MAEDI-JSPS Sakura program

- A bilateral cooperative program between France and Japan
- To form sustained networks evolved from individual scientist exchanges **including young scientists**
- France {Marquet, Gelis, Iancu, Schoeffel, Soyez, Royon, **Kohara, Petreska, Saimpert** }
- Japan {Fujii, Hatta, Itakura, Nara, Sako, Yamazaki, **Hagiwara, Taya, Zhou** }

Update of heavy quark production in pA

H. Fujii
(U Tokyo, Komaba)

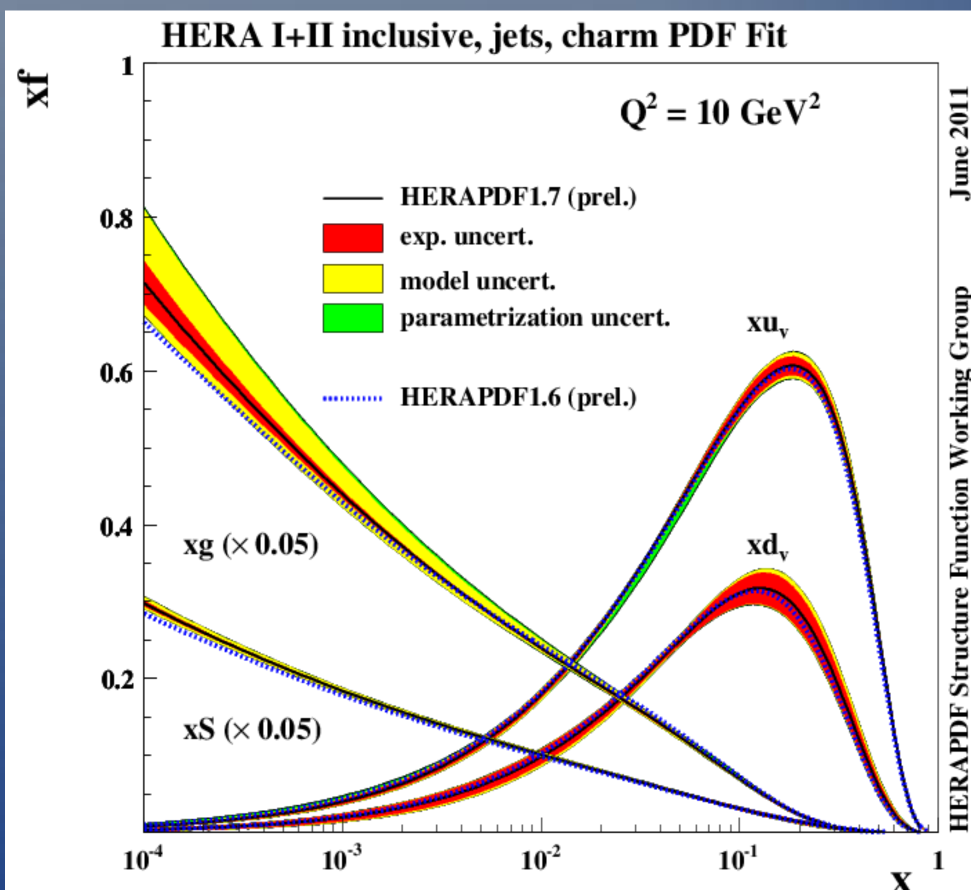
HF and K. Watanabe, NPA915(2013)1; 920(2013)78; 951(2016)45

Outline

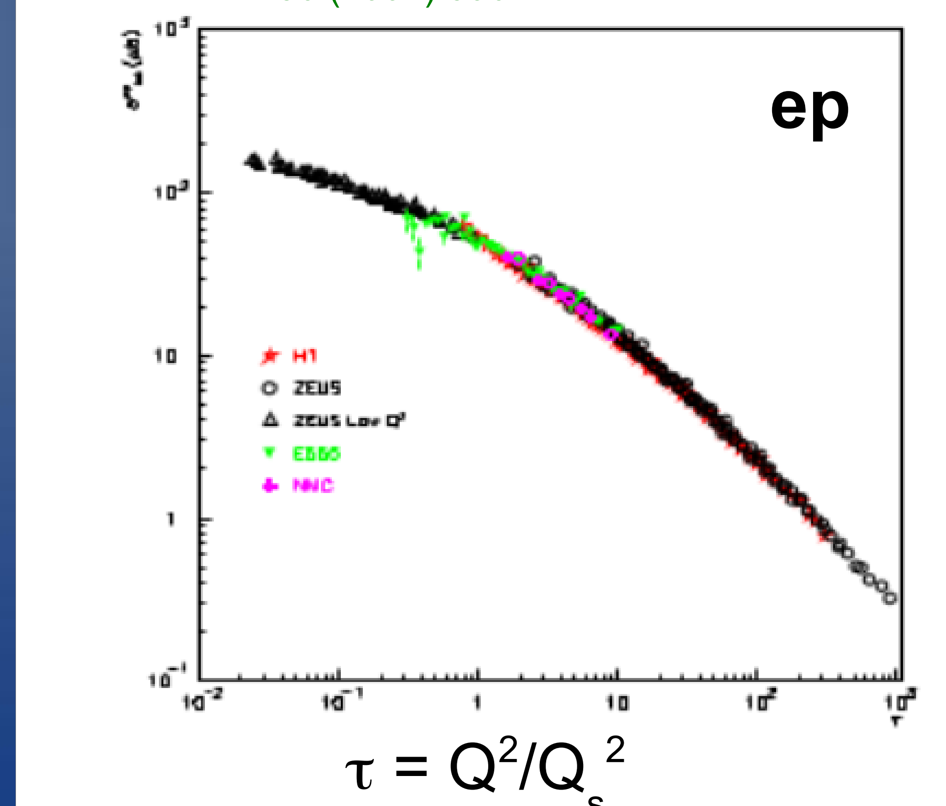
- Introduction
- Heavy quark production from CGC
- Numerical results
  - J/ψ
  - D meson
  - decay leptons
- Discussion & Summary

Parton saturation

- Dense partonic system at small x is characterized with the new scale, Qs^2



Stasto, Geloc-Bienat, Kwiecinski
PRL 86 (2001) 596



Parton saturation

- Recombination of partons becomes important at

Phase space density $$\frac{dN}{d^2r d^2p} \sim \frac{xG(x,Q_s^2)}{\pi R_h^2 Q_s^2(x)} \sim \frac{1}{\alpha_s}$$

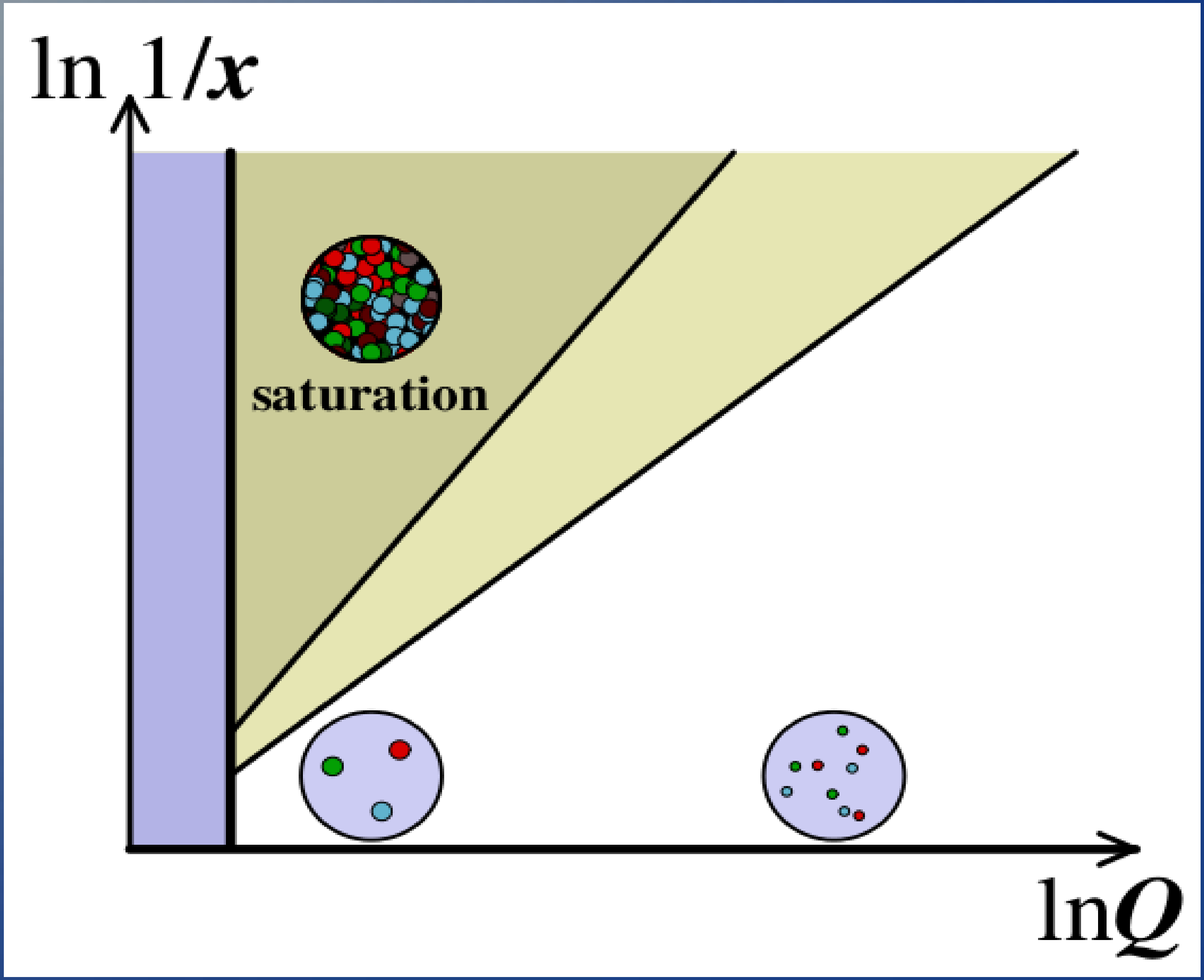
- suggesting a scale, below which saturation operates,

$$Q_s^2(x) \sim \alpha_s \cdot \frac{xG(x,Q_s^2)}{\pi R_h^2}$$

- For a nucleus, atomic number enhances the scale:

$$Q_{s,A}^2(x) \sim \alpha_s \cdot \frac{AxG(x,Q_s^2)}{A^{2/3}\pi R_0^2} = A^{1/3} Q_{s,p}^2$$

Phase diagram



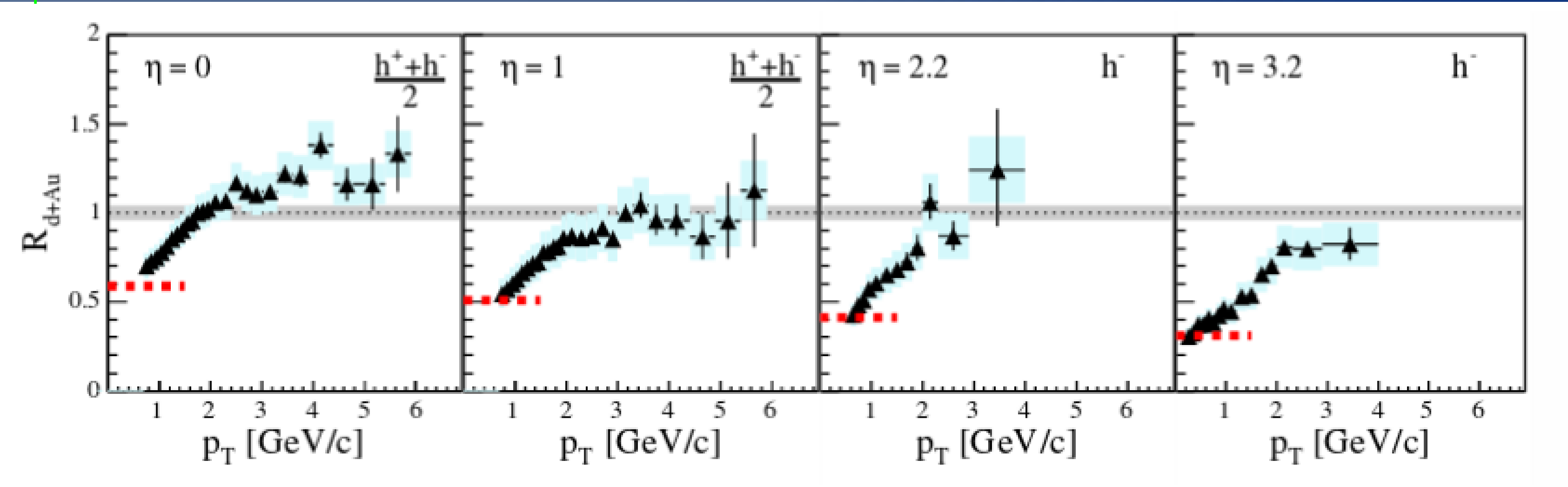
(c) Gelis

Classic evidence at RHIC

- Saturation is consistent with suppressed particle production in dA, compared to pp, at forward rapidity

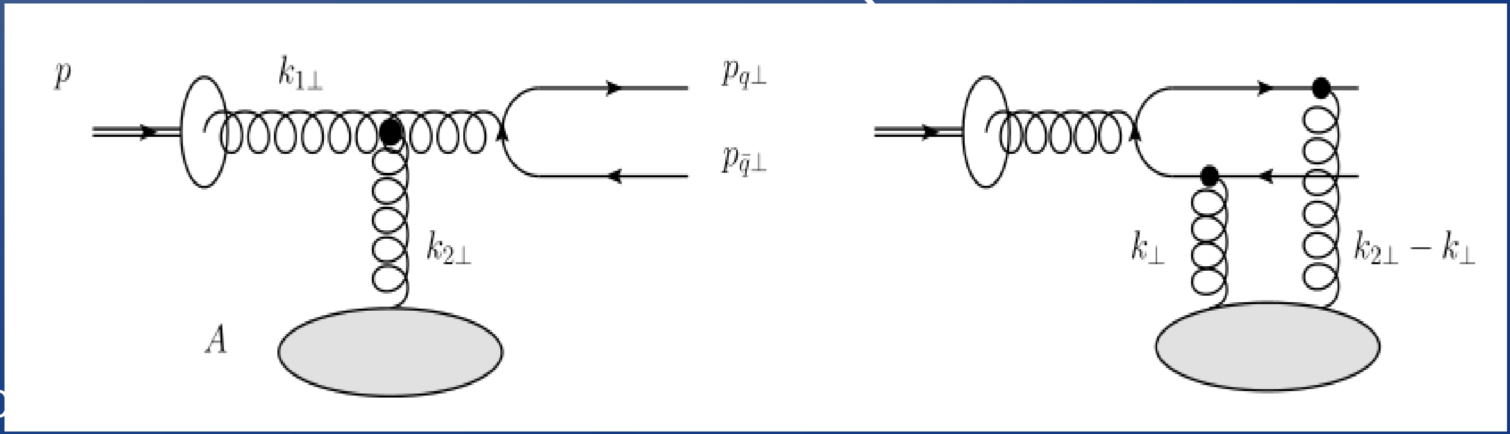
$$R_{dAu} \equiv \frac{1}{\langle N_{coll} \rangle} \frac{d^2N^{d+Au}/dp_T d\eta}{d^2N^{p+p}_{inel}/dp_T d\eta}$$

BRAHMS, Phys.Rev.Lett.93:242303,2004



Heavy quark production in pA

- **Why pA?**
  - to study saturation effects, enhanced by big A
- **Why heavy quark?**
  - produced from gluons
  - can probe saturation Qs (∼ mQ)
  - computed in pQCD as mQ ≫ Λ_{QCD}



Quark pair production in large Nc

- **kT-factorization** (for small x1,2)

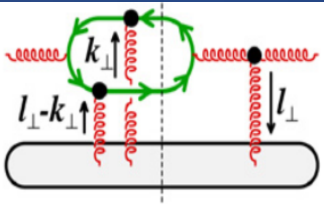
Blaizot-Gelis-Venugopalan 2002
HF-Watanabe 2013

$$\frac{d\sigma_{q\bar{q}}}{d^2p_{q\perp}d^2p_{\bar{q}\perp}dy_q dy_{\bar{q}}} = \frac{\alpha_s^2}{16\pi^4 C_F}\int \frac{d^2k_{2\perp}d^2k_\perp}{(2\pi)^4}\frac{\Xi(\boldsymbol{k}_{1\perp},\boldsymbol{k}_{2\perp},\boldsymbol{k}_\perp)}{k_{1\perp}^2 k_{2\perp}^2}\varphi_{p,x_1}(k_{1\perp})\,\phi_{A,x_2}^{q\bar{q},g}(\boldsymbol{k}_{2\perp},\boldsymbol{k}_\perp),$$

- **Hybrid formula** (for large x1 and small x2)

$$\frac{d\sigma_{q\bar{q}}}{d^2p_{q\perp}d^2p_{\bar{q}\perp}dy_q dy_{\bar{q}}} = \frac{\alpha_s^2}{16\pi^2 C_F}\int \frac{d^2k_\perp}{(2\pi)^2}\frac{\Xi_{\rm coll}(\boldsymbol{k}_{2\perp},\boldsymbol{k}_\perp)}{k_{2\perp}^2}\,x_1G(x_1,\mu)\,\phi_{A,x_2}^{q\bar{q},g}(\boldsymbol{k}_{2\perp},\boldsymbol{k}_\perp),$$

- probe the dense gluons through 3pt func.

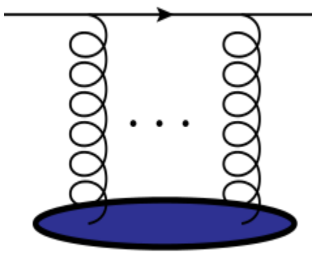
$\phi_A^{q\bar{q},g}(\boldsymbol{l}_\perp;\boldsymbol{k}_\perp) =$ 

Dipole amplitude

- **Wilson line - effective d.o.f.**

$$U(z_\perp) = \mathcal{P}\exp\left[ig\int dz^+ A^-(z^+,z)\right]$$

$$\mathcal{N}(\boldsymbol{x}_\perp,\boldsymbol{y}_\perp) = \int [D\rho] W_Y[\rho]\left[1-\frac{1}{N_c}\mathrm{tr}(U(\boldsymbol{x}_\perp)U^\dagger(\boldsymbol{y}_\perp))\right]$$



- **BK evolution & I.C.   constained by DIS data**

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

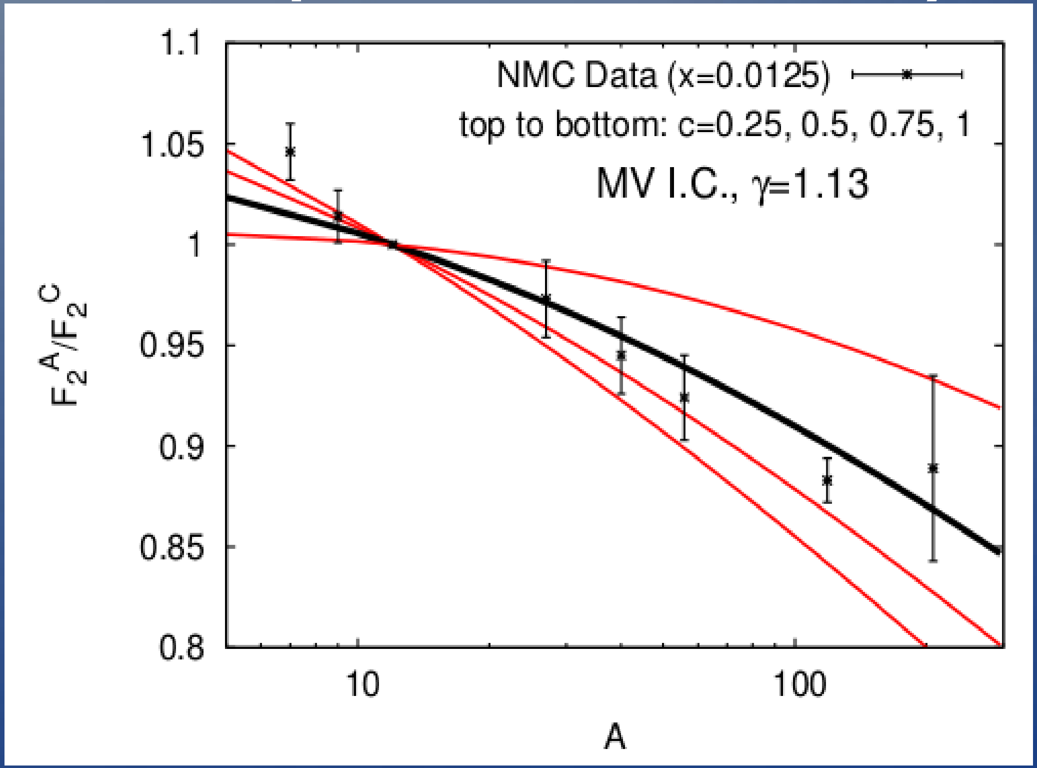
- **"gluon dist." (incl. higher twists):**

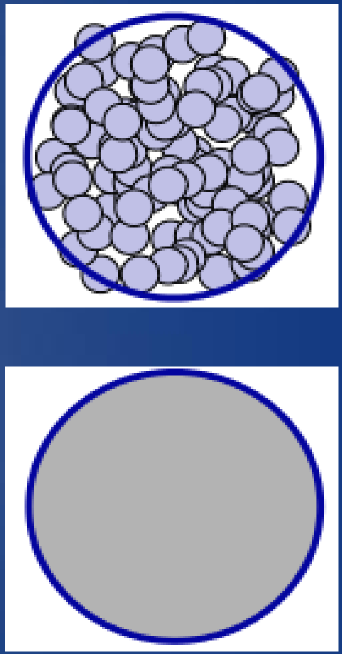
$$\varphi(k,y) = \boldsymbol{k}^2\,\mathrm{F.T.}\,N(r,y)$$

Choice of Qs for a nucleus

$$Q_{s0A}^{2} = c\,A^{1/3}\,Q_{s0}^{2} = (\,3?,\ 6?\,)\,Q_{s0}^{2}$$

- Effective Qs2 averaged over impact parameter
- c=0.5 is preferred for heavy nuclei

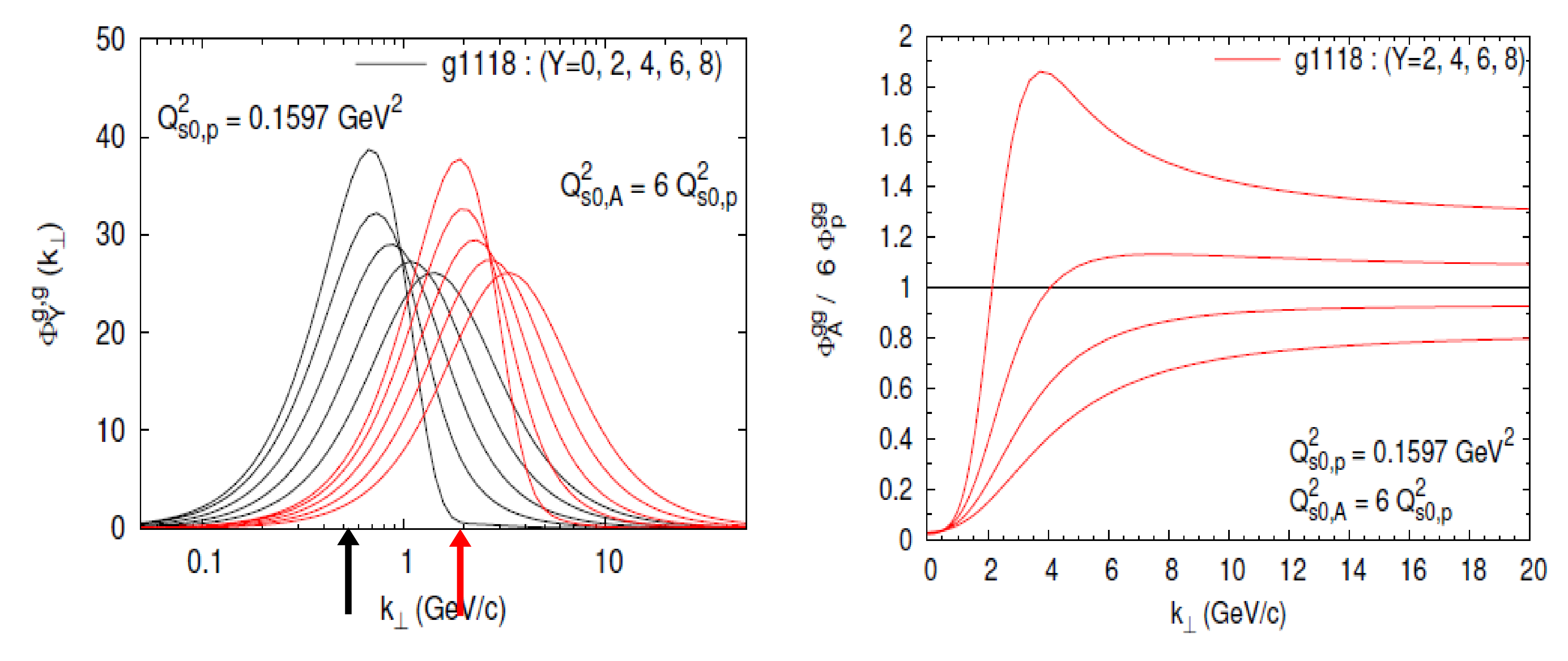




Dusling, et al., NPA836 (2010), 159

Evolution of dipole

- Non-linearity leads to a universal shape of ϕ
- More recombination in dense target
  - gluon suppression in heavy nuclei



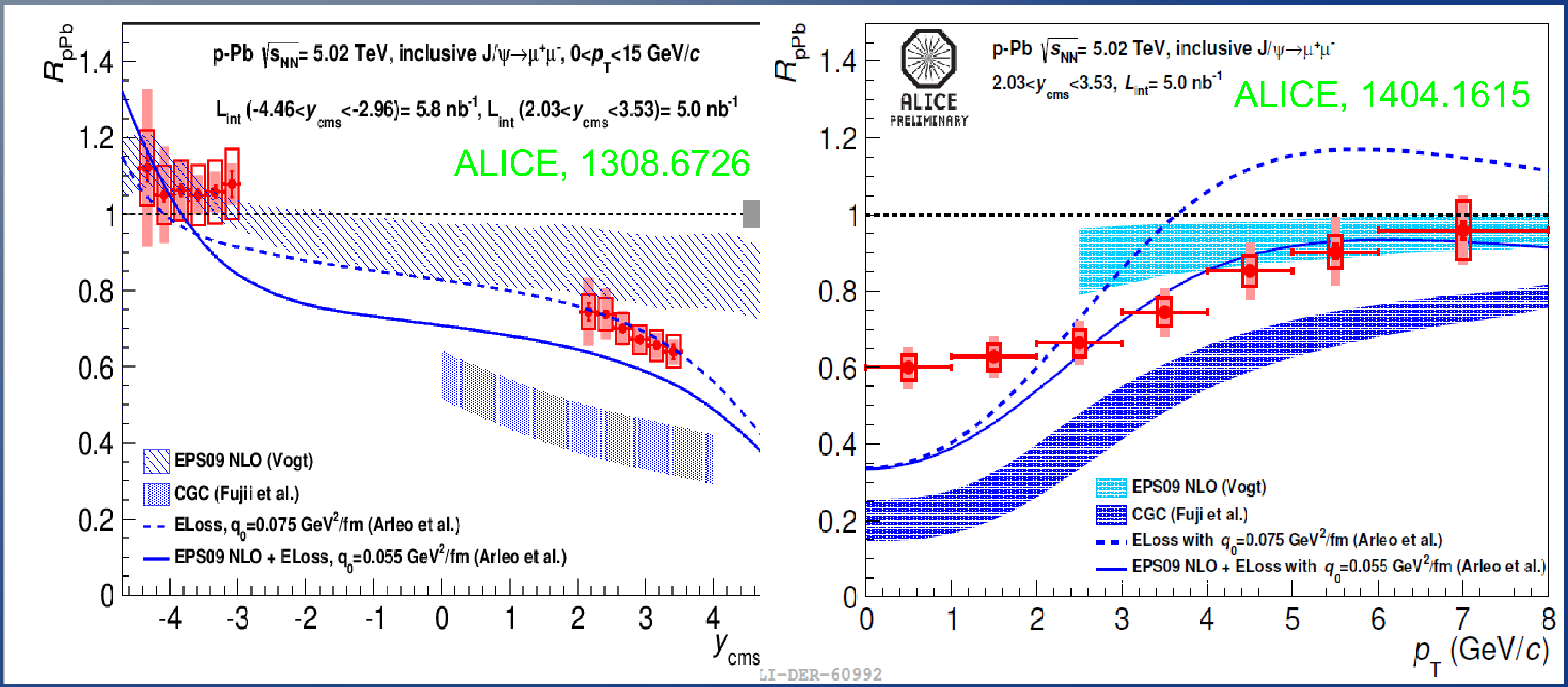
Numerical results

- Quarkonium

RpA for J/ψ at the LHC

- Color evaporation model – $Q_{s0A}^{\ 2} = (4 - 6)\, Q_{s0}^{\ 2}$

$$\frac{dN_{J/\psi}}{d^2\boldsymbol{P}_\perp dy} = F_{J/\psi} \int_{4m_c^2}^{4M_D^2} dM^2 \frac{dN_{c\bar{c}}}{d^2\boldsymbol{P}_\perp dM^2 dy}$$



HF, Watanabe, NPA915,1, 2013

RpA for J/ψ at the LHC

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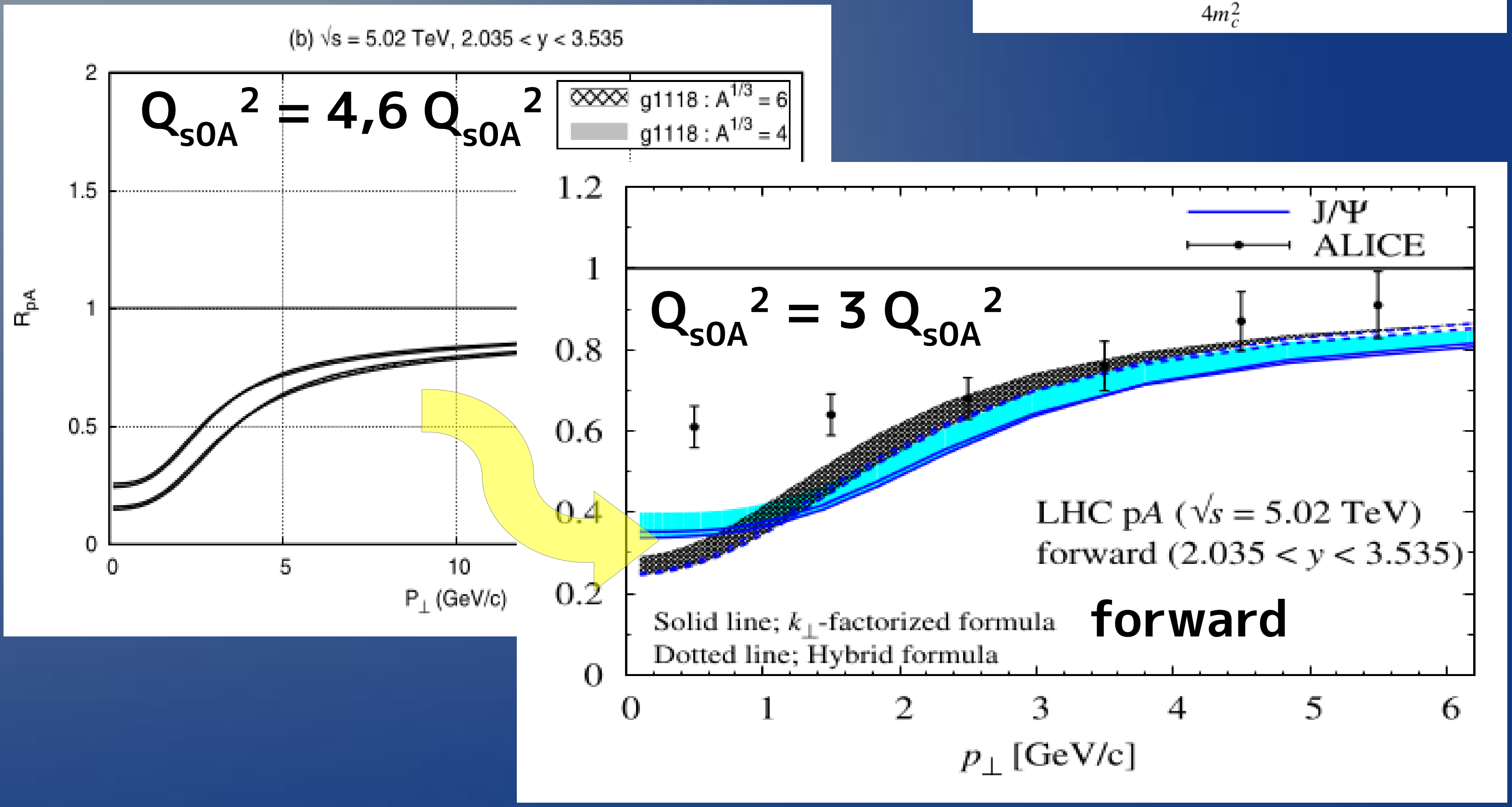

HF, Watanabe, NPA915,1 (2013); NPA951, 45 (2016)

RpA for J/ψ at the LHC

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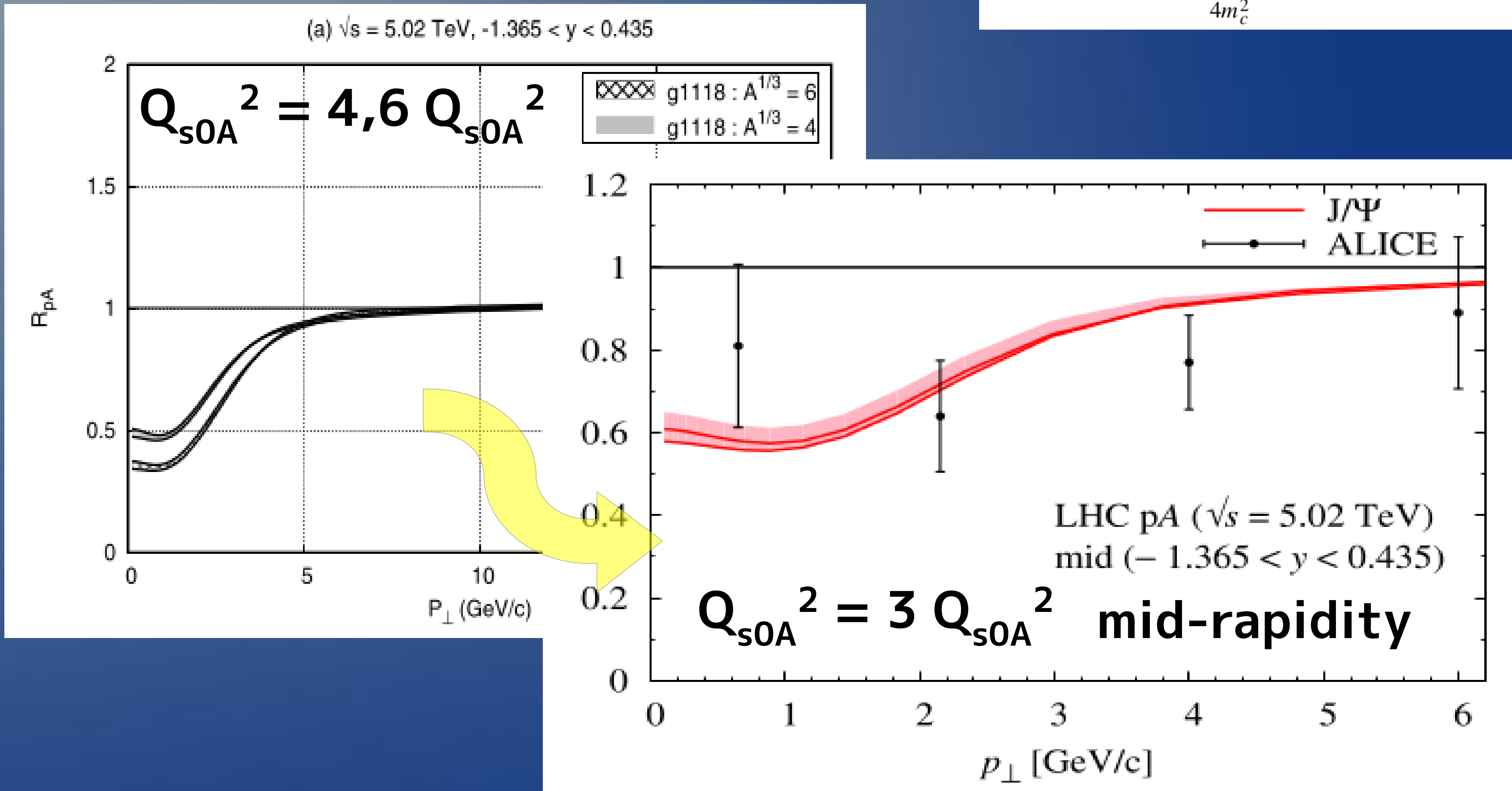
$$\frac{dN_{J/\psi}}{d^2\boldsymbol{P}_\perp dy} = F_{J/\psi} \int_{4m_c^2}^{4M_D^2} dM^2 \frac{dN_{c\bar{c}}}{d^2\boldsymbol{P}_\perp dM^2 dy}$$



HF, Watanabe, NPA915,1 (2013);
NPA951, 45 (2016)

Numerical results

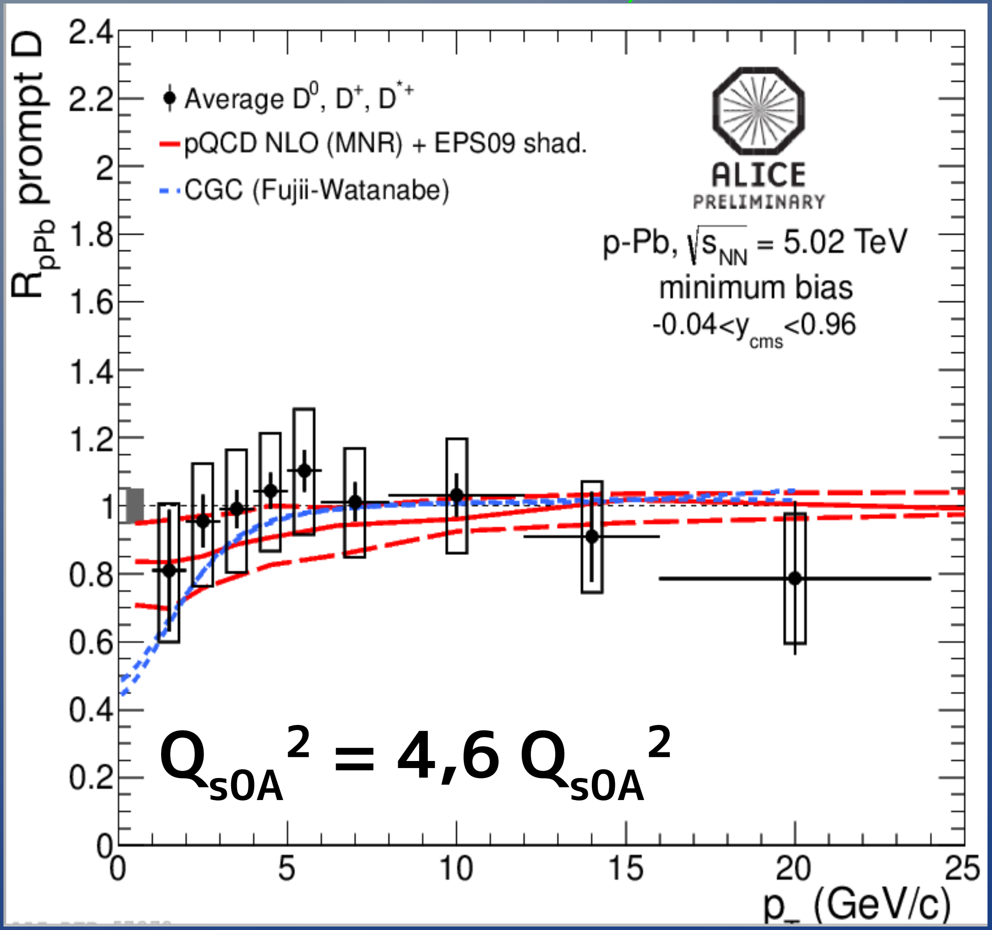
- D meson

RpA for D at the LHC

$$\frac{d\sigma_h}{d^2 \boldsymbol{p}_{h\perp} dy} = f_{q\to h} \int_{z_{\min}}^{1} dz \frac{D_q^h(z)}{z^2} \frac{d\sigma_q}{d^2 \boldsymbol{q}_\perp dy}$$

- using frag. fn.
-

ALICE, 1310.1714

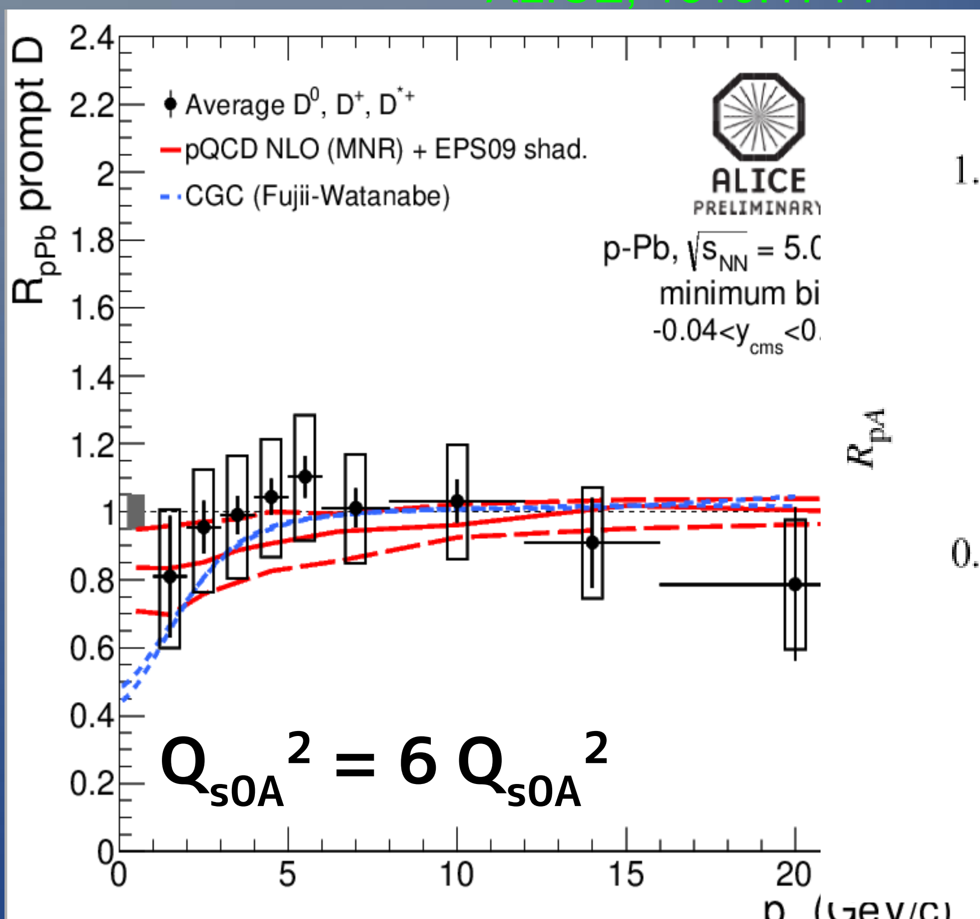


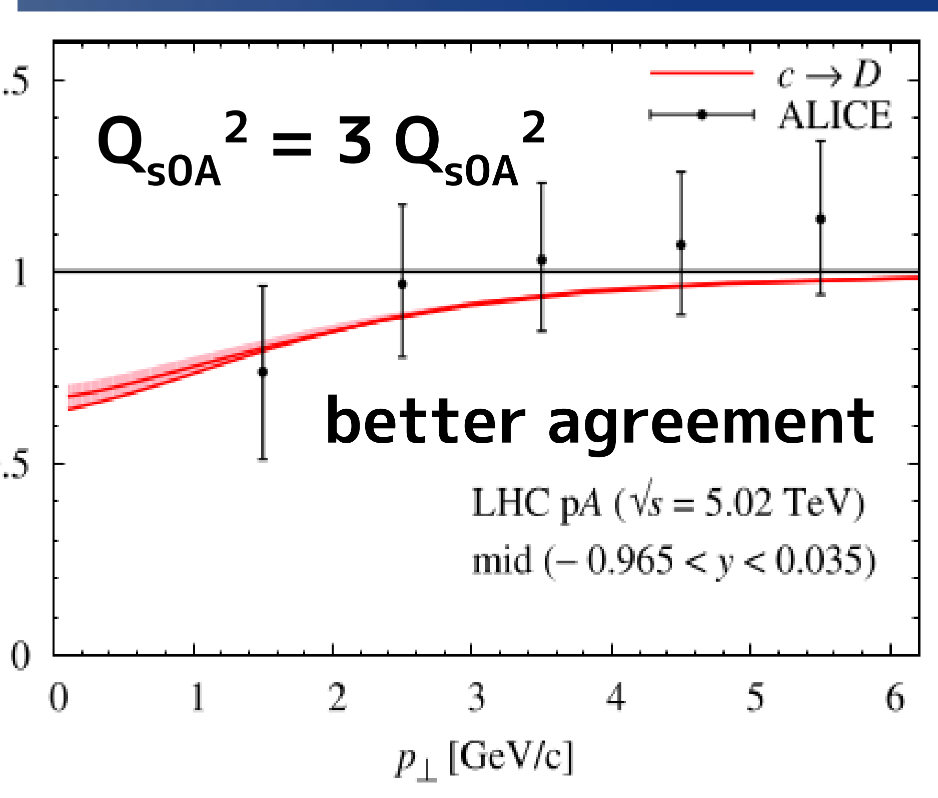
HF, Watanabe, NPA920 (2013); NPA951, 45 (2016)

RpA for D at the LHC

- At mid rapidity

ALICE, 1310.1714

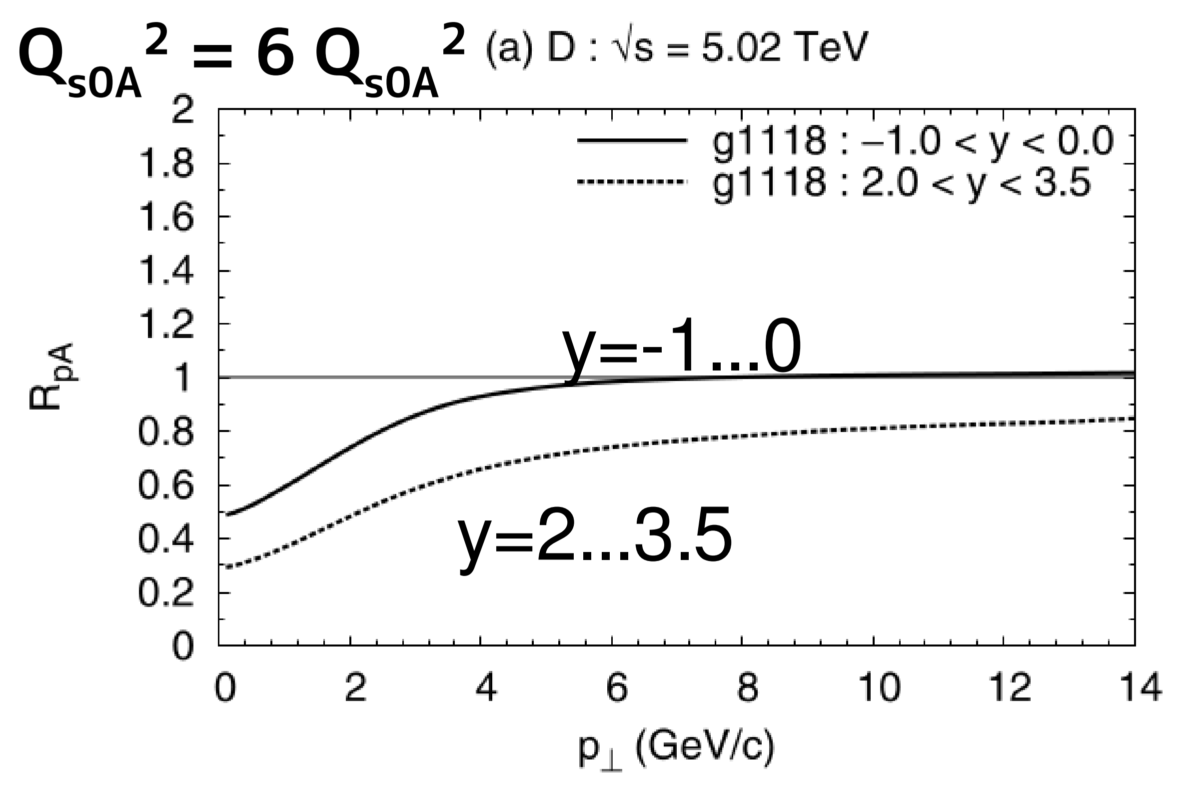




HF, Watanabe, NPA920 (2013); NPA951, 45 (2016)

RpA for D at the LHC

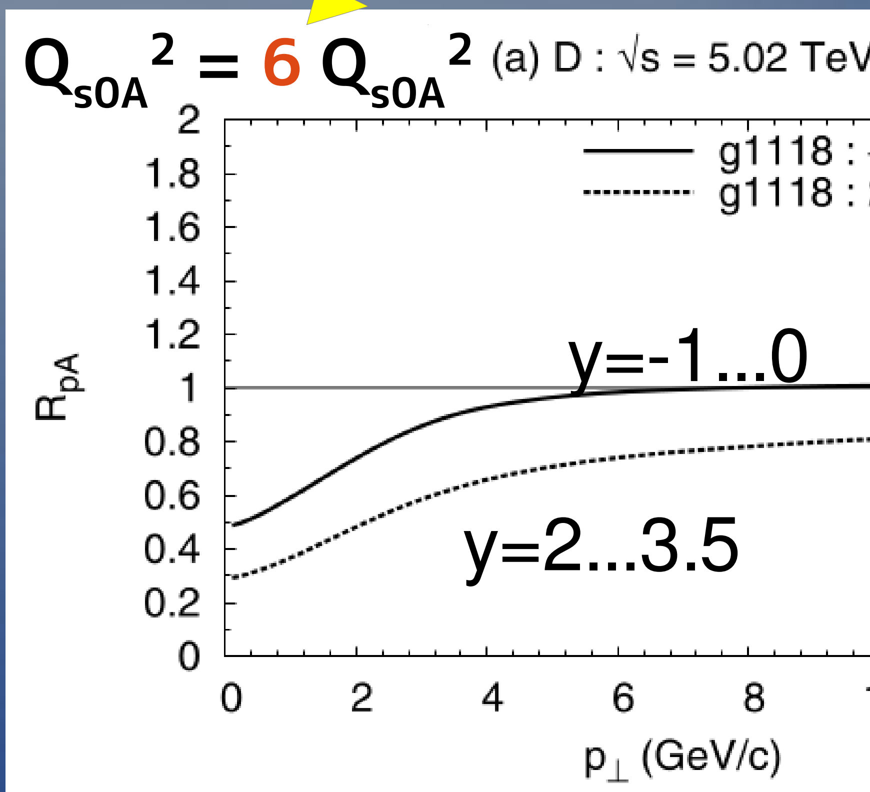
- at forward rapidity

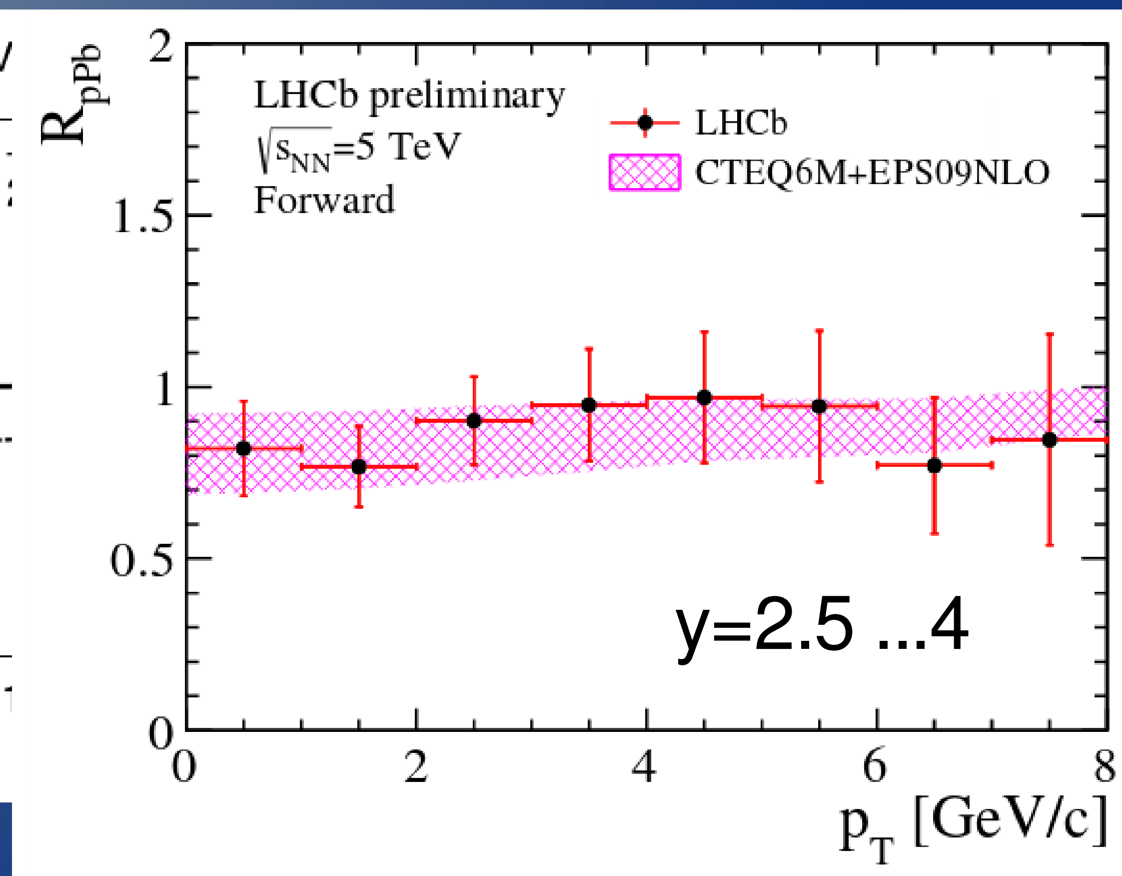


HF, Watanabe, NPA920 (2013)

RpA for D at the LHC

- at forward rapidity





HF, Watanabe, NPA920 (2013)

LHCB-CONF-2016-003

Numerical results

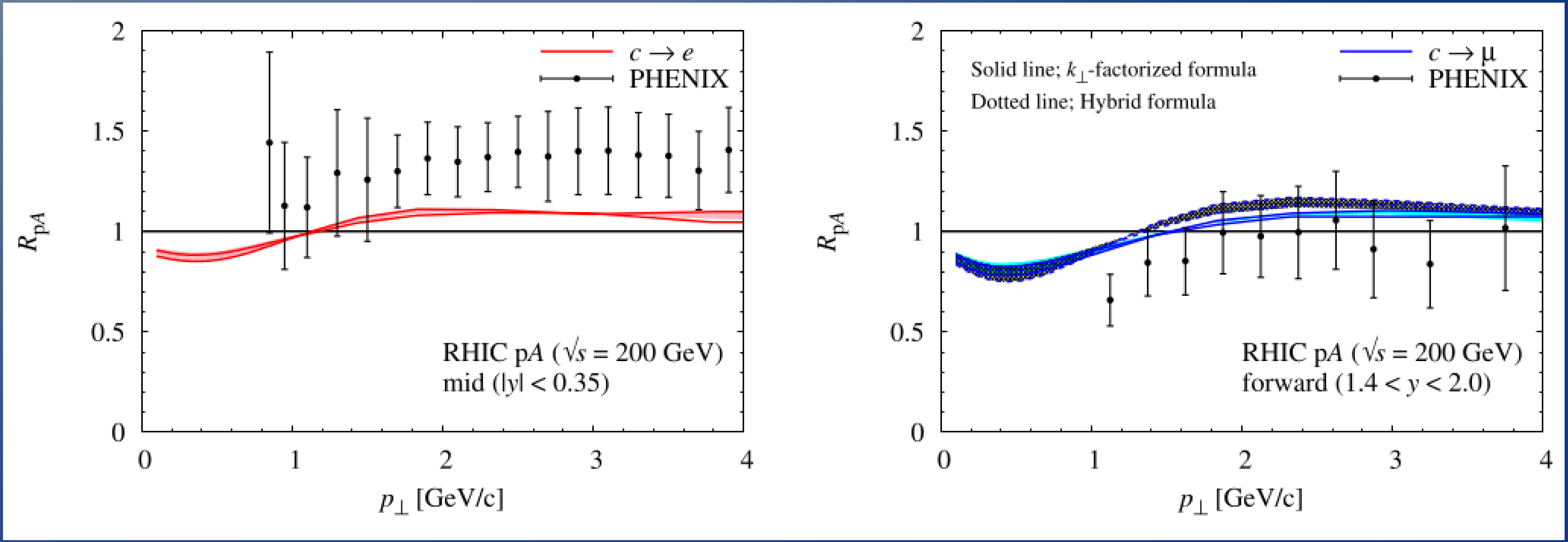
- Decay leptons

Decay leptons from D at RHIC

- Not inconsistent

RHIC

$Q_{s0A}^2 = 3\, Q_{s0A}^2$



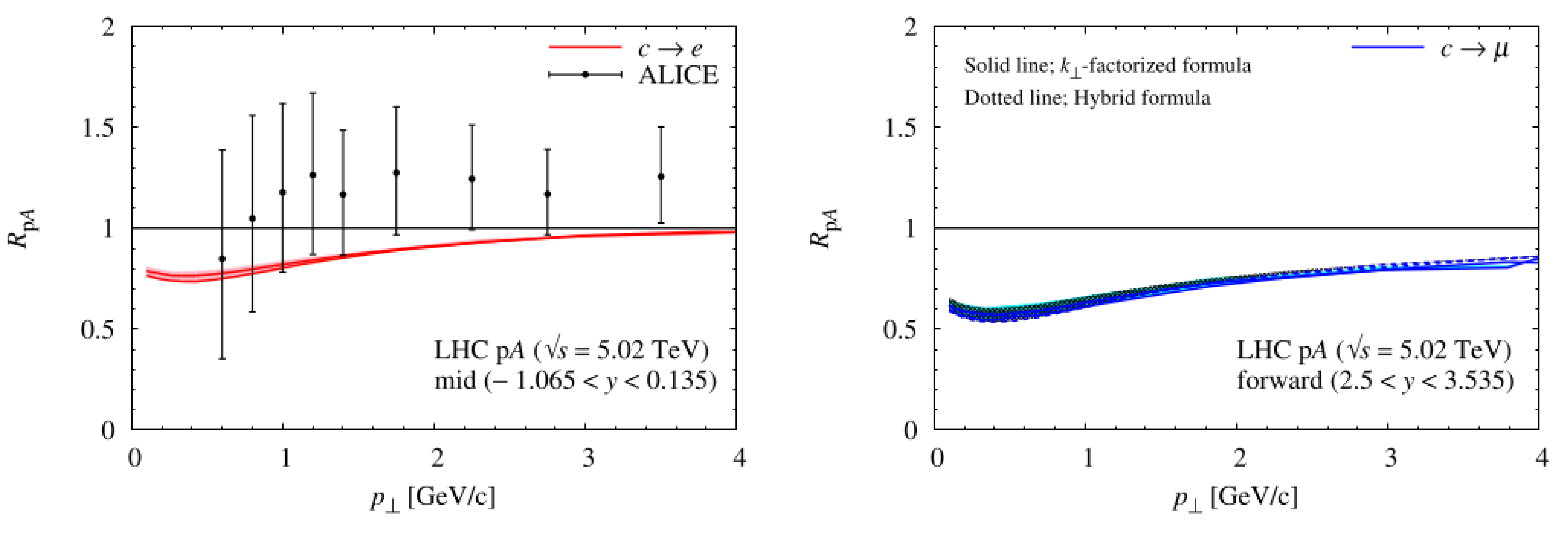
HF, Watanabe, NPA951 (2016)

Decay leptons from D at the LHC

- Not inconsistent, but systematically lower than the data

LHC

$Q_{s0A}^{2} = 3\,Q_{s0A}^{2}$



HF, Watanabe, NPA951 (2016)

Discussions

- Results with $Q_{s0A}^2 \sim 3Q_{s0p}^2$ is more consistent to data
- Optical Glauber model Ducloue et al. in effect corresponds to similar value of Q_{s0A}^2
- Fluctuations in centrality is large in pA
- Should use Monte Carlo to treat a nucleus

Summary

- Updated results with $Q_{s0A}{}^2 \sim 3Q_{s0p}{}^2$, which value is consistent with nDIS, describe the data on
  - J/y, D mesons, decay leptons
- Monte Carlo description for pA seems important
  - we plan to implement it

Thank you!

- Thank all of you for gathering at Komaba today.
- I hope the discussions today help your research tomorrow.
- Hope to expand the collaboration between France and Japan in our field.
- Look forward!