# *Space-time evolution of hadronization in heavy-ion collisions at RHIC*


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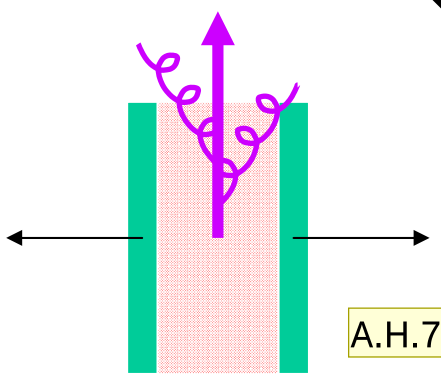
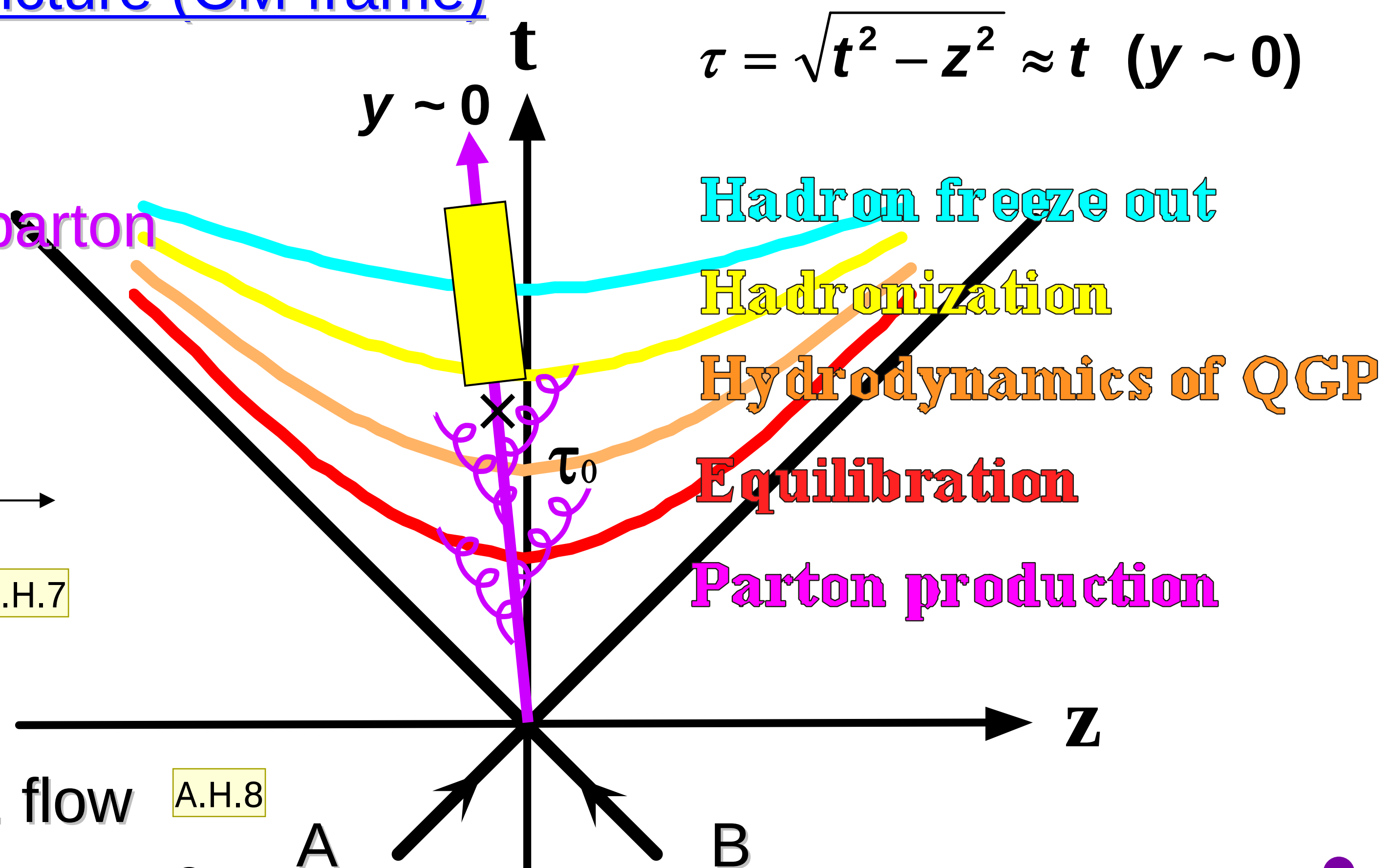
# Bjorken's S-T picture (CM frame)

A.H.6




Neglect transv. flow A.H.8

Matter is at rest at z~0.

$<\tau_0>$ **(thermalization)**

$\sim <\tau_p>$ **(production)**

$= \mathbf{0.4 \sim 1.2}$ **fm**

An energetic parton following different S-T evolution from soft background particles would be a good probe of the matter!

**A.H.6** Let's start with s-t evolution of high energy heavy-ion collision described by Bjorken model. Here the head-on collison of two equal nuclei in the CM frame can be considered on this t-z plane, where t is a clock on the lab. frame and z is collisional axis. So now we assume the translational invariance in the transverse direction. First, the projectile nucleus A comes from z=-infinity wiht a velocity close to the speed of light and the target nucleus B comes from +infinity similarly. So these nulei have a Lorentz contraction in the z-direction like thin disks. Then at t=0, z=0 they meet and collide, then they run away each other on this light-cone.
Arata Hayashigaki, 10/4/2005

**A.H.7** In a standard scenario, thus deposited energy in this hot/dense matter afer collision is carried away by parton production, and this leads to equilibration, hadrodynamical QGP, hadronization of parton and finally hadron freeze out. Their regions are naively classified by each proper time line in the frame of matter. Here tau_0 means thermalization time at which plasma is produced. If this plasma formation time is comparable to the particle production time, at whcih particles begin to be produced out of the field spontaneously, this could be in the range of 0.4(Schwinger particle production mechanism) to 1.2 fm(QED model, Lund model), naively.

Arata Hayashigaki, 10/4/2005

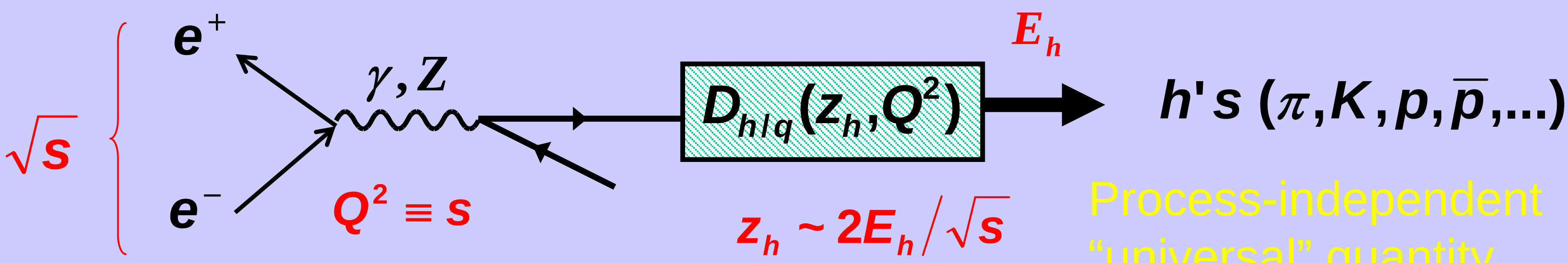
**A.H.8** If we consider high-pt energetic parton production at mid-rapidity region, then in this Bjorken's model transverse flow is neglected and matter is at rest at z=0, of course, then tau equals normal t.

I think this energetic parton obey different s-t evolution from these whole background particles.
I mean, especially in production time discussed later.
So then, this would be a good probe of the matter.
Arata Hayashigaki, 10/4/2005

# *Outline of strategy*

1. Construct parton fragmentation $D_{h/q}(z_h,Q^2)$
   coherence time, vacuum EL, …
   distribution function $W(t_p)$ in pQCD model
   $D_{h/q}$ vs. $W(t_p)$, $\langle t_p(z_h,Q^2)\rangle$
2. (pre-)hadron evolution ($t_f$) after color-bremsstr.
   light-cone Green function method
3. Numerics in Au+Au → $\pi^0$+X at RHIC(y=0)
   high-$p_T$ spectrum of $R_{AA}$
4. Summary

# Parton fragmentation




$$\sum_h \int_0^1 dz_h z_h D_{h/q}(z_h, Q^2) = 1$$ : momentum conservation

$$\int_0^1 dz_h D_{h/q}(z_h, Q^2) = \langle n_h \rangle$$ : average multiplicity for each h

If we focuses on only one hadron containing an energetic parent parton,

$$\int_0^1 dz_h D_{h/q}(z_h, Q^2) = 1$$

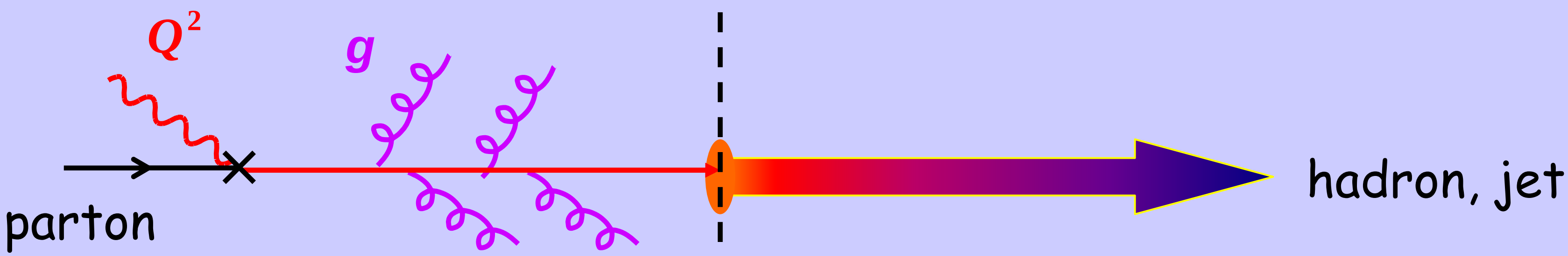
**BKK, KKP, Kretzer parametrizations:**

$$D_{h/q}(z_h, Q^2) \propto z_h^{\alpha(Q^2)} (1 - z_h)^{\beta(Q^2)} \left(1 + \gamma(Q^2)/z_h\right)$$

# Define S-T pattern of hadronization

$$D_{h/q}(z_h, Q^2) = \int_0^\infty dt \; W_q(t, z_h, Q^2)$$

Dynamically two separate stages for $W_q$

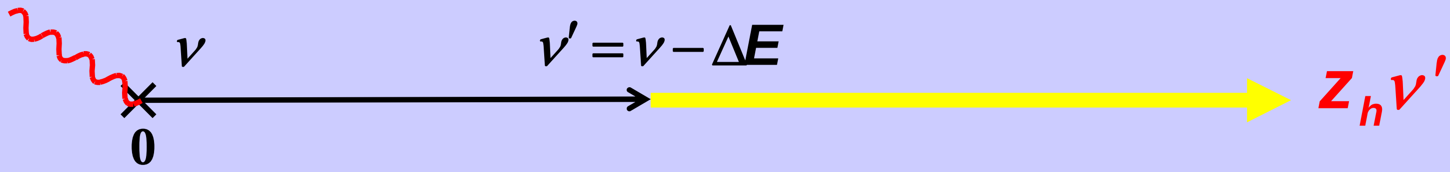



| "Perturbative" stage | "Non-perturbative" stage |
|---|---|
| ***Virtual state*** **of an energetic parton** | ***Color-singlet*** **(*colorless*) of pre-hadron (qqbar color-dipole)** |
| **Soft-gluon radiation *"with" energy loss*** | **Move to an eigenstate of the mass matrix (hadron formation) *"without" energy loss*** |
| ***" Production time"*** $t_p$ | ***" Formation time"*** $t_f$ |

# Naïve estimation of two time-scales

$Q^2 \gg 1$ $t_p$ $t_f$

**DIS**




*energy loss* $\Delta E$ *No energy loss*

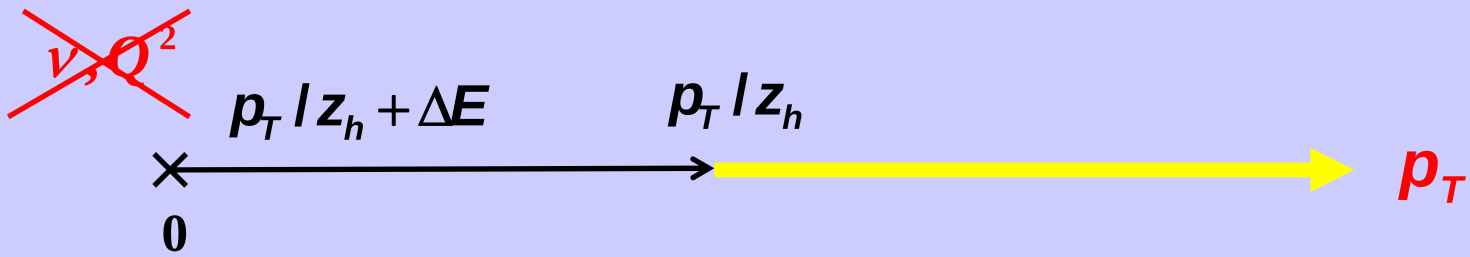
$$t_p \propto \frac{(1-z_h)\nu}{Q^2}$$

$$t_f \propto \frac{z_h \nu'}{m_{h'}^2 - m_h^2}$$

$m_{(h')h}$ : (excited) hadron mass

Bialas, Gyulassy('87)

**AA**




$\nu \to p_T$

$Q^2 \to p_T^2$

$$t_p \propto \frac{1}{p_T}$$

$$t_f \propto \frac{p_T}{m_{h'}^2 - m_h^2}$$

| | ***HERMES(DIS)*** | ***RHIC(AA)*** |
|---|---|---|
| **energetic parton** <br> **large $\nu$ or $p_T$** ⟶ | $t_p \propto \frac{\nu}{Q^2}$ | $t_p \propto \frac{1}{p_T}$ |
| | $r_A \le t_p \le t_f$ | $t_p \ll r_A \le t_f$ |
| hadronization: | outside nucleus | inside nucleus or matter |

*Nemchik's talk*

***high-$p_T$*** hadron productions at RHIC:

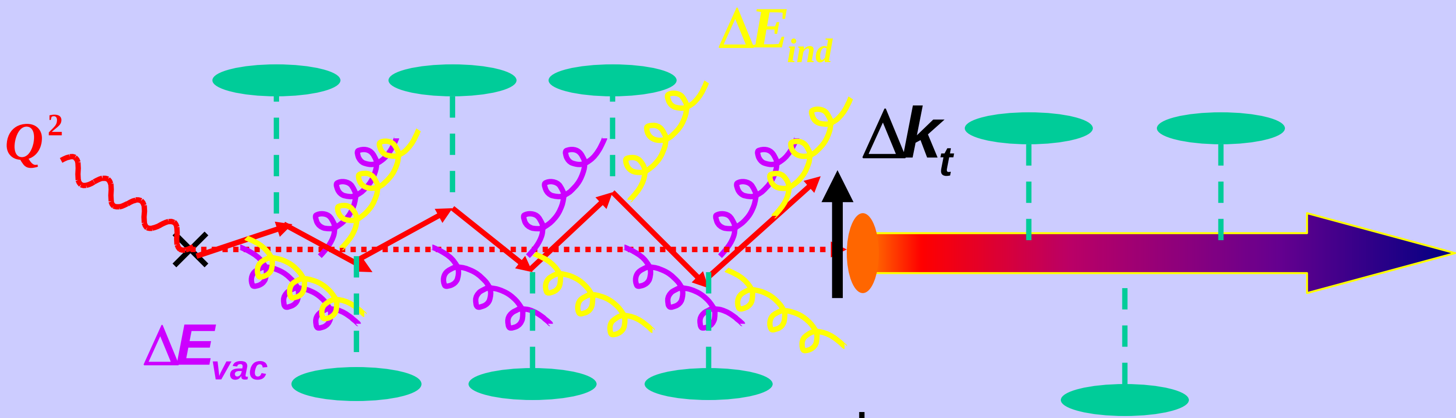
"Less" important *parton energy loss even in hot/dense matter?!*

"More" important *attenuation of compact pre-hadron?!*

$$\langle r_T \rangle_{q\bar{q}} \le r_D = 0.3 \sim 0.8\, fm$$

$$D_{h/q}^{mat}(z_h, Q^2) = D_{h/q}^{vac}(z_h, Q^2) + \Delta D_{h/q}(z_h, Q^2)$$

# Additional effect to S-T pattern by matter




Multiple scattering with matter

Medium-induced energy loss

$$\Delta E_{vac} \Rightarrow \Delta E_{vac} + \Delta E_{ind}$$

**hadron suppression**

$k_t$-broadening of a parton

$$Q^2 \Rightarrow Q^2 + \Delta k_t^2$$

Absorption of colorless qqbar dipole by matter

**hadron suppression**

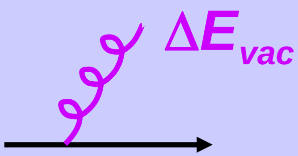
**Leading hadron ( $z_h \geq 0.5$ )**

$$D_{h/q}^{mat}(z_h, Q^2) < D_{h/q}^{vac}(z_h, Q^2)$$

# Radiative energy loss of a parton

$$\Delta E(t) = \Delta E_{vac}(t) + \Delta E_{ind}(t)$$

**Low energy**

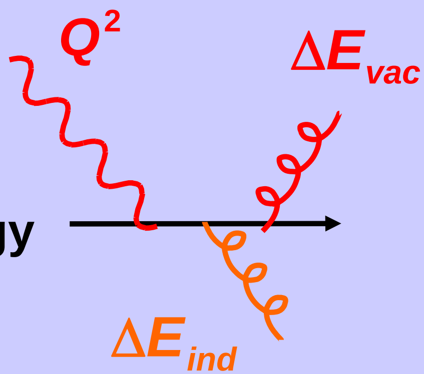



"String model"

$$\Delta E_{vac} = \kappa\, t \qquad \kappa = 1 \sim 2\ GeV/fm$$

Casher, Neuberger, Nussinov ('79)

**High energy**




$$\Delta E_{vac} = \frac{2}{3\pi}\alpha_s(Q^2)\, Q^2\, t$$

Niedermayer ('86)

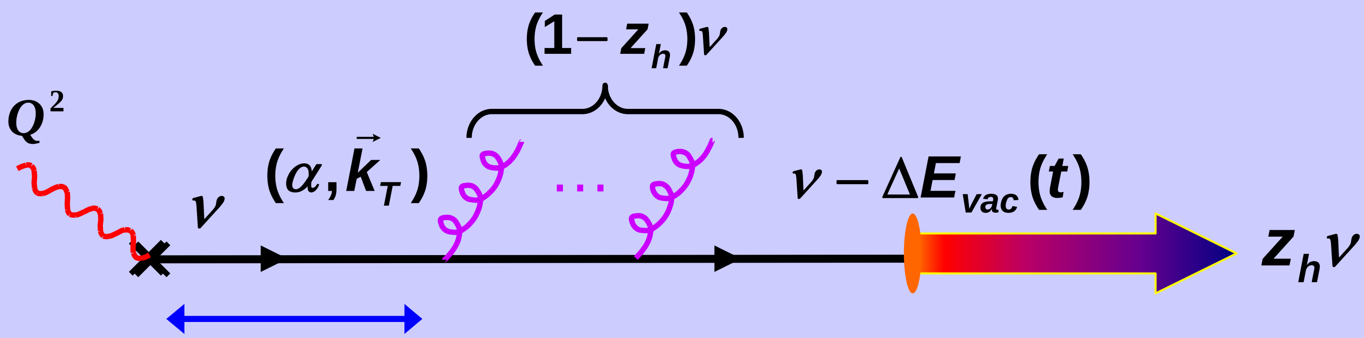
$$\Delta E_{ind} = \frac{3}{8}\alpha_s(Q^2)\, \Delta k_t^2\, t$$

Baier et al. ('97)

$$Q^2 \sim p_T^2 \geq \Delta k_t^2$$

$$\begin{cases} \Delta k_t^2 \approx 0.2\ GeV^2 \dfrac{t}{10\ fm} & \text{(Nuclear matter)} \\ \Delta k_t^2 \approx 5\ GeV^2 \dfrac{t}{10\ fm} & \text{(T=250 MeV hot matter)} \end{cases}$$

# Vacuum energy loss in pQCD model




coherence time: $t_c \sim \dfrac{2\nu}{M_{qg}^2} = \dfrac{2\nu}{k_T^2}\alpha(1-\alpha)$ ⟹ $\Theta(t-t_c)$

smooth out

$$\Delta E_{vac}(t; z_h, \nu, Q^2)$$

$$= \int_0^1 d\alpha \int_{\lambda^2}^{Q^2} dk_T^2 \;\; \alpha\nu \;\; \frac{dn_g}{d\alpha\, dk_T^2} \;\; \left(1-e^{-t/t_c}\right)\Theta\big((1-z_h)\nu - \alpha\nu\big)$$

$\alpha << 1$

$\lambda = \Lambda_{QCD}$

Gluon energy

Number of radiated gluons

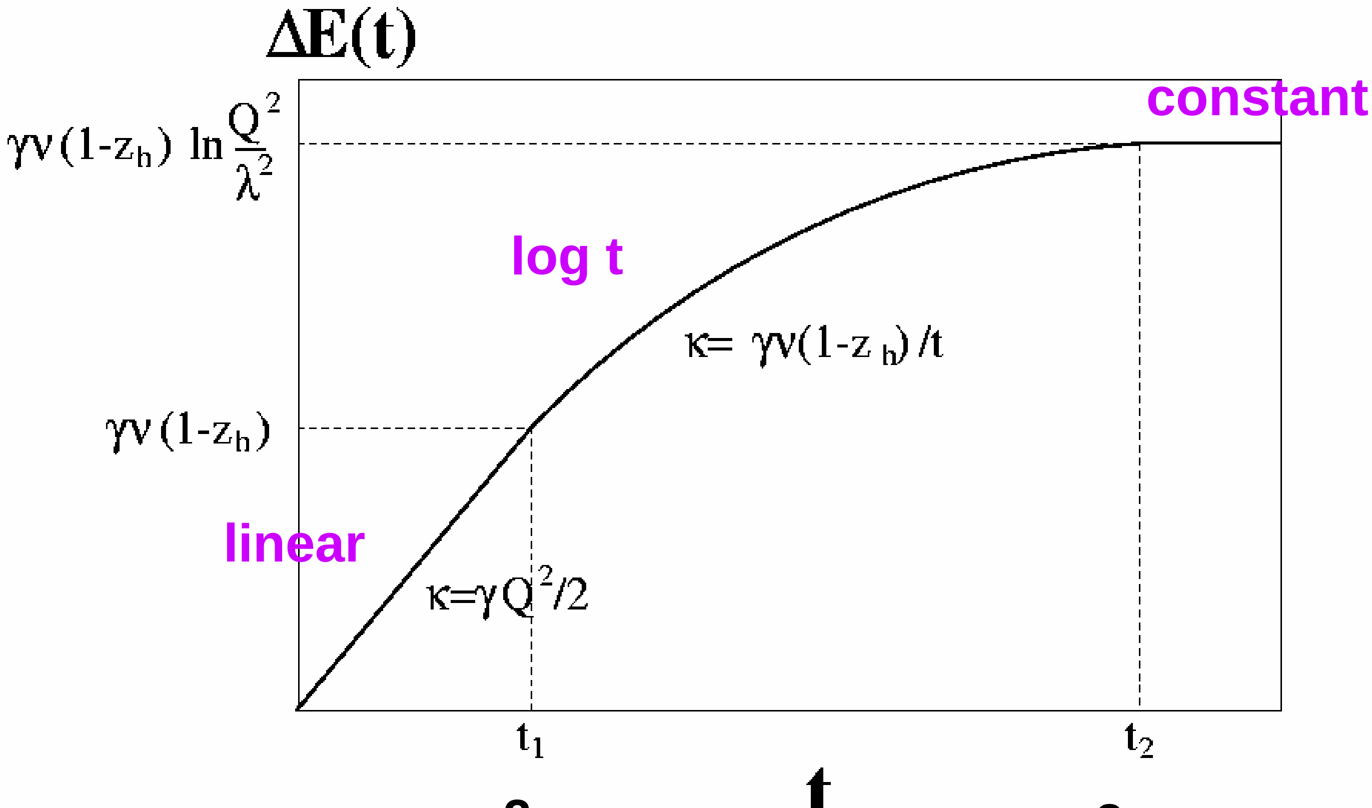
Energy conservation

$$\frac{4\alpha_s(Q^2)}{3\pi}\frac{1}{\alpha\, k_T^2}$$

Gunion, Bertsch ('82)

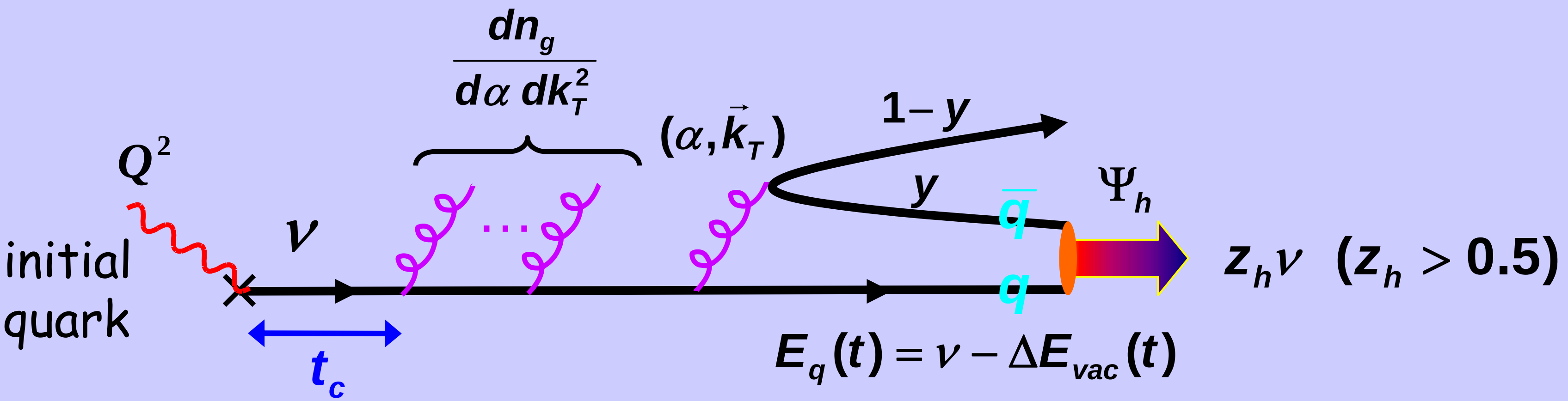
$$\Delta E_{vac}(t) = \gamma\nu\left[(1-z_h)\ln\left(\frac{Q^2}{\lambda^2}\right) - \int_0^{1-z_h} d\alpha\left(E_1(\lambda^2\xi) - E_1(Q^2\xi)\right)\right]$$

$$\gamma = \frac{4\alpha_s(Q^2)}{3\pi} \qquad E_1(x) = \int_x^\infty dt\,\frac{e^{-t}}{t} \qquad \xi \equiv \frac{t}{2k_T\alpha(1-\alpha)}$$




$$t_1 \equiv \frac{2\nu}{Q^2}(1-z_h) \qquad t_2 \equiv \frac{2\nu}{\lambda^2}(1-z_h)$$

# Quark distribution function $W_q$ in *pQCD* model



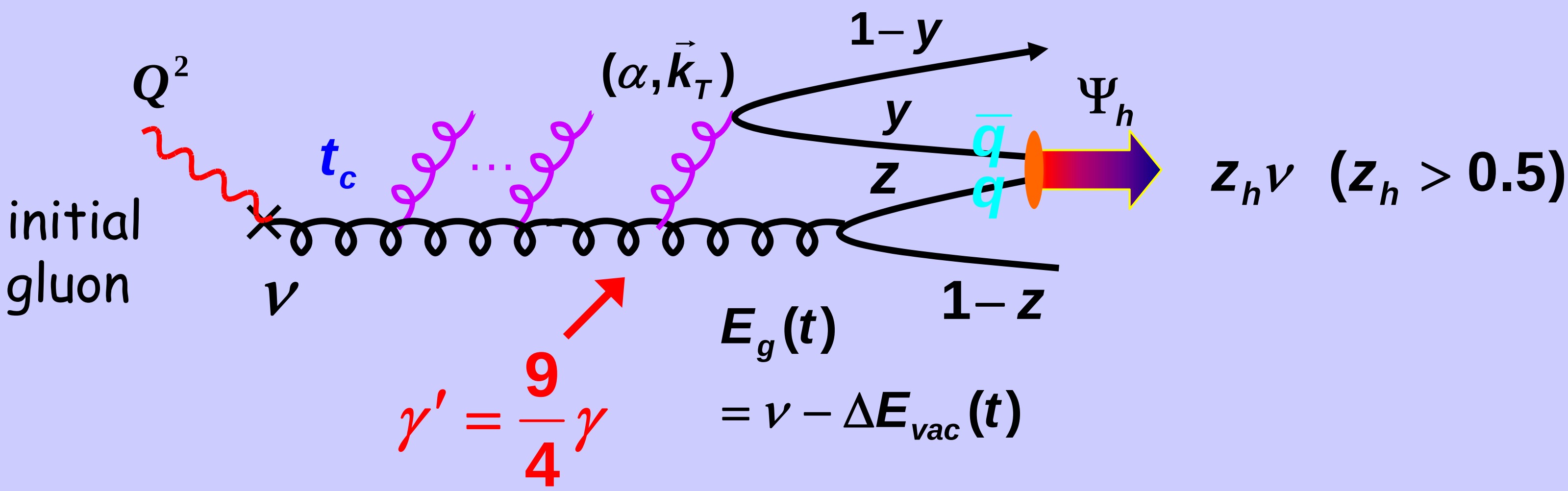

$$W_q(t; z_h, \nu, Q^2) \propto \int d\alpha\, dk_T^2 dy\, \frac{dn_g}{d\alpha\, dk_T^2} \frac{d}{dt}\left(1 - e^{-t/t_c}\right) \delta\left(z_h - \frac{E_q(t)}{\nu}\{1 - \alpha(1-y)\}\right)$$

$$\times \int d\beta\, dl_T^2 \; \left|\Psi_h(\beta, l_T^2)\right|^2 \delta\left(l_T^2 - \frac{1}{4}(1+y)^2 k_T^2\right) \delta\left(\beta - \frac{\alpha y}{\alpha y + (1-\alpha)}\right)$$

$$\times \exp\left[-\frac{\gamma}{2\nu}\left(\frac{z_h}{1-z_h}\right)^{\kappa} (Q^2 - \lambda^2)\, t\right]$$

$$\Psi_h(\beta, l_T^2) \propto \frac{\beta(1-\beta)}{\beta(1-\beta) + a_0} \exp\left[-\frac{(8/3) < r_h^2 >_{em} \times 3 l_T^2}{\beta(1-\beta) + a_0}\right]$$

# Gluon distribution function $W_g$ in *pQCD* model




$$W_g(t; z_h, \nu, Q^2)$$

$$\propto \int d\alpha\, dk_T^2\, dy\, dz \frac{dn_g}{d\alpha\, dk_T^2} \frac{d}{dt}\left(1 - e^{-t/t_c}\right) \delta\left( z_h - \frac{E_g(t)}{\nu} \{ z + \alpha(y - z) \} \right)$$

$$\times \int d\beta\, dl_T^2\, \delta\left( l_T^2 - \frac{(y+z)^2}{4} k_T^2 \right) \delta\left( \beta - \frac{\alpha y}{\alpha y + (1-\alpha) z} \right) \left| \Psi_h(\beta, l_T^2) \right|^2$$

$$\times \exp\left[ -\frac{\gamma}{2\nu} \left( \frac{z_h}{1 - z_h} \right)^{\kappa} (Q^2 - \lambda^2)\, t \right]$$

# Normalization of distribution functions $W_{q,g}$

$$D_{q,g}(z_h,\nu,Q^2) = \int_0^\infty dt\, W_{q,g}(t;z_h,\nu,Q^2)$$

$$\int_0^1 dz_h \int_0^\infty dt\, W_{q,g}(t;z_h,\nu,Q^2) = \langle n_h \rangle \quad \Rightarrow \quad 1$$

$$D_{q,g}(z_h,\nu,Q^2) = \frac{\int_0^\infty dt\, W_{q,g}(t;z_h,\nu,Q^2)}{\int_0^1 dz_h \int_0^\infty dt\, W_{q,g}(t;z_h,\nu,Q^2)}$$

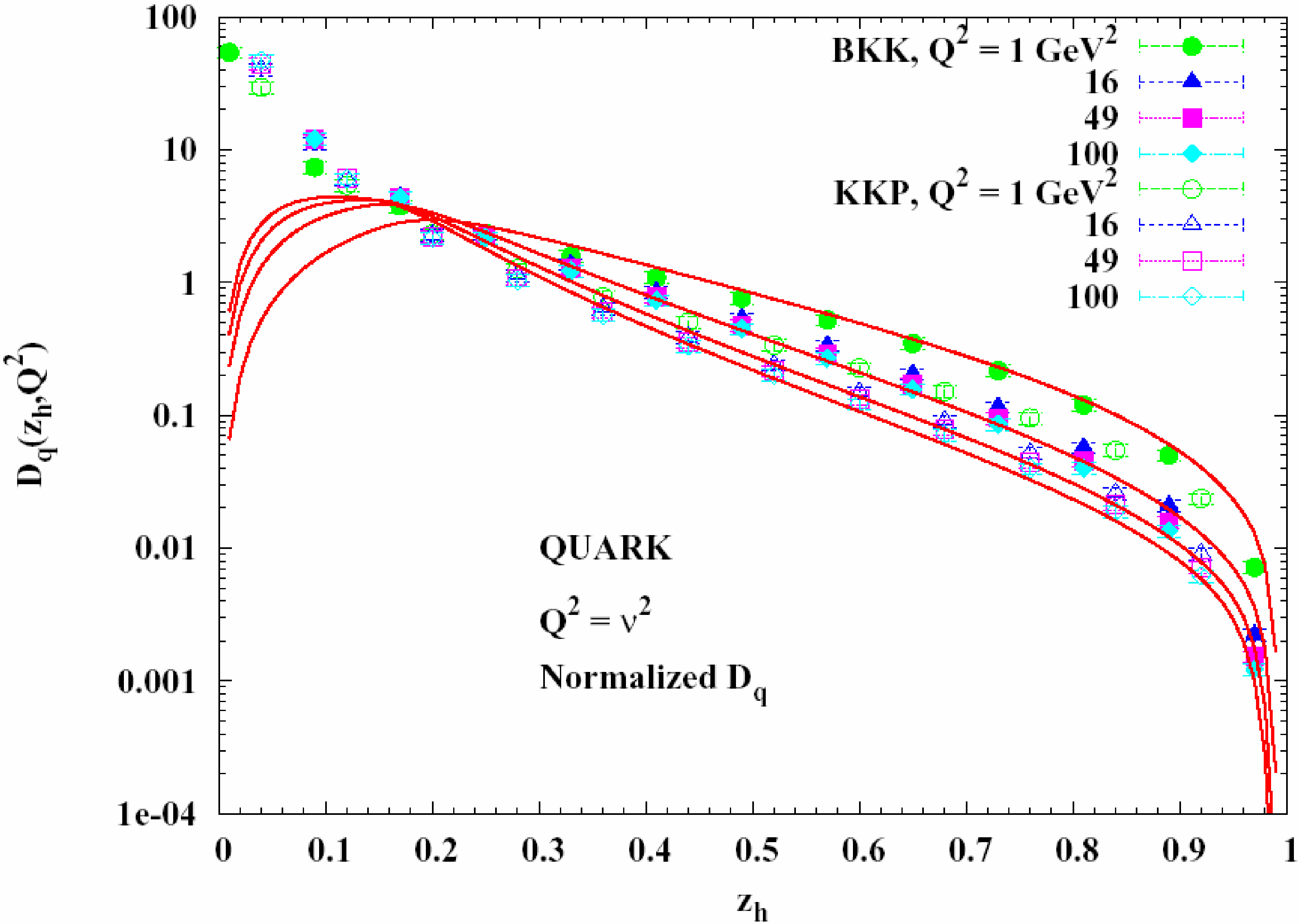
$D_{q,g}^{\pi^0}(z_h,Q^2)$ : BKK,KKP parametrizations

VS.

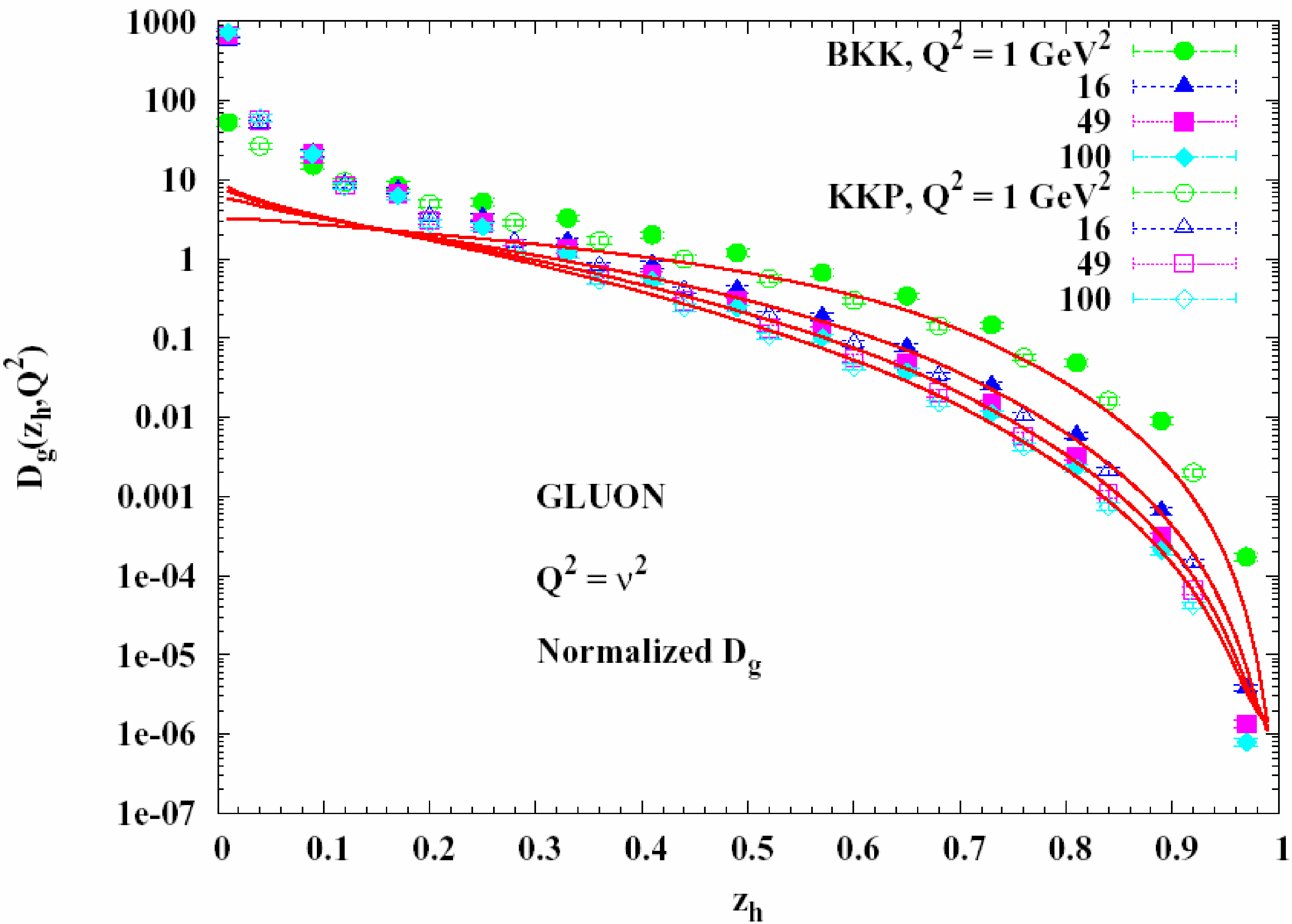
$D_{q,g}^{\pi^0}(z_h,\nu,Q^2=\nu^2)$

$\langle r_\pi^2 \rangle_{em} = 0.44\ \text{fm}^2$

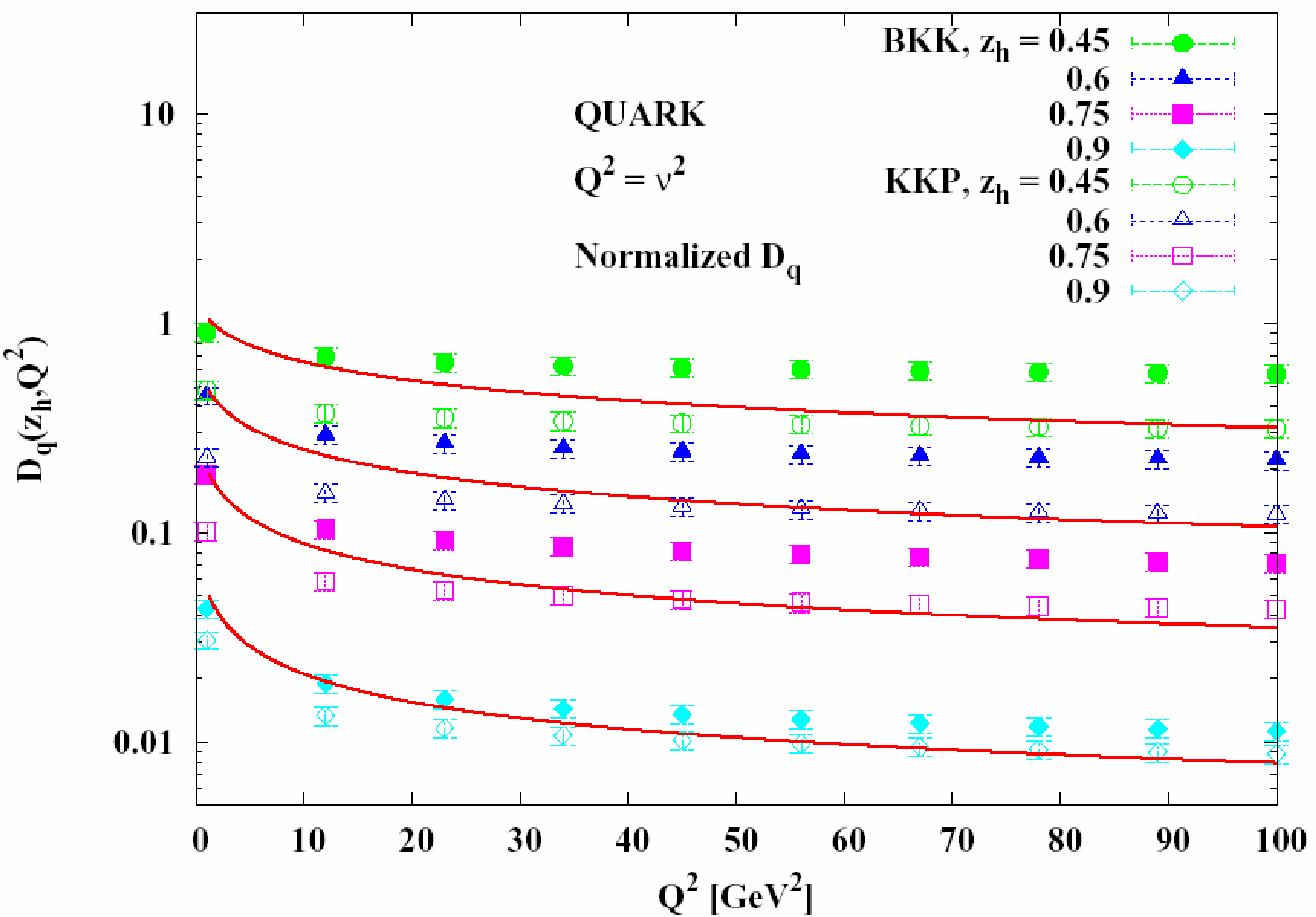
$a_0 = 1/12$



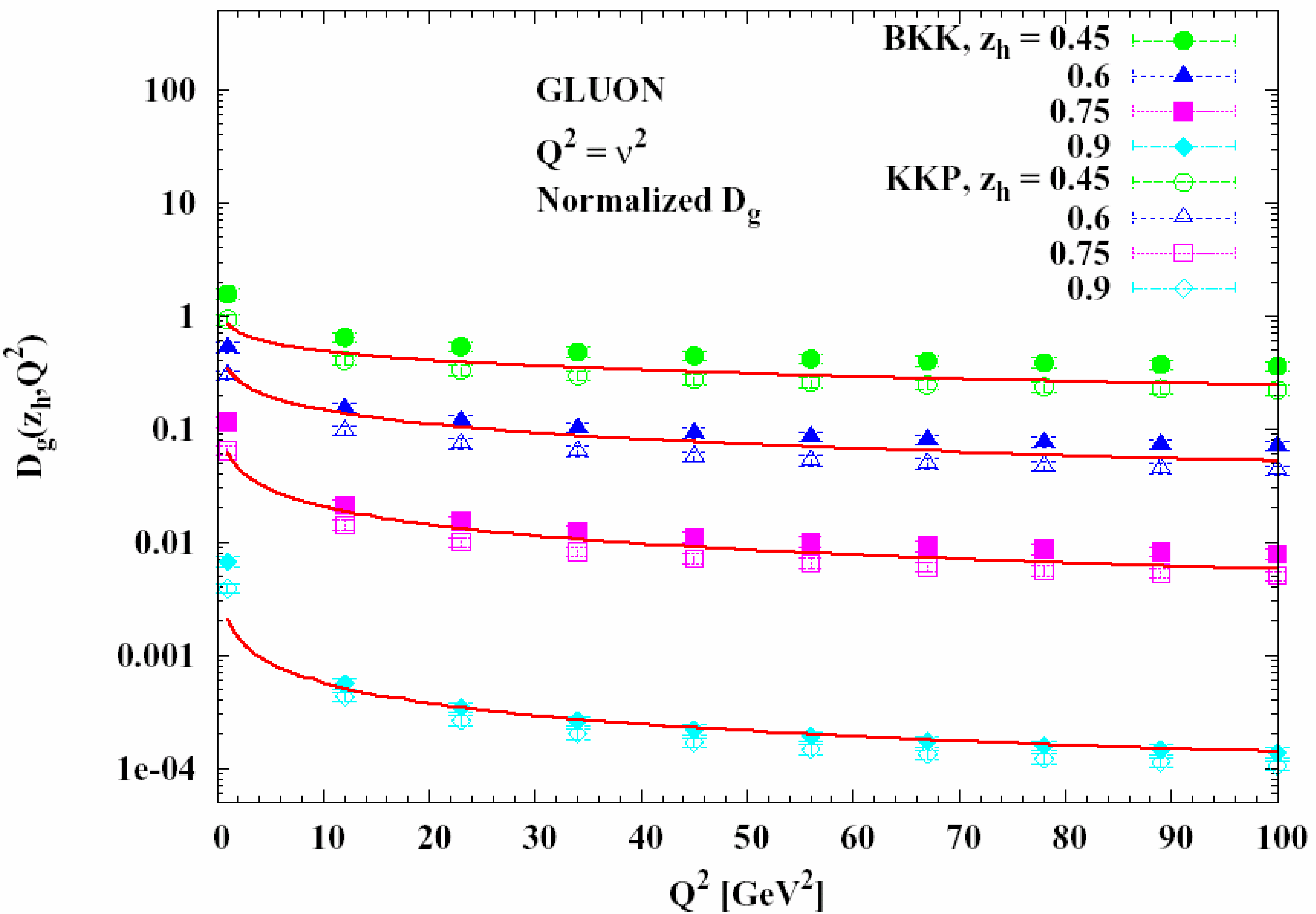

$$\int_0^{40\,fm} dt \int_0^{0.23} dy \cdots (\kappa = 1)$$




$$\int_0^{20\,fm} dt \int_{0.7}^{1} dz \int_0^{0.5} dy \cdots (\kappa = 2.2)$$



BKK, $z_h$ = 0.45
0.6
0.75
0.9
KKP, $z_h$ = 0.45
0.6
0.75
0.9
QUARK
$Q^2 = \nu^2$
Normalized $D_q$
$D_q(z_h,Q^2)$
$Q^2$ [GeV$^2$]
10
1
0.1
0.01
0
10
20
30
40
50
60
70
80
90
100

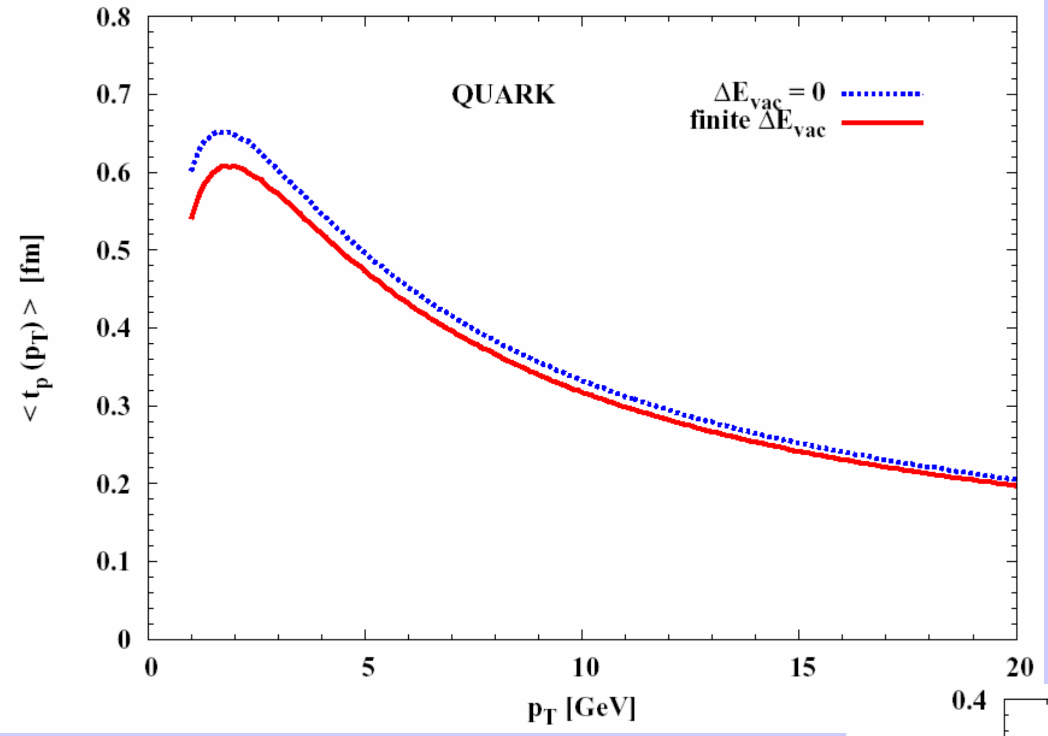


GLUON
$Q^2 = \nu^2$
Normalized $D_g$
BKK, $z_h$ = 0.45
0.6
0.75
0.9
KKP, $z_h$ = 0.45
0.6
0.75
0.9
$D_g(z_h,Q^2)$
100
10
1
0.1
0.01
0.001
1e-04
0
10
20
30
40
50
60
70
80
90
100
$Q^2$ [GeV$^2$]

$$t \sim t_p \propto \frac{(1-z_h)\nu}{Q^2} \xrightarrow[Q^2 \sim p_T^2]{\nu \sim p_T} \frac{1-z_h}{p_T}$$

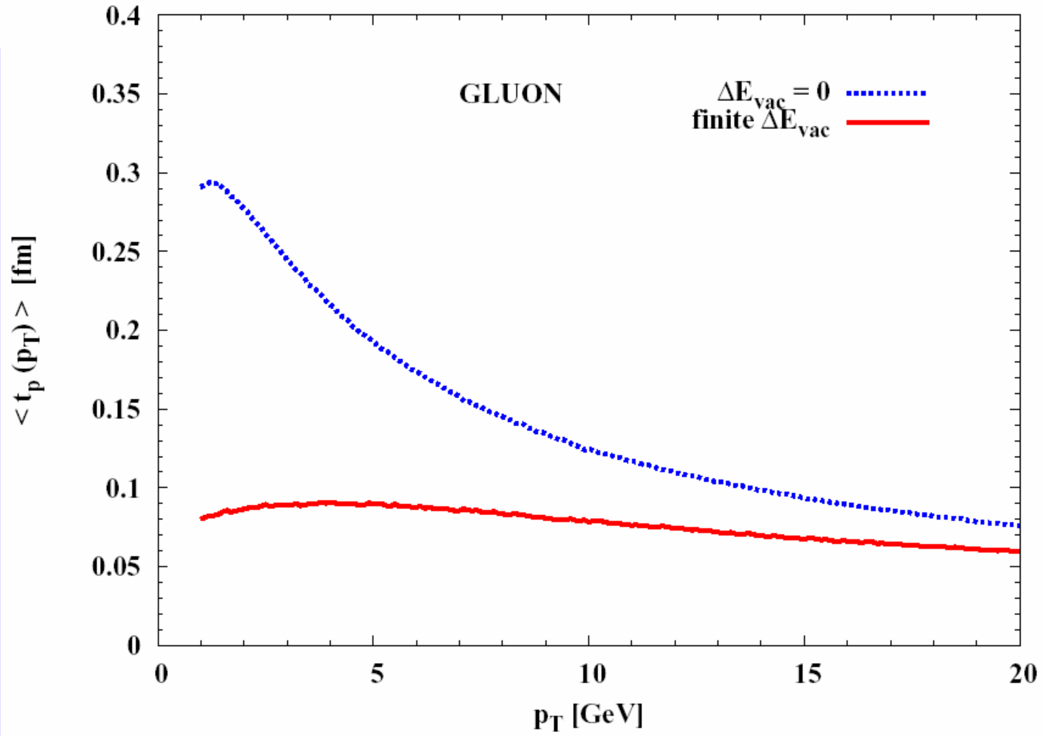
$$< t_p(p_T) > = \frac{\int_0^\infty dt_p \int_0^1 dz_h \; t_p \; W_{q,g}(t_p; z_h, p_T)}{\int_0^\infty dt_p \int_0^1 dz_h \; W_{q,g}(t_p; z_h, p_T)}$$

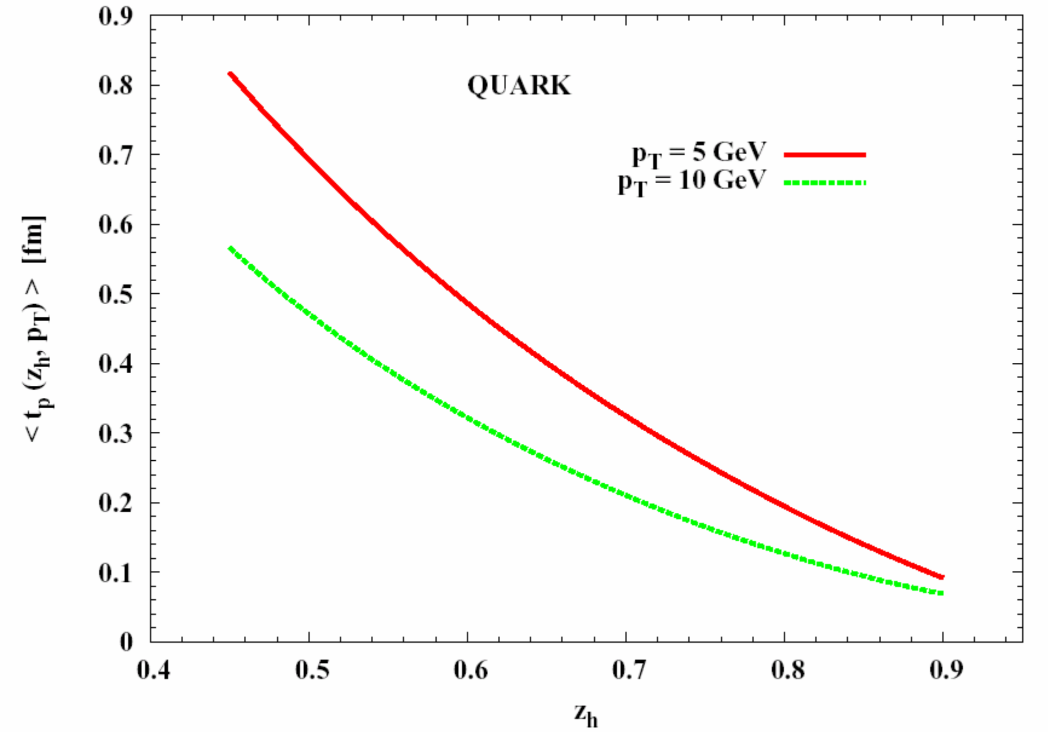
$$< t_p(z_h, p_T) > = \frac{\int_0^\infty dt_p \; t_p \; W_{q,g}(t_p; z_h, p_T)}{\int_0^\infty dt_p \; W_{q,g}(t_p; z_h, p_T)}$$



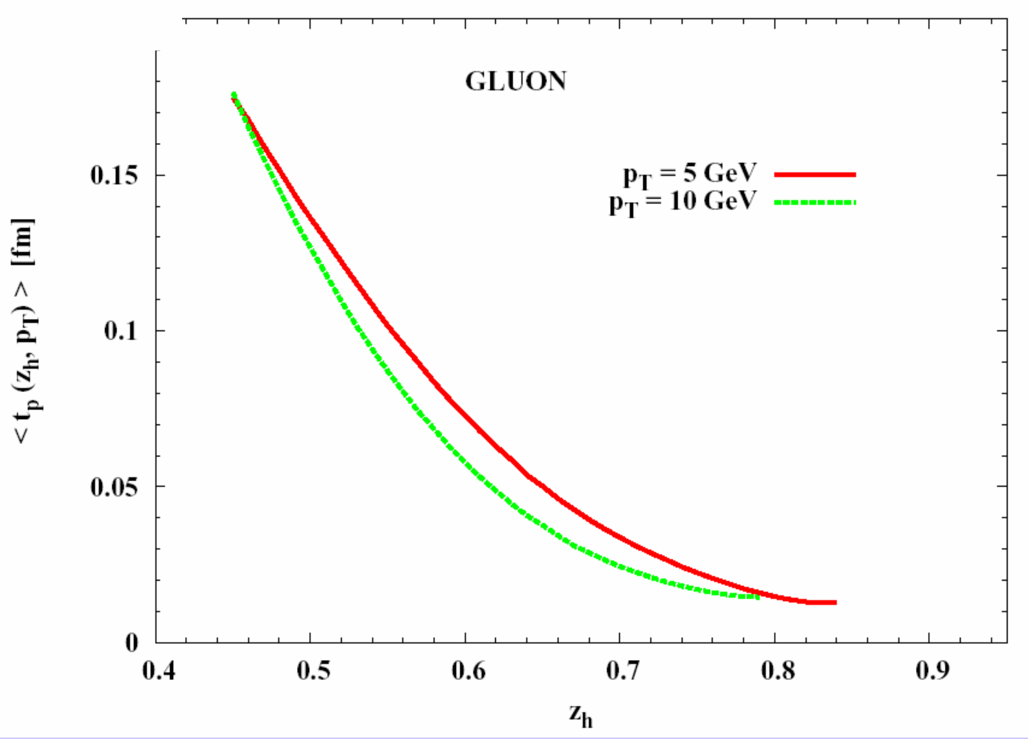

$$< t_p(p_T \geq 3\,\text{GeV}) >_{quark} = 0.2 \sim 0.6 \text{ fm}$$

$$< t_p(p_T \geq 3\,\text{GeV}) >_{gluon} = 0.05 \sim 0.1 \text{ fm}$$

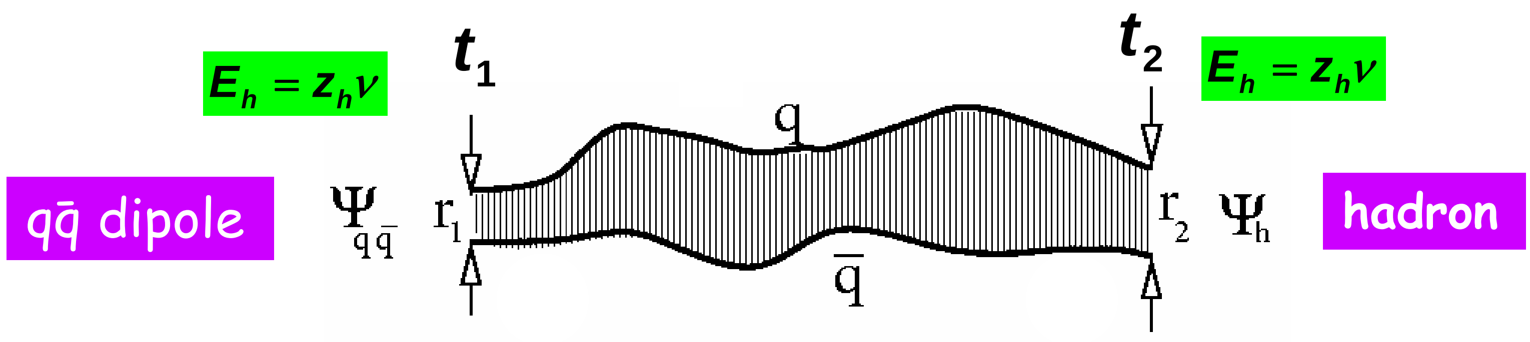





$$< t_p(\text{larger } z_h) > \rightarrow 0$$



# Dipole propagation during formation time $t_f$




Possible trajectories with quantum fluctuation

$$G_{q\bar{q}}(t_2,\vec{r}_2;t_1,\vec{r}_1\,|\,\rho_{matter}(t))$$

**Two-dimensional LC Schroedinger eq. :**

$$i\frac{d}{dt_2}G_{q\bar{q}}(t_2,\vec{r}_2;t_1,\vec{r}_1\,|\,\rho_{matter}(t))$$

$$=\left[\frac{m_q^2-\Delta_{\vec{r}_2}}{2E_h\alpha(1-\alpha)}+V_{q\bar{q}}(t_2,\vec{r}_2,\alpha)\right]G_{q\bar{q}}(t_2,\vec{r}_2;t_1,\vec{r}_1\,|\,\rho_{matter}(t))$$

$$V_{q\bar{q}}(t,\vec{r},\alpha)=\left[\frac{a(\alpha)^4}{2E_h\alpha(1-\alpha)}\vec{r}^{\,2}\right]_{vac}+i\left[-\frac{1}{2}\,\rho_{matter}(t)\;C_1(E_h)\,\vec{r}^{\,2}\right]_{matter}$$

dipole approx.

**Boundary condition:**

$$G_{q\bar{q}}(t_2,\vec{r}_2;t_1,\vec{r}_1\,|\,\rho_{matter}(t))\Big|_{t_2=t_1} = \delta^2(\vec{r}_2-\vec{r}_1)$$

**Solution in constant $\rho$:**

$$G_{q\bar{q}}(t_2,\vec{r}_2;t_1,\vec{r}_1\,|\,\rho_{matter})$$

$$\propto \frac{E_h\alpha(1-\alpha)\xi}{2\pi i\sin(\xi\Delta t)}\exp\left[i\,\frac{E_h\alpha(1-\alpha)\,\xi}{2\sin(\xi\Delta t)}\left\{(\vec{r}_1^{\,2}+\vec{r}_2^{\,2})\cos(\xi\Delta t)-2\vec{r}_1\cdot\vec{r}_2\right\}\right]$$

$$\Delta t = t_2 - t_1 \qquad \xi = \frac{\sqrt{a(\alpha)^4 - i\,E_h\alpha(1-\alpha)C_1(E_h)\rho_{matter}}}{E_h\alpha(1-\alpha)}$$

**For pion,**

$$a(\alpha)^2 = v^{1.15}\times(0.112\ \text{GeV})^2 + (1-v)^{1.15}\times(0.165\ \text{GeV})^2,\quad 0<v<1$$

$$C_1(E_h) = \frac{\sigma_{tot}^{\pi N}}{\langle r_T^2\rangle_\pi} = \frac{25\ \text{mb}}{\frac{8}{3}\times 0.44\ \text{fm}^2}\ \sim\ 1.9$$

**In varying $\rho$, use recursion formula for multi-step $t$.**

# Survival probability of pre-hadron in matter

$$Tr(t_1,t_2 \mid \rho_{matter}(t)) = \left| \frac{\int d^2r_1 d^2r_2 \; \Psi_h^*(\vec{r}_2)\, G_{q\bar{q}}(t_2,\vec{r}_2;t_1,\vec{r}_1 \mid \rho_{matter}(t))\; \Psi_{q\bar{q}}(\vec{r}_1)}{\int d^2r \; \Psi_h^*(\vec{r})\, \Psi_{q\bar{q}}(\vec{r})} \right|^2$$

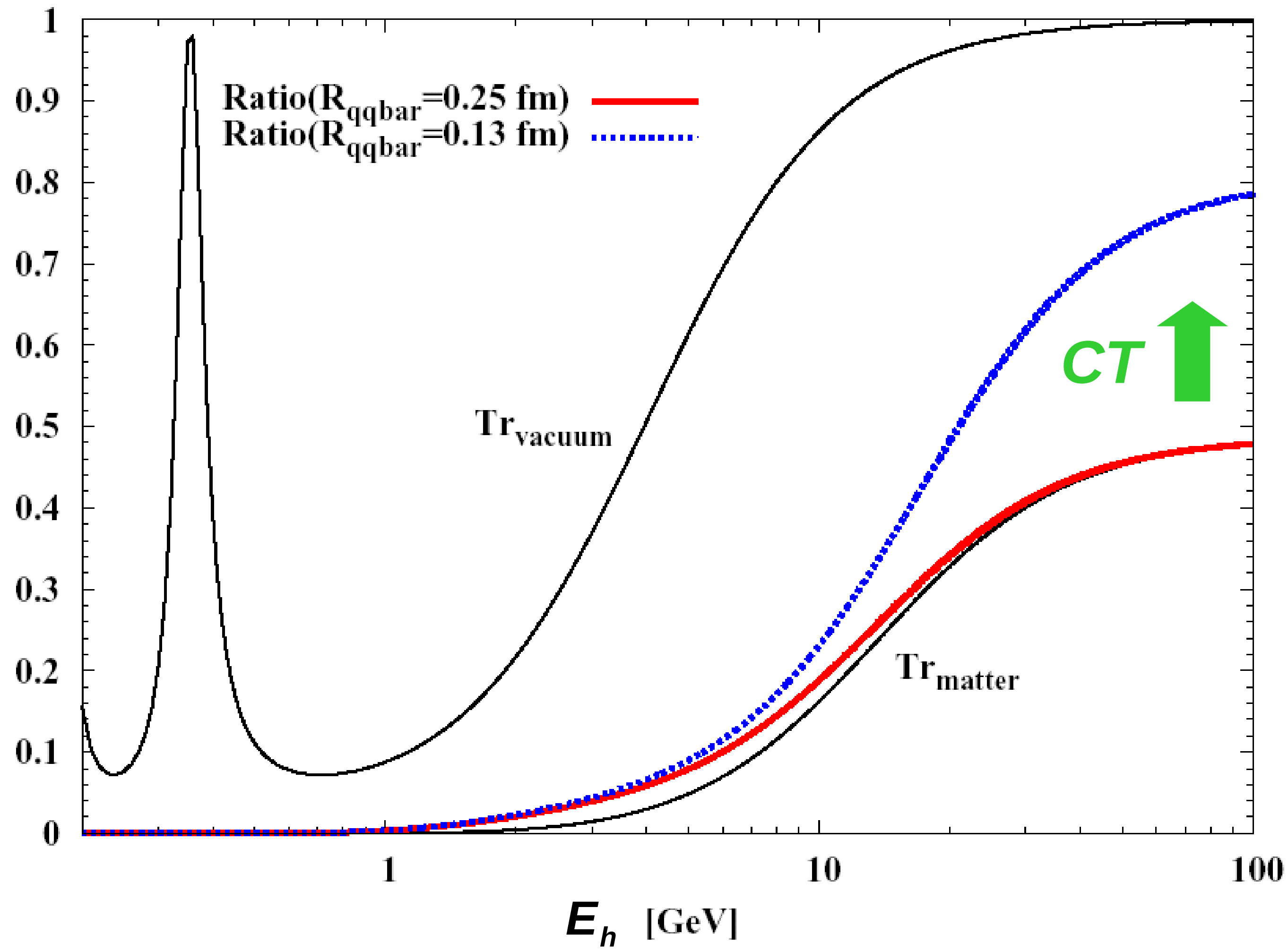
$$\Psi_h(\vec{r}_2) \propto \exp\left( -\frac{\vec{r}_2^{\,2}}{2\langle r_T^2 \rangle_h} \right) \qquad \Psi_{q\bar{q}}(\vec{r}_1) \propto \exp\left( -\frac{\vec{r}_1^{\,2}}{2\langle r_T^2(t_p,\nu,Q^2) \rangle_{q\bar{q}}} \right)$$

$$\langle r_T^2 \rangle_\pi \sim (1\,\mathrm{fm})^2$$

$$\langle r_T^2(t_p;\nu,Q^2,z_h) \rangle_{q\bar{q}} = \frac{64}{9} \frac{\int_{\lambda^2}^{Q^2} dk_T^2 \left[ dW_{q,g}^*(t_p;k_T^2,\nu,Q^2,z_h) / dk_T^2 \right]}{\int_{\lambda^2}^{Q^2} dk_T^2 \left[ dW_{q,g}^*(t_p;k_T^2,\nu,Q^2,z_h) / d\ln k_T^2 \right]}$$

$\xrightarrow{\text{large } \nu}$ **smaller**

One possible origin of color transparency




$Tr_{matter}$ ( constant $\rho$)

$\langle r_T^2 \rangle_{q\bar{q}} = 0.25$ fm

$t_2 - t_1 = R_{Au}$

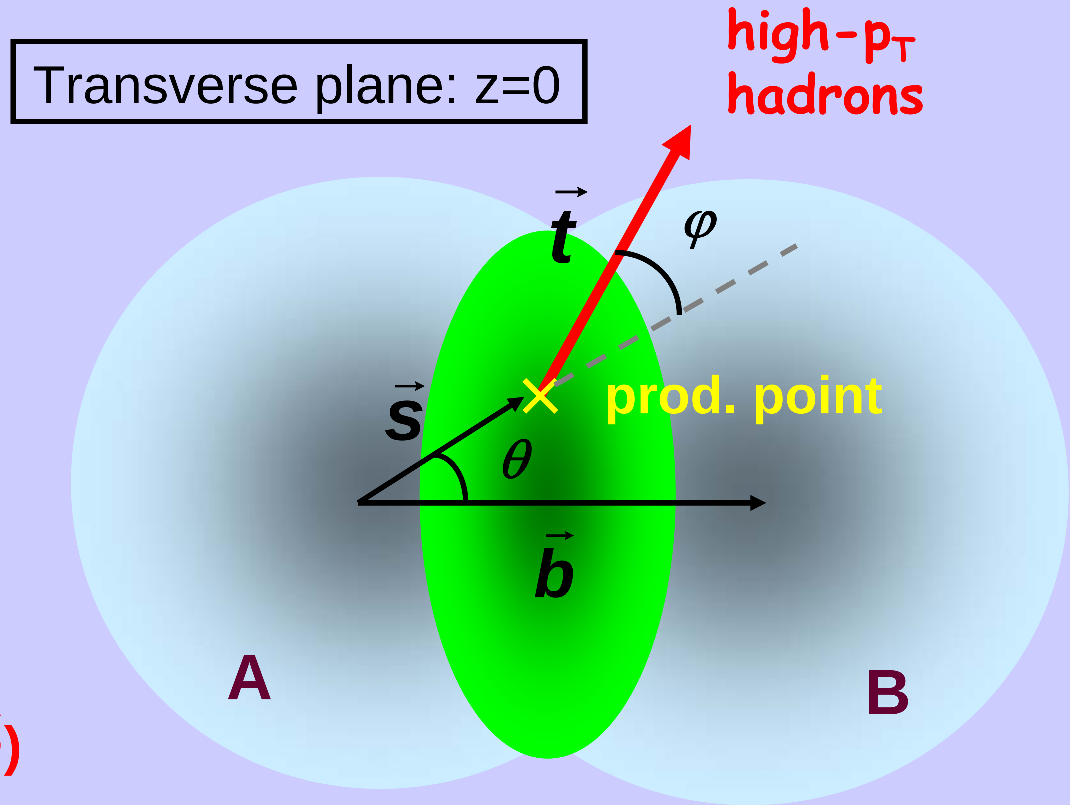
$$Ratio = \frac{Tr_{matter}}{Tr_{vacuum}}$$

$E_h \to \infty$ ( "Frozen" limit )

$$G_{q\bar{q}}(t_2,\vec{r}_2;t_1,\vec{r}_1 \mid \rho_{matter}(t)) \propto \delta^2(\vec{r}_2 - \vec{r}_1)\exp\left[-\frac{1}{2}C_1(E_h)\vec{r}_2^{\,2}\int_{t_1}^{t_2} dt\ \rho_{matter}(t)\right]$$

# Leading hadron production in AA collision

## Bjorken model




**Nuclear thickness function:**

$$T_A(\vec{s}) = \int_{-\infty}^{\infty} dz \frac{\rho_N}{1 + \exp\left(\frac{\sqrt{\vec{s}^2 + z^2} - R_{A,B}}{a_{A,B}}\right)}$$

**Binary collision scaling:** A.H.2

$$\frac{d^2 N_{coll}}{d^2 s} = \sigma_{NN}^{inel} T_A(\vec{s}) T_B(\vec{s} - \vec{b})$$

**Wounded nucleon scaling:** A.H.3

$$\frac{d^2 N_{part}}{d^2 s} = T_A(\vec{s})\left(1 - e^{-\sigma_{NN}^{inel} T_B(\vec{s}-\vec{b})}\right) + T_B(\vec{s} - \vec{b})\left(1 - e^{-\sigma_{NN}^{inel} T_A(\vec{s})}\right)$$

**Dilution of matter density due to expansion** A.H.1

$$\times \frac{C_2}{\tau + \tau_0}$$

$\sigma_{NN}^{inel} = 40\ \mathrm{mb}$

$\tau_0 \sim 1\ \mathrm{fm}$: B. Müller, PRC67('03)061901

**A.H.1** To get dilution of matter density due to expansion, we multiply this by a factor "". This is modeled to represent longitudinally Loretz-boost invariant expansion. At RHIC energy we use tau=1 fm as pointed in B.Muller's paper. C2 is an unknown factor to fit the data later.
Arata Hayashigaki, 10/2/2005

**A.H.2** For high-pt hadrons yield, we take a binary NN collision profile like this, here inelastic NN Xsec about 40 mb.
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**A.H.3** For produced comoving medium density which is this green region, we assume this participant nucleon profile based on glauber model.
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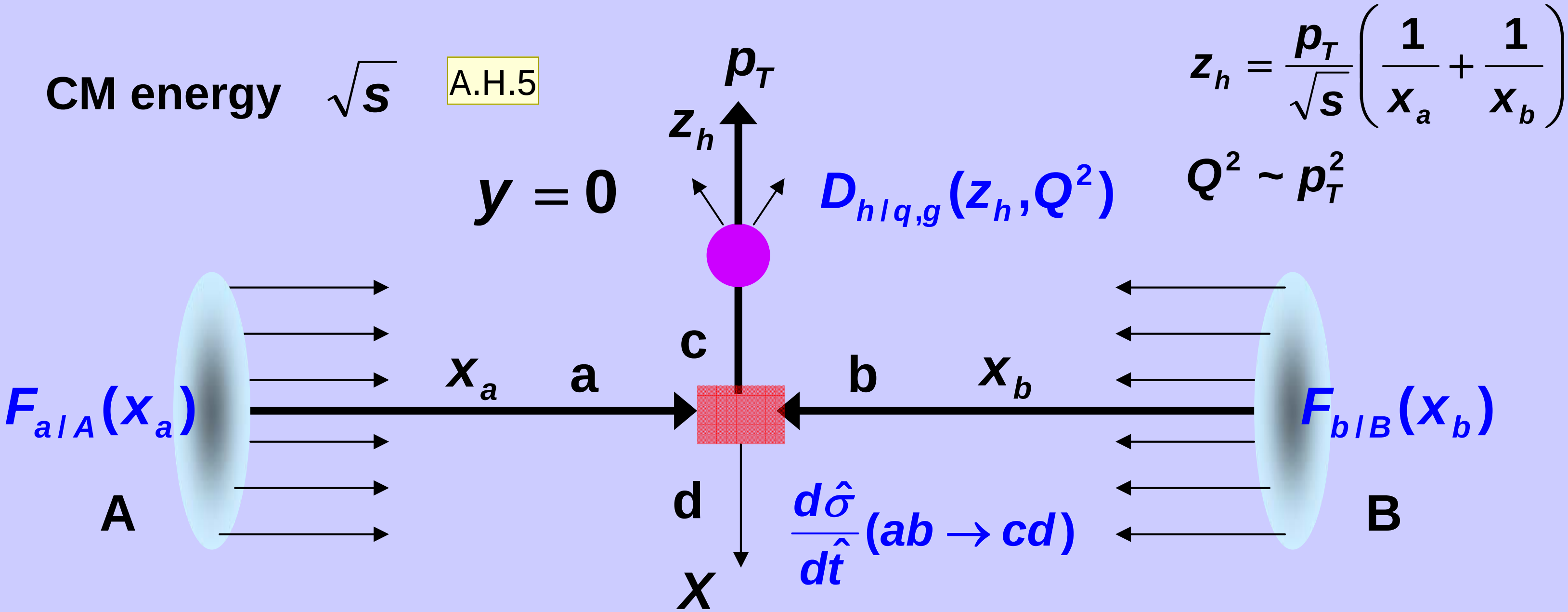
# 2-to-2 hard parton scatterings in LO




**QCD factorization ( $p_T$ > 3 GeV ) :** A.H.4

$$d\sigma = F_{a/A}(x_a, Q^2)dx_a \; F_{b/B}(x_a, Q^2)dx_b \; \frac{d\hat{\sigma}}{d\hat{t}}(ab \to cd)d\hat{t} \; D_{h/q,g}(z_h, Q^2)dz_h$$

**LO pQCD :** $$\frac{d\hat{\sigma}}{d\hat{t}}(ab \to cd) = \frac{\pi\alpha_s^2(Q^2)}{\hat{s}^2}\left|M(ab \to cd)\right|^2$$

$SU_f(2)$, g

Feynman et al. ('78)

**A.H.4** If we assum QCD collinear factorization at large pT, the single particle Xsec is given by this form. The last integral of zh is done easily due to delta function, because we have this momentum conservation among zh, xa and xb. Here is parton-parton differential Xsec, which is the sum of totally 8 independent leading order diagrams. For parton species, for now we consider u,d quark and gluon.

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**A.H.5** In the center of mass frame at the energy root s, we consider head-on collision of two equal nuclei.
Each parton collides here with respective momentum fraction xa and xb, so F is nuclear parton distribution.

In this point, new partons c, d are produced and parton c finally hadronize with pT momentum and fraction zh. If we consider only mid-rapidity region, zh is this function of xa and xb. We assum naively Q^2 evolution of D as pT^2.

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$$\left.\frac{d\sigma(AB\to hX)}{d^2p_T dy}\right|_{y=0} = \sum_{a,b,c,d}\int_{x_a^{\min}}^{1} dx_a \int_{x_b^{\min}}^{1} dx_b\, F_{a/A}(x_a,Q^2)F_{b/B}(x_b,Q^2)$$

$$\times \frac{d\hat{\sigma}(ab\to cd)}{d\hat{t}}\frac{D_{h/c}(z_h,Q^2)}{\pi z_h}$$

$$x_a^{\min} = \frac{p_T}{\sqrt{s}-p_T} \qquad x_b^{\min} = \frac{p_T x_a}{\sqrt{s}x_a - p_T} \qquad \geq \frac{p_T}{\sqrt{s}} \sim 0.01 \text{ at RHIC}$$

$F_{A,B}(x)$ : EKS nuclear PDF ('99) $F_N(x)$ : CTEQ5L nucleon PDF ('99)

**Explicit $t$ -dependence:** $D_{h/q,g}(z_h,Q^2) = \int_0^\infty dt_p\, W_{q,g}(t_p;z_h,Q^2)$

$$\left.\frac{d\sigma(AB\to hX)}{d^2p_T dy}\right|_{y=0} = \int_0^\infty dt_p \left.\frac{d\sigma(AB\to hX;W_{q,g}(t_p))}{d^2p_T\, dy\, dt_p}\right|_{y=0}$$

$$\times Tr(t_1=t_p, t_2=\infty \,|\, \rho_{matter}(\vec{s},\vec{b},\vec{t}))$$

# Nuclear modification factor

$$\left.\frac{d\sigma_{AB}^{pp}}{d^2p_T dy d^2b}\right|_{y=0} = \int_0^\infty dss \int_0^{2\pi} d\theta\, T_A(\vec{s}) T_B(\vec{s}-\vec{b}) \int_0^{2\pi} d\varphi$$

$$\times \int_0^\infty dt_p \left.\frac{d\sigma^{pp}(AB \to hX; W_{q,g}(t_p))}{d^2p_T\, dy\;\, dt_p}\right|_{y=0}$$

$$\times Tr(t_1 = t_p, t_2 = \infty \,|\, \rho_{matter}(\vec{s},\vec{b},\vec{t}))$$

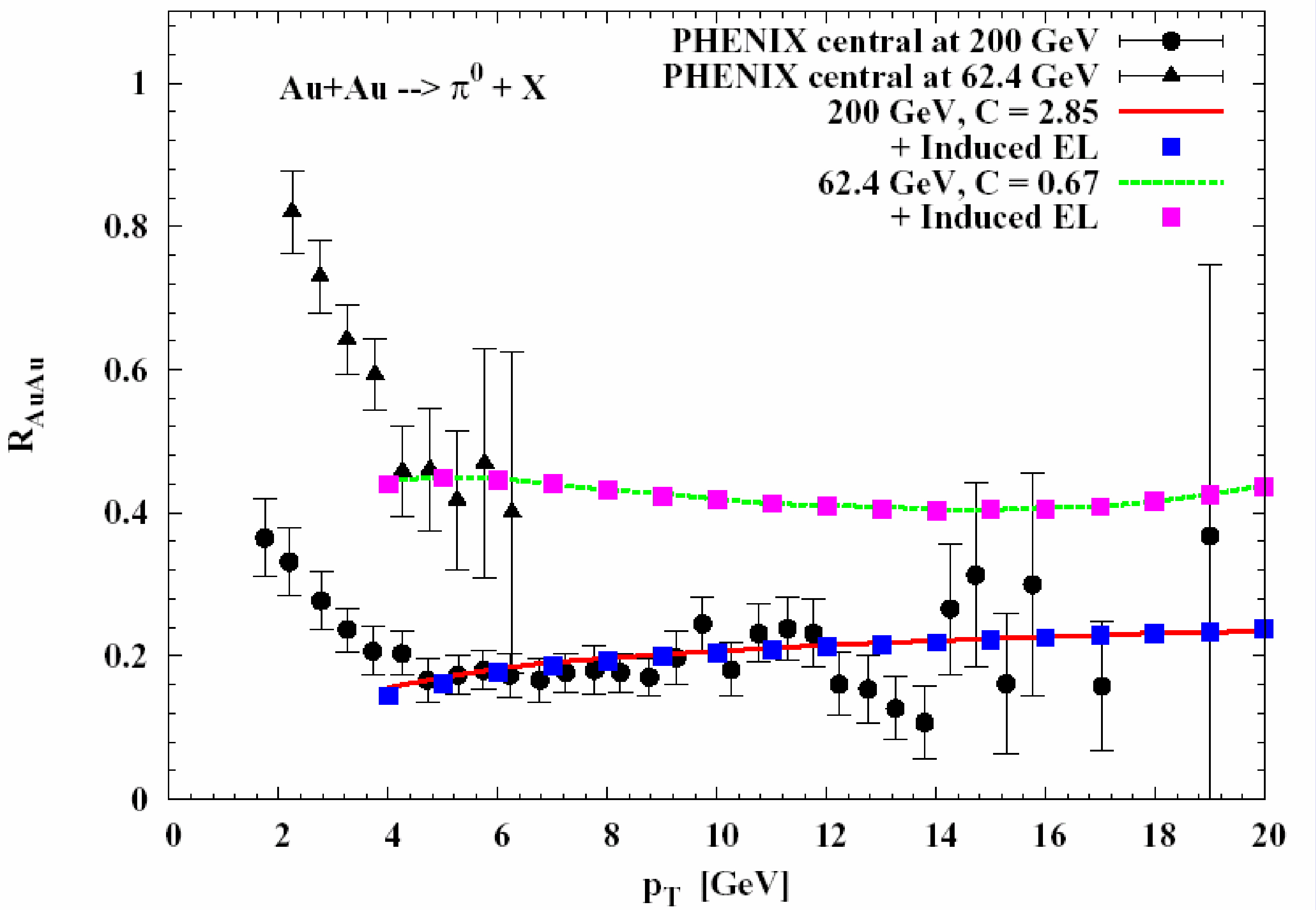
$$\rho_{matter} = 0$$

$$R_{AA}(p_T,\vec{b}) = \frac{d\sigma_{AB} \big/ d^2p_T dy d^2b\big|_{y=0}}{d\sigma_{pp} \big/ d^2p_T dy d^2b\big|_{y=0}}$$

$$C_1(E_h)\rho_{matter}(t,\vec{s},\vec{b}) = C_1(E_h)\frac{C_2}{\tau+\tau_0}\frac{d^2N_{part}}{d^2s}$$

dimensionless

$$C = C_1 \times C_2$$




**Almost flat.**

**Due to small <$t_p$>, small parton EL, dominant dipole attenuation.**

**Disregard Cronin effect.**

**Small effect from nuclear PDF (< 10 %).**

$$\Delta E_{ind} = \frac{3}{8}\alpha_s(Q^2)\,\Delta k_t^2\ t$$

$$= \frac{3}{4}\alpha_s(Q^2) C_1(E_h)\rho_{matter} t$$

$$\sqrt{\langle r_T^2 \rangle_{q\bar{q}}} = 0.25\ \text{fm}$$

$$\frac{C_1 \times C_2\big|_{200\,\text{GeV}}}{C_1 \times C_2\big|_{62.4\,\text{GeV}}} \sim 4.3$$

$$\frac{C_1\big|_{200\,\text{GeV}}}{C_1\big|_{62.4\,\text{GeV}}} \sim 4.3\,\frac{dN/dy\big|_{62.4\,\text{GeV}}}{dN/dy\big|_{200\,\text{GeV}}} \sim 4.3\,\frac{430}{650} = 2.8$$

## Summary

1. Distribution function $W_{q,g}(t)$ based on a pQCD model.
2. Good agreement with BKK and KKP.
3. A shrinkage of W(t) with rising $p_T$ like $\langle t_p \rangle \propto 1/p_T$ at variance with DIS, where $\langle t_p \rangle \propto \nu / Q^2$.
4. At high $p_T$, earlier hadronization leads to a dominant (pre-)hadron absorption in matter.
5. Induced EL doesn't work well due to small $t_p$.
6. This explains well a flat $R_{AA}$ from recent PHENIX data, but shows slight increase with $p_T$ due to color transparency.
7. Similar behavior ($p_T > 4$ GeV) to (GLV) partonic EL scenario (X.Wang, I.Vitev's talks)