Jet Energy Loss and Photon Production in QGP
– Putting it all together –

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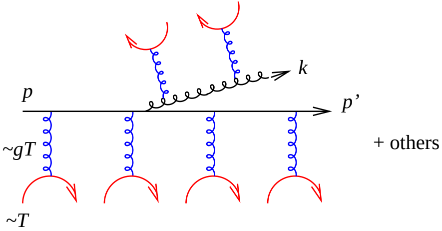
Plan

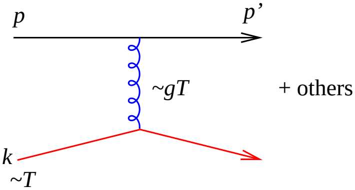
- Energy loss (jet quenching)
- Photons

E-loss - The Issue

- QGP makes jets lose energy
  - Radiational (Inelastic)



  - Elastic



- Can we use this to characterize QGP?
- Effects on photons ?

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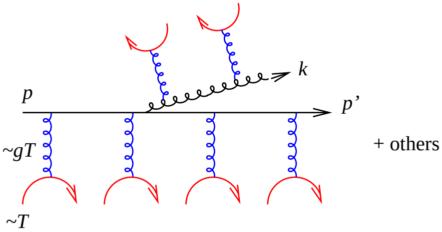

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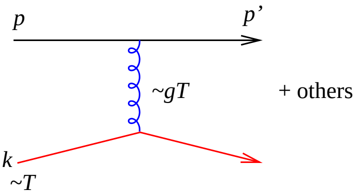

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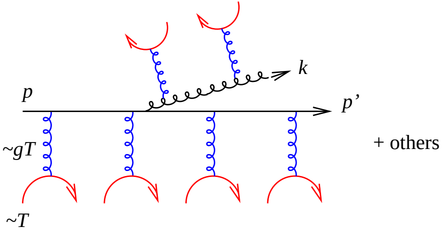

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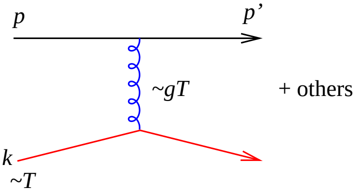


- Can we use this to characterize QGP?
- Effects on photons ?

E-loss - The Big Picture

- $\sum\!\!\!\!\int \left(f_{a/A} \otimes f_{b/A} \otimes \frac{d\sigma_{ab\to cd}}{dx} \right) \otimes (\text{E-loss module}) \otimes D_{\rm frag}$
- Parton-parton scattering: $\left(f_{a/A} \otimes f_{b/A} \otimes \frac{d\sigma_{ab\to cd}}{dx} \right)$
- $D_{\rm frag}$: As in vacuum but with reduced energy.
- Energy loss module – Three separate pieces
  - Energy change rate: $\frac{d\Gamma}{dtdk}(\epsilon, k; T)$: Thermal QCD
  - Evolution (q, g coupled $+$ keeps track of the radiated q, g):

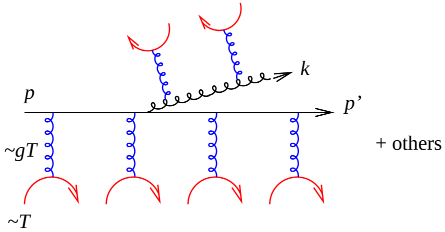
$$\frac{dP(\epsilon, t)}{dt} = \int dk \frac{d\Gamma(\epsilon+k, k)}{dtdk} P(\epsilon + k, t) - \int dk \frac{d\Gamma(\epsilon, k)}{dtdk} P(\epsilon, t)$$

  - $T(\mathbf{x}, t), u^\mu(\mathbf{x}, t)$: Must be obtained independently.
- Still schematic. There are theoretical and conceptual problems to further consider.

McGill-AMY approach

- Uses *full leading order* thermal QCD/QED rates - LPM and BH limits are both correctly included.
- Dynamic medium: Thermal quarks and gluons in the medium. T and α_s characterizes the medium.
- Keeps track of radiated gluons and $q\bar{q}$ pairs.
- Thermal absorption included.
- The "jet" propagates in a hydrodynamically evolving medium.
- Flow is taken into account: Perform calc in the local rest frame, and then boost back to the lab frame.

Rough Idea - Radiational (following BDMPS)



- Point here: Radiated gluon also undergoes multiple scatterings.
- Bethe-Heitler Spectrum (low ω)

$$\omega \frac{dI}{d\omega} \approx \frac{\alpha_s N_c}{\pi}$$

- Medium dependence comes through a scattering length scale l

$$\omega \frac{dI}{d\omega dz} \approx \frac{1}{l} \frac{\alpha_s N_c}{\pi}$$

Rough Idea - Radiational (following BDMPS)

- If all scatterings are incoherent

$$l = l_{\rm mfp} = 1/\rho\sigma \ \text{ and } \ \omega\frac{dI}{d\omega dz} \approx \frac{\alpha_s N_c}{\pi l_{\rm mfp}}$$

- Coherence matters when multiple scatterings are needed to get $O(1)$ phase change: $1 \sim l_{\rm coh}\omega(1 - \hat{\mathbf{k}}\cdot\hat{\mathbf{v}}) \sim l_{\rm coh}\omega \left\langle \theta^2 \right\rangle$
  Both the radiated gluon and the original parton undergo random walk:

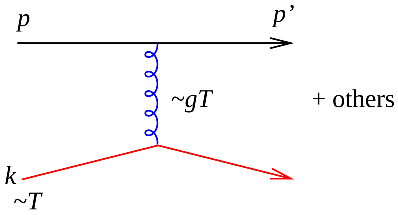
$$\left\langle \theta^2 \right\rangle \approx N_{\rm coh}\left(\bar{\theta}_g^2 + \bar{\theta}_q^2\right) \approx \frac{l_{\rm coh}}{l_{\rm mfp}}\left(\frac{\mu^2}{\omega^2} + \frac{\mu^2}{E^2}\right)$$

or

$$l_{\rm coh} = l_{\rm mfp}\sqrt{\frac{\omega}{E_{\rm LPM}}}\sqrt{\frac{E^2}{E^2+\omega^2}} \ \text{ and } \ \omega\frac{dI}{d\omega dz} \approx \frac{\alpha_s N_c}{\pi l_{\rm mfp}}\sqrt{\frac{E_{\rm LPM}}{\omega}}$$

for $E \gg \omega$ and $\omega > E_{\rm LPM} \equiv \mu^2 l_{\rm mfp} \sim T$.

Rough Idea - Collisional (Following Bjorken)



- Energy loss per unit length

$$\frac{dE}{dz} \approx \int d^3k\, \rho(k) \int dq^2\, (1 - \cos\theta_{pk})\Delta E \frac{d\sigma^{\rm el}}{dq^2}$$

where

- $\rho(k)$: density, $(1 - \cos\theta_{pk})\Delta E \approx q^2/2k$: flux factor
- Elastic cross-section (Coulombic) $\dfrac{d\sigma}{dq^2} \approx C_R \dfrac{2\pi\alpha_s^2}{(q^2)^2}$

Rough Idea - Collisional

- with thermal ρ, this yields

$$\left(\frac{dE}{dz}\right)_{\rm coll} \propto \alpha_s^2 T^2 \ln(E/\alpha_s T)$$

- Compare:

$$\left(\frac{dE}{dz}\right)_{\rm rad} \propto \alpha_s^2 T \sqrt{TE}$$

- NOTE: We actually need $\omega dI/d\omega dz$ in place of dE/dz.

Rough Idea - The behavior of R_{AA}

Use BDMPS expression for the quenching factor for $1/p^n$ with a large n but with the energy range extended to $\omega < 0$:

$$R_{AA}(p) \approx \exp\left(-\int_{-\infty}^{\infty} d\omega \int_0^t dt' \, (d\Gamma_{\rm inel+el}/d\omega dt)(1 - e^{-\omega n/p})\right)$$

For the radiation rate, use simple estimates

$$\frac{d\Gamma}{d\omega dt} \approx \frac{\alpha}{\pi\omega}\frac{N_c}{l_{\rm mfp}} \quad \text{for} \quad 0 < \omega < l_{\rm mfp}\mu^2$$

$$\frac{d\Gamma}{d\omega dt} \approx \frac{\alpha}{\pi\omega} N_c \sqrt{\frac{\mu^2}{l_{\rm mfp}\omega}} \quad \text{for} \quad l_{\rm mfp}\mu^2 < \omega < l_{\rm mfp}\mu^2 (L/l_{\rm mfp})^2$$

$$\frac{d\Gamma}{d\omega dt} \approx \frac{\alpha}{\pi|\omega|}\frac{N_c}{l_{\rm mfp}} e^{-|\omega|/T} \quad \text{for} \quad \omega < 0$$

Rough Idea - R_{AA}

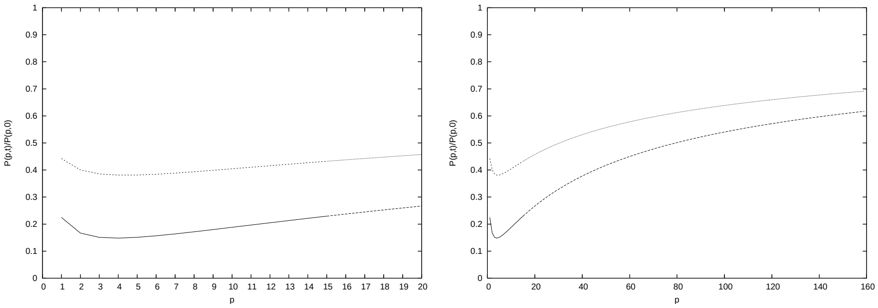
For elastic energy loss,

$$R_{AA}^{\rm el} \approx \exp\left(-\int_{-\infty}^{\infty} d\omega \int_0^t dt'\,(d\Gamma_{\rm el}/d\omega dt)(1-e^{-\omega n/p})\right)$$
$$\approx \exp\left(-t\left(\frac{dE}{dt}\frac{K(\omega_0)}{|\omega_0|}\right)\right)$$
$$\approx \exp\left(-t\left(\frac{dE}{dt}\right)\left(\frac{n}{p}\right)\left(1-\frac{nT}{p}\right)\right)$$

valid for $p > nT$ and we used

$$K(\omega_0) = (1+n_B(|\omega_0|))(1-e^{-|\omega_0|n/p}) + n_B(|\omega_0|)(1-e^{|\omega_0|n/p})$$
$$\approx |\omega_0|\left(\frac{n}{p}\right)\left(1-\frac{nT}{p}\right) \quad \text{for small } \omega_0$$

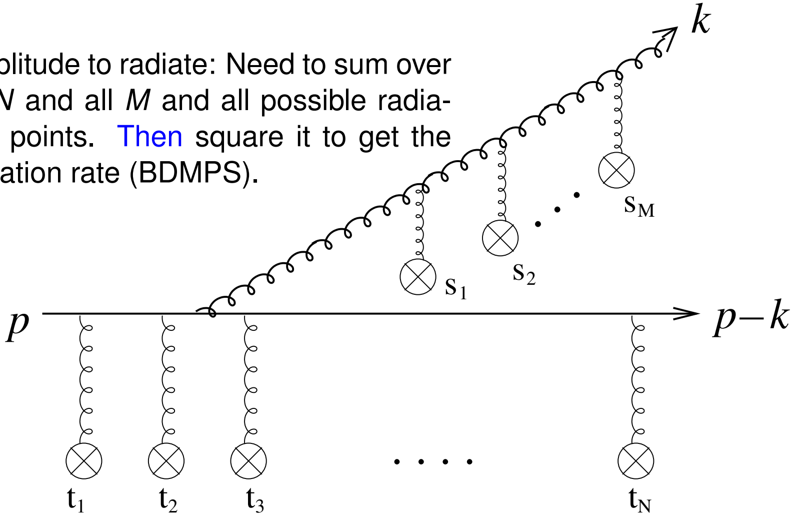
Rough Idea - R_{AA}



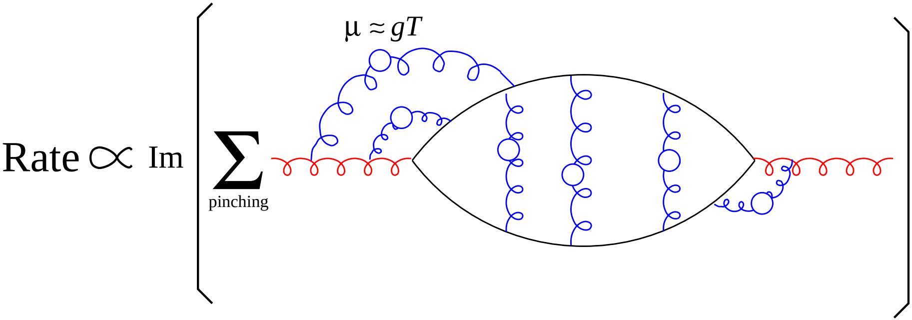
- Upper line: Without elastic
- Lower line: With elastic
- Flat R is produced in both cases up to $O(10\,T)$.
- R just not that sensitive to p in the RHIC-relevant range.

Gluon Radiation Calculation

Amplitude to radiate: Need to sum over all N and all M and all possible radiation points. Then square it to get the radiation rate (BDMPS).



Diagrams

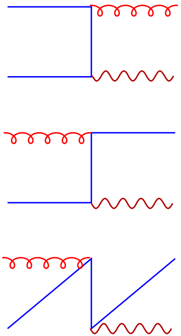


: HTL resumed

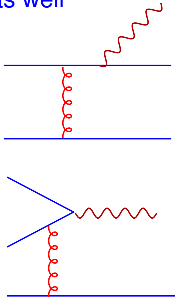
Why is this so hard?

- Collinear enhancement in photon & gluon radiations
  Aurenche, Gelis, Kobes and Zaraket, PRD58:085003,1998, Arnold, Moore and Yaffe (AMY), JHEP 0206:030,2002; JHEP 0112:009,2001; JHEP 0111:057,2001

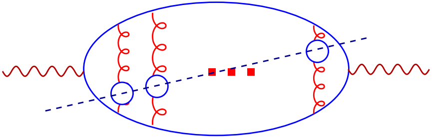
Leading order



Collinear enhancement makes these leading order as well

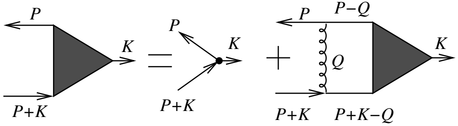


Need to resum all these, too (AMY)



◯ : Hard Thermal Loop

Photon SD (Simpler) – Sketch



$$F(P, P+K) = G_R(P)G_A(P+K)V(P,K) + G_R(P)G_A(P+K)\mathcal{G}(Q)F(P-Q, P-Q+K)$$

- Bare vertex: $V(P,K)$, Resummed vertex: $F(P,K)$
- p^0 integrated legs (with $K^2 = 0$):

$$\int dp^0 G_R(P+K)G_A(P) \approx$$

$$\int dp^0 \frac{1}{E_{pk}E_p}\frac{1}{p^0 + k^0 - E_{pk} - i\Gamma_{pk}/2}\frac{1}{p^0 - E_p + i\Gamma_p/2}$$

$$\approx \frac{i}{E_{pk}E_p}\frac{1}{\delta E(p,k) - i(\Gamma_{pk}+\Gamma_p)/2}$$

Photons – Cont.

- Integral eq (schematic):

$$(i\delta E(P,K) + \Gamma)F(P,P+K) = V(P,K) + \mathcal{G}(Q)F(P-Q,P-Q+K)$$

or

$$i\delta E(P,K)F(P,P+K) = V(P,K) + \mathcal{G}(Q)\left[F(P-Q,P-Q+K) - F(P,P+K)\right]$$

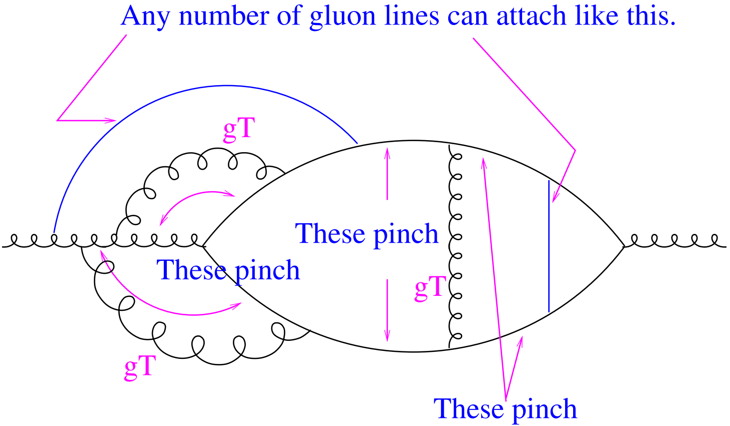
- Γ turned out to be independent of P, K:

$$\Gamma \approx \int_Q \mathcal{G}(Q)$$

with

$$\mathcal{G} = \frac{m_D^2}{\mathbf{q}_\perp^2(\mathbf{q}_\perp^2 + m_D^2)}$$

Gluon radiation is similar but more complicated ...



Adding one more rung = O(1).
Need to resum.

SD equation for the vertex

Equation for the vertex **F**

$$
\begin{aligned}
2\mathbf{h} &= i\delta E(\mathbf{h},p,k)\mathbf{F}(\mathbf{h}) + g^2 \int \frac{d^2\mathbf{q}_\perp}{(2\pi)^2} C(\mathbf{q}_\perp) \times \\
&\times \Big\{ (C_s - C_{\rm A}/2)[\mathbf{F}(\mathbf{h}) - \mathbf{F}(\mathbf{h}-k\,\mathbf{q}_\perp)] \\
&\quad + (C_{\rm A}/2)[\mathbf{F}(\mathbf{h}) - \mathbf{F}(\mathbf{h}+p\,\mathbf{q}_\perp)] \\
&\quad + (C_{\rm A}/2)[\mathbf{F}(\mathbf{h}) - \mathbf{F}(\mathbf{h}-(p-k)\,\mathbf{q}_\perp)] \Big\}, \\
\delta E(\mathbf{h},p,k) &= \frac{\mathbf{h}^2}{2pk(p-k)} + \frac{m_k^2}{2k} + \frac{m_{p-k}^2}{2(p-k)} - \frac{m_p^2}{2p} .
\end{aligned}
$$

- m^2: Medium induced thermal masses.
- $\mathbf{h} = (\mathbf{p}\times\mathbf{k})\times\mathbf{e}_{||}$ — Must keep track of both $\mathbf{p}_\perp$ and $\mathbf{k}_\perp$ now. For photons, we could just set $\mathbf{k}_\perp = 0$.

Gluon Radiation Rate

Rate using **F**

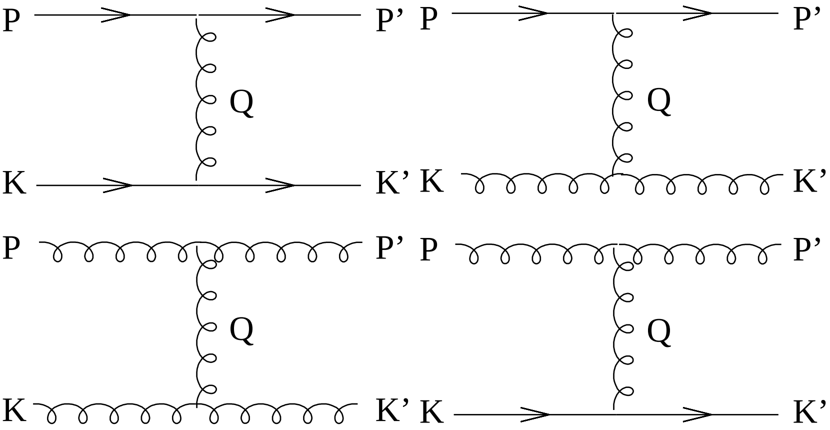
$$\frac{d\Gamma_g(p,k)}{dkdt} = \frac{C_s g_s^2}{16\pi p^7} \frac{1}{1 \pm e^{-k/T}} \frac{1}{1 \pm e^{-(p-k)/T}} \times$$
$$\times \left\{ \begin{array}{cc} \frac{1+(1-x)^2}{x^3(1-x)^2} & q \to qg \\ N_f \frac{x^2+(1-x)^2}{x^2(1-x)^2} & g \to qq \\ \frac{1+x^4+(1-x)^4}{x^3(1-x)^3} & g \to gg \end{array} \right\}$$
$$\times \int \frac{d^2\mathbf{h}}{(2\pi)^2} 2\mathbf{h} \cdot \mathrm{Re}\, \mathbf{F}(\mathbf{h}, p, k)\,,$$

where $x \equiv k/p$ is the momentum fraction in the gluon (or either quark, for the case $g \to qq$). $\mathbf{h} \equiv \mathbf{p} \times \mathbf{k}$: 2-D vector. $O(gT^2)$

- Correctly incorporates *both* the BH limit and the LPM limit.

Elastic scattering rate

Coulombic *t*-channel dominates



Elastic scattering rate

We need

$$\frac{dE}{dt} = \frac{1}{2E}\int_{k,k',p'} \delta^4(p+k-p'-k')\,(E-E')|M|^2 f(E_k)[1 \pm f(E'_k)]$$
$$= C_r\pi\,\alpha_s^2 T^2 \left[\ln(ET/m_g^2) + D_r\right]$$

where C_r and D_r are channel dependent $O(1)$ constants.

Putting them together

- Fokker-Planck Eqn.

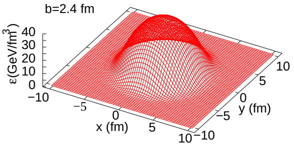
$$\frac{dP_{q\bar{q}}(p)}{dt} = \int_k P_{q\bar{q}}(p+k)\frac{d\Gamma^q_{qg}(p+k,k)}{dkdt} - P_{q\bar{q}}(p)\frac{d\Gamma^q_{qg}(p,k)}{dkdt} + 2P_g(p+k)\frac{d\Gamma^g_{q\bar{q}}(p+k,k)}{dkdt},$$

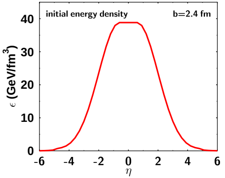
$$\frac{dP_g(p)}{dt} = \int_k P_{q\bar{q}}(p+k)\frac{d\Gamma^q_{qg}(p+k,p)}{dkdt} + P_g(p+k)\frac{d\Gamma^g_{gg}(p+k,k)}{dkdt} - P_g(p)\left(\frac{d\Gamma^g_{q\bar{q}}(p,k)}{dkdt} + \frac{d\Gamma^g_{gg}(p,k)}{dkdt}\Theta(k-p/2)\right)$$

- $\Gamma = \Gamma_{\mathrm{el}} + \Gamma_{\mathrm{inel}}$
- Inelastic part is solved as it is.
- Elastic part – Soft exchange dominated. Implement it as drag + diffusion
- Get $T(x,t)$ and $u^\mu(x,t)$ from 3+1 D Hydro

(3+1)-D relativistic hydrodynamics (Nonaka & Bass)

- Based on conservation laws: $\partial_\mu T^{\mu\nu} = 0, \partial_\mu j^\mu = 0$.
- For ideal fluid, $T^{\mu\nu} = (\epsilon + p)U^\mu U^\nu - pg^{\mu\nu}, j^\mu = n_B U^\mu$.
- EOS: Bag model + Hadron with extended volume
- Initial conditions: $\epsilon(x, y, \eta) = \epsilon_{\max} W(x, y; b)H(\eta)$, $n_B(x, y, \eta) = n_{B\max} W(x, y; b)H(\eta)$





- Particle spectra: Cooper-Frye Formula

$$E\frac{dN_i}{d^3p} = \int_\Sigma p \cdot d\sigma \frac{g_i}{(2\pi)^3} \frac{1}{\exp\left[(p \cdot U - \mu_i)/T_{\rm f}\right] \pm 1}$$

Nonaka and Bass, Phys.Rev.C75:014902,2007

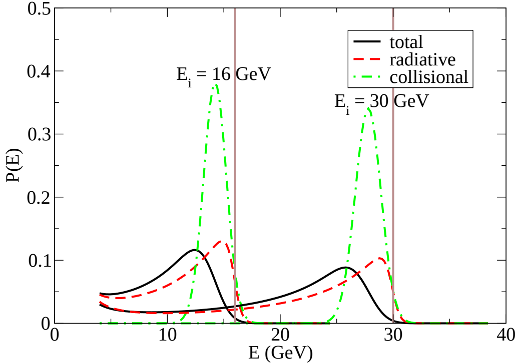
Following calculations mostly by

Guangyou Qin (Rad + Coll, 3+1 Hydro)
and
Simon Turbide (Rad only, Bjorken Hydro)

with C. Gale, S. Jeon, G. Moore and J. Ruppert
(McGill-AMY)

Example evolution of a single jet (Qin)

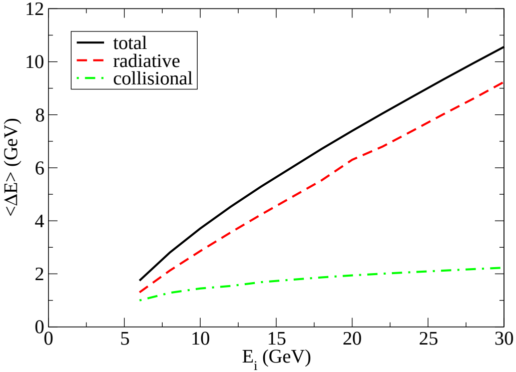
- The final momentum distribution $P(E, t_f)$ of a single quark jet after passing through RHIC medium ($b = 2.4$ fm)



- Medium described by (3+1)D ideal hydrodynamics.
- The jet starts at the center and propagates in plane.
- Jet energy loss turned off in hadronic phase.

Averaged energy loss of a single jet (Qin)

- The averaged energy loss of a quark jet after passing through RHIC medium ($b = 2.4$ fm)



- Averaged energy: $\langle E \rangle = \int dEEP(E)/\int dEP(E)$

Qin *et al.*, arXiv:0710.0605 [hep-ph], PRC, in press, arXiv:0705.2575 [hep-ph]

Pion Production

- Fold in the nuclear geometry, local production rate, jet angles, with the energy loss

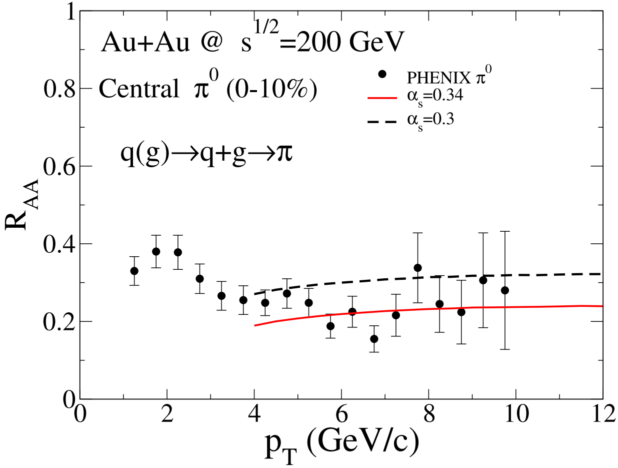
$$\frac{dN_{AA}}{dyd^2\mathbf{p}_T} = \frac{\langle N_{\rm coll}\rangle}{\sigma_{in}} \sum_{a,b,c,d} \int dx_a dx_b\, g_A(x_a, Q) g_A(x_b, Q) \times K_{\rm jet} \frac{d\sigma_{a+b\to c+d}}{dt} \frac{\tilde{D}_{\pi^0/c}(z, Q)}{\pi z}$$

with $\tilde{D}_{\pi^0/c}(z, Q) = \int d^2 r_\perp\, \mathcal{P}(\mathbf{r}_\perp) \tilde{D}_{\pi^0/c}(z, Q, \mathbf{r}_\perp, \mathbf{n})$, and $\tilde{D}_{\pi^0/c}(z, Q, \mathbf{r}_\perp, \mathbf{n}) =$

$$\int dp_f \frac{z'}{z} \Big(P_{qq/c}(p_f; p_i; \Delta t)\, D_{\pi^0/c}(z', Q) + P_{g/c}(p_f; p_i; \Delta t)\, D_{\pi^0/c}(z', Q) \Big)$$

with $z = p_T/p_i$ and $z' = p_T/p_f$.

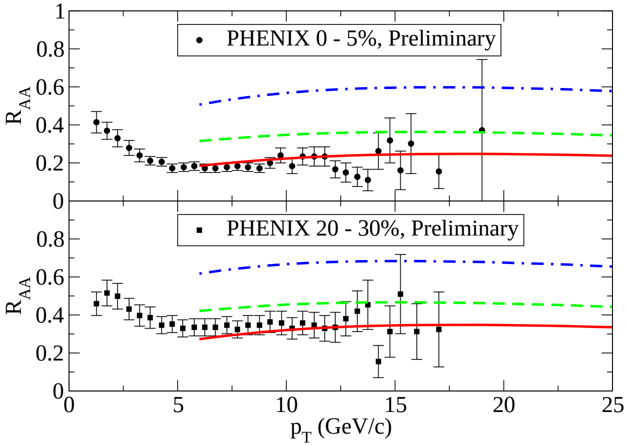
R_{AA} at RHIC - π^0 - Radiation only (Turbide)



$T_i = 370\,\text{MeV}$, $dN/dy = 1260$. 1-D Bjorken expansion.

Best $\alpha_s = 0.33$ S.Turbide, C.Gale, S.J. and G.Moore, PRC72:014906,2005

R_{AA} at RHIC – π^0 - Full (Qin)

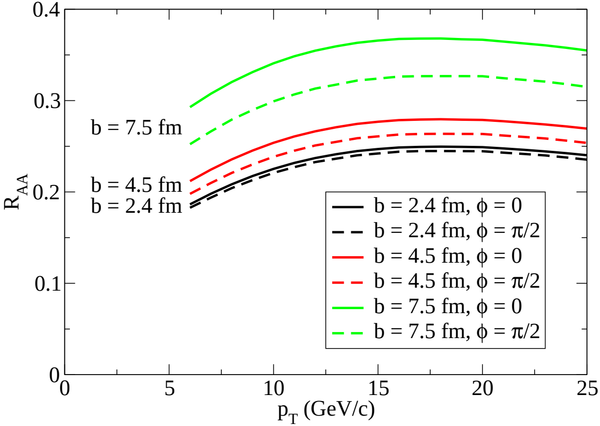


- total, rad, coll
- Strong coupling α_s tuned from 0.33 to 0.27

Qin *et al.*, arXiv:0710.0605 [hep-ph], PRC, in press, arXiv:0705.2575 [hep-ph]

R_{AA} vs. reaction plane at RHIC (Qin)

- R_{AA} for π^0 in plane and out of plane at RHIC (different b)

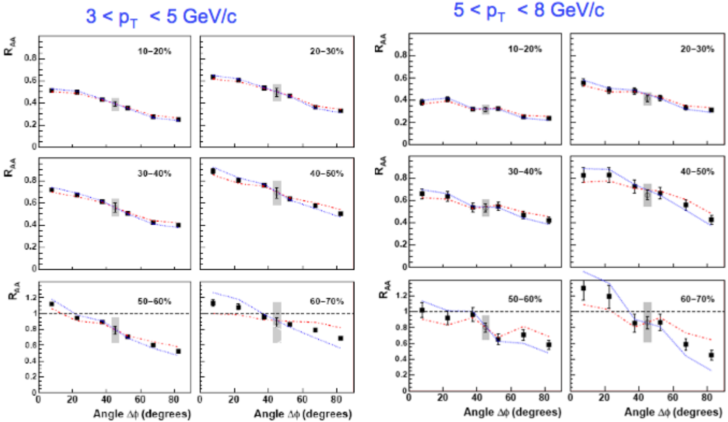


- Jets propagating out of plane ($\phi = \pi/2$) are suppressed more than in plane ($\phi = 0$)

PHENIX data from QM06 (Pantuev's talk)

The results:

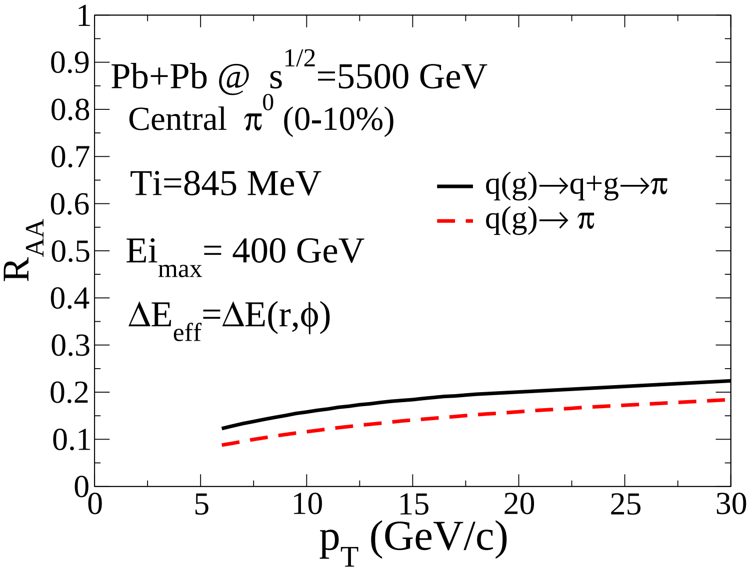
PHENIX Run2, nucl-ex/0611007, submitted PRC



-R_{AA} in plane and out of plane changes by factor ~2

- For peripheral bins no suppression in plane, while a factor ~2 out of plane 13

LHC R_{AA} (Turbide)



What now?

Where are we now?

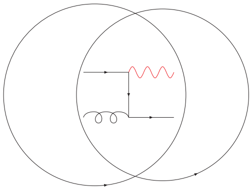
- Most models have jet quenching under control in the hadronic part.
- But R_{AA} too simple to be the full story.

More information? – γ production

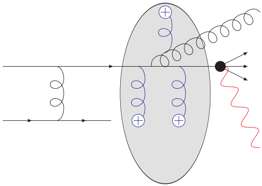
- Need:
  - Thermal photon radiation rate (AMY)
  - Jet bremsstrahlung rate (AMY)
  - Jet-photon conversion rate (Fries, Mueller, Srivastava)

Various sources of photons

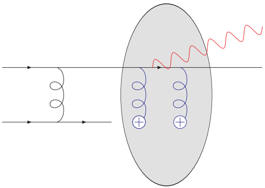
Direct photons:



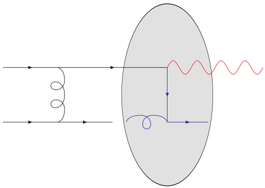
Fragmentation photons:



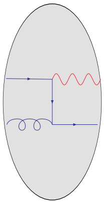
Bremsstrahlung photons:



Jet-conversion photons:



Thermal photons:



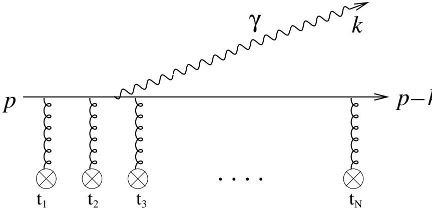
Photon Radiation

Arnold, Moore and Yaffe (AMY), JHEP 0206:030,2002; JHEP 0112:009,2001; JHEP 0111:057,2001

Thermal Radiation rate:

$$\omega \frac{dR}{d^3k} = -\frac{g^{\mu\nu}}{(2\pi)^3} \frac{1}{e^{\omega/T} - 1} \mathrm{Im}\, \Pi^R_{\mu\nu}(k)$$

Physical process:

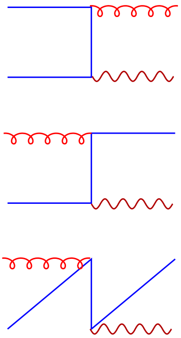


Need to sum over the scattering centers and the radiation points.

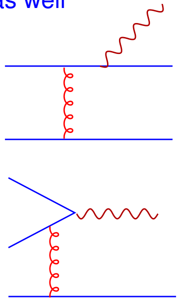
Remember this slide?

- Collinear enhancement in photon & gluon radiations
  Aurenche, Gelis, Kobes and Zaraket, PRD58:085003,1998, Arnold, Moore and Yaffe (AMY), JHEP 0206:030,2002; JHEP 0112:009,2001; JHEP 0111:057,2001

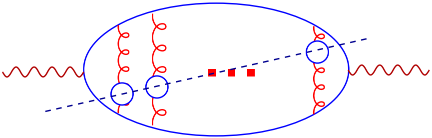
Leading order



Collinear enhancement makes these leading order as well

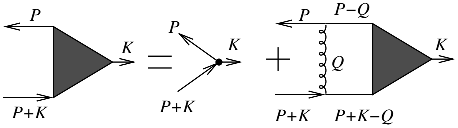


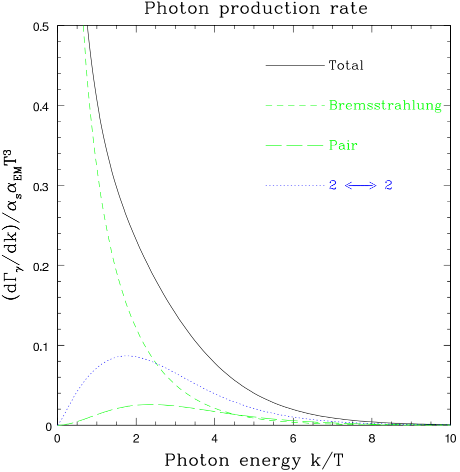
Need to resum all these, too (AMY)



○ : Hard Thermal Loop

Schwinger-Dyson Equation

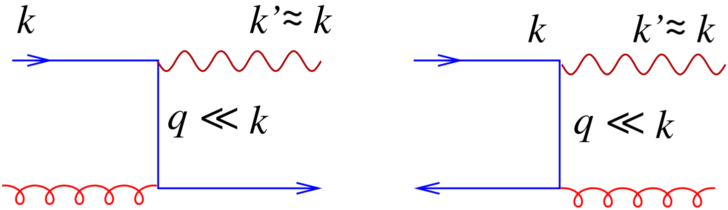




Arnold, Moore and Yaffe, JHEP 0112 (2001) 009

The same formalism can be used to calculate thermal radiation ($P \sim T$) and bremsstrahlung from jets ($P \gg T$).

Jet-Thermal Conversion



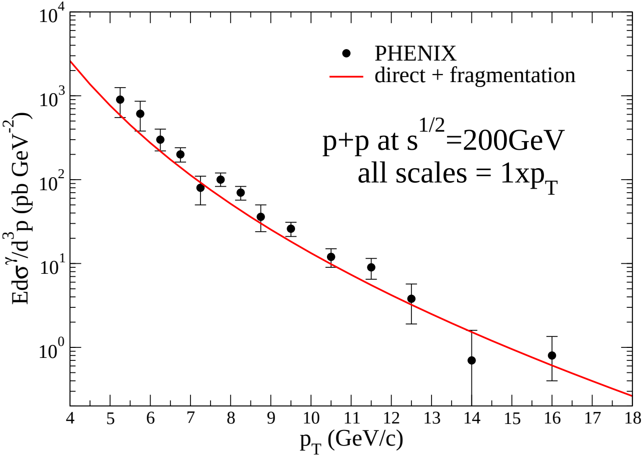
Fries, Mueller, Srivastava (nucl-th/0208001)

$$\frac{dR}{dy d^2 p_T} = \sum_f \left(\frac{e_f}{e}\right)^2 \frac{T^2 \alpha \alpha_s}{8\pi^2} [f_q(\vec{p_\gamma}) + f_{\bar{q}}(\vec{p_\gamma})] \left[2 \ln\left(\frac{4 E_\gamma T}{m^2}\right) - C\right]$$

with $C \approx 2.33$.

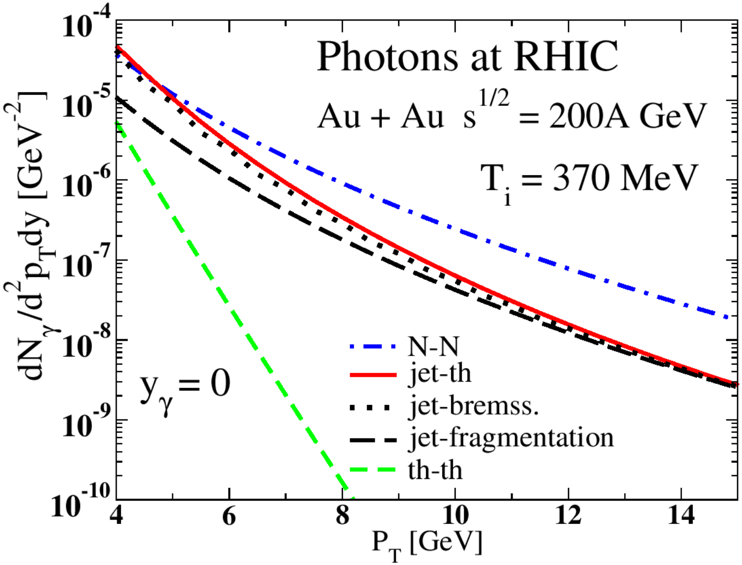
Putting everything together for γ...

γ – Baseline

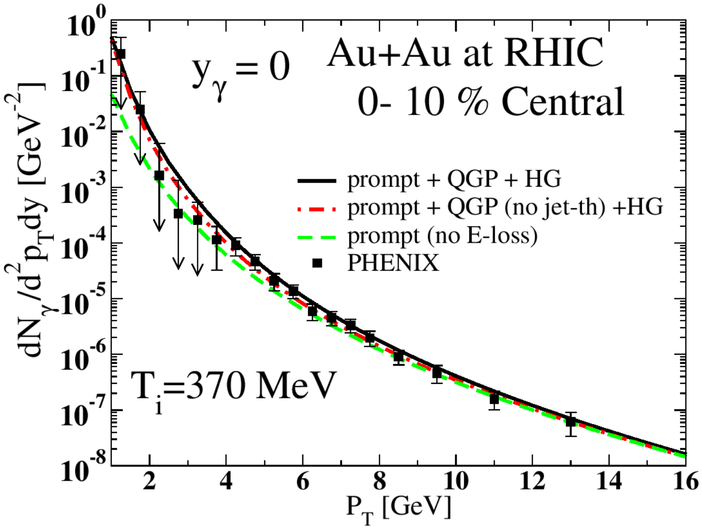


Using P.Aurenche et al.'s pQCD program.

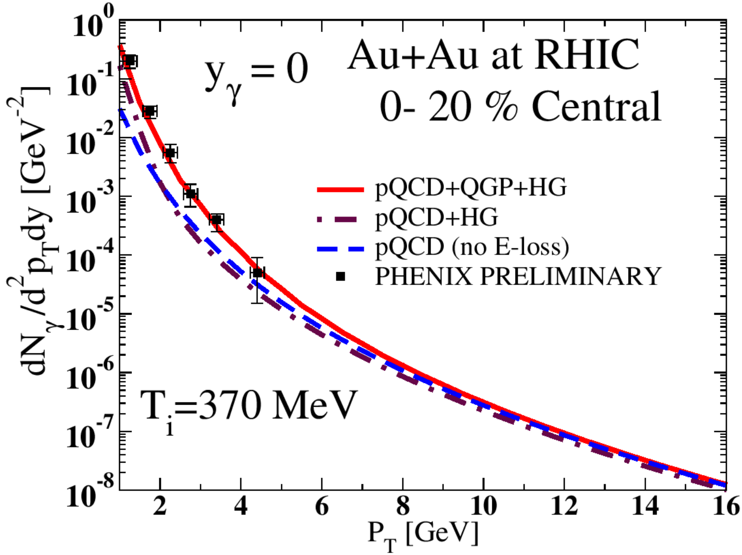
γ – Composition (Turbide)

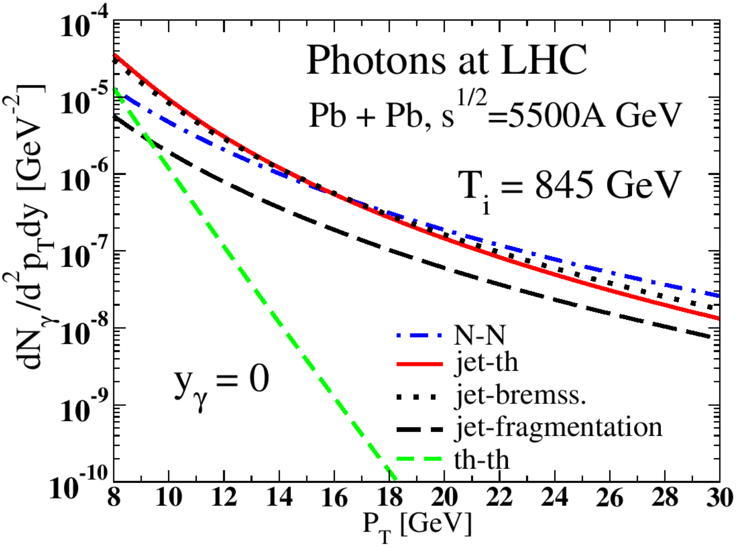


γ – Our Calc vs. PHENIX Data (Turbide)



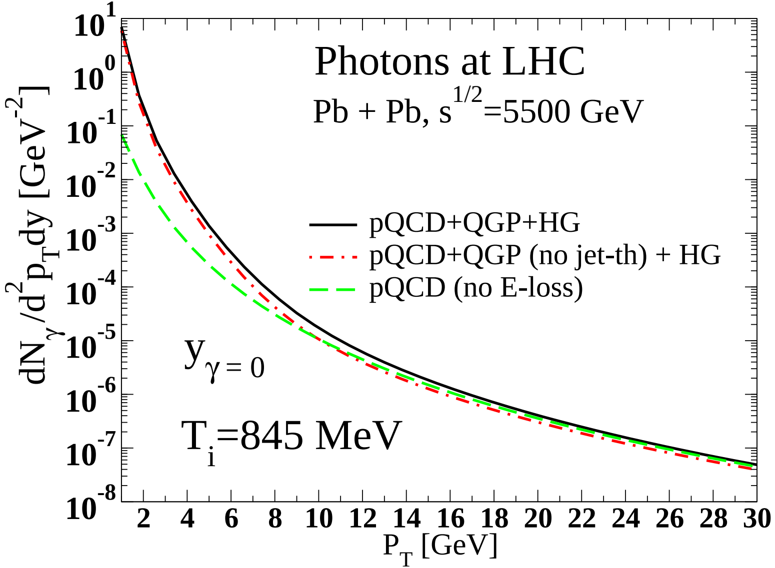
γ – Our Prediction vs. Data (Turbide)



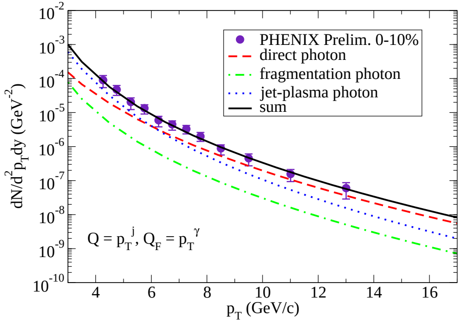


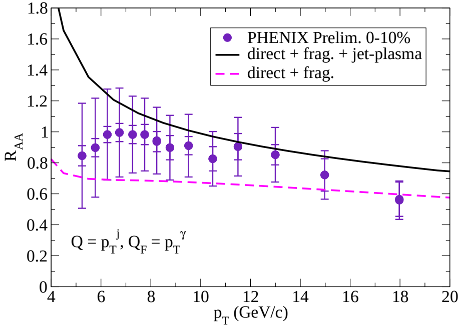
Photons at LHC
Pb + Pb, s^1/2=5500A GeV
T_i = 845 GeV
y_γ = 0
N-N
jet-th
jet-bremss.
jet-fragmentation
th-th
dN_γ/d^2p_Tdy [GeV^-2]
P_T [GeV]
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
8
10
12
14
16
18
20
22
24
26
28
30

γ – LHC prediction (Turbide)



Photon production in Au+Au collisions at RHIC from various sources:





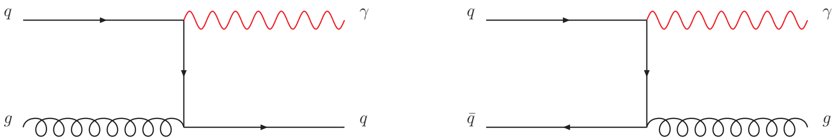
3+1 D hydro. Rad + Coll E-loss.

Jet-plasma photons (bremsstrahlung and jet-conversion) are significant to understand the photon data in AA collisions

Qin *et al*, in preparation

G. Qin - Application: Photon-tagged jets

At LO, Compton scattering and annihilation process:



Wang, Huang, Sarcevic, PRL **77**, 231-234 (1996)
Proposed advantage for photon-tagged jets (at LO):

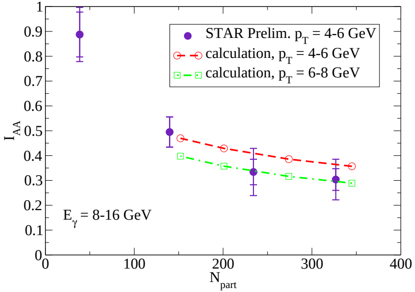
$$E_{\rm jet} = E_\gamma$$

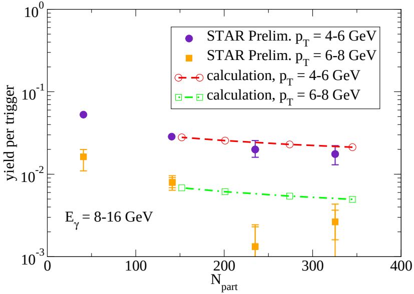
The photon is strongly correlated with the away-side jet
$\rightarrow$ a calibrated probe of the QGP.

How does it look like in a full calculation?

Results for photon-hadron correlations (Qin)

Centrality dependence of I_{AA} and yield per trigger for away-side π^0:





$$I_{AA}(E_h|E_\gamma) = \frac{P_{A+A}(E_h|E_\gamma)}{P_{p+p}(E_h|E_\gamma)} \qquad P(E_h|E_\gamma) = \frac{P(E_h, E_\gamma)}{P(E_\gamma)}$$

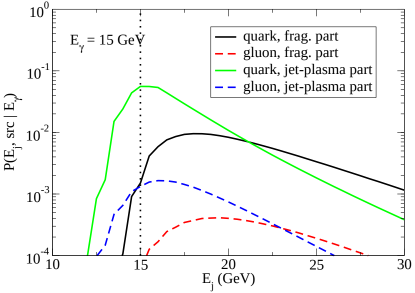
Both I_{AA} and yield per trigger are consistent with current data!

Qin *et al*, in preparation

Data from QM2008: Mohanty's plenary talk and Hamed's parallel talk

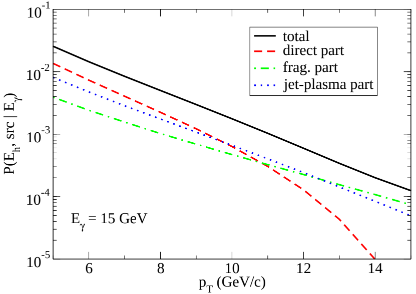
G. Qin - Contributions from different source of photons

Probability distributions of the initial jets tagged by different photons:



$$P(E_j|E_\gamma) = \sum_{\mathrm{src}} P(E_j, \mathrm{src}|E_\gamma)$$

Different contributions to yield per trigger for away-side π^0:



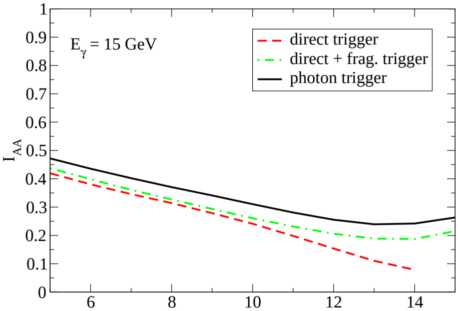
$$P(E_h|E_\gamma) = \sum_{\mathrm{src}} P(E_h, \mathrm{src}|E_\gamma)$$

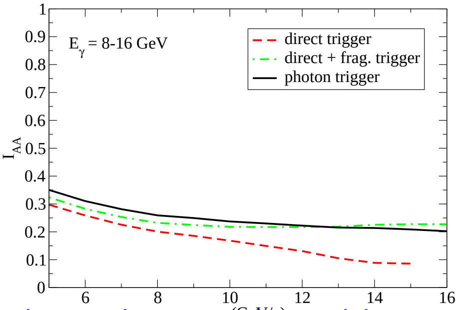
Direct photon-tagged jets dominate at lower p_T, jet-plasma and fragmentation photon-tagged jets dominated at higher p_T.

Qin *et al*, in preparation

G. Qin - What is the importance of additional processes?

I_{AA} for the away-side π^0 for different photon triggers:





Jet-plasma interaction and fragmentation are important for studying photon-hadron correlations, even dominant close to photon-trigged energy.

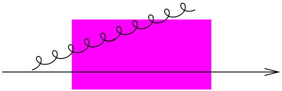
Qin *et al*, in preparation

Conclusions and Caveats

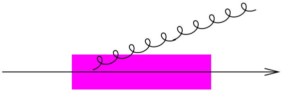
- Calculated Jet Quenching with radiational *and* collisional energy loss
- Radiational part plays bigger role, but collisional part not negligible.
- Best fit α_s reduced by 10 %
- Important to use the full momentum distribution at any given time, not just *dE/dx*.
- Geometry and 3+1 D expansion included.
- Best we can do using perturbative results (We keep track of radiated partons as well)
- Good description of existing data – pions and photons.
- For photons, jet-thermal interaction is crucial.
- LHC predictions – Should be better since pQCD should work better there.
- Photon spectra + Photon tagged jets - Preview version at HP08, full version soon

Conclusions and Caveats

- Calculations consistent in the $g \ll 1$ limit for momenta $T < p$. Yet for quantitative calculations, we needed $\alpha_s \approx 1/3$ or $g \approx 2$! So in reality, one must sum all diagrams, not just pinching part of the ladder diagrams!
  - At this leading order, α_s is an overall factor. So one might hope that the structure of the solution is OK.
  - Right now, this is best we can do with perturbative calculation.



Included in the PDF scale dependence



Correctly dealt with in the AMY−McGill approach

Part of this in the fragmentation function

These two can interfere.

Conclusions and Caveats

- What about jet correlations? – Need to keep track of the evolution of the joint probability function of two jet energies. Much harder than single particle distributions!
- Most energy-loss calculations these days do get R_{AA} right. Is there an experimental way to distinguish?
  – Photon bremsstrahlung + jet-photon conversion should be able to distinguish different scenarios. How to fish that out of all others is another matter.
- It is important to keep in mind that photon tagging is not 100 % efficient!