Probing small-x gluons by low-mass Drell-Yan pairs at RHIC and LHC

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- Poor knowledge of nuclear gluon distributions
- Low-mass and high transverse momentum Drell-Yan
- Production rate at RHIC
- Drell-Yan in forward region

In collaboration with George Fai and Jianwei Qiu

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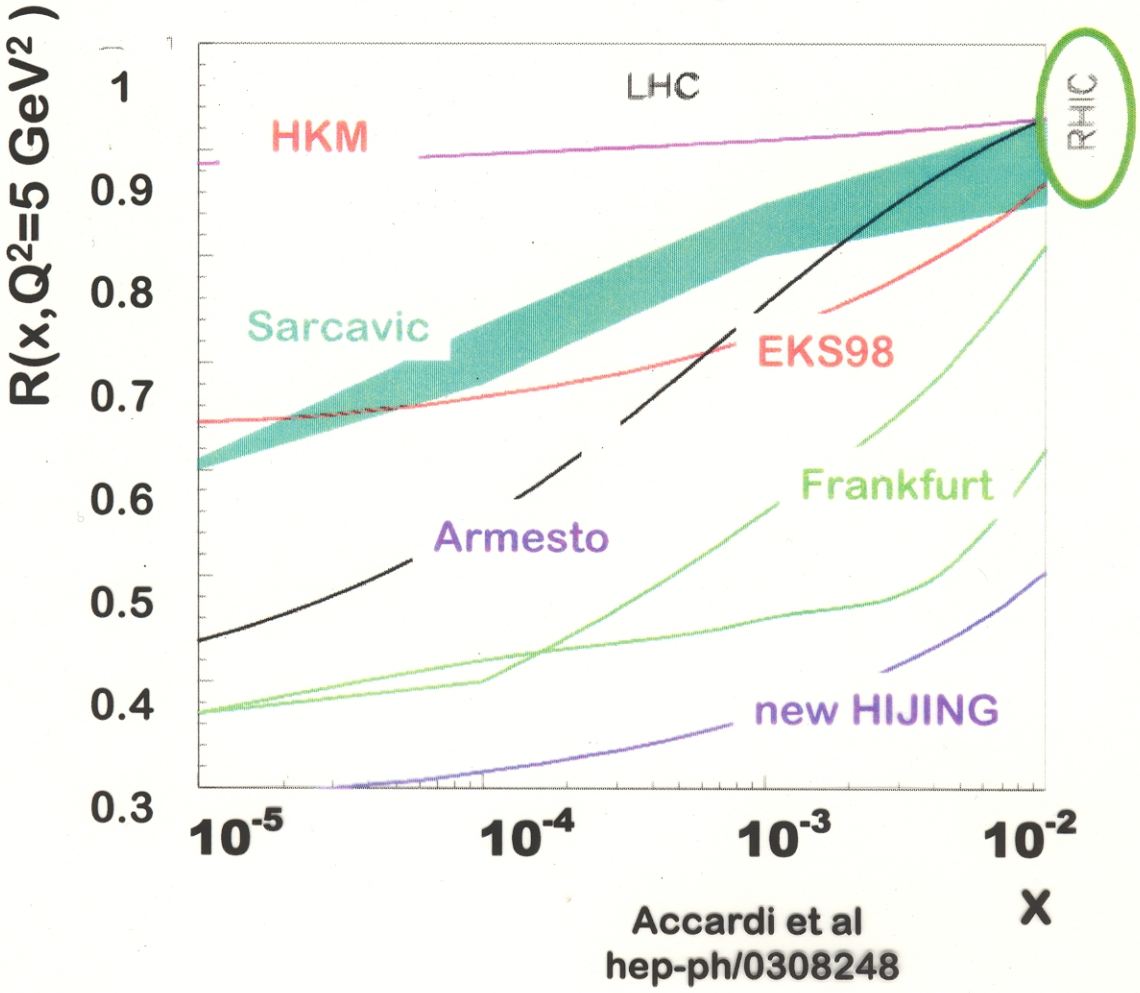
Probes of nuclear effect in gluon distribution

- Poor knowledge of nuclear gluon distribution

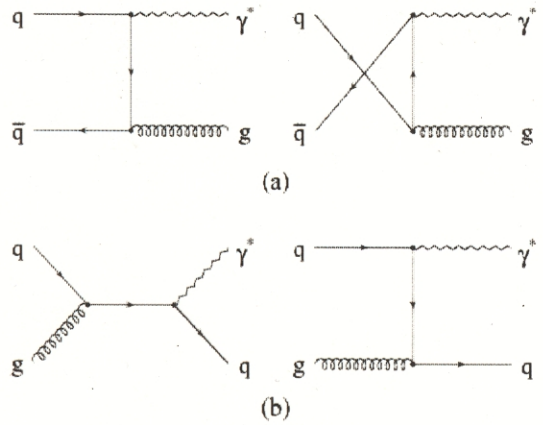


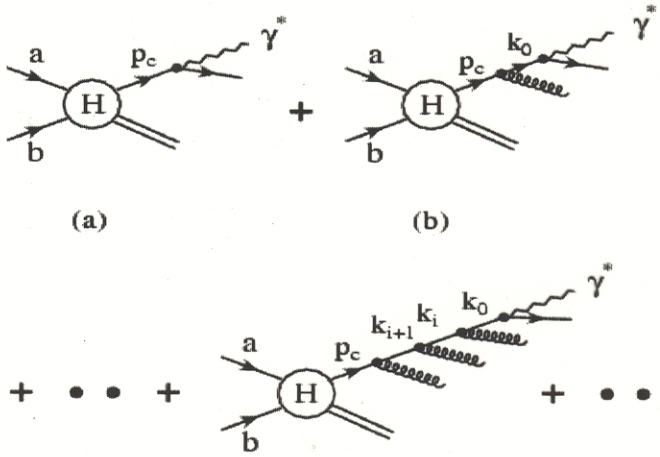
Accardi et al
hep-ph/0308248

- Need processes that are sensitive to gluons
  - → Low-mass Drell-Yan dileptons at large Q_T and y
- Predictive power requires these processes to be factorizable and calculable
  - → pQCD factorization works fine for low mass Drell-Yan at large Q_T and y at RHIC energies

Low-mass Drell-Yan dilepton production

- Clean probe without strong final-state interactions





Lowest order | **All-order fragmentation**

- QCD factorization including all-order resummation

$$\frac{d\sigma_{AB\to\gamma^*(Q)X}}{dQ_T^2\,dy} = \sum_{a,b}\int dx_1\phi_{a/A}(x_1,\mu)\int dx_2\phi_{b/B}(x_2,\mu)$$

$$\times\left\{\frac{d\hat{\sigma}^{(Dir)}_{ab\to\gamma^*(Q)X}}{dQ_T^2\,dy}(x_1,x_2,Q,Q_T,y;\mu_F,\mu)\right.$$

$$\left.+\sum_c\int\frac{dz}{z^2}\left[\frac{d\hat{\sigma}^{(F)}_{ab\to cX}}{dp_{cT}^2\,dy}\left(x_1,x_2,p_c=\frac{\hat{Q}}{z};\mu_F,\mu\right)\right]D_{c\to\gamma^*(Q)X}(z,\mu_F^2;Q^2)\right\}.$$

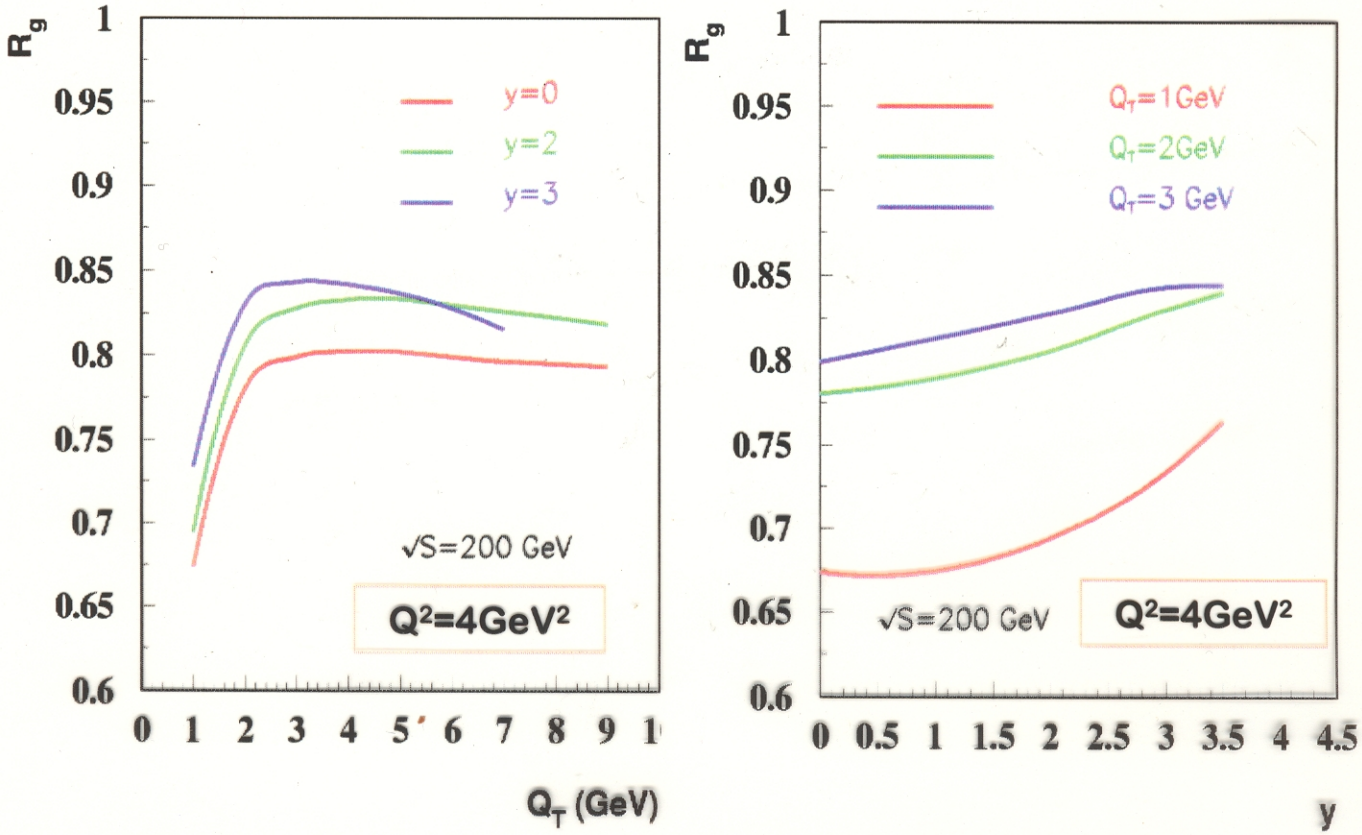
Berger,Qiu,Zhang, PRD65, 2002

- Large virtuality limits the fragmenting partons' interaction length in medium – less energy loss

Low-mass and high Q_T Drell-Yan

- Gluon-initiated partonic subprocesses dominate the production rate for $Q_T > Q/2$

$$R_g = \frac{d\sigma_{AB\to\gamma^*(Q)X}\,(\text{gluon-initiated})}{dQ_T^2\,dy} \Big/ \frac{d\sigma_{AB\to\gamma^*(Q)X}}{dQ_T^2\,dy}.$$



- No complications of isolation cuts, suffered by the direct photon signal at high Q_T
- Forward region in rapidity y to probe the small-x gluon distribution

Production rate

- It suffers a lower production rate (Drell-Yan factor)

$$\frac{d\sigma_{AB\to\ell^+\ell^-(Q)}}{dQ^2 dy dQ_T^2} = \left(\frac{\alpha_{\rm em}}{3\pi Q^2}\right)\frac{d\sigma_{AB\to\gamma^*(Q)}}{dy dQ_T^2}$$

10^{-4} for $Q \geq 2$ GeV

⇨ Low-mass Drell-Yan

- Push Q^2 as small as possible, need to worry about resonances

- Need resummation of final-state bremsstrahlung logarithms, if $Q_T^2 >> Q^2$.

⇨ Virtual photon fragmentation functions

$$\mu^2 \frac{d}{\mu^2} D_{c\to\gamma^*}(z,\mu;Q) = \left(\frac{\alpha_{em}}{2\pi}\right)\gamma_{c\to\gamma^*}(z,\mu,\alpha_s;Q) + \left(\frac{\alpha_s}{2\pi}\right)\sum_d \int_z^1 \frac{dz'}{z'} P_{c\to d}\left(\frac{z}{z'},\alpha_s\right) D_{d\to\gamma^*}(z',\mu;Q)$$

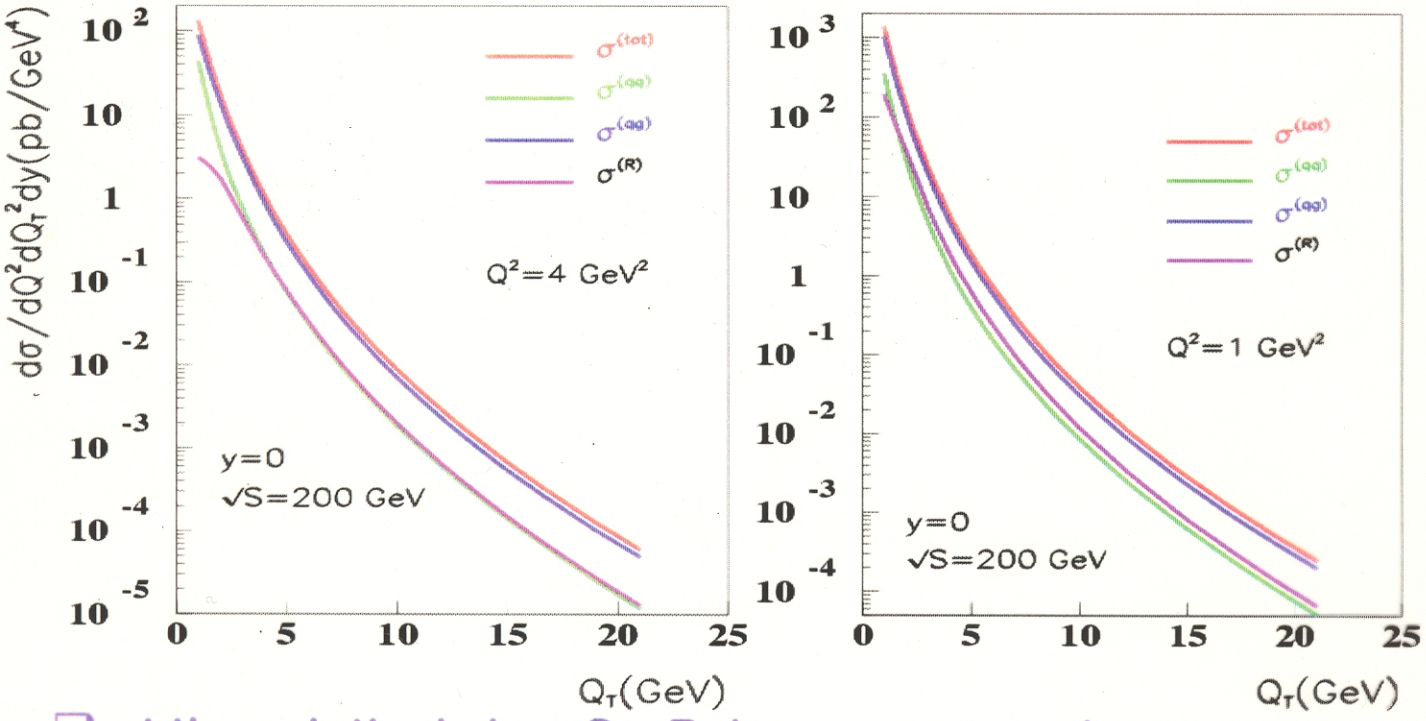
Initial condition: $D_{c\to\gamma^*}(z,\mu^2 \leq Q^2/z;Q) = 0$

Qiu and Zhang, PRD (2001)

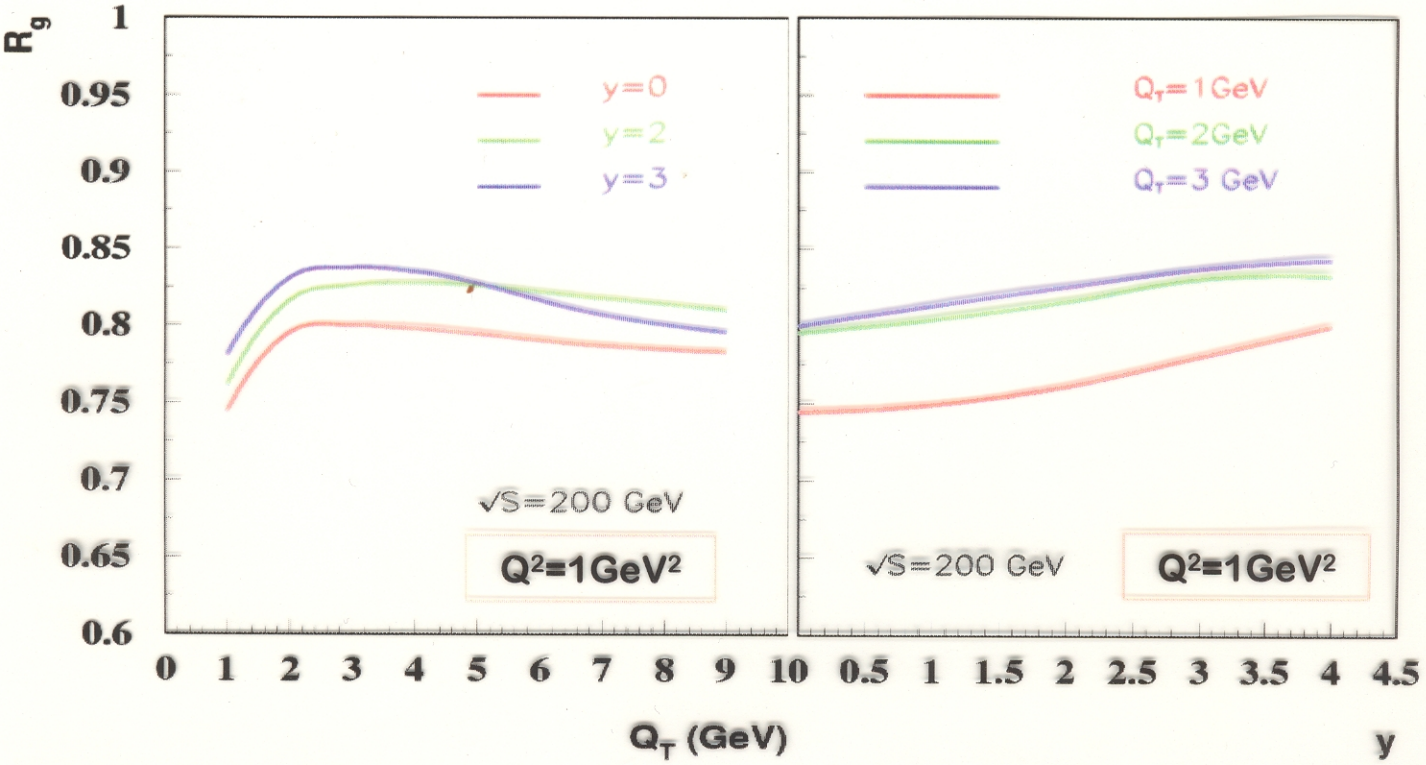
Virtual Photon Fragmentation Functions are perturbative!

High Q_T and low-mass (Q)Drell-Yan dilepton

- small Q^2 improves the rate at RHIC energies



- at the relatively low Q_T, R_g becomes even larger

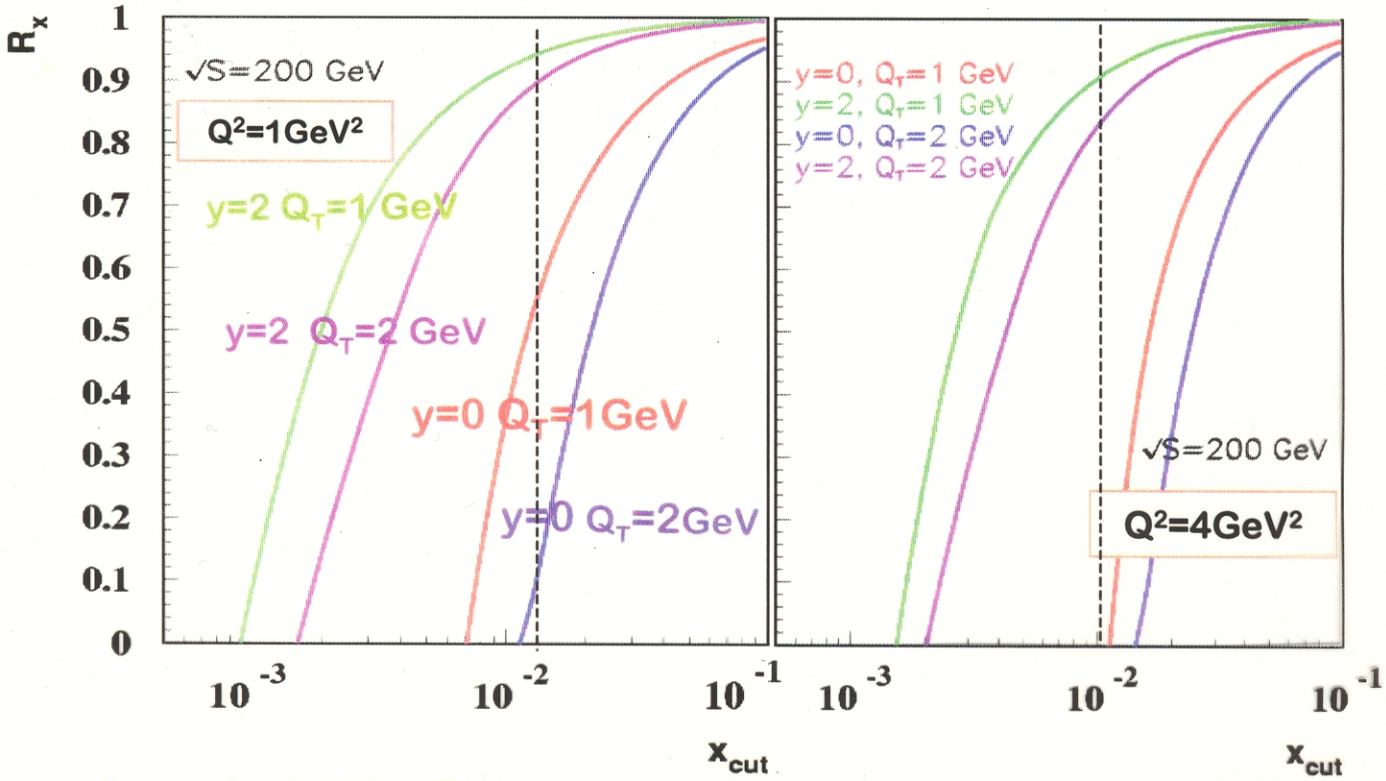


- Low Q_T Drell-Yan dileptons have large power corrections

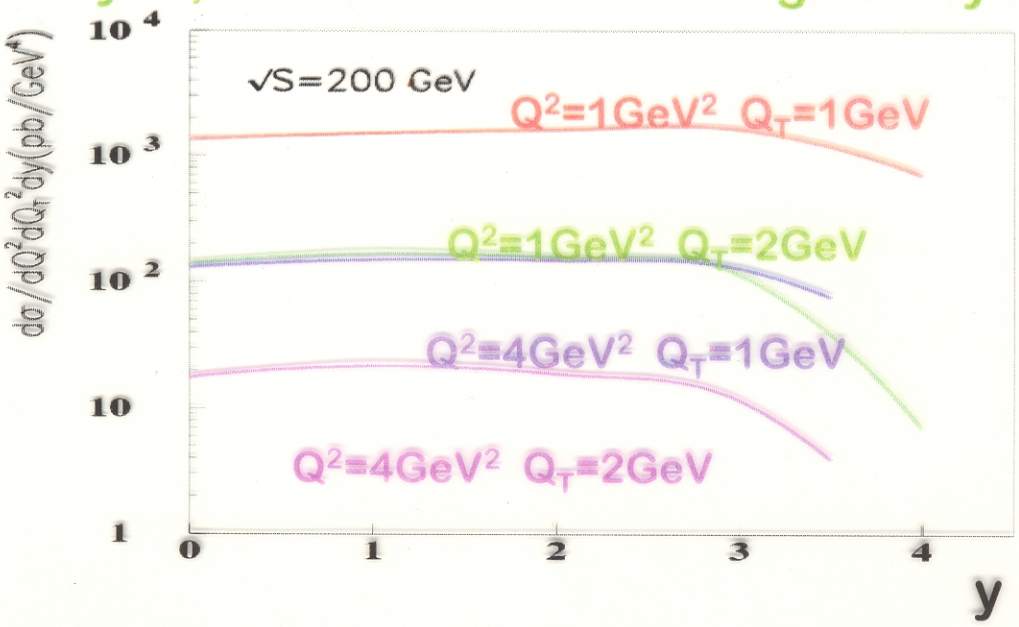
Drell-Yan in forward region

- Range of x probed:

$$R_x = \int_{x_{\min}}^{x_{\rm cut}} dx_2 \left(\frac{d\sigma^{\rm DY-LO}}{dx_2}\right) \Big/ \int_{x_{\min}}^{1} dx_2 \left(\frac{d\sigma^{\rm DY-LO}}{dx_2}\right)$$



At y=2, 90% of cross-section given by $x_2 < 0.01$!



Conclusions

- Low-mass Drell-Yan dilepton production in forward region is a potentially clean probe of small-x gluons, because the gluon initiated subprocesses contribute more than 70% to the cross section

- It suffers from low production rate at RHIC due to the Drell-Yan factor (~10^{-4} for Q~2GeV)

- If RHIC detectors can measure the low-mass dileptons at $Q_T > 1$ GeV, such low-mass dileptons can provide excellent information on small-x gluons

- At $Q^2=1GeV^2$ and y=2, 90% of the cross section is produced by gluons of $x_2 < 0.01$

- At LHC energies, high Q_T low-mass Drell-Yan production is an excellent probe of gluon distributions