Quarkonium production and propagation in partonic media

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1997.9 – 1999.3

at RBRC Alumni workshop, 19 June, 2006

Prologue

PHYSICS OF
THE QUARK-GLUON PLASMA
AND
RELATIVISTIC HEAVY-ION
COLLISIONS

Proceedings
of
the International School on Physics of
the Quark-Gluon Plasma
June
(June 3-6, 1997, Hiroshima)

and
the YITP Workshop on Physics of
Relativistic Heavy-Ion Collisions
(June 9-11, 1997, YITP, Kyoto)

Edited by
Masayuki Asakawa and Osamu Miyamura
+Hatsuda, Matsui, Sugitate

PROGRESS OF THEORETICAL PHYSICS SUPPLEMENT No. 129, 1997

Just before
the inauguration ceremony
of RBRC in September, 1997

My first attendance
to a school/meeting
dedicated to RHIC physics

Generating a strong tide
toward RHIC in Japan

Prologue

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In retrospect,

The school/meeting captured the future direction correctly

And encouraged young people to this field and to the center "RBRC"

Very grateful to people who initiated RBRC very timely, and let me join it!

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Outline

- Quarkonium interactions

  at low/high energies
- Quarkonium production in pA collisions

  from the CGC
- Remarks

Why heavy quarks?

- Produced in a hard interaction
- Heavy quarkonia are naturally small
  - Perturbative method may be useful

- Information on gluon dist. in a nucleus
- Plasma signal *a la* Matsui-Satz

Onium interaction at low energy

RIKEN-BNL Lunch Seminar Jan. 8, '98.

INTERACTION OF COLOR DIPOLES

&

QCD SYMMETRIES

D. Kharzeev and H.F.

RIKEN-BNL Research Center

Onium interaction at low energy

HF & D.Kharzeev '99

- Short time scale($\tau c = 1/\alpha_s^2 m$)

  as compared with $1/\Lambda_{QCD}$

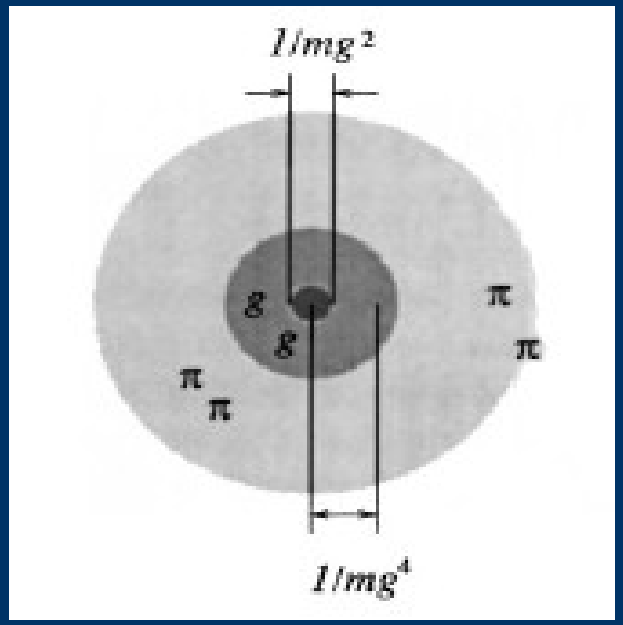
- Multipole expansion:

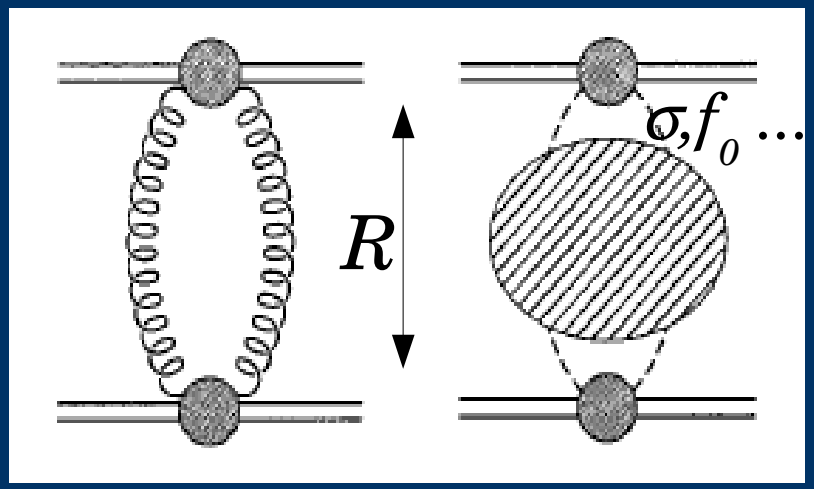
  separation of long & short distance parts

$$\sum_i c_i O_i \sim d_2 \frac{g^2}{2} \boldsymbol{E}^2 + \cdots$$

- Matching onto chiral theory using anomaly relation -->

  'van der Waals force' of QCD

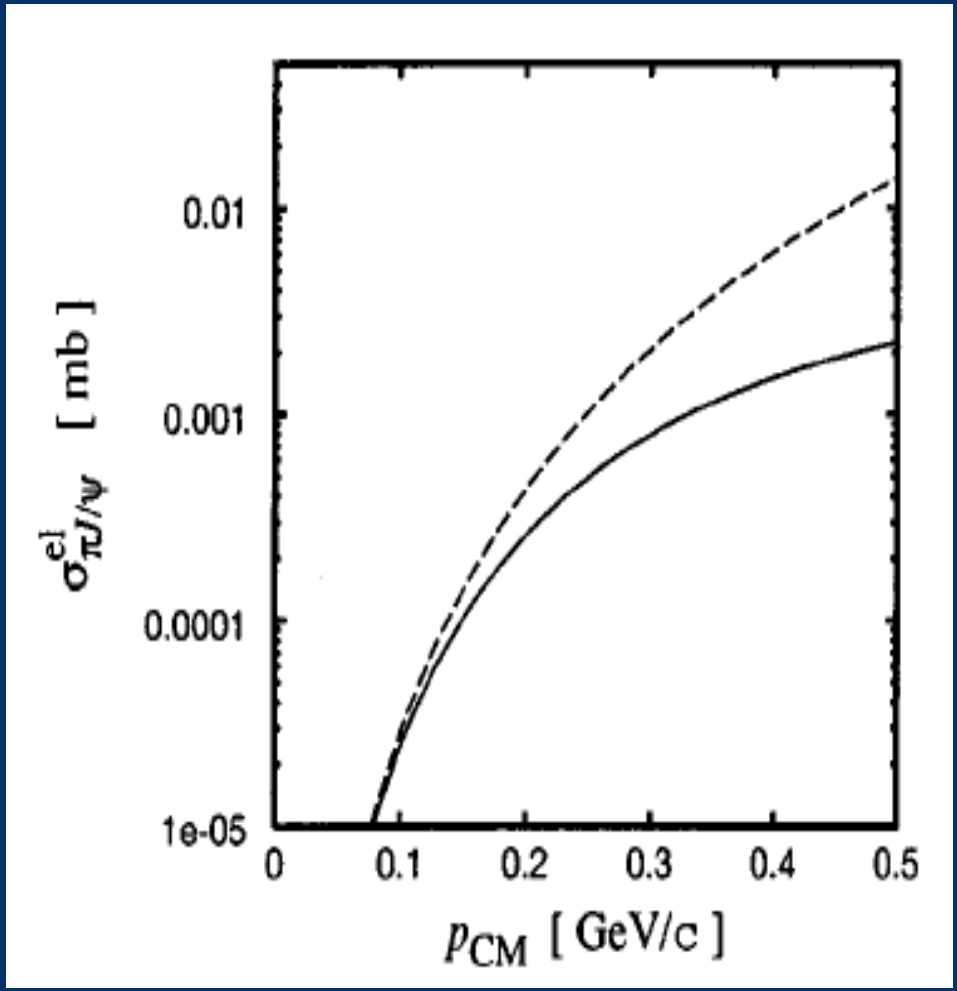




Onium interaction at low energy

- Onium coupling to soft ext ernal field is weak ~ r^2/ε_0
- Effects of hadron gas on oniua expected small
- Recent lattice atempt

Yokokawa et al. '06



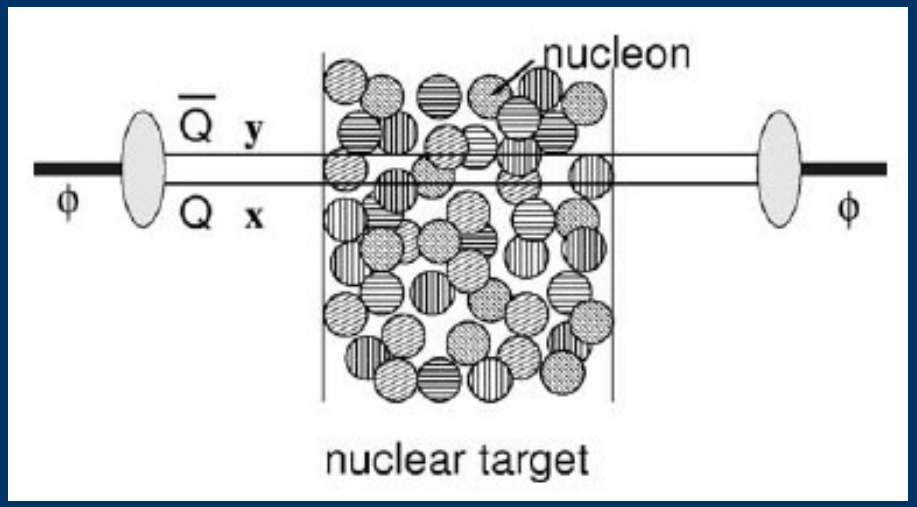
dashed = w/o FormFactor

Onium projected on a nucleus at high energy

H.F. & T.Matsui,'02

- When we boost the onium to higher energy, coherence time τc (= 1/B.E. ~ 0.3 fm for J/ψ) is no longer short:

$$\tau_C \gamma = 30\,fm(RHIC),\ 600\,fm(LHC) \geqslant R$$



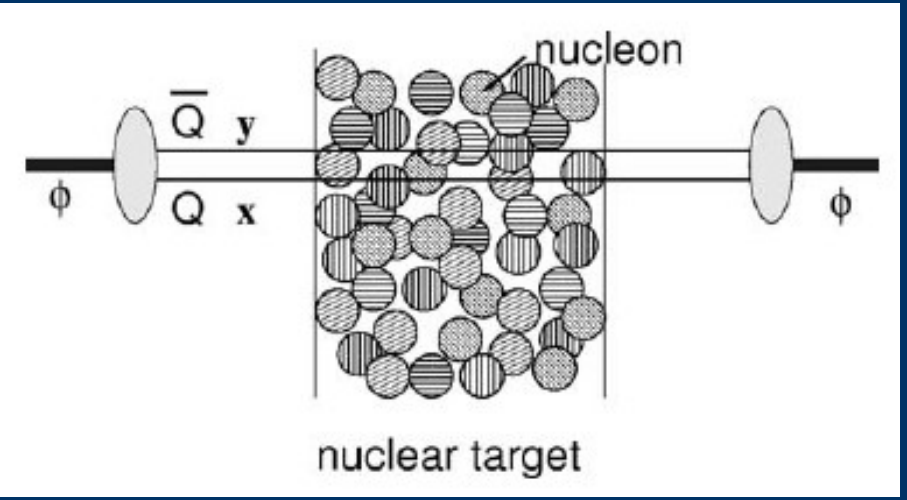
Onium projected on a nucleus at high energy

Buchmuller-Hebecker
McLerran-Venugopalan

- The model:
  - Nucleus = random gauge field config.
  - Frozen color dipole traversing straight through a nucleus --> eikonal approx.

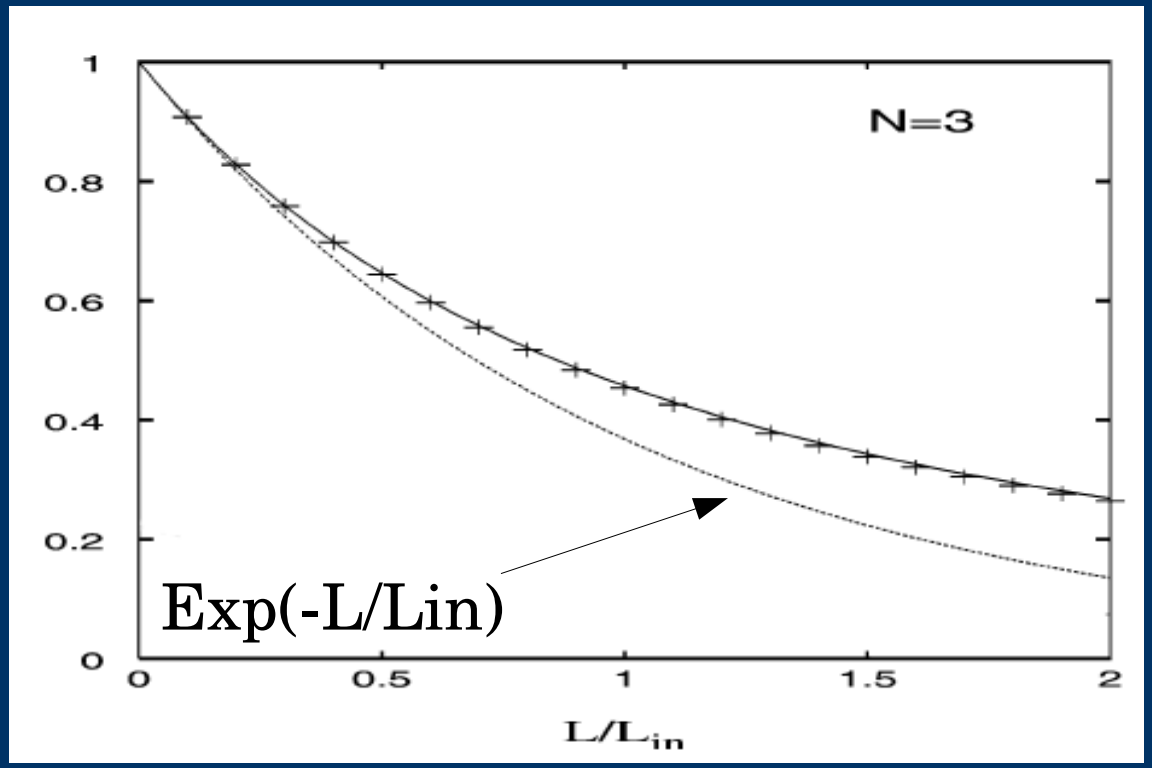
$$S(x,y;A)=\frac{1}{N}Tr[\tilde{U}(x;A)\ \tilde{U}^{+}(y;A)]$$

- Multiple scatterings of Q, Q^{bar}
  - Momentum diffusion
- S=1 for x=y;
  color transparency



Onium projected on a nucleus at high energy

- Implication:
  - Survival probability = $\overline{|(\varphi|S|\varphi)|^2}$
  - Non-exponential power-law behavior



H.F& T.Matsui, '02

Quarkonium production in pA collisions from the CGC

- Extension of onium attenuation model
  - Needs heavy pair production part..
    we have no onium beam anyway
  - Energy dependence

- Use the CGC framework See Kazu's talk

Quarkonium production in pA collisions from the CGC

McLerran-Venugopalan, '94
Blaizot-Gelis-Venugopalan, '04
...

- A dilute proton probes a 'saturated' nucleus
  - Solution known to $O(\rho_p^{\,1}\,\rho_A^{\,\infty})$ in the MV model
  - Need to know 4-pt fn, and integrate numerically

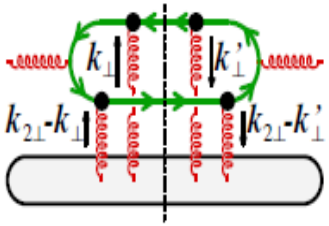
$$\frac{d\sigma_{q\bar{q}}}{d^2\vec{p}_\perp d^2\vec{q}_\perp dy_p dy_q} = \frac{\alpha_s^2 N}{8\pi^4 d_A} \int_{\vec{k}_{1\perp},\vec{k}_{2\perp}} \frac{\delta(\vec{p}_\perp + \vec{q}_\perp - \vec{k}_{1\perp} - \vec{k}_{2\perp})}{k_{1\perp}^2 k_{2\perp}^2}$$

$$\times\Big\{ \int_{\vec{k}_\perp,\vec{k}'_\perp} \mathrm{tr}\Big[(\not{q}+m)T_{q\bar{q}}(\vec{k}_\perp)(\not{p}-m)T^*_{q\bar{q}}(\vec{k}'_\perp)\Big]\phi_A^{q\bar{q},q\bar{q}}(\vec{k}_{2\perp}|\vec{k}_\perp,\vec{k}'_\perp)$$

$$+\int_{\vec{k}_\perp} \mathrm{tr}\Big[(\not{q}+m)T_{q\bar{q}}(\vec{k}_\perp)(\not{p}-m)L^* + \mathrm{h.c.}\Big]\phi_A^{q\bar{q},g}(\vec{k}_{2\perp}|\vec{k}_\perp)$$

$$+\mathrm{tr}\Big[(\not{q}+m)L(\not{p}-m)L^*\Big]\phi_A^{g,g}(\vec{k}_{2\perp})\Big\}\varphi_p(\vec{k}_{1\perp})$$

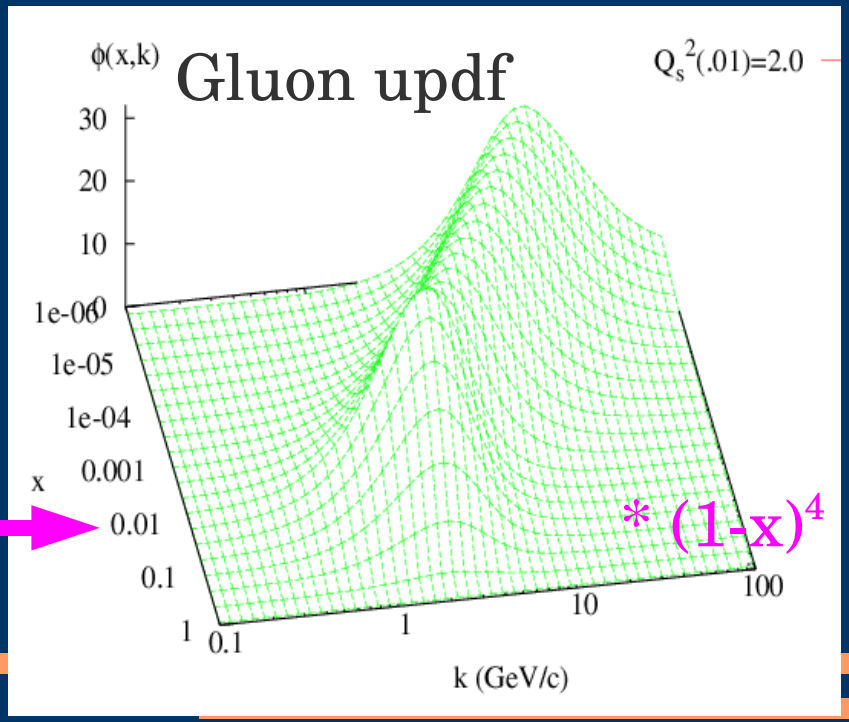
$$\phi_A^{q\bar{q},q\bar{q}} \sim \mathrm{FT}\ \mathrm{tr}\langle \widetilde{U}\, t^a\, \widetilde{U}^\dagger \widetilde{U}\, t^a \widetilde{U}\rangle \ \propto$$

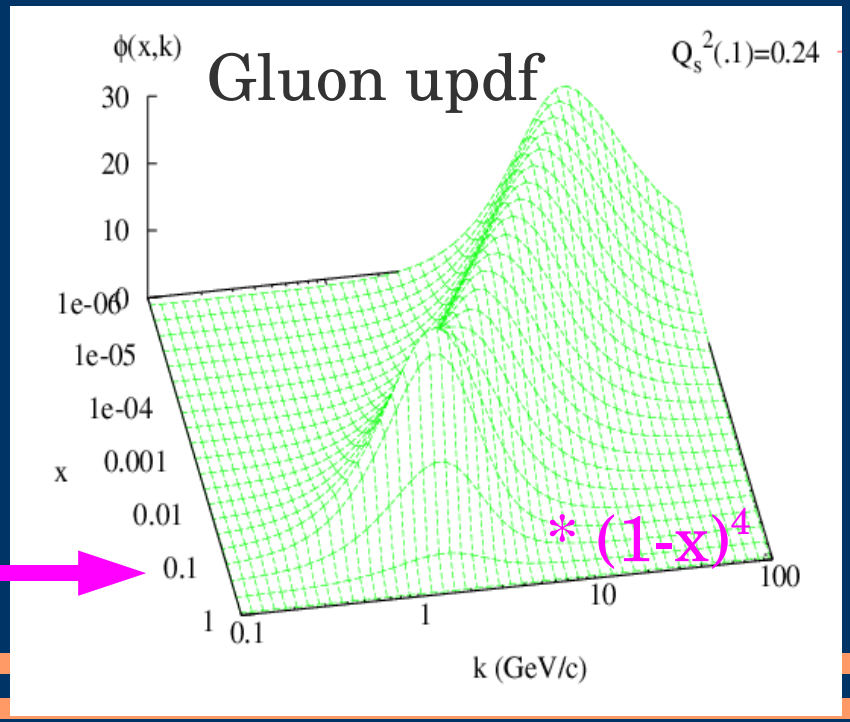


Quarkonium production in pA collisions from the CGC

- BK evolution in the large N
  - In the large N, the 4-pt fn reduces to (2-pt fn)^2
  - BK evlution is appropriate
  - Try x0 = 0.1

$$\phi_A^{q\bar{q},q\bar{q}} \propto FT\langle \tilde{U}(x)\tilde{U}^{\dagger}(y)\rangle FT\langle \tilde{U}(u)\tilde{U}^{\dagger}(v)\rangle$$

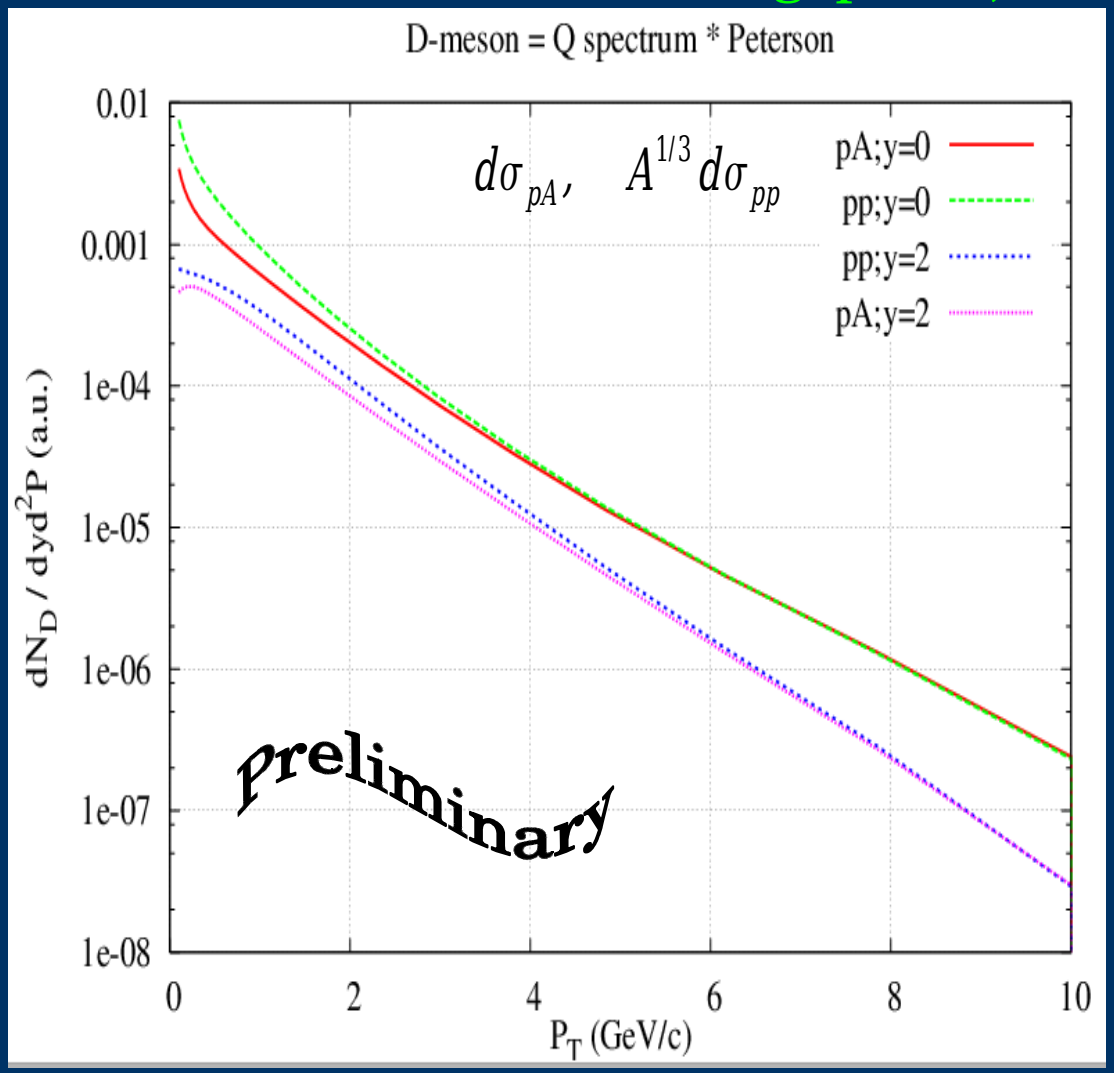




Open charm production

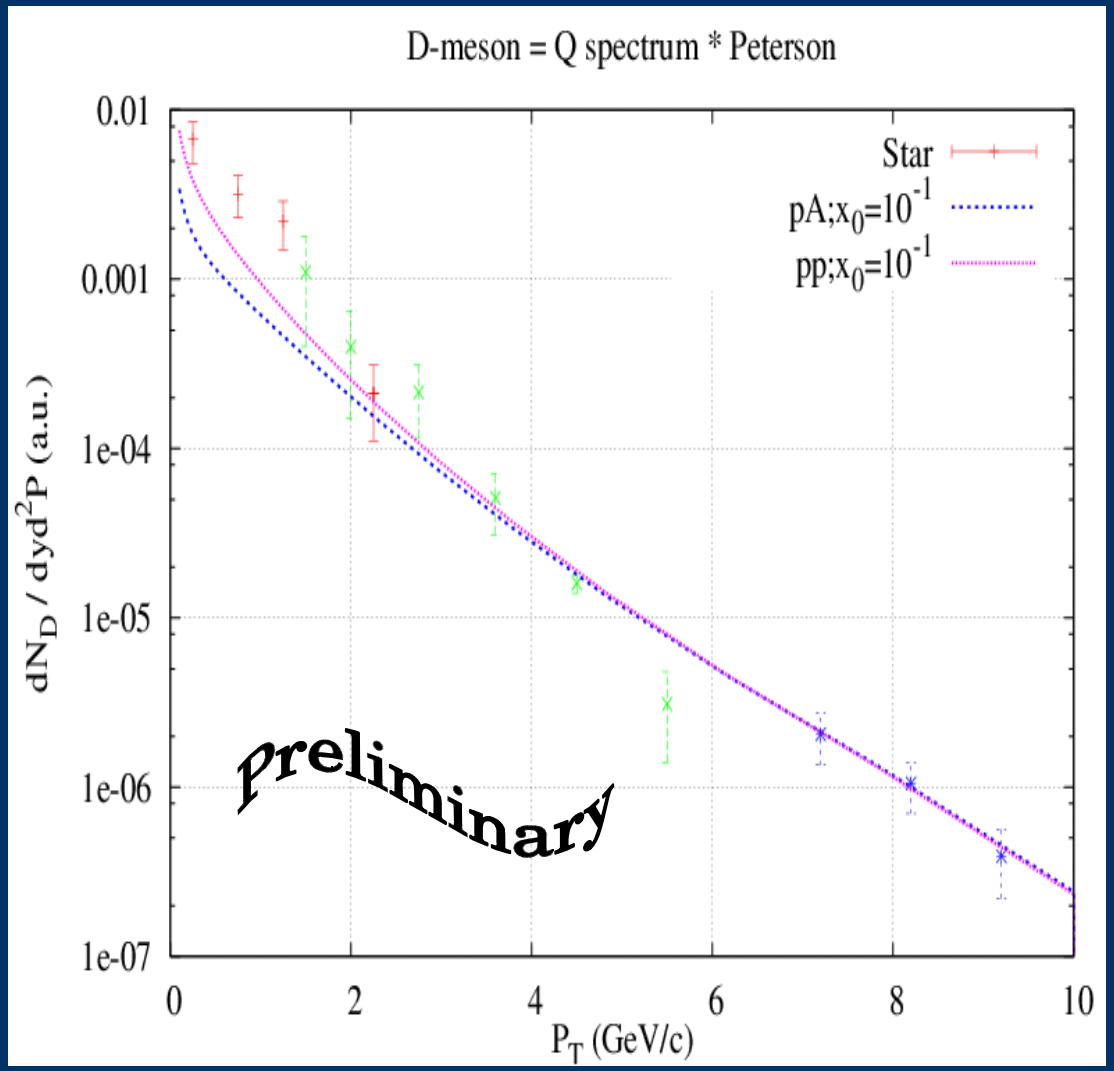
HF-Gelis-Venugopalan, '06

- Comparion btwn pp & pA in our model
- 'Saturation' effect seen only for $p_T \lesssim Qs$;
  suppression in pA
- Higher p_T,
  pA = sum of pp



Open charm production

- Comparison with data
- Note arbitrary normal ization on theory side
  (Just overlaid to see p_T-dep)

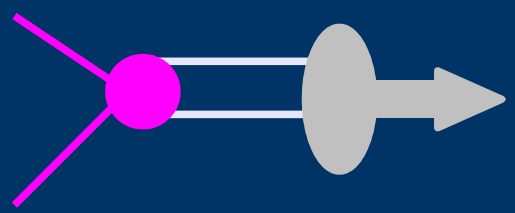


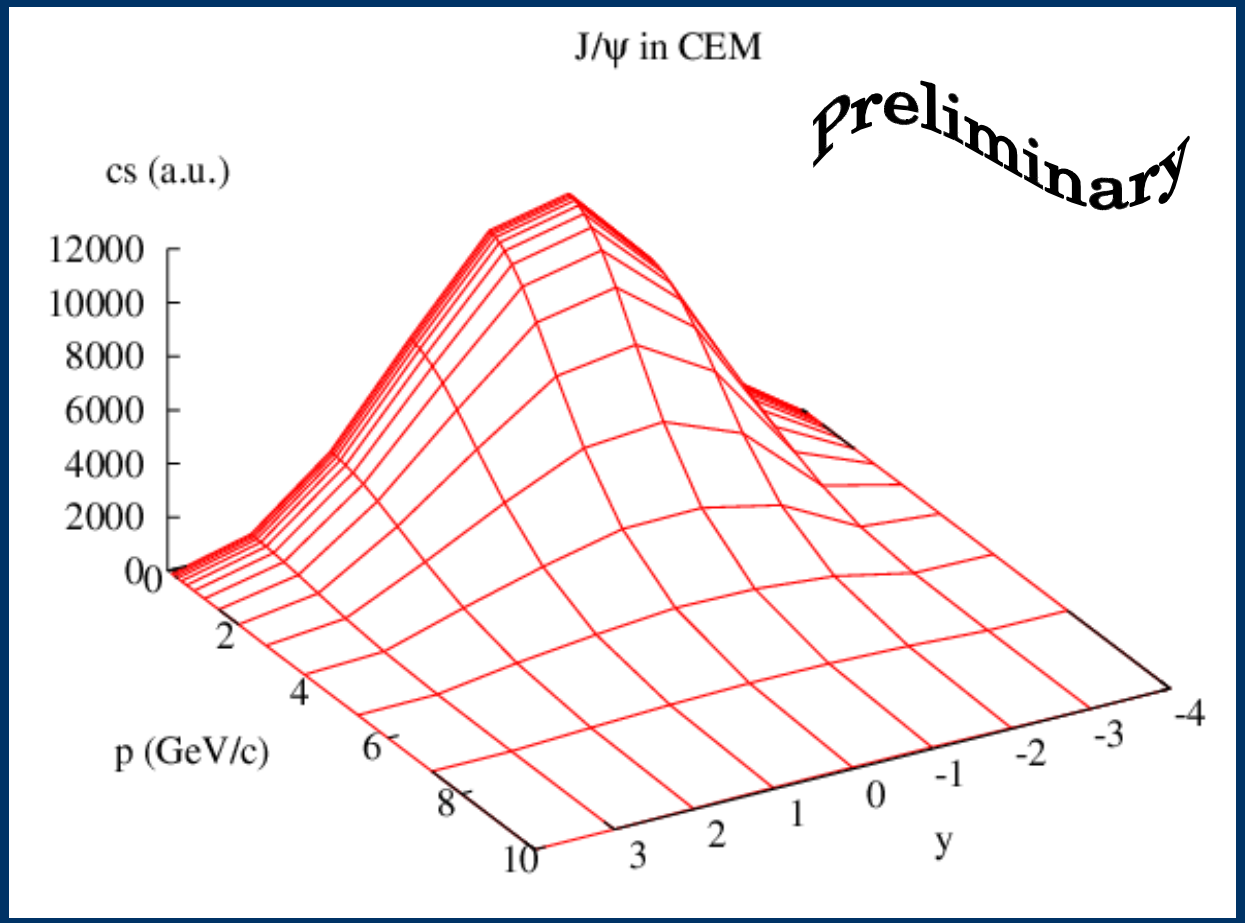
See also Kharzeev-Tuchin '03

J/Ψ production

- use Color Evaporation Model (CEM) to convert pair cross section to quarkonium cross section

$$\frac{dN_{J/\psi}}{dY\,d^2\boldsymbol{P}_\perp} \underset{CEM}{=} F_{J/\psi} \int_{4m^2}^{4m_D^2} dM^2 \, \frac{dN}{dY\,d^2\boldsymbol{P}_\perp dM^2}$$



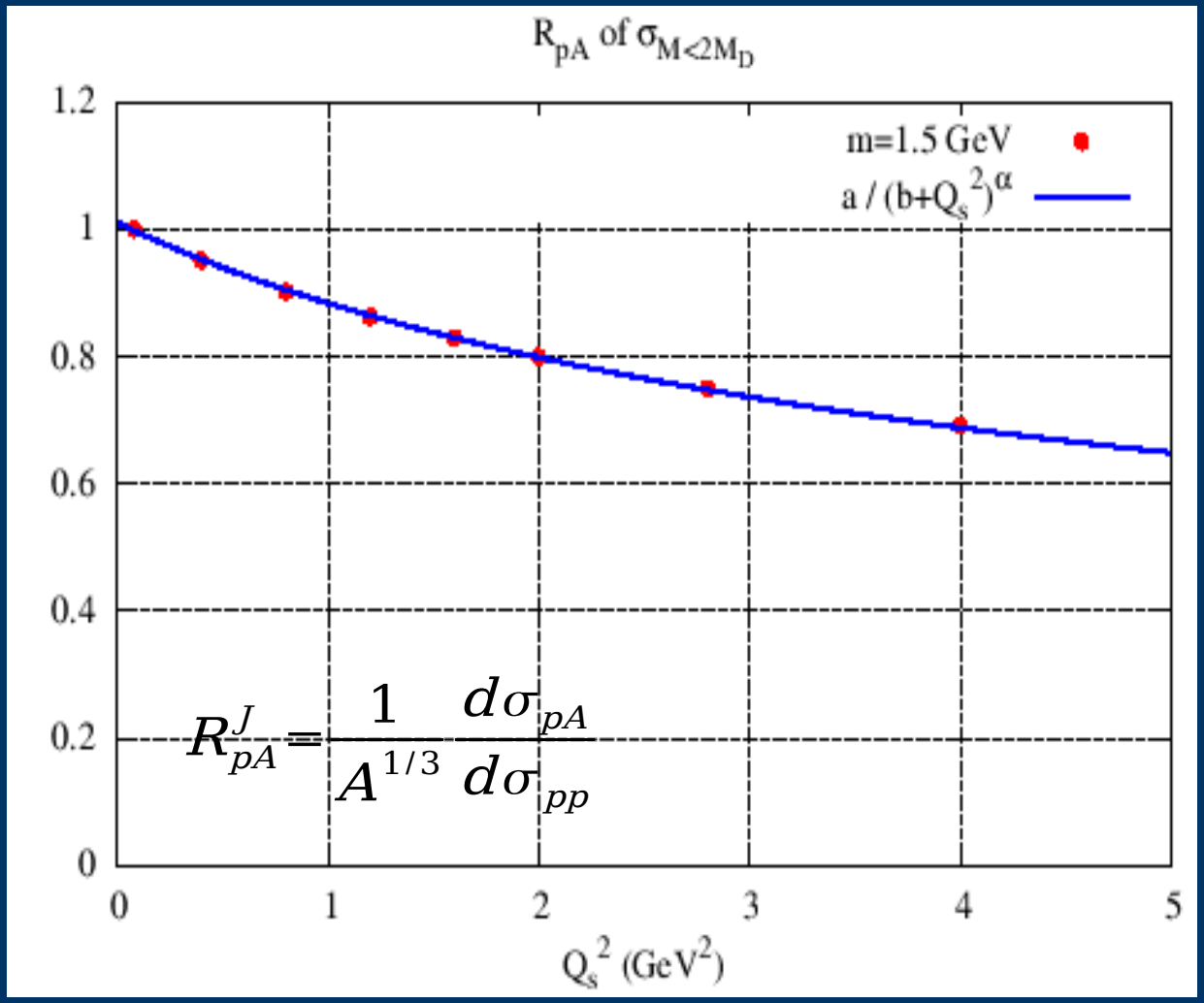


J/Ψ production

- Suppression pattern fits into power-law form in MV model; $Q_s^2 \sim A^{1/3} \sim L$

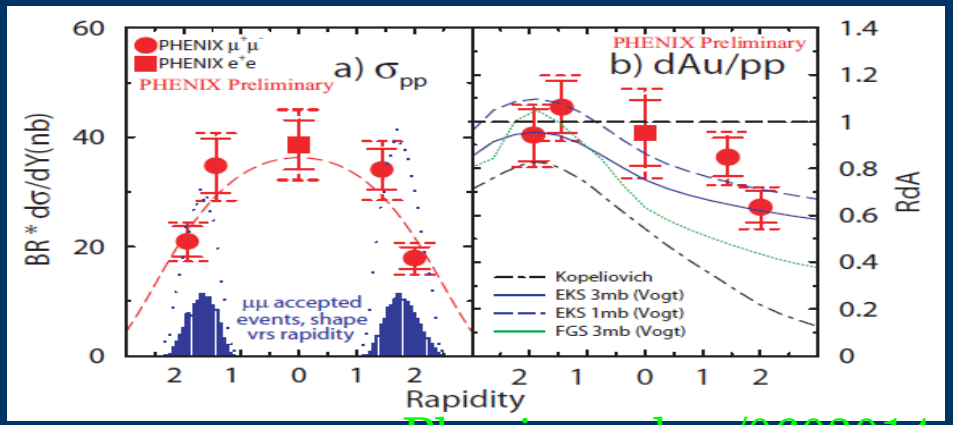
  $\alpha \sim 0.42$

Plain MV model

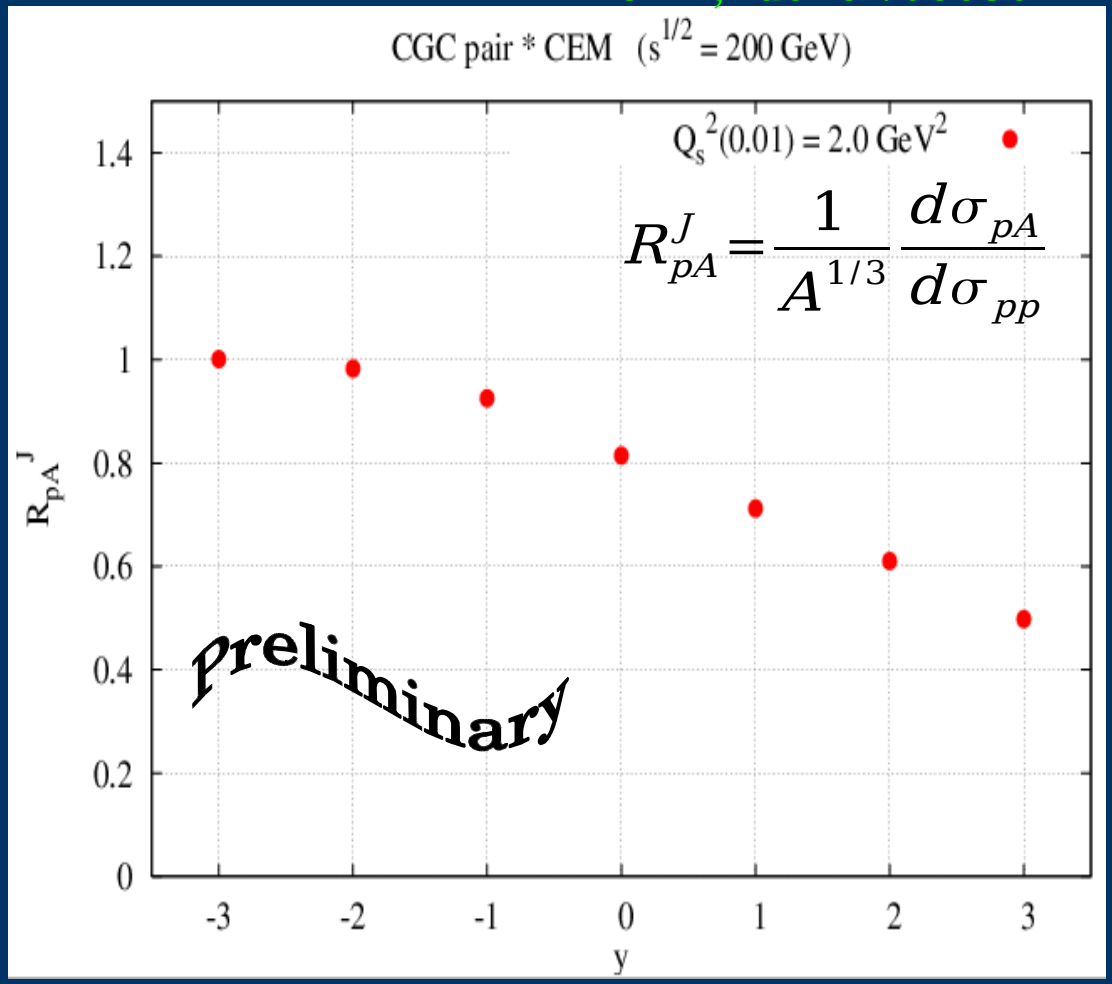


J/Ψ production

- Y-dependence of norm al suppression
- Comparison with data in progress – no para meter search yet
- Other production mech anisms than CEM to be studied as well



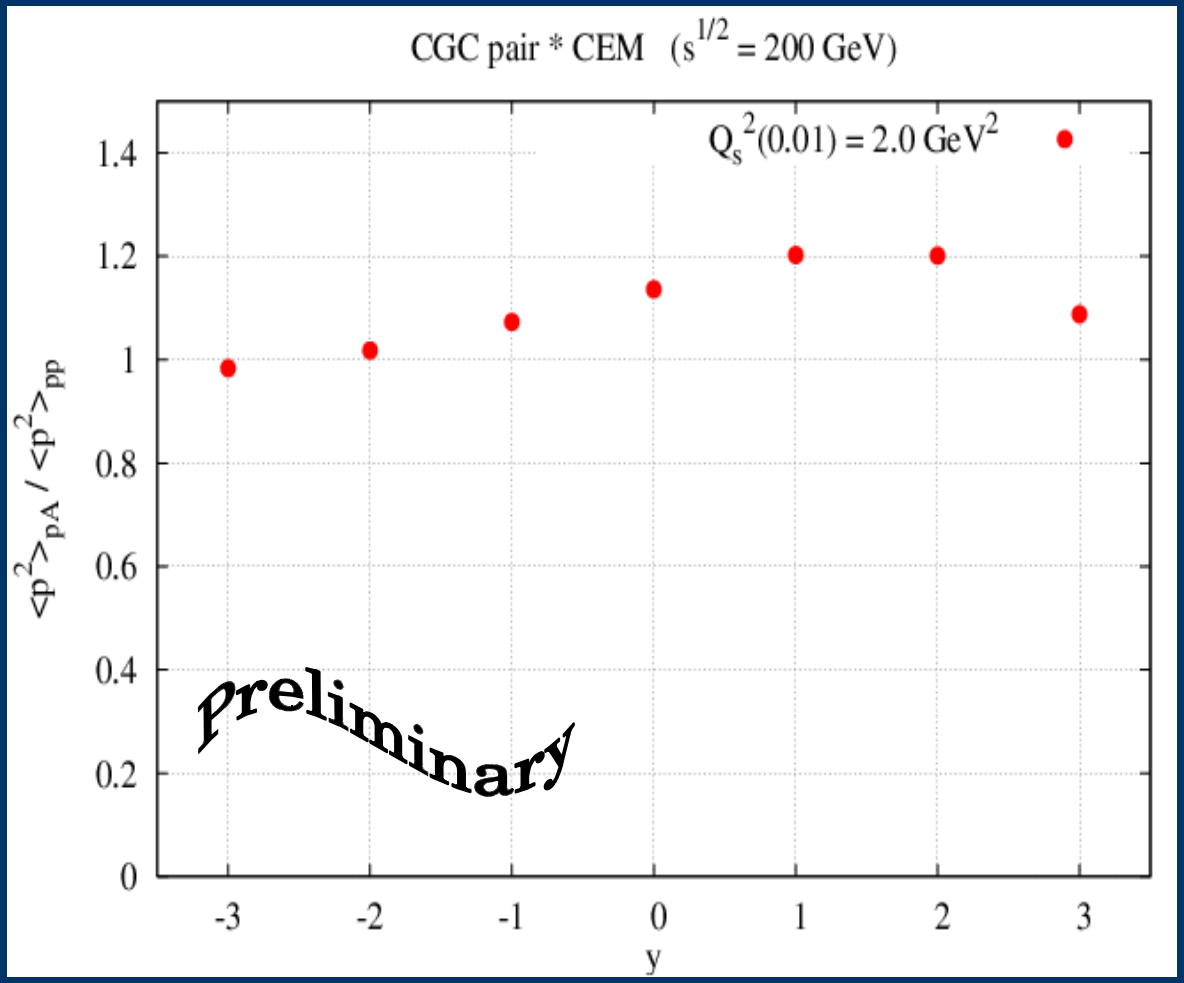
Phenix,nucl-ex/0603014



Kharzeev-Tuchin

J/Ψ production

- Y-dependence of mean p_T



Some remarks

- Quarkonia are good test ground to apply per turbative/non-perturbative methods in QCD
  - Van der Waals force of QCD, CGC approach, ...
- In CGC framework, we can now compute $Q\bar{Q}$ production with both the multiple scatte rings and the saturation effect of gluons
- Systematic parameter scan is underway

Conclusion

- *I wish to thank people in RBRC and BNL for continuous encouragements, collaborations and supports so far...*

and in the future

I hope continuous advances achieved in the center