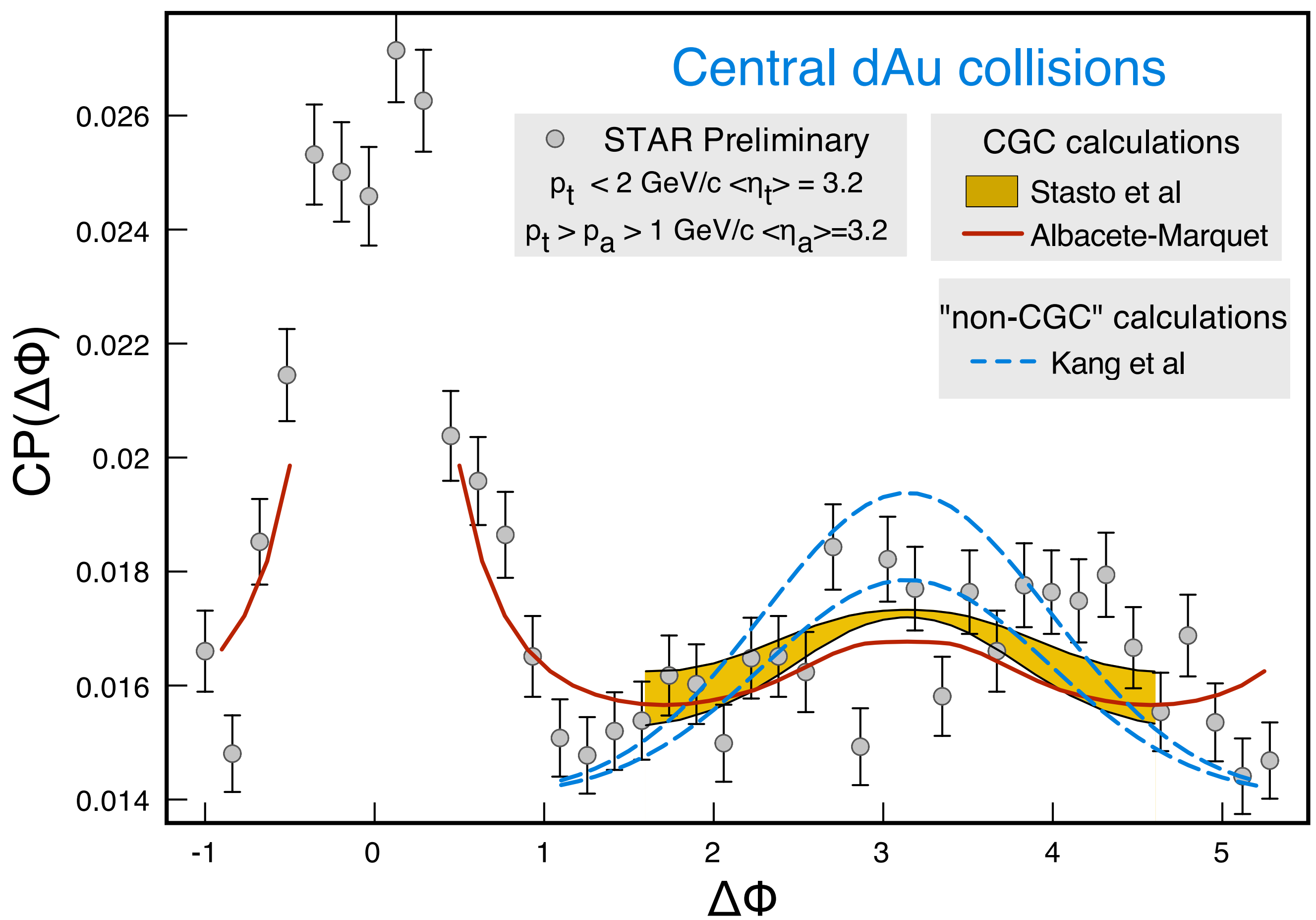


PHENIX data

Observed decorrelation IS stronger with

- Increasing rapidity of the pair
- Increasing collision centrality
- Decreasing hadron momentum

Forward di-hadron angular correlations in RHIC dAu data

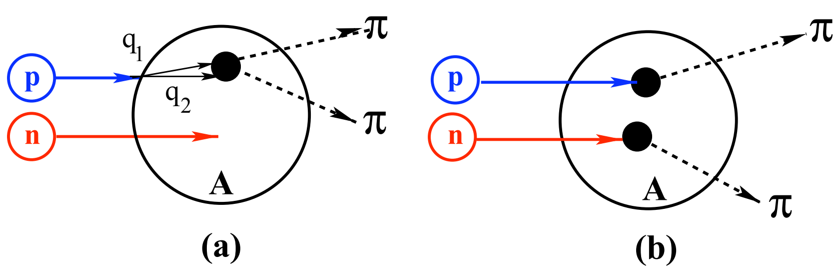


Uncertainties in current CGC phenomenological works:

- Need for a better description of n-point functions: [D. Triantafyllopoulos's and T. Lappi's talk]
- Better determination of the pedestal: K-factors in single inclusive production? Role of double parton scattering?

[Heikki Mäntysaari's talk]

correlated



uncorrelated

Strikman, Vogelsang, 1009.6123

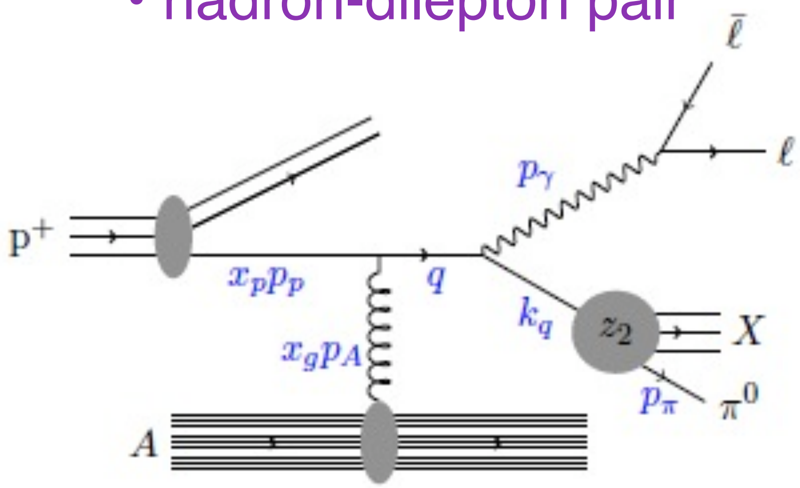
- Alternative descriptions including resummation of multiple scatterings, nuclear shadowing and cold nuclear matter energy loss seem possible...

di-hadron angular correlations at the LHC

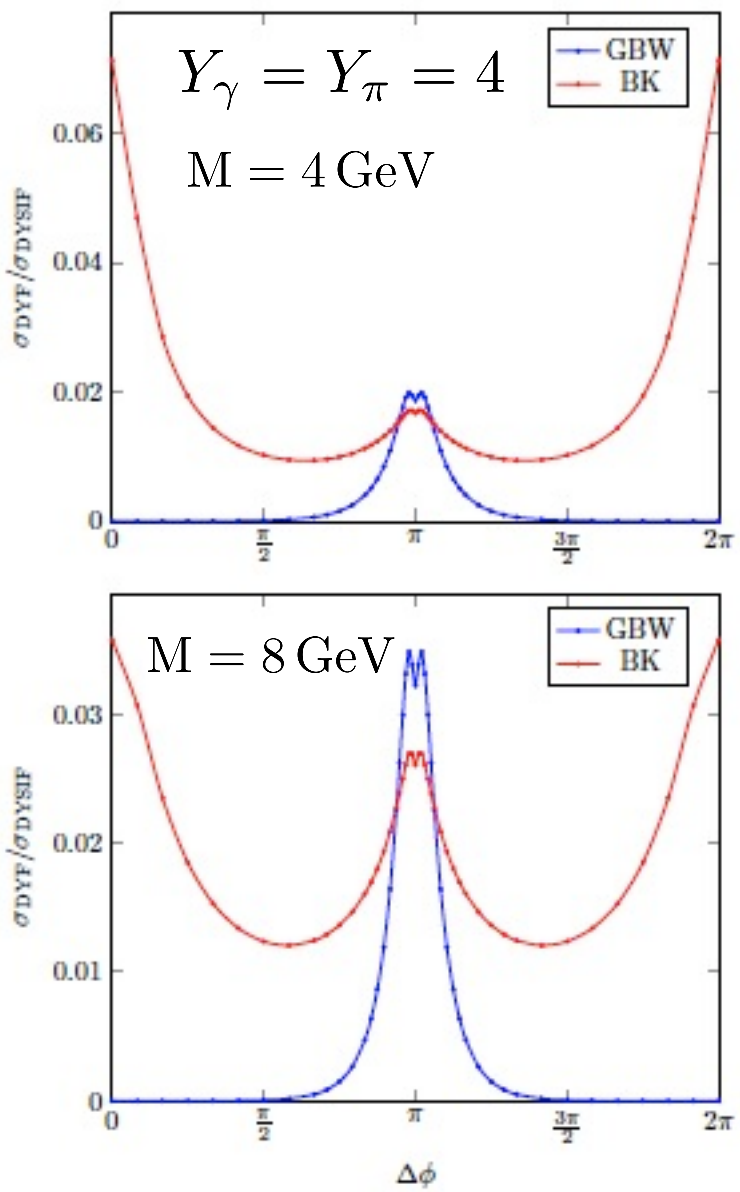
- Analogous decorrelation phenomena should be seen at the LHC
- The increase in collision energy implies that they should be visible at
  * Lower rapidities of the produced pair
  * Higher transverse momentum
- All previously mentioned details are been taken care of. Stay tuned!!! [Heikki Mäntysaari's talk]

hadron-photon* correlations in pPb collisions at the LHC

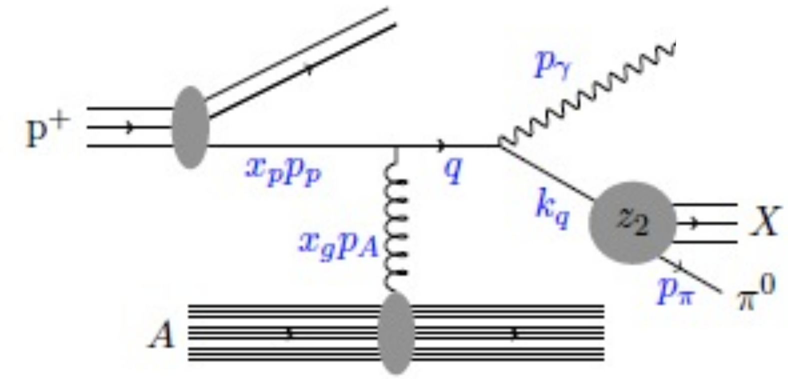
- hadron-dilepton pair



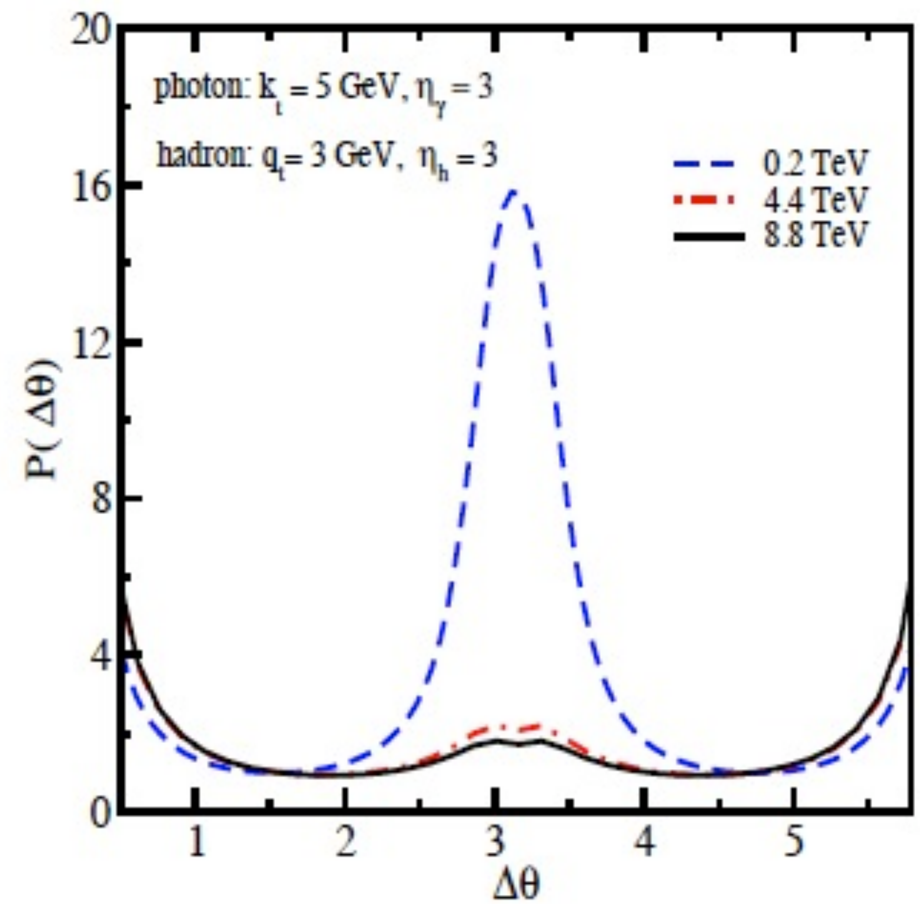
Stasto et al 1204.4861



- hadron-photon



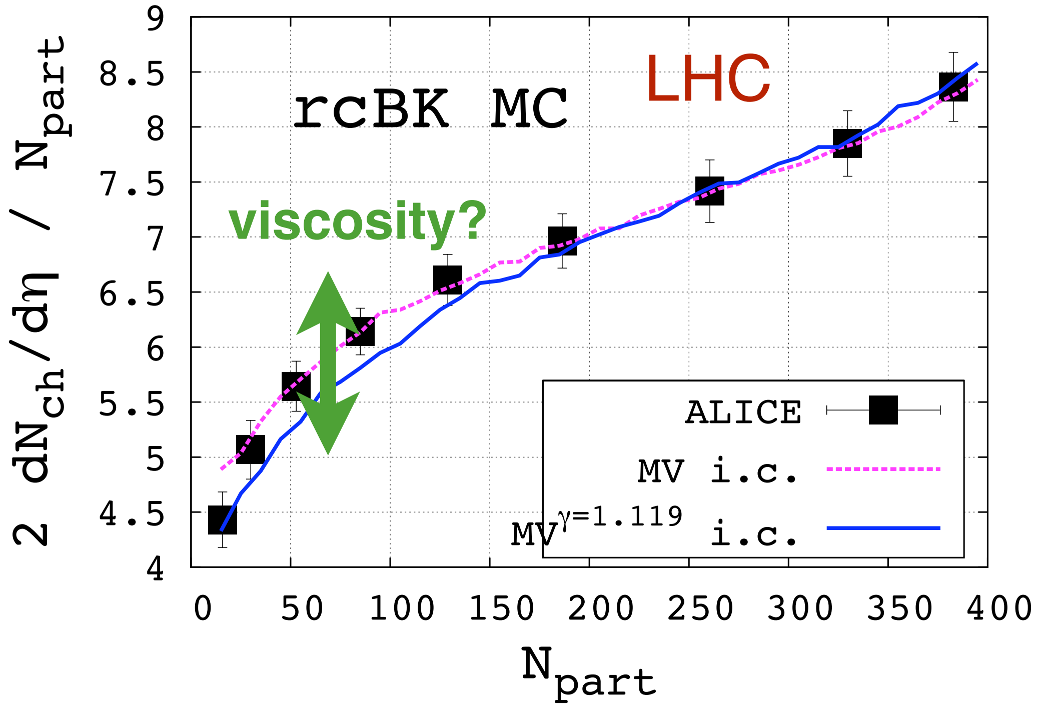
Jalilian-Marian's talk



These processes are theoretically cleaner:
Only knowledge of 2-point needed!!

Miscellanea

- CGC gives a very good descriptions of bulk features of multiparticle production

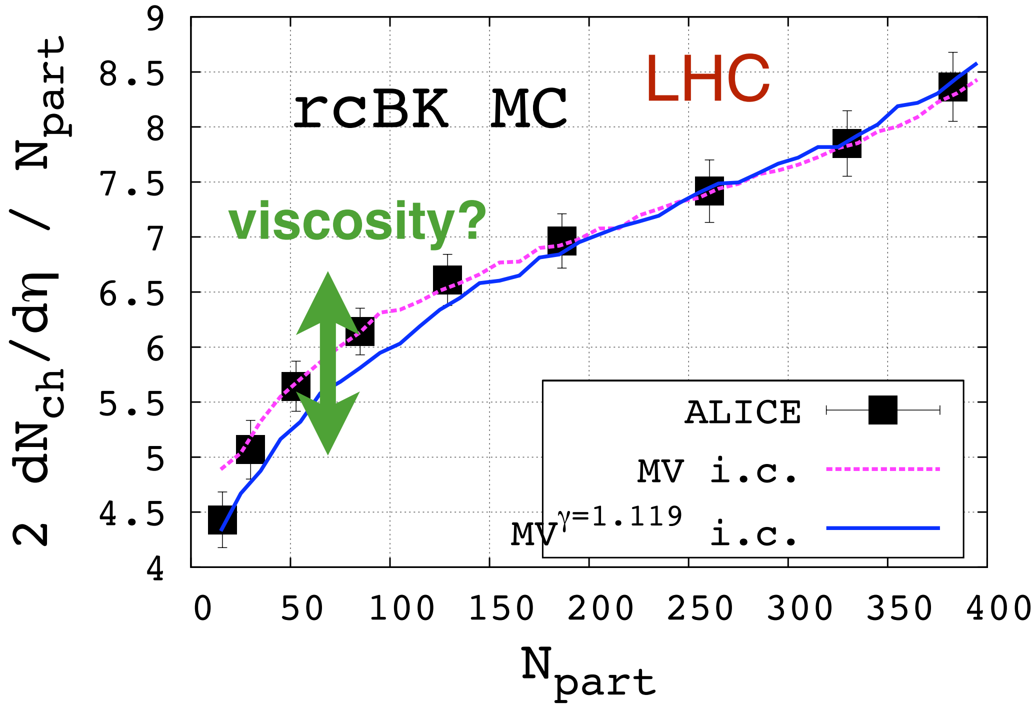


CGC: Non-linear and non-local

Knowledge of the “hard” part of nuclear UGD would further constrain the description of the initial state!

Miscellanea

- CGC gives a very good descriptions of bulk features of multiparticle production

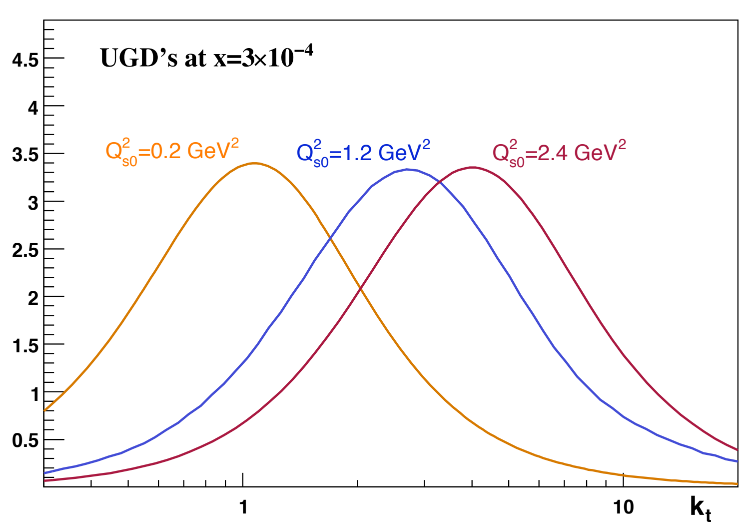


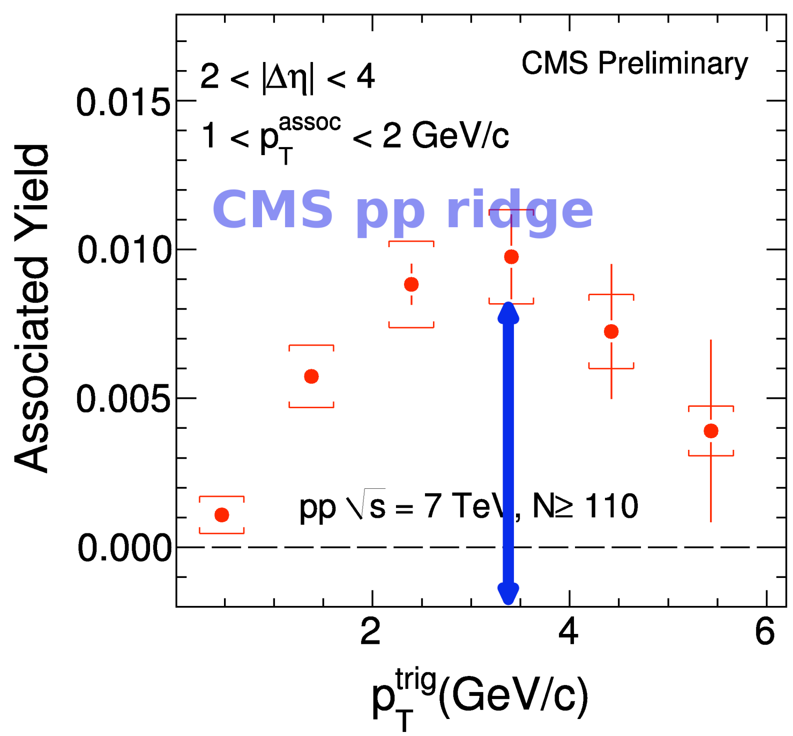
CGC: Non-linear and non-local

Knowledge of the “hard” part of nuclear UGD would further constrain the description of the initial state!

- Can we see the saturation scale??

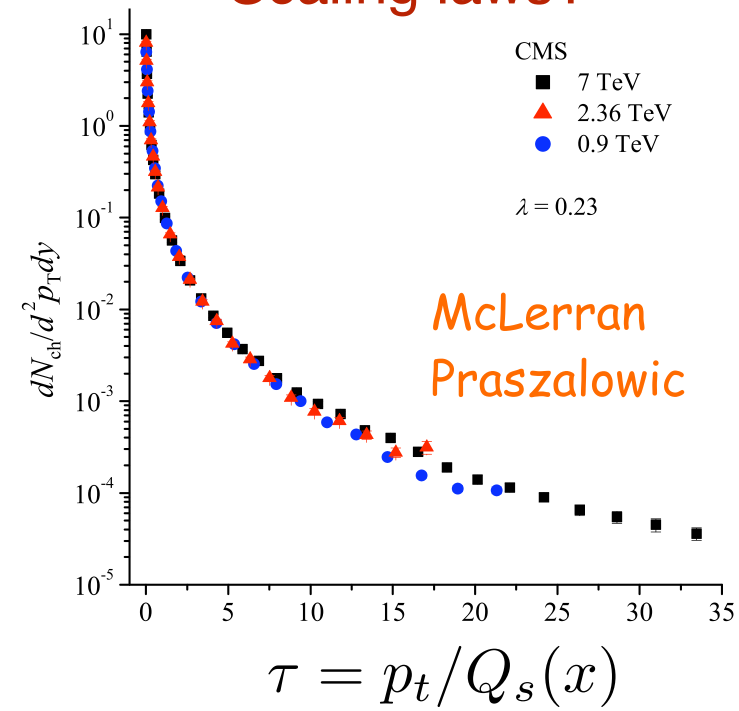
Semihard scale in p+p ridge





Dumitru et al

Scaling laws?



Outlook

✔ Important steps have been taken in promoting GCG to an useful quantitative tool
- Continuos progress on the theoretical side
- Phenomenological effort to systematically describe data from different systems (e+p, e+A, p+p, d+Au, Aa+Au and Pb+Pb) in an unified framework

✔ Most solid CGC predictions for the upcoming p+Pb run:
- Suppression of nuclear modification factors at moderate pt already at mid-rapidity
- Stronger suppression at more forward rapidities (evolution)
- Suppression of di-hadron and photon-hadron angular correlations

✔ Current predictions carry some uncertainty due to lack of data to constrain NP aspects of nuclear UGD. This problem can be largely fixed through the measurement of simple observables (i.e. single inclusive spectra) in p+Pb collisions

✔ The CGC will not be neither proven nor disproven at the LHC, it will be improved

GRAZIE!

Back up