

Cold nuclear matter effects in p-A at LHC

1st ReteQuarkonii Workshop

Nantes, 25-28 Oct 2010

Smbat Grigoryan & Cynthia Hadjidakis



- p-A collisions: physics motivations and LHC feasibility
- Studying CNM effects: models and event generators
- Quarkonia production in p-Pb & Pb-p at LHC with

ALICE Muon Spectrometer (MS)

Quarkonium measurements: lessons from RHIC

How to estimate QGP effects in A-A?

Measure of nuclear modification factor vs centrality

$$R_{AA} = N_{AA} / (N_{coll} \times N_{pp})$$

But R_{AA} includes hot and cold (nuclear absorption, shadowing, gluon saturation, ...) nuclear matter effects: how to disentangle these effects?

What have we learned from RHIC?

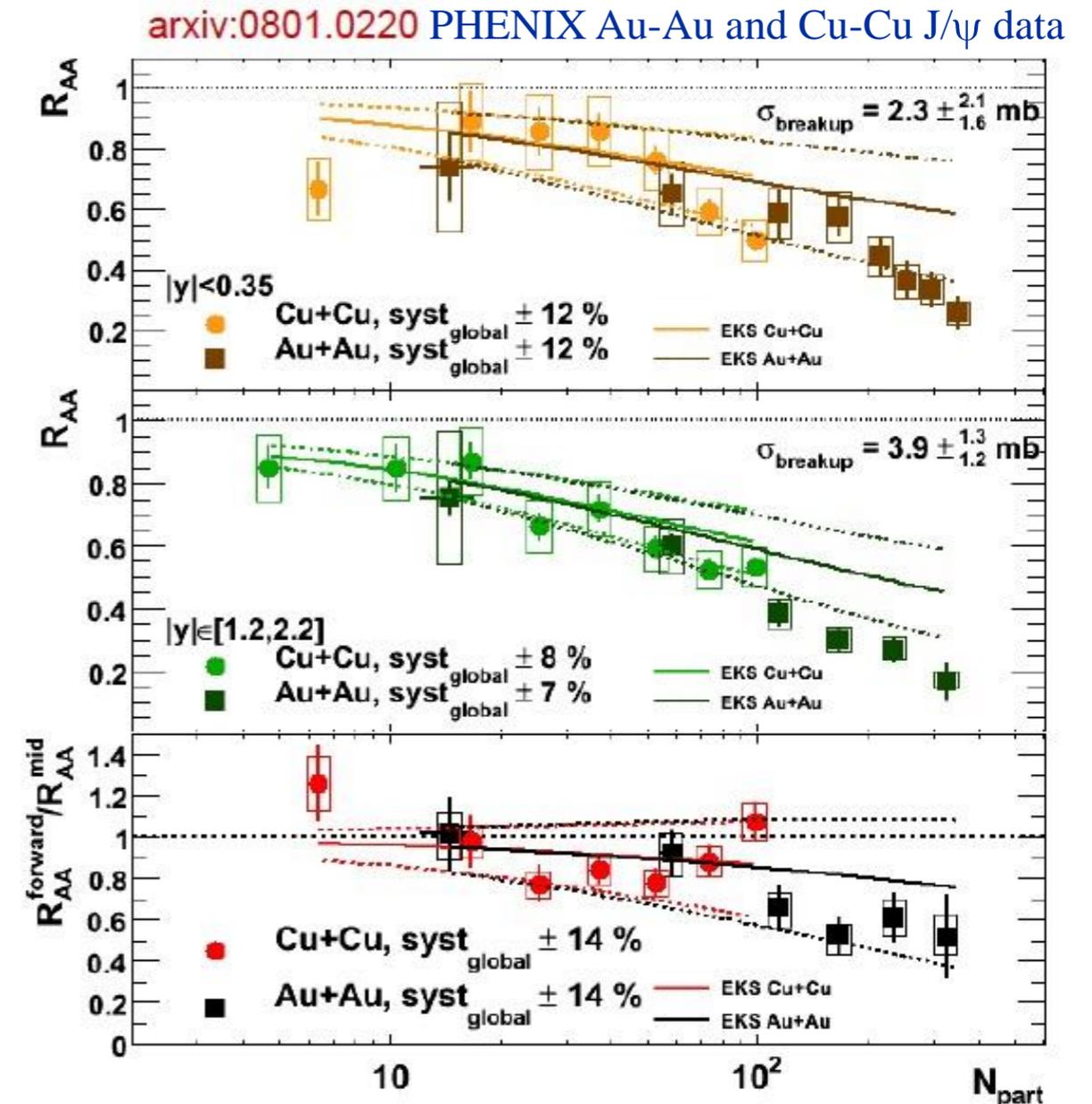
Measurement of J/ψ R_{dAu} at 200 GeV to estimate cold nuclear effects (RHIC data analysis include shadowing and effective absorption effects) → extrapolation of d-Au to Au-Au and Cu-Cu

Large uncertainty of $\sigma_{break-up}$ (depends on shadowing model) does not allow to conclude on hot nuclear matter effects (QGP)

Interpretation of R_{AA} needs **precise measurement of CNM effects at LHC**

- high statistics p-A data as a reference for A-A with $A=Pb$ and $A=lighter\ ion$ (Ar, ...)
- p-A and A-p needed (ALICE Muon Spectrometer is only on one side...)

But first interpretation of 2010-2011 Pb-Pb data will be based on lower energy CNM measurements and theoretical extrapolation methods

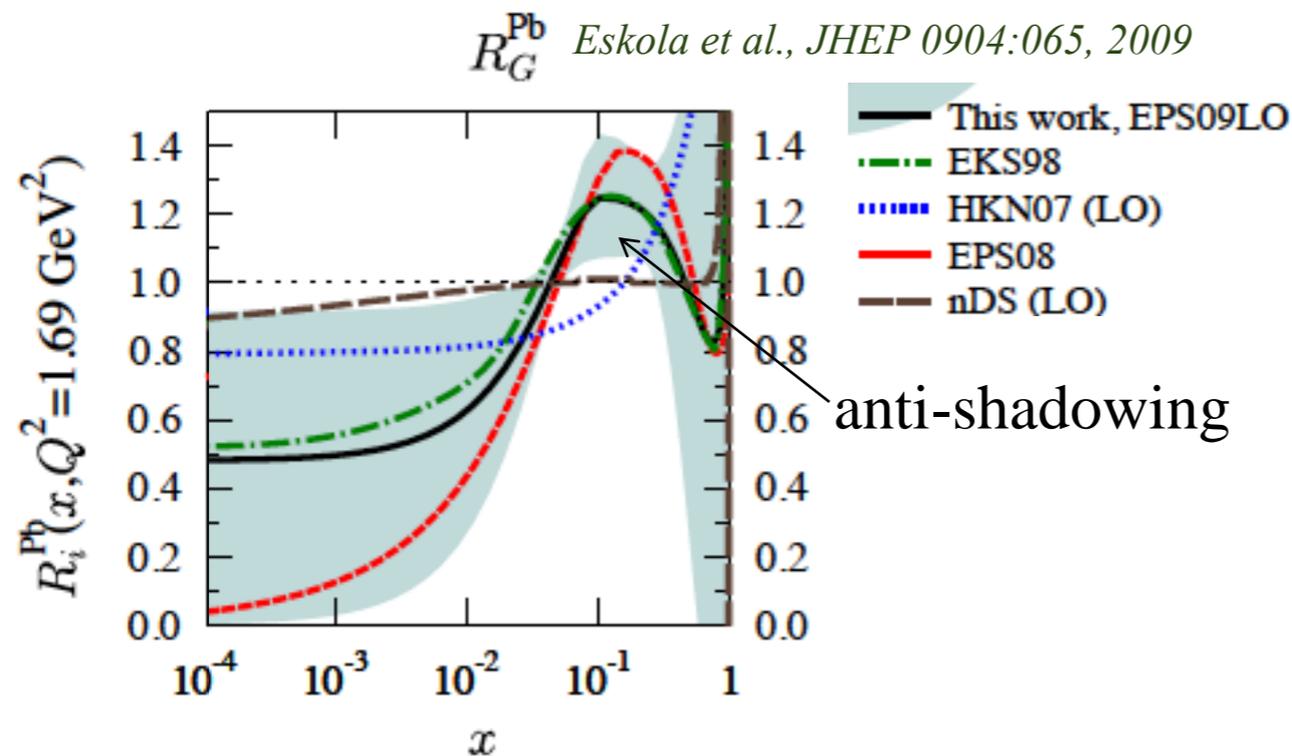


Cold nuclear effects at LHC

What do we expect at LHC?

- Nuclear absorption :
at LHC, quarkonium formation far outside nucleus,
so smaller nuclear absorption expected

- Gluon shadowing:



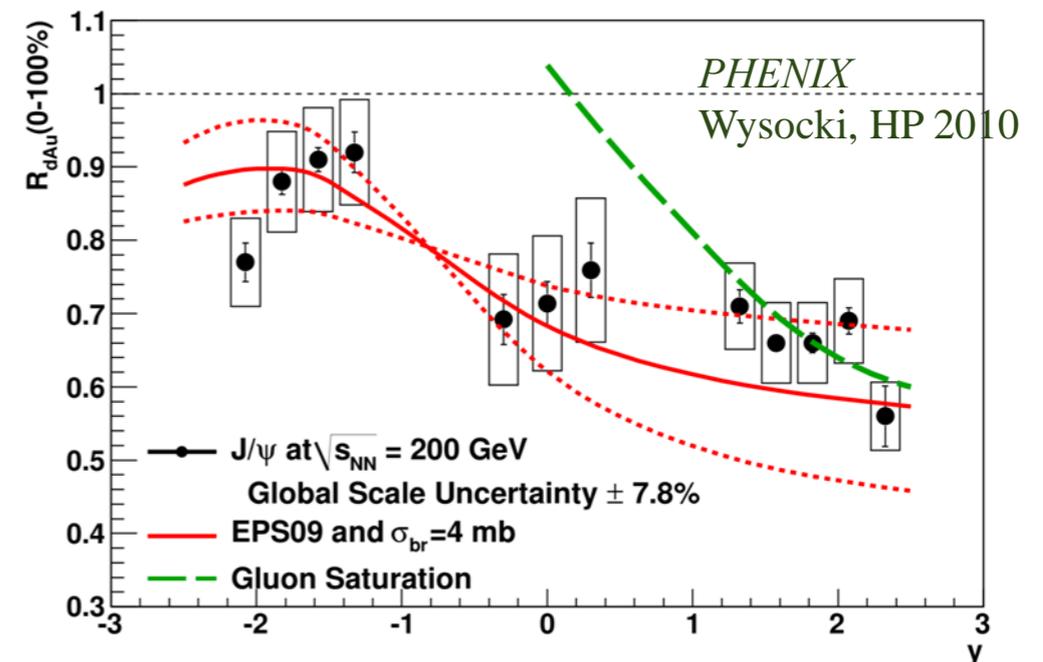
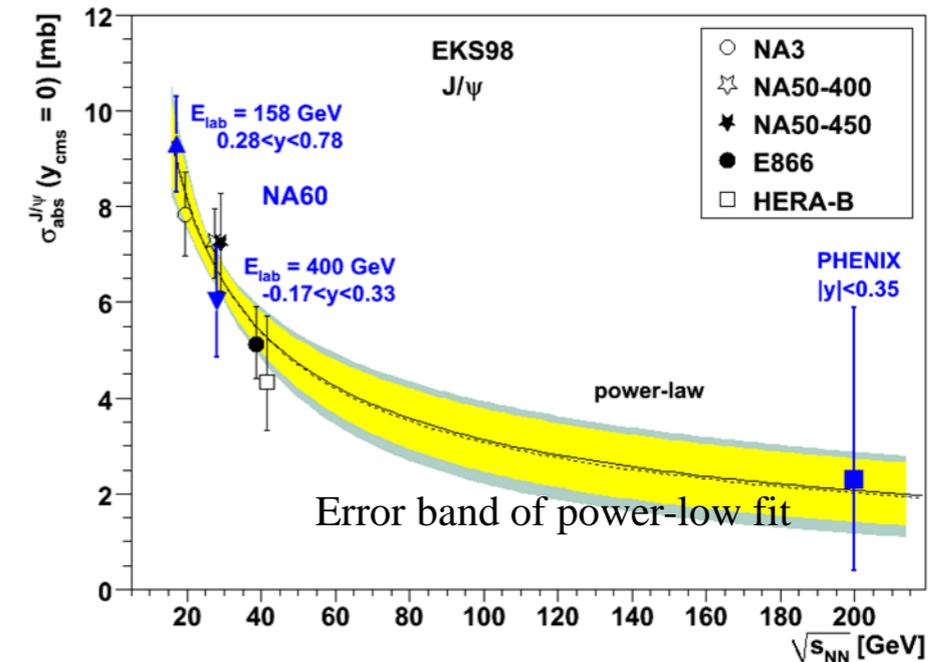
at LHC (= small x) a large shadowing expected
but huge uncertainty on nPDFs at low Q^2

- Gluon saturation:

qualitative description of R_{dAu} at RHIC for $y > 1$
at LHC: important at all y (for $p_T < 5-10 \text{ GeV}/c$)

→ saturation scale $Q_{s,\text{LHC}}^2(y=0) \simeq Q_{s,\text{RHIC}}^2(y=3)$

Lourenco et al., JHEP 0902:014, 2009



LHC feasibility for p-Pb collisions

ALICE requirements for the first 4 years of LHC running (from ALICE PPR, 2004)

Coll. system	$\sqrt{s_{NN}}$ (TeV)	L_0 (cm ⁻² s ⁻¹)	Run time (s)	σ_{geom} (b)
p-p	7 / 14	$3 \cdot 10^{30}$ *	$4 \cdot 10^7$	0.07
Pb-Pb	2.76 / 5.5	$5 \cdot 10^{26}$	$2 \cdot 10^6$	7.7
p-Pb	8.8	$1.1 \cdot 10^{29}$	$1 \cdot 10^6$	1.9

(*ATLAS/CMS $L_0 = 10^{34}$, LHCb $L_0 = 10^{32}$)

LHC current planning (2012 – 2013 1st half → shutdown) :

2010 – 2011: p-p → 7 TeV, Pb-Pb → 2.76 TeV (1 month per year)

2013 2nd half or 2014: p-p → 14 TeV, Pb-Pb → 5.5 TeV (1 month)

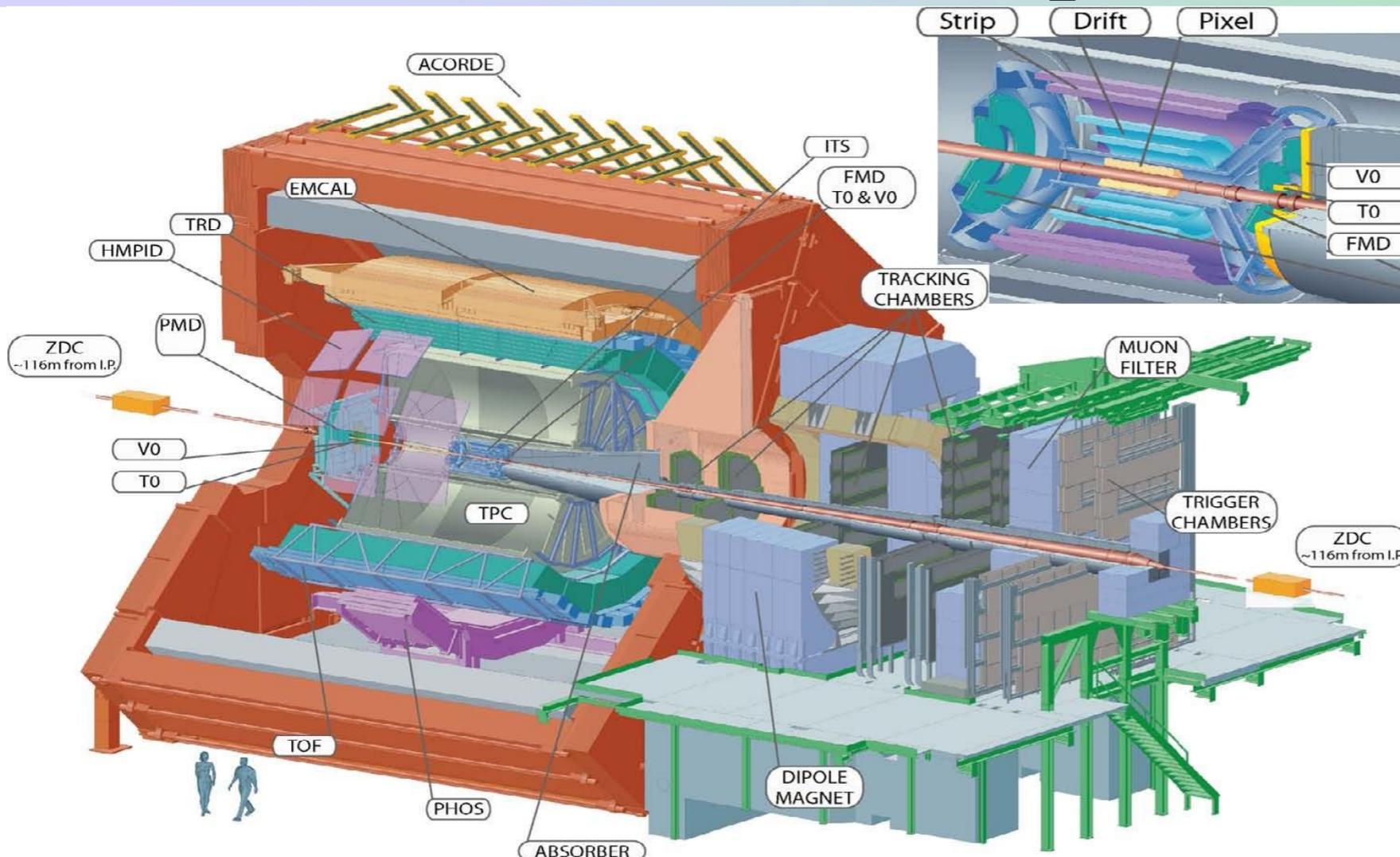
2014 or 2015: p-p → 14 TeV, p-Pb & Pb-p → 8.8 TeV (1 month)

- Single magnet ring with two beam aperture imposes:
 - Pb beam momentum $(Z/A) \times p_p = 2.76$ TeV per nucleon if $p_p = 7$ TeV
 - $\sqrt{s} = \sqrt{(Z_1 Z_2 / A_1 A_2)} \times 2 \times p_p = 8.8$ TeV for p-Pb
 - one may require $p_p < 7$ TeV → $p_p = 4.4$ TeV leads to $\sqrt{s} = 5.5$ TeV for p-Pb
- $\Delta y = 0.5 \ln(Z_1 A_2 / Z_2 A_1) = 0.47$ for p-Pb
- Running with d-Pb? $\Delta y = 0.1$: almost same acceptance than Pb-Pb, centrality tagging with forward neutron, nucleon probe (average of proton and neutron) → **new injection source needed, a strong request from the user community would be a first step to get it**
- How much time needed to go from p-Pb to Pb-p?

Other ions?

Probable candidates are Ar-Ar and p-Ar but these are less studied yet

Quarkonia studies in p-A with ALICE MS



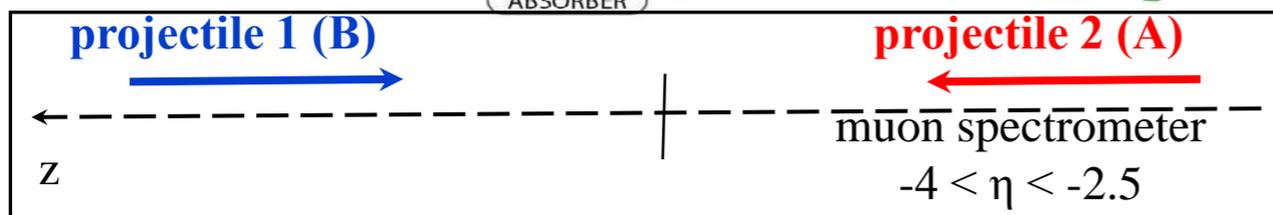
Quarkonia ($J/\psi, \Upsilon$) production

Central Barrel $y=[-0.9, 0.9]$

$$J/\psi(\Upsilon) \rightarrow e^+e^-$$

Muon Spectrometer $y=[-4, -2.5]$

$$J/\psi(\Upsilon) \rightarrow \mu^+\mu^-$$



For B-A collision ALICE uses the convention of first indicating the particle moving towards the Muon Spectrometer

We consider two models for the CNM effects on quarkonia production in p-A:

- Shadowing model (based on EKS98, nuclear absorption ignored)
- Gluon saturation : Colour Glass Condensate (CGC) model

Quarkonia expected yields in p-Pb & Pb-p at 8.8 TeV measured via dimuon channel with ALICE Muon Spectrometer will be given

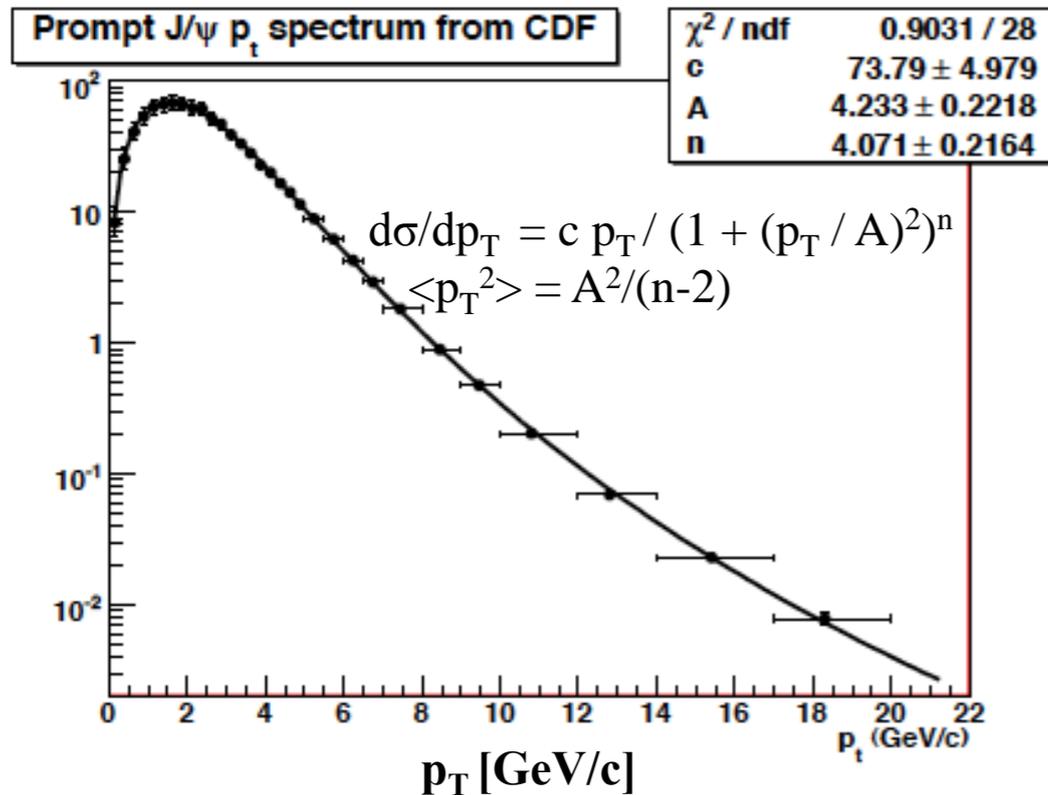
Shadowing model for quarkonia production (1)

Quarkonia production in p-p:

factorization for p_T and y dependence of cross section $d^2\sigma^{pp}/dp_T dy$ is assumed
 y -dependence from Color Evaporation Model (CEM)

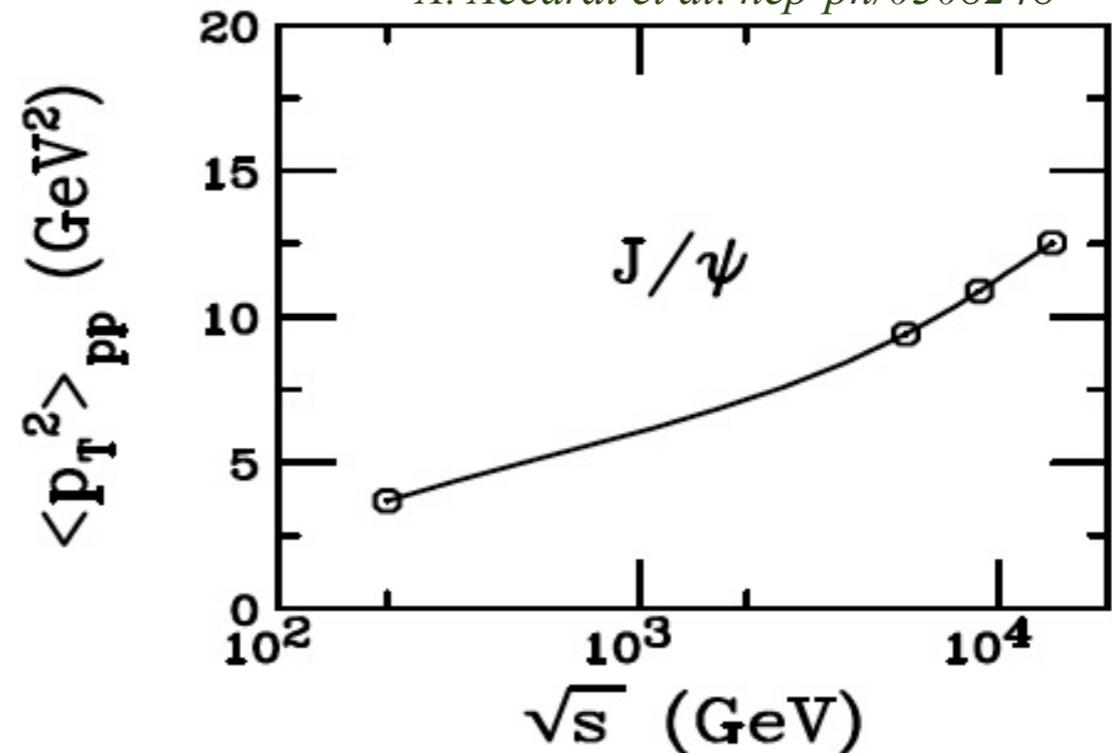
p_T -dependence from CDF data extrapolation (*S. Grigoryan and A. De Falco ALICE-INT-2008-016*)

CDF, D. Acosta et al. PR D71 (2005) 032001



$\langle p_T^2 \rangle$ energy-dependence from NLO CEM

A. Accardi et al. hep-ph/0308248



Result for J/ψ : $n = 4.071$ and $A = 4.87, 5.07, 5.25, 5.63$ GeV for $\sqrt{s} = 5.5, 7, 8.8, 14$ TeV

Similar fit and extrapolation for Υ gives:

$n = 3.051$ and $A = 7.56, 7.82, 8.05, 8.61$ GeV for $\sqrt{s} = 5.5, 7, 8.8, 14$ TeV

These parametrized p_T and y -distributions included in ALICE software for the quarkonia generation in p-p using MC generator AliGenParam + AliGenMUONlib

Shadowing model for quarkonia production (2)

p-Pb and Pb-p minimum bias cross section:

at LHC energies the production dominant partonic mechanism is gluon-gluon scattering: $gg \rightarrow Q\bar{Q} + X$

In LO CEM approach one has (assuming same N-N energy for p-A, A-p and p-p):

$$d^2\sigma^{pA}/dp_T dy = A R_A(x_2, m_T^2) d^2\sigma^{pp}/dp_T dy$$

$$d^2\sigma^{Ap}/dp_T dy = A R_A(x_1, m_T^2) d^2\sigma^{pp}/dp_T dy$$

where gluon shadowing factor

$$R_A(x, m_T^2) = g_A(x, m_T^2) / g_p(x, m_T^2)$$

Note that shadowing depends on the partonic process:

(E. Ferreiro et al. PL B60, 50, 2009; PR C81:064911, 2010)

1. in «intrinsic» case $gg \rightarrow Q\bar{Q}$ sum of gluon intrinsic transfer momenta gives quarkonium p_T
2. in «extrinsic» case $gg \rightarrow Q\bar{Q} + g$ the quarkonium p_T is balanced by the emission of recoiling gluon

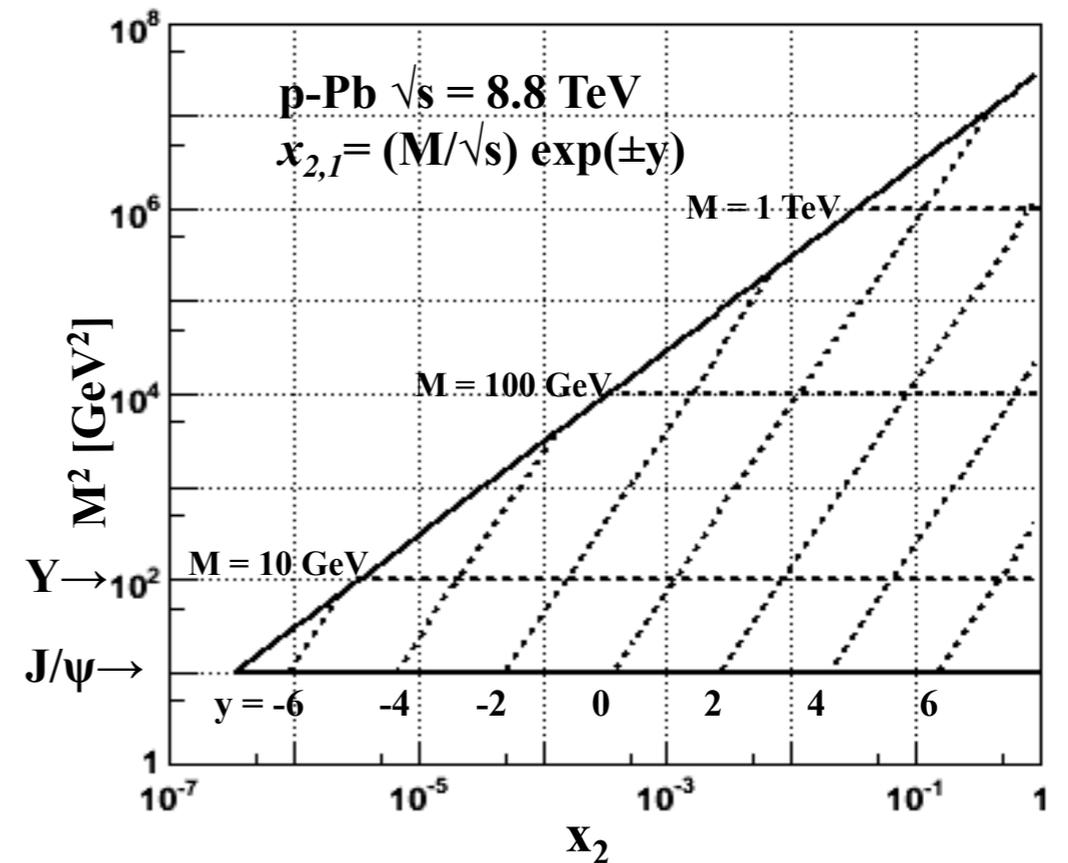
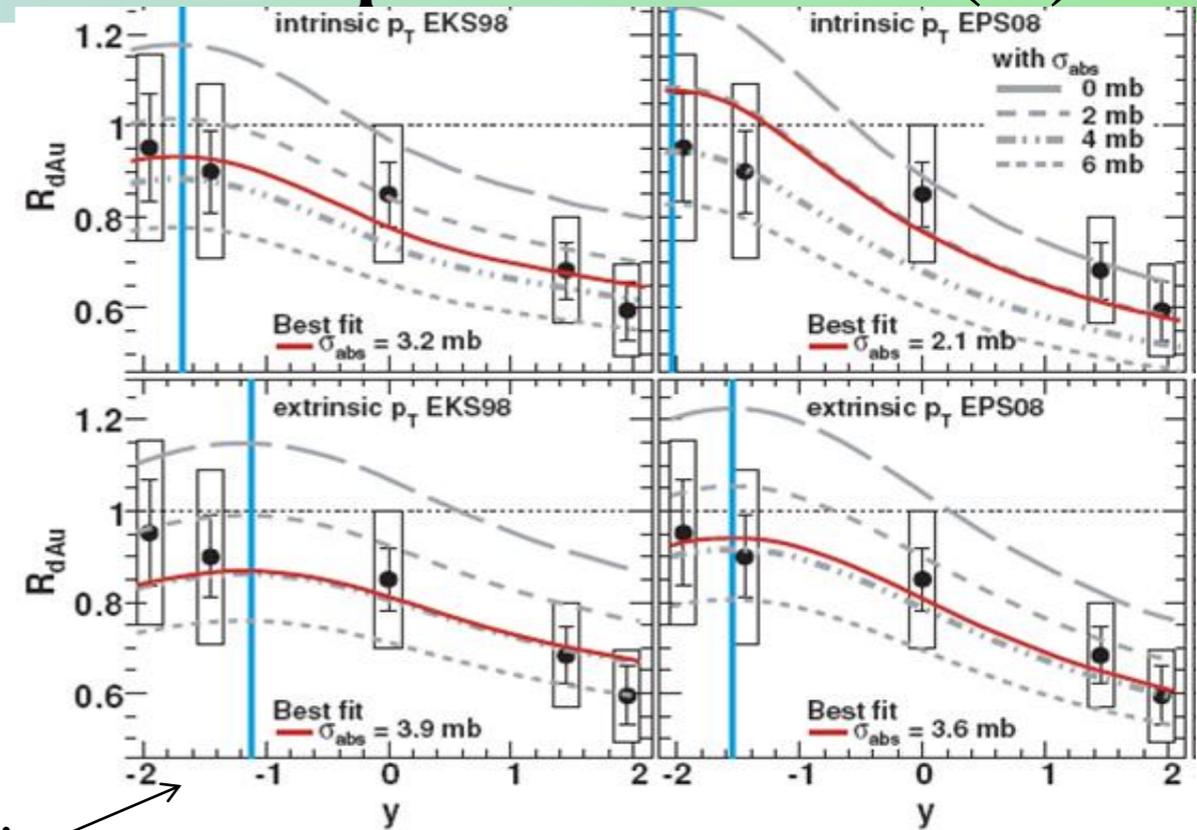
Both cases describe RHIC data rather well (upper fig)

We will use the intrinsic scheme $gg \rightarrow Q\bar{Q}(y, p_T)$ with a simple $2 \rightarrow 1$ kinematics:

$$x_{2,I} = m_T / \sqrt{s} \exp(\pm y), \quad m_T^2 = (2 m_Q)^2 + p_T^2$$

$$m_c = 1.2 \text{ GeV}, \quad m_b = 4.75 \text{ GeV}$$

For ALICE muon acceptance $y = [-4, -2.5] \rightarrow x_2 \ll x_1$
 x_2 is in shadowing and x_1 in anti-shadowing regions

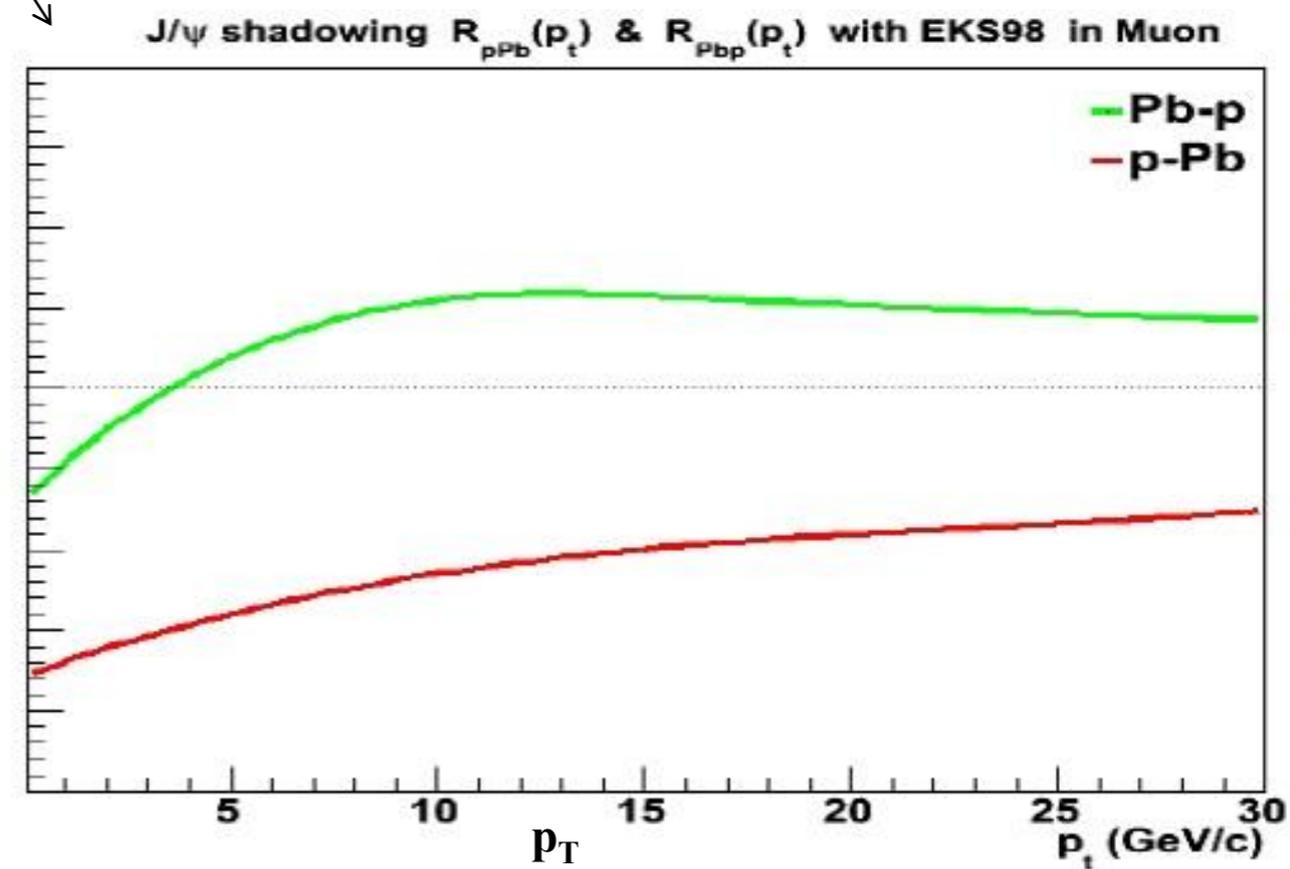
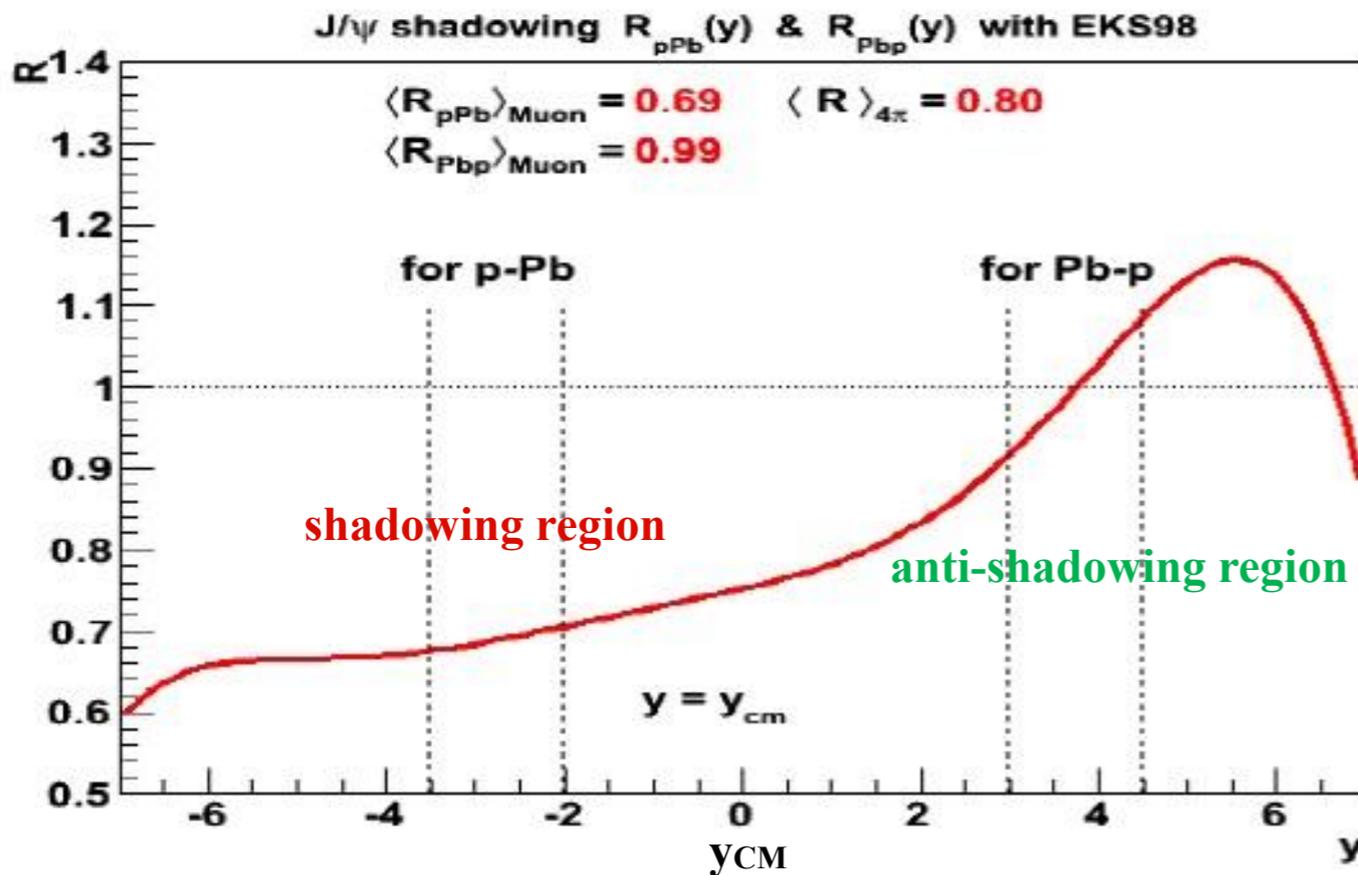
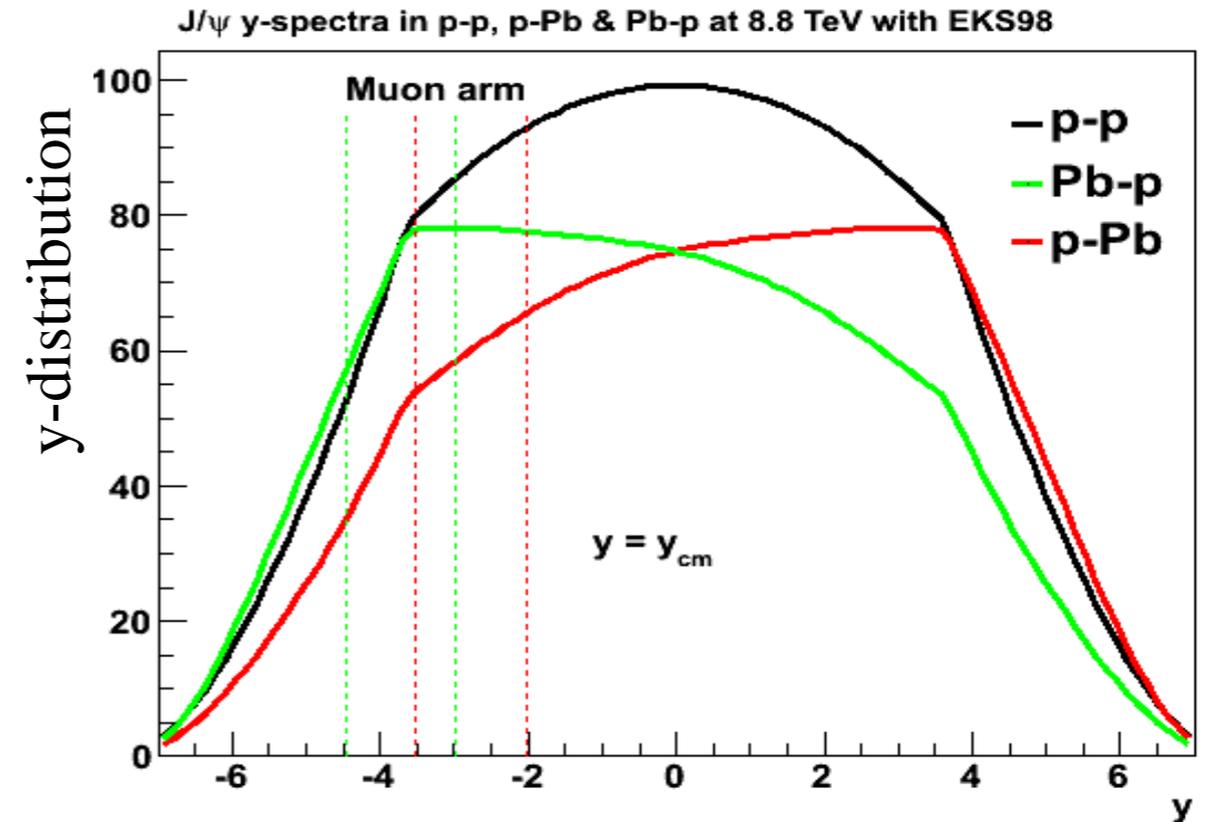


Results for J/ψ in p-Pb & Pb-p at 8.8 TeV

Muon Arm acceptance, boost $\Delta y = \pm 0.47$

	y_{CM}	$x_1^{\min} (p_T=0)$	$x_2^{\min} (p_T=0)$
p-p	(-4, -2.5)	$0.3 \cdot 10^{-2}$	$0.5 \cdot 10^{-5}$
p-Pb	(-3.53, -2.03)	$0.2 \cdot 10^{-2}$	$0.8 \cdot 10^{-5}$
Pb-p	(-4.47, -2.97)	$0.5 \cdot 10^{-2}$	$0.3 \cdot 10^{-5}$

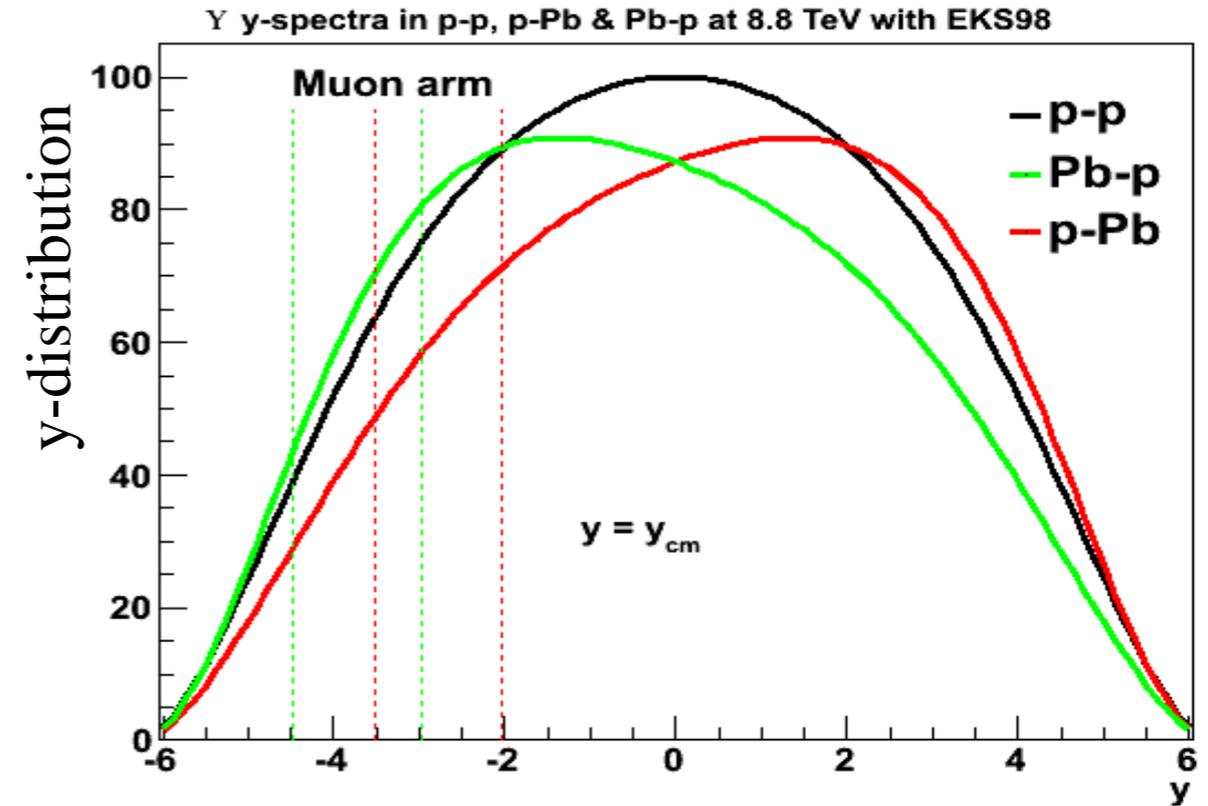
shadowing factor
 $R(y)$ $R(p_T)$



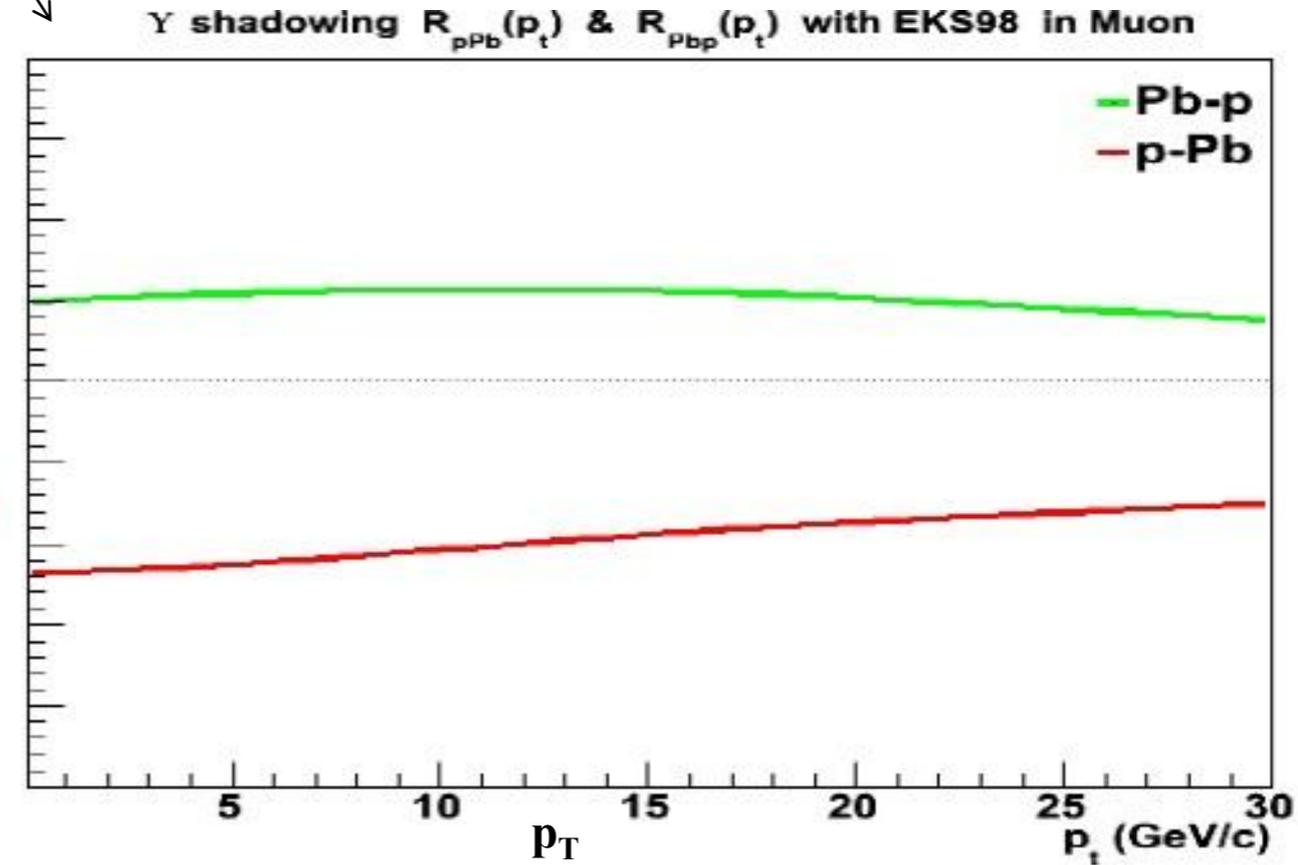
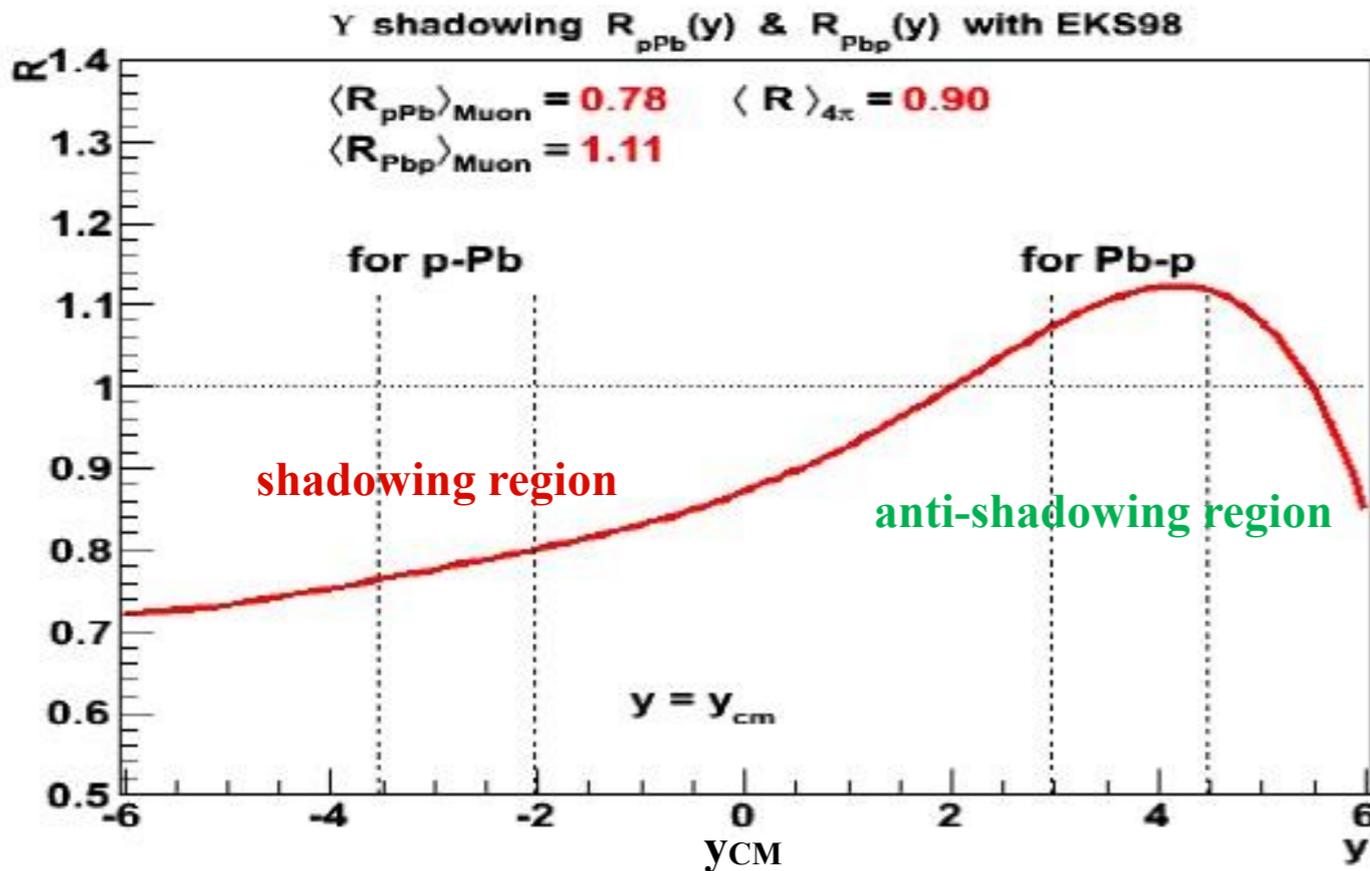
Results for Υ in p-Pb & Pb-p at 8.8 TeV

Muon Arm acceptance, boost $\Delta y = \pm 0.47$

	y_{CM}	$x_1^{\min} (p_T=0)$	$x_2^{\min} (p_T=0)$
p-p	(-4, -2.5)	$1.3 \cdot 10^{-2}$	$2.0 \cdot 10^{-5}$
p-Pb	(-3.53, -2.03)	$0.8 \cdot 10^{-2}$	$3.2 \cdot 10^{-5}$
Pb-p	(-4.47, -2.97)	$2.1 \cdot 10^{-2}$	$1.2 \cdot 10^{-5}$



shadowing factor
 $R(y)$ $R(p_T)$



Shadowing model and quarkonia yields

The parametrized p_T and y -distributions in previous slides for EKS98 model included in ALICE software for the quarkonia generation in min. bias p-Pb & Pb-p collisions at 8.8 TeV.

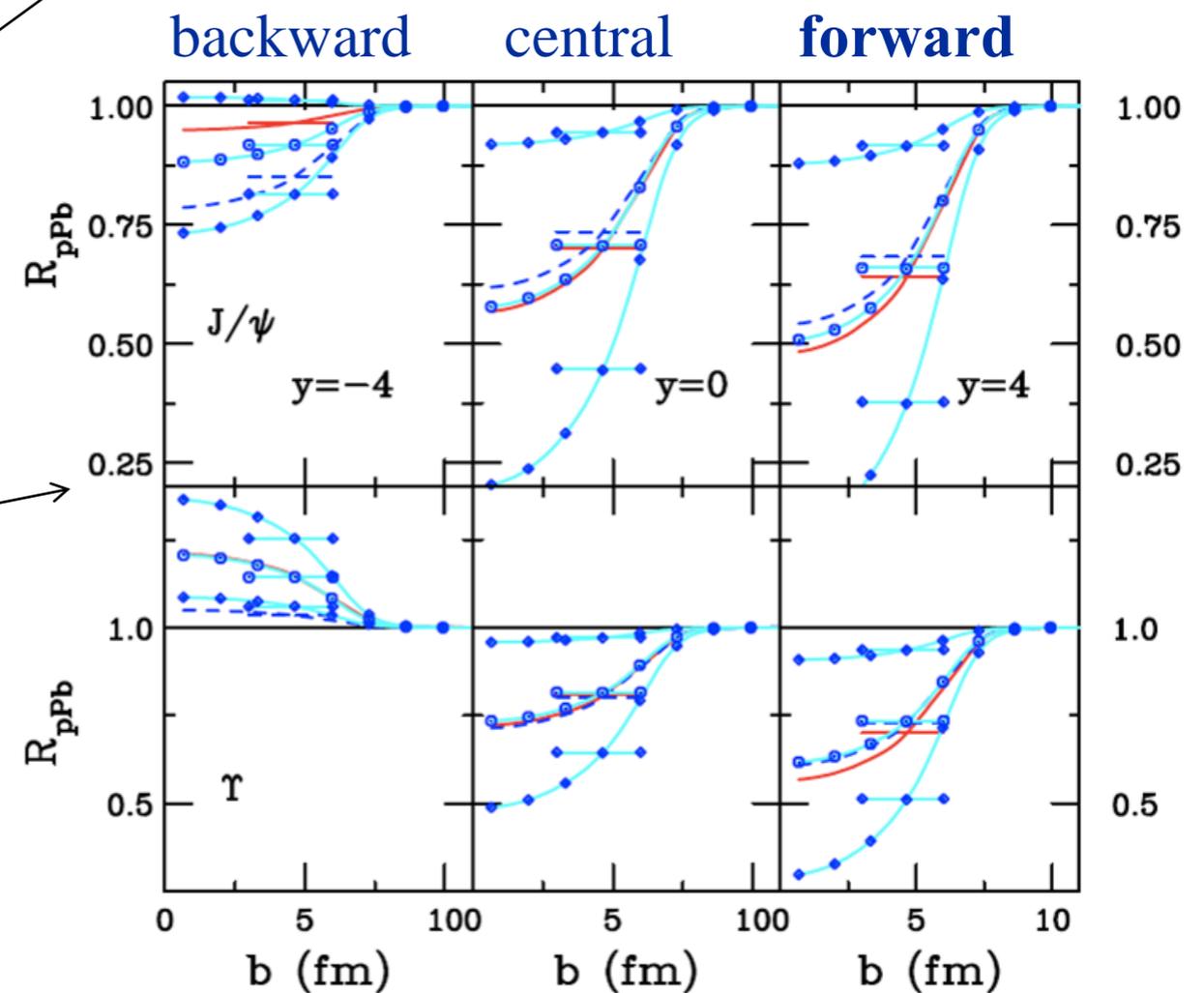
Prompt quarkonia (with feed-down) production cross sections taken from: *R.Vogt PR C81:044903, 2010*
 Resulting quarkonia yields in dimuon mode for $5 \cdot 10^5$ s running time and 60% detection efficiency of two muons with low p_T trigger (1 GeV) are

More complete simulation should include:

- other CNM effects: nuclear absorption, Cronin effect (p_T broadening)
- centrality dependence: could be done using phenomenology of *R.Vogt PR C81:044903, 2010*
- ALICE Zero Degree Calorimeters measurements provide 4-5 centrality bins for p-Pb \rightarrow one can measure central-to-peripheral ratios R_{CP}
- contribution of B-hadron decays into J/ψ (15%) and ψ' (30%) – no nuclear absorption
- dimuon background sources: HF hadron (Pythia) and charged π/K meson (HIJING) decays

Quarkonia expected yields in p-Pb & Pb-p for ALICE MS. J/ψ (Y) : 20% (6%) more yield in Pb-p than in p-Pb due to shadowing and $\Delta y=0.47$ boost

	time, s	J/ψ	ψ'	Υ	Υ'	Υ''
p-Pb	$5 \cdot 10^5$	740k	13k	4800	1800	900
Pb-p	$5 \cdot 10^5$	890k	16k	5100	1900	950



EKS98 (red), nDSg (dashed), EPS09 (blue symbols with uncertainty bands), horizontal lines – minimum bias result

Gluon saturation: CGC model for forward $Q\bar{Q}$ production

Saturation of the gluon density (recombination effect) expected at low x and $Q^2 < Q_s^2$

In high energy heavy ion collision, the gluon density of initial nuclei saturates and can be described as **C**olour **G**lass **C**ondensate (CGC) (*McLerran, Venugopalan, Iancu, Leonidov, Mueller, ...*)

Hand-pocket formula $Q_s^2 \propto x^{-0.3} A^{1/3} \rightarrow$ saturation for low x (high $\sqrt{s}=1/x$) and large A
 $Q_{s,LHC}^2 = 3 Q_{s,RHIC}^2$ $Q_{s,Pb}^2 = 6 Q_{s,p}^2$ $Q_s^2(y=3) = 2.5 Q_s^2(y=0)$ (for $gg \rightarrow Q\bar{Q}$ kinematics)
 \rightarrow larger saturation expected at LHC (and even more effect at forward rapidity)

Heavy quark pair production in CGC model of *Fujii, Gelis, Venugopalan Nucl.Phys.A780, 146, 2006* employs gluon fusion. To simplify calculations, consider forward production of $Q\bar{Q}$ in **p-Pb** (**p-p**) when $x_2 \ll x_1$ and only the 2nd projectile is saturated (not applicable to **Pb-p**)

For **p-Pb** (similarly for **p-p**) the model gives:

$$\frac{dN_{Q\bar{Q}}^{pPb}}{dyd^2p_t} = \overset{\text{dilute}}{f_g^{(p)}(x_1)} \otimes \overset{\text{dense}}{\varphi_A(x_2)} \otimes \overset{\text{partonic yield}}{\frac{dN_{gg \rightarrow Q\bar{Q}}^{\text{sat}}}{dyd^2p_t}}$$

◆ proton = dilute system = $f_g(x_1)$ standard gluon PDFs (e.g. CTEQ6) but including gluon intrinsic k_T kick distribution (with $k_0 = 1.33$ GeV) \rightarrow unintegrated gluon PDF

◆ nucleus/proton = saturated dense system = $\varphi_A(x_2)$ CGC gluon distribution in a saturated nucleus

◆ $gg \rightarrow Q\bar{Q}$ production evaluated in a strong background colour field

Notes: 1) collision geometry is simplified by considering nucleus of constant thickness \rightarrow no impact parameter dependence, only most central collisions considered

2) yields are not normalized, but their ratio $R_{pA} = 1/A^{1/3} N^{pA} / N^{pp}$ calculated correctly

Gluon saturation: CGC model for forward $Q\bar{Q}$ production

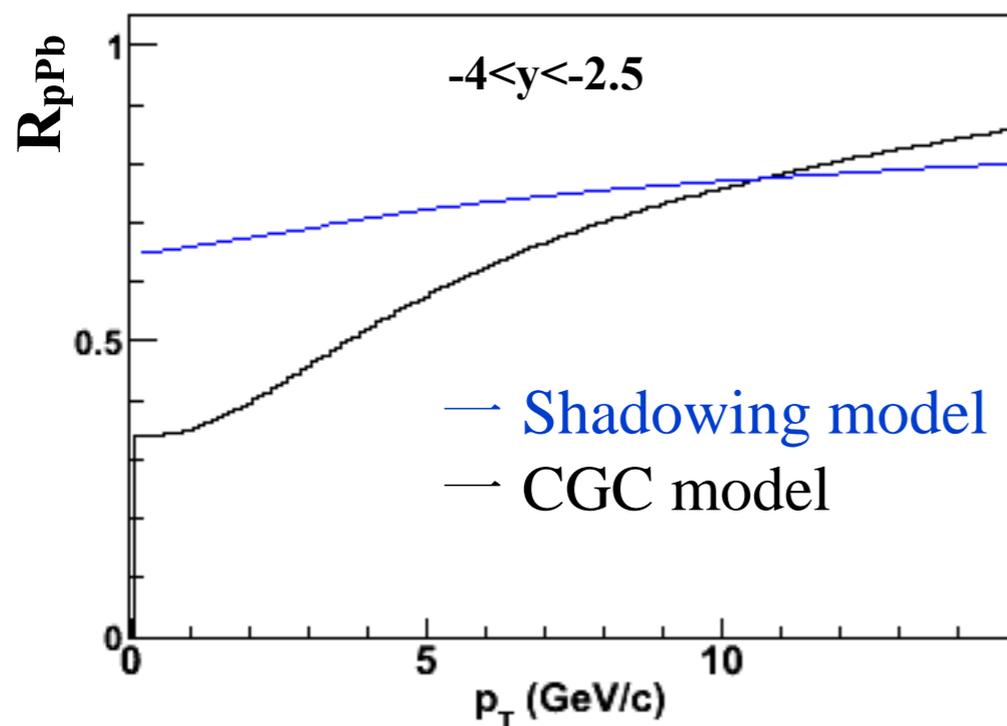
The described model was used to simulate the ALICE MS measurement of CNM effects in p-Pb at 8.8 TeV for forward production of HF hadrons (A.Charpy et al. ALICE-INT-2009-043)

Consider quarkonia forward production:

$Q\bar{Q} \rightarrow J/\psi$ transition calculated as in CEM

Note: CGC model includes p_T broadening naturally due to the multiple scatterings of gluons at initial state

Resulting J/ψ nuclear modification factor & comparison with EKS98 shadowing



➡ CGC gives $\simeq 30\%$ more suppression than EKS98 (CGC most central collision while EKS98 averaged over impact parameter)

➡ Different p_T dependence: $\simeq 50\%$ difference at low p_T

➡ Large model dependence in both cases

Corresponding MC generator AliGenCGC is implemented in ALICE software

Performance studies needed to see if ALICE MS measurements can discriminate between different models of CNM effects

Conclusion and Outlooks

- **p-A runs crucial to understand CNM effects in our R_{AA} measurements**
- two models (**shadowing** and **CGC**) and corresponding two Monte Carlo generators considered to estimate R_{pA} and to study quarkonium production in p-A (A-p)
- **large difference seen for R_{pPb} at low p_T (<50%)** but large model uncertainties
- quarkonia yields to be measured by ALICE MS for 1 month of p-Pb (Pb-p) running at 8.8 TeV estimated → **large statistics** allowing detailed studies of different quarkonia states

Ongoing/next studies:

- add nuclear absorption and other CNM effects to shadowing model
- include centrality dependence
- performance study of ALICE capabilities to measure quarkonia CNM effects, simulation of the full p-A (A-p) event, including besides the prompt quarkonia signals also:
 - the underlying event with expected at LHC energies hadron multiplicities (HIJING) → gives dimuon background from charged π/K meson decays
 - generation of HF hadrons with NLO kinematics and cross sections (tuned Pythia + Glauber scaling) → main dimuon background at J/ψ mass region and higher; B-hadron decays into J/ψ and ψ'

ALICE software allows to combine all these components into one Cocktail generator

- extrapolate CNM effects measured in p-A (A-p) to A-A
- same studies for $A = Pb, Ar, \dots$
- ...

Some topics for the forthcoming discussion on CNM

- problem of the normalization to p-p data, since the c.m.s. energies for p-A and p-p probably will be different at LHC (8.8 and 14 (7) TeV).
 - interpolation of p-p data to p-A energy? (large discussion expected in Thursday)
- how disentangle quarkonium nuclear absorption (though expected to be small) from shadowing? for example:
 - normalization to open HF production in p-A – same shadowing, no absorption
 - shadowing measurement from quarkonia production in UPC – no absorption
- absence of a full p-A (or B-A) event generator including the underlying event and production of the HF hadrons and quarkonia states with a «correct» (corresponding to NLO QCD predictions) kinematics and cross sections. Even the last version of HIJING2.0 largely underestimates the HF and quarkonia production.

In ALICE we use the method of cocktail generators instead, but for centrality studies it becomes too complex, many parameterizations of the quarkonia p_T and y -distributions needed for different centrality bins and different shadowing models.

- ...