Υ suppression in pPb collisions

Viet Hung Dinh

July 6, 2018

Motivation

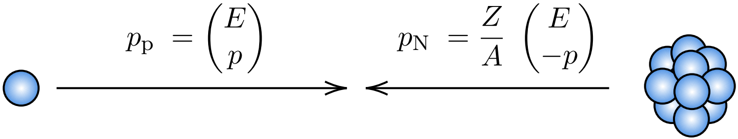
- pp collision – QCD baseline
    - production mechanisms
- PbPb collision – Hot Matter effects
    - Screening, Damping, Gluodissociation, Feed-Down reduction
- pPb collision – Cold Nuclear Matter effects
    - Shadowing, Energy loss

Outline

1. Basic Kinematics
    - Lab System
    - Lead Rest Frame
2. Cold Nuclear Matter Effects
    - Collinear Factorization Theorem
    - Nuclear Parton Distribution Function
    - Coherent Parton Energy Loss
3. Υ Results
4. Summary

Basic Kinematics

Lab system

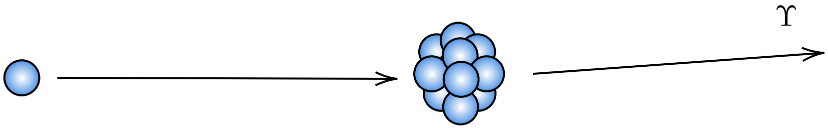


$$p_{\mathrm{p}} = \begin{pmatrix} E \\ p \end{pmatrix} \qquad p_{\mathrm{N}} = \frac{Z}{A} \begin{pmatrix} E \\ -p \end{pmatrix}$$

- $\sqrt{s_{\mathrm{NN}}} = \sqrt{(p_{\mathrm{p}} + p_{\mathrm{N}})^2} = \sqrt{s_{\mathrm{pp}}}\sqrt{\frac{Z}{A}} = 8.16\ \mathrm{TeV}$
- $\Delta y = \frac{1}{2} \ln \frac{E_{\mathrm{cms}} + p_{\mathrm{cms}}}{E_{\mathrm{cms}} - p_{\mathrm{cms}}} = \frac{1}{2} \ln \frac{A}{Z} = +\,0.465$
- $y_{\mathrm{beam}} = \pm \ln \frac{\sqrt{s_{\mathrm{NN}}}}{m_{\mathrm{p}}} = \pm\,9.07$

Basic Kinematics

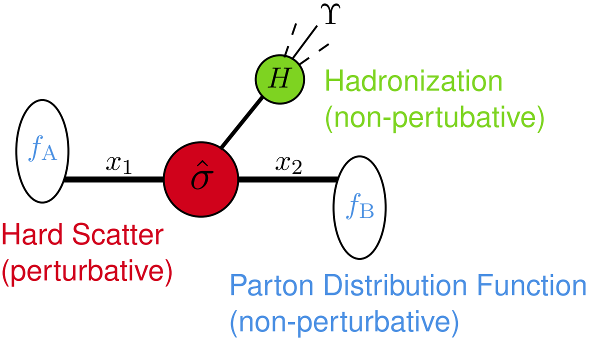
Lead rest frame



- $s_{\mathrm{NN}} = 2E_{\mathrm{p}}m_{\mathrm{p}} \rightarrow E_{\mathrm{p}} = \frac{s_{\mathrm{NN}}}{2m_{\mathrm{p}}}$
- $E_{\Upsilon} = M_{\perp}\cosh y' = M_{\perp}\cosh(y + y_{\mathrm{beam}})$
- Suppression factor $R^{\Upsilon}_{\mathrm{pPb}} = \frac{N^{\Upsilon}_{\mathrm{pPb}}}{AN^{\Upsilon}_{\mathrm{pp}}} = \frac{1}{A}\frac{\frac{\mathrm{d}\sigma_{\mathrm{pPb}}}{\mathrm{d}y}}{\frac{\mathrm{d}\sigma_{\mathrm{pp}}}{\mathrm{d}y}}$

Outline

Quarkonium Production mechanism



Hadronization
(non-pertubative)

Hard Scatter
(perturbative)

Parton Distribution Function
(non-perturbative)

Collinear factorization theorem:

$$\sigma\left(\mathrm{pPb}\rightarrow\Upsilon+X\right)=\sum_{\mathrm{ij}}\int \mathrm{d}x_1\mathrm{d}x_2 f_{\mathrm{i}}^{\mathrm{p}}\left(x_1\right)f_{\mathrm{j}}^{\mathrm{Pb}}\left(x_2\right)\sigma\left(\mathrm{ij}\rightarrow\Upsilon\right)$$

Parton Production

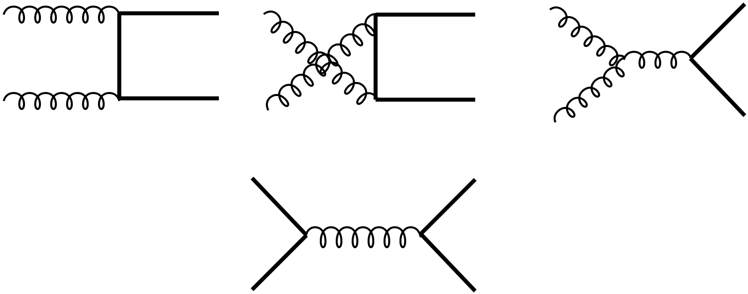
Color Evaporation Model

- Idea: Quark–Hadron duality
- $b\bar{b}$ pair will evaporate to a given color-singlet state via multiple soft gluon interaction
- Universal fraction to hadronize into Υ from a produced $b\hat{b}$ pair

$$\sigma\left(\mathrm{ij} \to \Upsilon\right) = F_{\Upsilon} \int_{4m^2}^{4M^2} \mathrm{d}s\ \hat{\sigma}\left(\mathrm{ij} \to b\bar{b}\right)$$

- where $m(b) = 4.18$ GeV and $M(B) = 5.28$ GeV

$b\bar{b}$ Production



- Above are leading order diagrams in QCD to calculate $b\hat{b}$ productions
- exclusive NLO heavy flavor calculations for $\frac{\mathrm{d}\hat{\sigma}_{\mathrm{ij}}}{\mathrm{d}y\mathrm{d}p_{\perp}}$ are available as MNR code

Outline

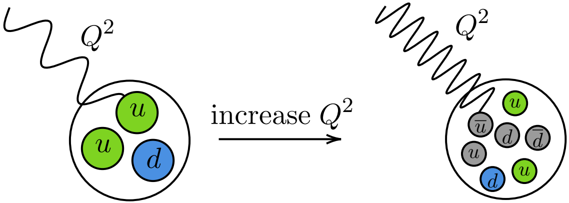
1. Basic Kinematics
   - Lab System
   - Lead Rest Frame

2. Cold Nuclear Matter Effects
   - Collinear Factorization Theorem
   - Nuclear Parton Distribution Function
   - Coherent Parton Energy Loss

3. Υ Results

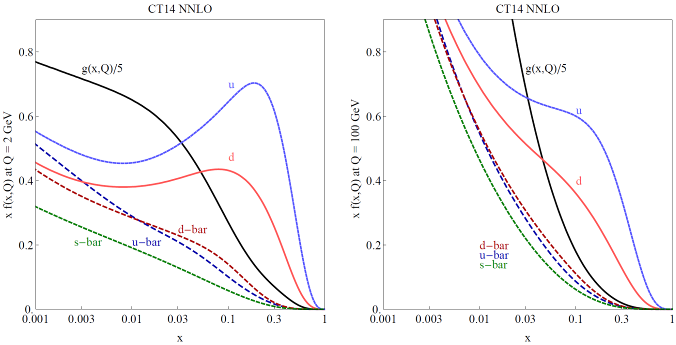
4. Summary

Partons



- $f_i^p(x, Q^2)$: probability distribution for finding a parton i depending on protons momentum fraction x and momentum transfer Q^2
- At higher energies there are not only valence quarks but also sea quarks and gluons

Parton Distribution Function

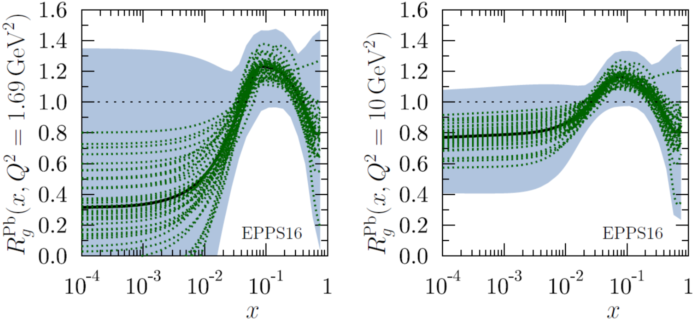


source: PHYSICAL REVIEW D 93, 033006 (2016)

- Energy scale dependence given by DGLAP–equation

$$\frac{\partial f_i}{\partial \ln Q^2} = \frac{\alpha_s}{2\pi} \sum_j P_{i \leftarrow j} \otimes f_j$$

Nuclear Modification

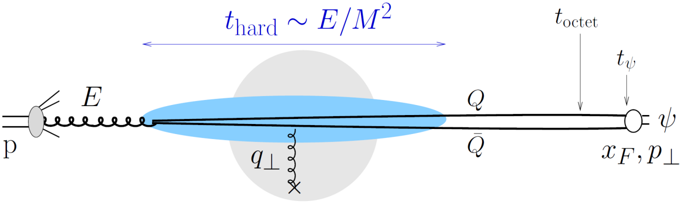


source: European Physical Journal C (2017) 77:163

- $f_i^{\mathrm{Pb}}(x, Q^2) = R_i^{\mathrm{Pb}}(x, Q^2) f_i^{\mathrm{p}}(x, Q^2)$
- shadowing/depletion at small x, caused by gluon recombination
- anti-shadowing, an excess at $x \approx 0.1$ and EMC effect at higher x

Outline

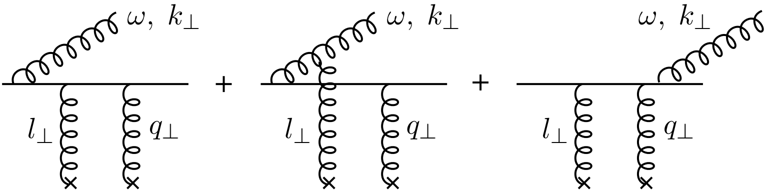
Coherent parton energy loss



source: Journal of High Energy Physics (2013) 2013: 122

- Assumption: The Υ forms outside of the nucleus
- Gluonbremsstrahlung of the partons and the produced heavy quarks

coherent radiation



- Initial & Final state effect
- $q_\perp \gg l_\perp$ hard exchange;
  $l_\perp^2 = \triangle q_\perp^2$ nuclear momentum broadening
- Interference terms do not cancel in induced spectrum

$$\omega \frac{\mathrm{dI}}{\mathrm{d}\omega} = \frac{F_c \alpha_s}{\pi} \ln\left(1 + \frac{\hat{q} L E^2}{M_\perp^2 \omega^2}\right)$$

Energy shift

- Modification of the cross section

$$\frac{1}{A}\frac{\mathrm{d}\sigma_{\mathrm{pPb}}}{\mathrm{d}E}(E,\sqrt{s}) = \int_0^{\varepsilon_{\max}} P(\varepsilon,E)\frac{\mathrm{d}\sigma_{\mathrm{pp}}}{\mathrm{d}E}(E+\varepsilon,\sqrt{s})\mathrm{d}\varepsilon$$

- $P(\epsilon)$: Quenching weight

$$P(\varepsilon) = \frac{\mathrm{dI}}{\mathrm{d}\omega}(\varepsilon)\exp\left(-\int_\varepsilon^\infty \mathrm{d}\omega\frac{\mathrm{dI}}{\mathrm{d}\omega}\right)$$

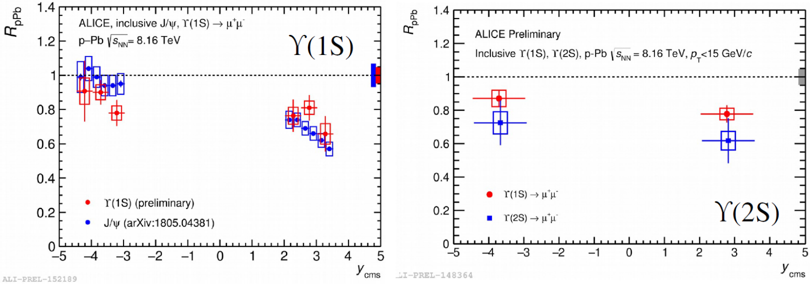
- Average Energy Loss

$$\triangle E = \int \mathrm{d}\omega\,\omega\frac{\mathrm{dI}}{\mathrm{d}\omega} \sim \alpha_s\frac{\sqrt{\hat{q}L}}{M_\perp}E$$

Outline

1. Basic Kinematics
    - Lab System
    - Lead Rest Frame
2. Cold Nuclear Matter Effects
    - Collinear Factorization Theorem
    - Nuclear Parton Distribution Function
    - Coherent Parton Energy Loss
3. Υ Results
4. Summary

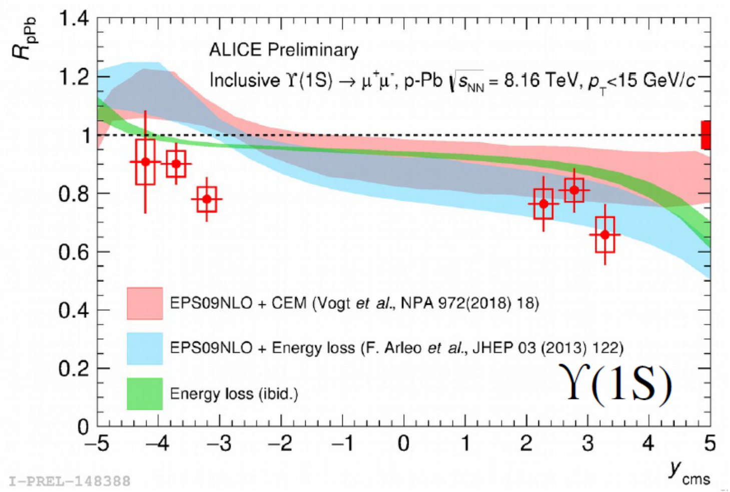
Υ Results



source: Preliminary Results from the Quark Matter 2018 conference

- Similar Υ suppression at forward and backward rapidity
- However significant forward suppression for J/ψ
- $\Upsilon(2\mathrm{S})$ is slightly more suppressed than $\Upsilon(1\mathrm{S})$

Υ Predictions



source: Preliminary Results from the Quark Matter 2018 conference

Summary

- Nuclear Modification of the Quarkonium Production

$$\sigma^{\mathrm{pPb}} = F_{\Upsilon} \sum_{\mathrm{ij}} \int_{4m^2}^{4M^2} \mathrm{d}s \int \mathrm{d}x_1 \mathrm{d}x_2 f_{\mathrm{i}}^{\mathrm{p}}\left(x_1\right) f_{\mathrm{j}}^{\mathrm{p}}\left(x_2\right) R_j^{\mathrm{Pb}}(x_2) \hat{\sigma}_{\mathrm{ij}}$$

- Average Energy Loss $\triangle E \sim E$
- Both reproduce the stronger forward suppression, however the prediction slightly overestimate the results
- Color Evaporation Model fails to explain the stronger suppression of the excited state $\Upsilon(2S)$
- Does the Hot Matter Effect play a role?

Thanks for your attention!