Compton back-scattering photons for QGP tomography

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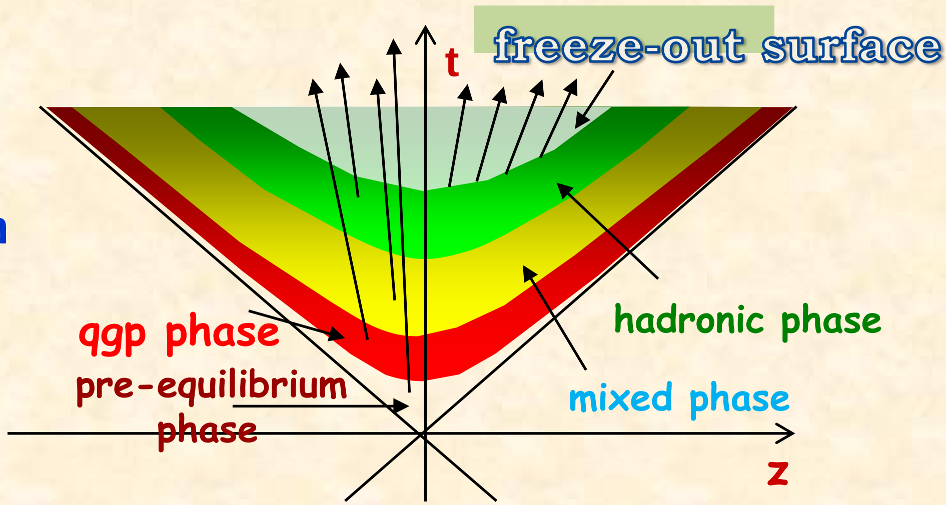
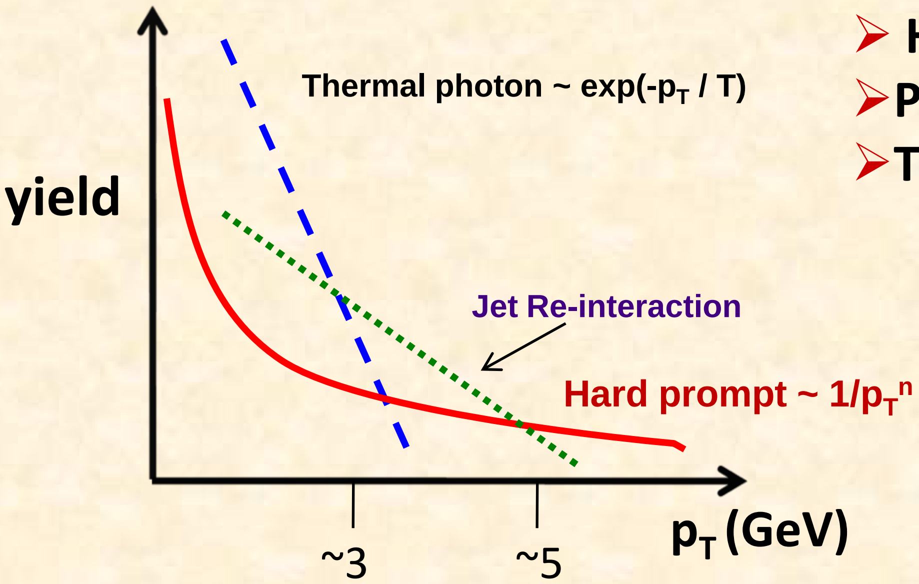
Electromagnetic probes in Heavy Ion Collisions:

✓Direct photons are considered as the most cleanest probe in HIC

✓Due to weak coupling ($\alpha_e/\alpha_s \sim 10^{-2}$) with medium, direct photons carry information undistorted from each stages of evolution



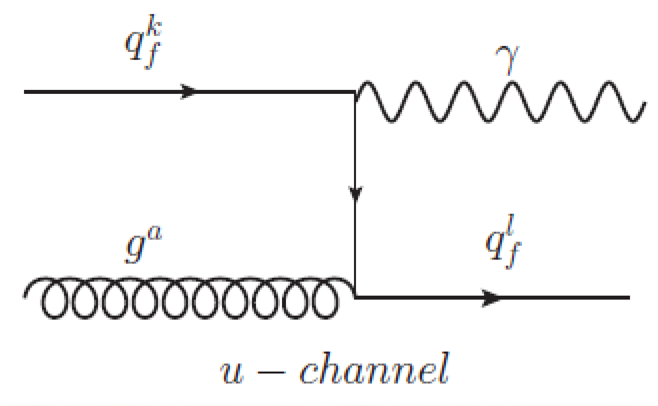


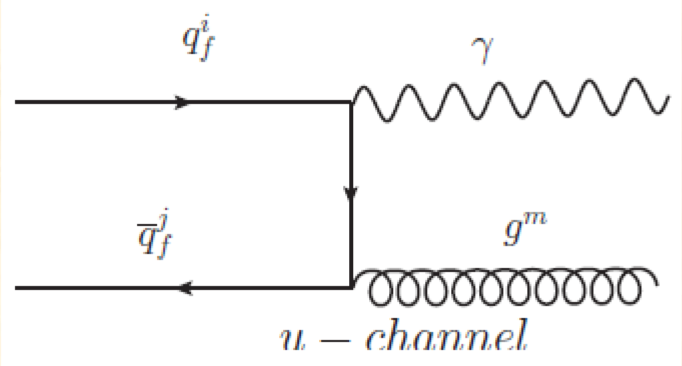
- Hard photons (Direct + Jet fragment)
- Pre-equilibrium and jet-medium photons
- Thermal photons (QGP + Hadron matter)

Experimental challenge to separate different sources of direct photon

Photons from re-scattering of jets in quark gluon plasma

- QCD Compton and Annihilation process :





$$\frac{d\sigma}{dt} = -\frac{\pi\alpha\alpha_s e_q^2}{3s^2}\left(\frac{u}{s} + \frac{s}{u}\right)$$

$$\frac{d\sigma}{dt} = \frac{8\pi\alpha\alpha_s e_q^2}{9s^2}\left(\frac{u}{t} + \frac{t}{u}\right)$$

Cross sections are maximum for small values of t and u

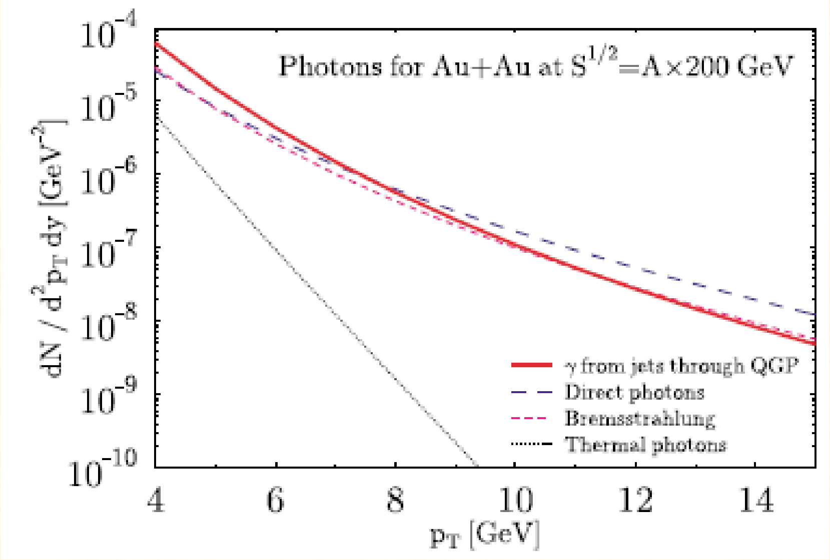
Backward scatt. $\vec{p}_\gamma \approx \vec{p}_q(\vec{p}_{jet})$ $\vec{p}_\gamma \approx \vec{p}_{\bar{q}}(\vec{p}_{jet})$

➢Compton back-scattering is often used for the production of high energy laser beam

Jet-photon contd..

- **Total inclusive yield:**

$$E_\gamma \frac{dN}{d^4x d^3p_\gamma} = \frac{\alpha\alpha_s}{4\pi^2}\sum_f \left(\frac{e_f}{e}\right)^2 [f_q(x,p_\gamma)+f_{\bar{q}}(x,p_\gamma)]T^2[\ln\frac{3E_\gamma}{\alpha_s\pi T}+C]$$



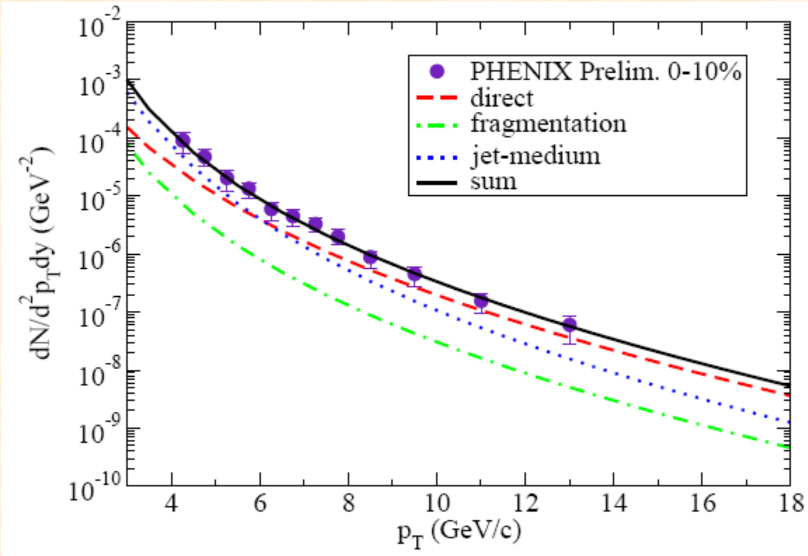
First proposed by : Fries, Muller, Srivastava (PRL,90, 132301 (2003))

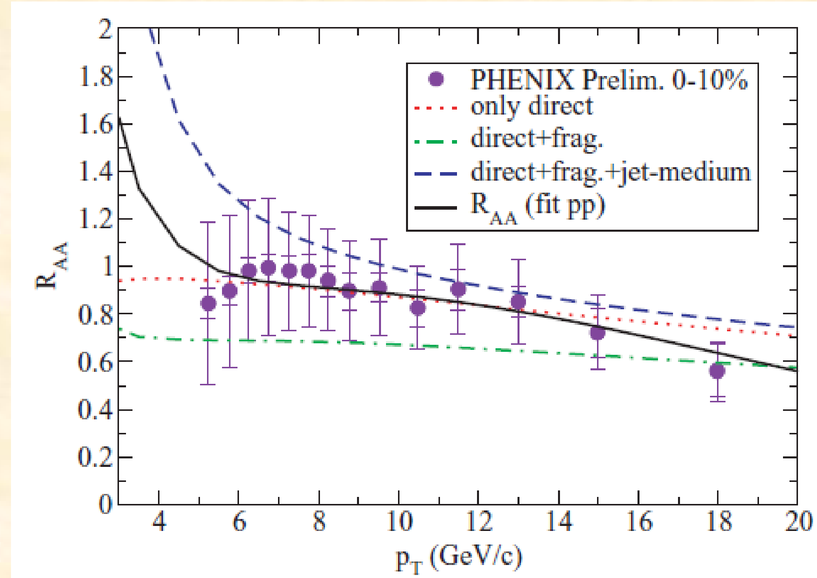
Shows substantial contribution for $p_T \leq 6$ GeV at RHIC energies

Experimental measurement of photons :

- Inclusive yield and Nuclear modification factor of direct photons
- Azimuthal momentum anisotropy coeff. (v_2)

Inclusive yield and R_{AA}:



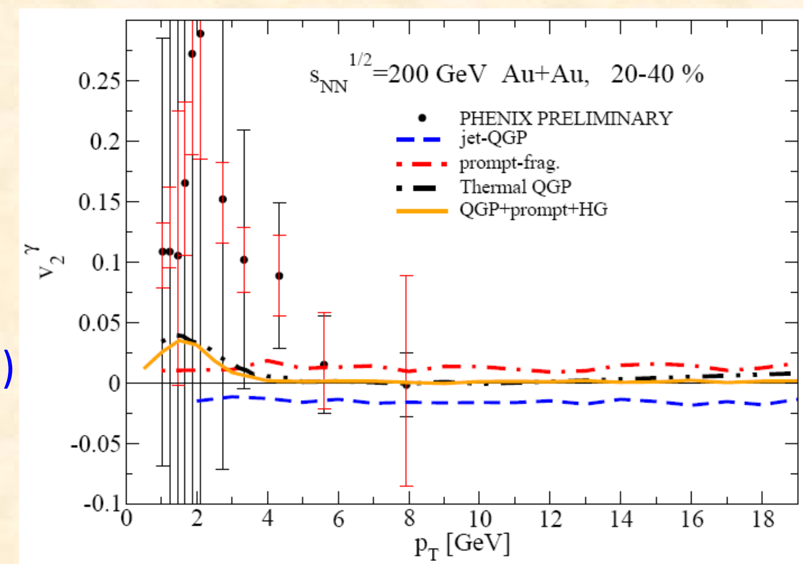


Qin, Ruppert, Gale, Jeon & Moore, PRC 80 (2009)

Azimuthal momentum anisotropy:

- **Jet-medium photons shows negative v_2.**
- **Theoretical predictions are inconclusive.**

Chatterjee, Frodermann, Heinz, Srivastava; PRL 96 (2006)
Turbide, Gale, Fries ; PRL 96 (2006)



Turbide et al. PRC 77 (2008)

Not promising, so far…

Jet - tagged photon measurement:

▪Motivation:

❖The back-scattered photons has strong correlation with the parent jet momentum

❖ Jets are produced back-to back in the medium

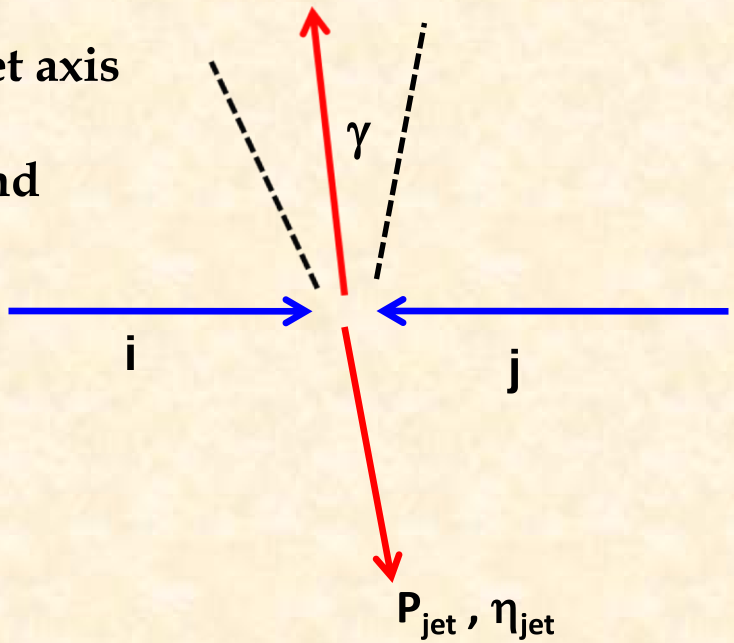
▪Strategy:

➢ Fix the momentum and rapidity of the away-side leading jet

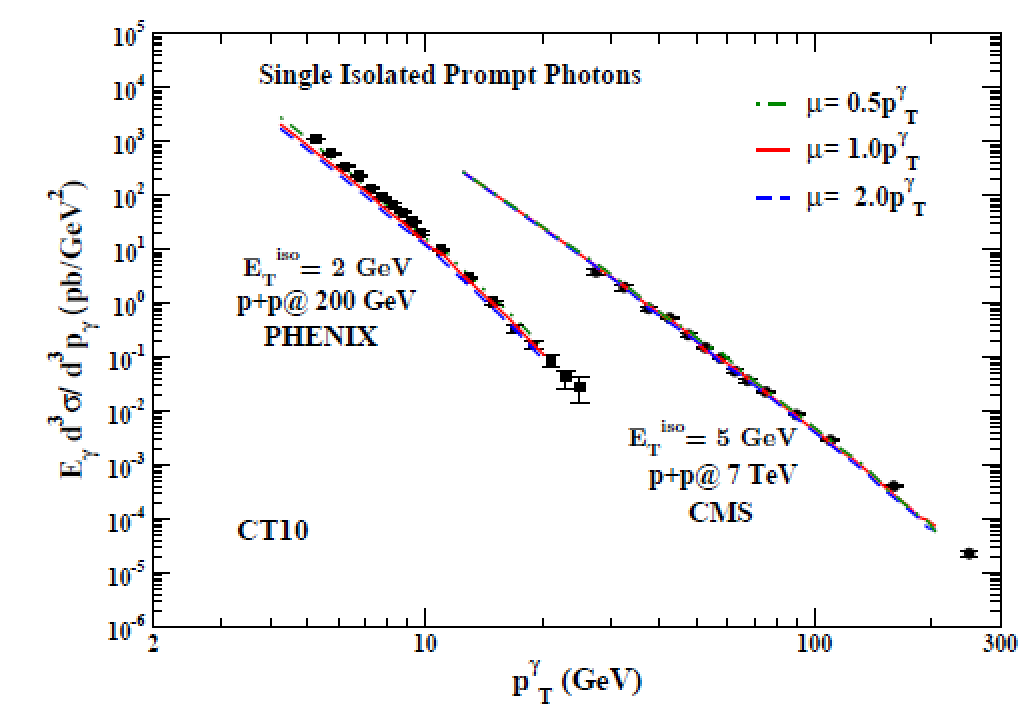
➢ Study the photons, very close to the away-side jet axis

➢The initial hard photons are treated as background

➢Get rid of thermal and pre-equilibrium photons



Estimation of Background



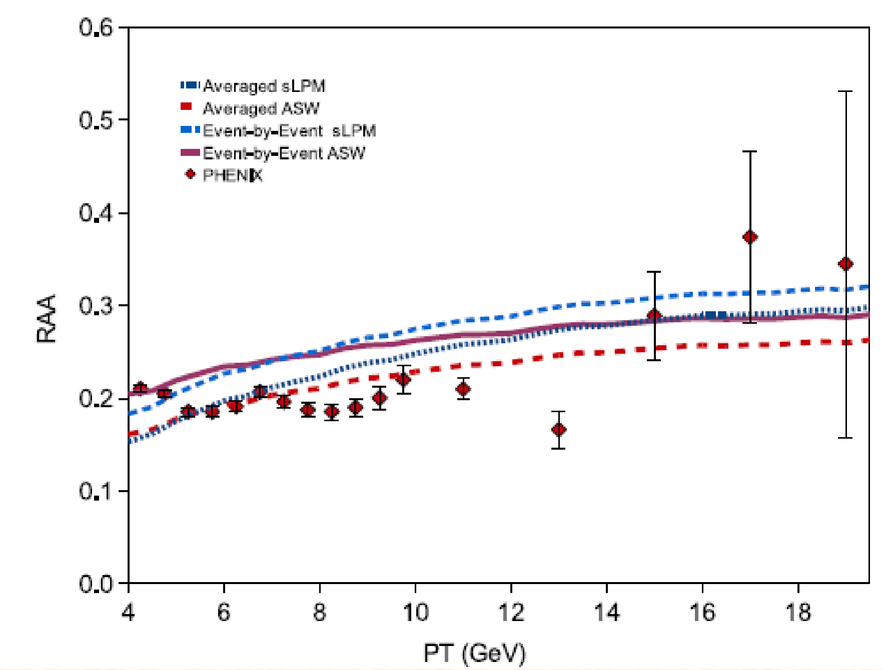
SD, Pramana 82 (2014)

JETPHOX: S.Catani, M. Fontannaz, J. Ph. Guillet, E. Pilon JHEP 05 (2002) 028

- **Photons from initial hard collision + Fragmentation of jets**
- **The background is calculated from the NLO package JETPHOX**
- **EPS09 nuclear pdf is used for A+A collisions**
- **No E_T cut for A+A case**

The energy loss model : ppm

We have used a longitudinally expanding, boost-invariant fireball model by:
Rodriguez, Fries, Ramirez
PLB 693 (2010)



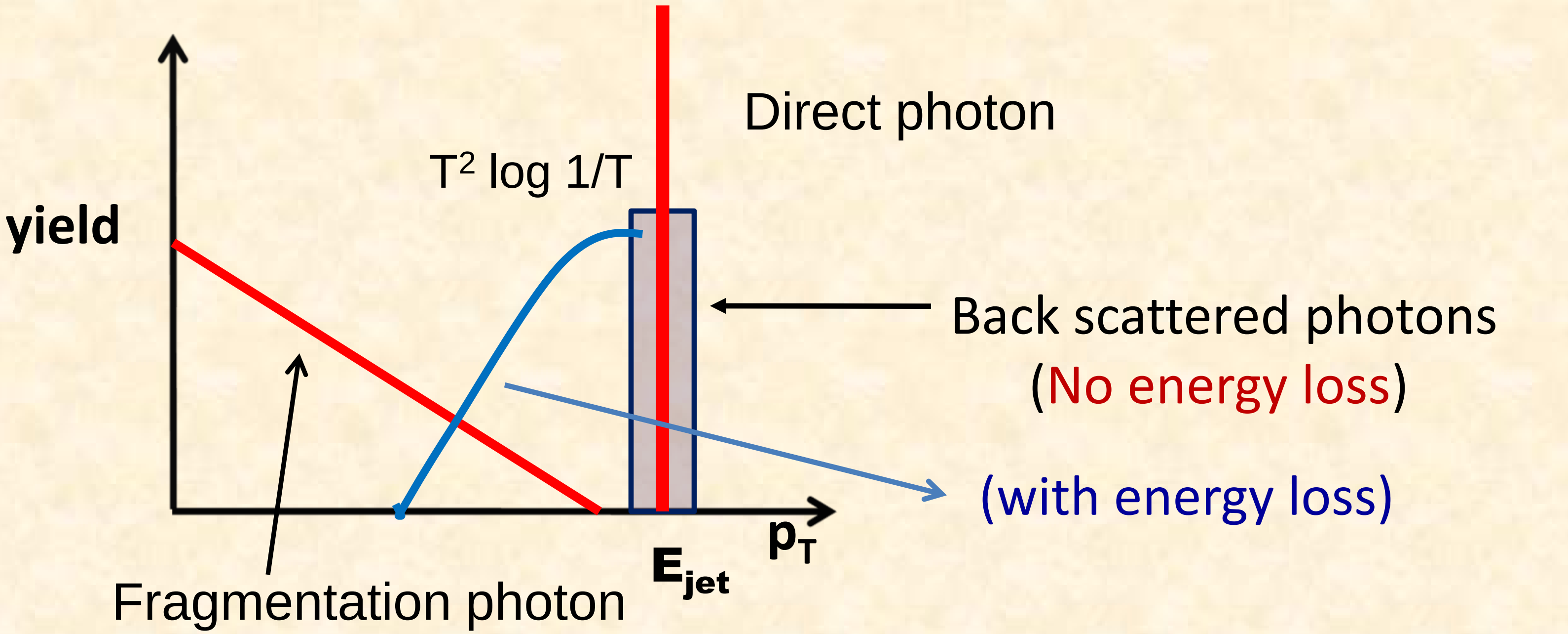
Path travelled by the jet:

$$I_\beta(\vec{r},\varphi) = \int d\tau \tau^\beta \rho(\vec{r} + \tau \vec{e}_\varphi)$$

We have used LPM type of energy loss; β=1 $\Delta E = C_{LPM} I_1(r,\varphi)$

The coeff. C_{LPM} is determined from the fitting of R_{AA} of hadrons

Jet- tagged photons at Leading order: a schematic view

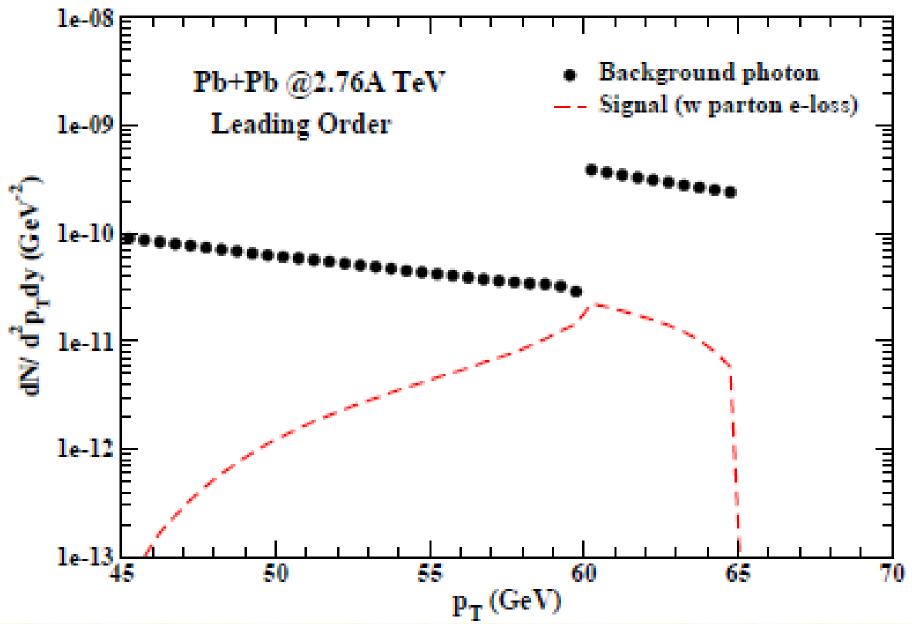


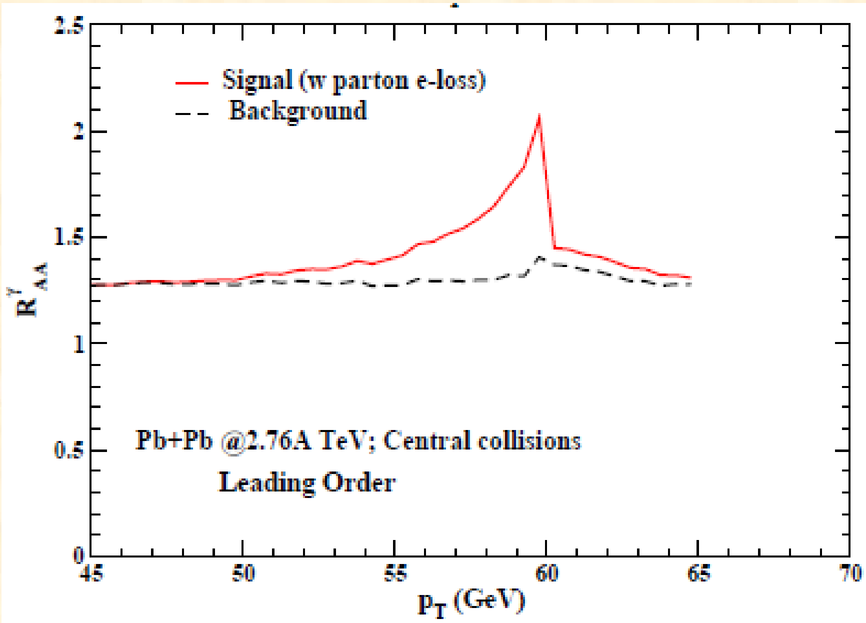
- Important Information: Temperature of the medium
  Energy loss of partons before back-scattering

QCD back-scattering photons at LHC : LO

R_{AA} : $(\text{Signal} + \text{Background})_{AA} \;/\; N_{coll} \times (\text{Background})_{pp}$

- For central Pb+Pb collisions at 2.76 TeV at mid rapidity
- Photons opposite to the 60-65 GeV jet within ± 15 degrees
- The quarks suffer energy loss before conversion

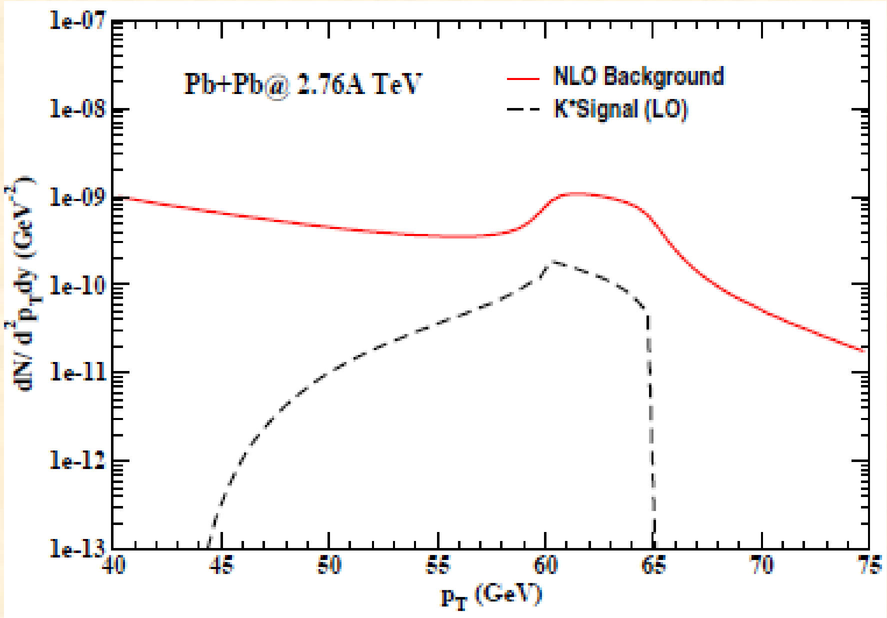


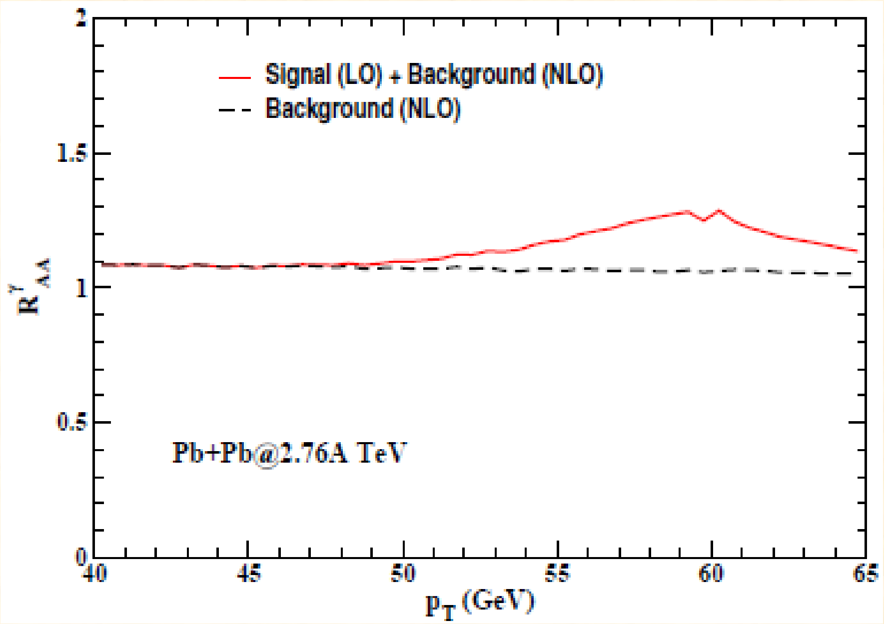


A clear back scattering peak can be seen just below trigger window

QCD back-scattering photons at LHC : NLO

- Back ground is calculated in the Next-to Leading order
- Kinematics of jet-conversion is still leading order
- Parton energy loss is accounted





Signal weakens but survives at NLO

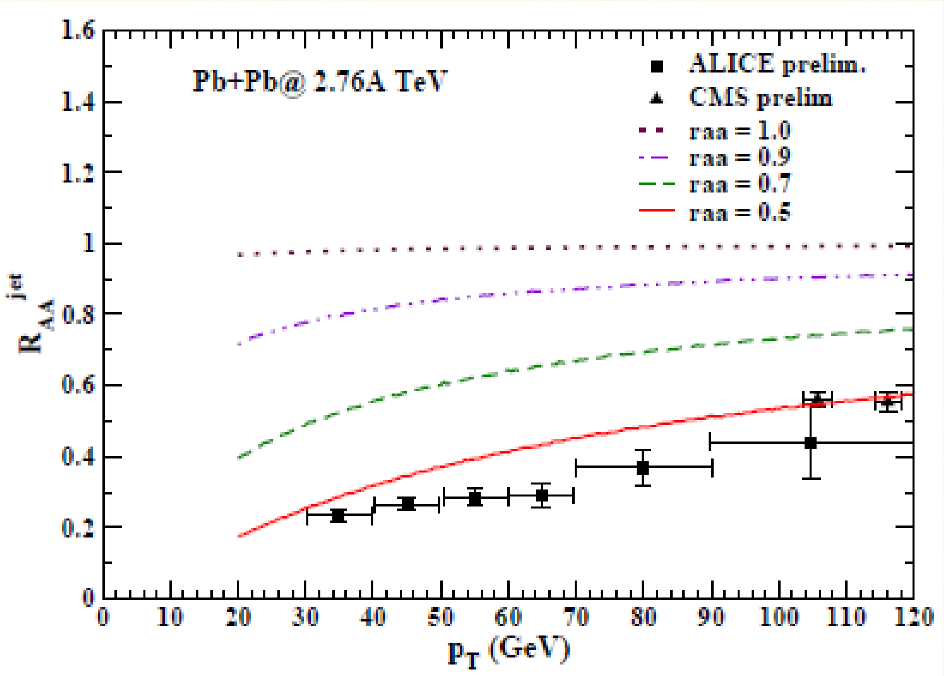
Effect of trigger jet energy loss

❖ Recent measurements at LHC (arXiv:1304.5945, PLB 2015) suggest a strong suppression of trigger jets in central collisions.

We model the trigger jet energy loss as:

$$\frac{dE_T}{d\tau} = -\hat{r}\ln\left(\frac{E_T}{\Lambda}\right)$$

$\hat{r}$ is proportional to local entropy density, Λ= 0.2 GeV



SD, R J Fries, D K Srivastava
PRC 90 (2014)

➢ Trigger jet energy loss affects the Background (direct and fragmentation photon) and as well as the Signal

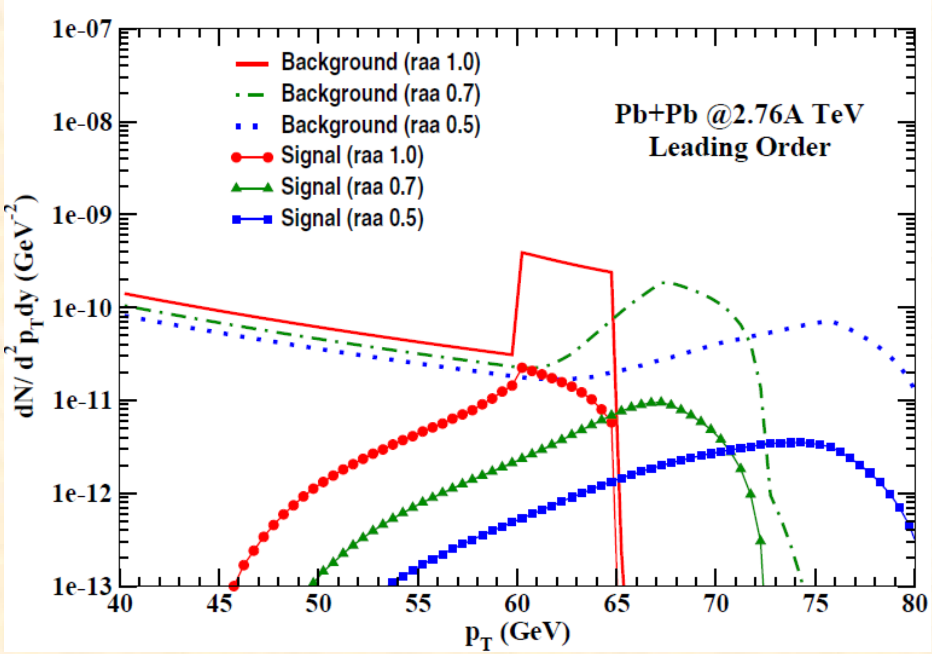
The parton-jet pair distribution:

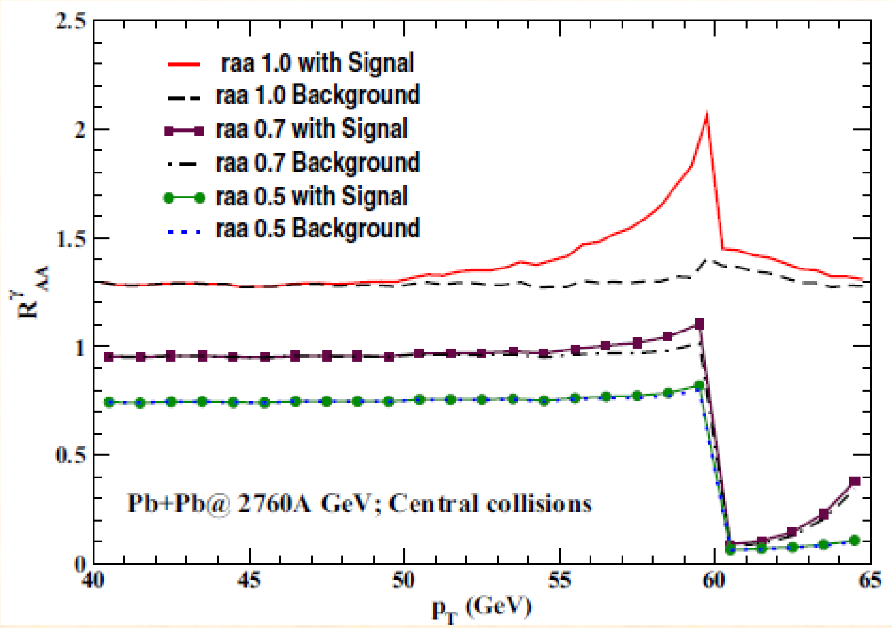
The parton-jet pair distribution integrated over a window Γ in E_T - ϕ-η space

$$f_q^{\mathcal{T}_\jmath}(\mathbf{p}_q, x) = \frac{(2\pi)^3}{g_q \tau p_T} \delta(y-\eta) \rho(\tau, \mathbf{x}_\perp^0) \times \int_{\mathcal{T}_\jmath} dE_T \, dy_j \, d\phi_j \, E_q \frac{dN}{d^3p_q \, dE_T \, dy_j \, d\phi_j} \Bigg|_{\substack{\mathbf{p}_q^0 = \mathbf{p}_q + \Delta \mathbf{p}_q \\ E_T^0 = E_T + \Delta E_T}}$$

- The parton-jet pair are evolved through the medium while their respective energy losses are also accounted.
- The parton back-scattering probability is also computed along the way.

❑Background and Signal: w trigger jet energy loss





SD, R J Fries, D K Srivastava
PRC 90 (2014)

- **Signal and Background are calculated for Leading order kinematics**
- **Both trigger jet and parton energy loss are taken into account**
- **Trigger jet energy loss tends to wash out the strong correlation with parent jet**

Summary & Conclusion:

- Jet-medium back scattering photon is an important signature of thermalized matter created in relativistic heavy ion collisions.
- We propose the use of trigger jet to identify this particular source of direct photons.
- Jet-medium photons shows characteristic enhancement in the nuclear modification factor of direct photon production at large momentum.
- The peak is clearly visible in Leading order but weakens for the radiative corrections to the process and trigger jet energy loss.
- The shift of the peak from the trigger jet window provides complimentary measure of parton energy loss in the medium.
- Separation of this signal from other photon sources depends crucially on the initial trigger jet energy estimation.


Thank you
STAR

Jet-Photon Conversion

The rate of production:

$$E_\gamma \frac{dN^{(A)}}{d^4x d^3p_\gamma} = \frac{16E_\gamma}{2(2\pi)^6} \sum_{q=1}^{N_f} f_q(p_\gamma)$$

$$\times \int d^3p\, f_{\bar{q}}(p)[1 + f_g(p)]\sigma^{(A)}(s) \frac{\sqrt{s(s-4m^2)}}{2E_\gamma E} + (q \leftrightarrow \bar{q})$$

$$E_\gamma \frac{dN^{(C)}}{d^4x d^3p_\gamma} = \frac{16E_\gamma}{2(2\pi)^6} \sum_{q=1}^{N_f} f_q(p_\gamma)$$

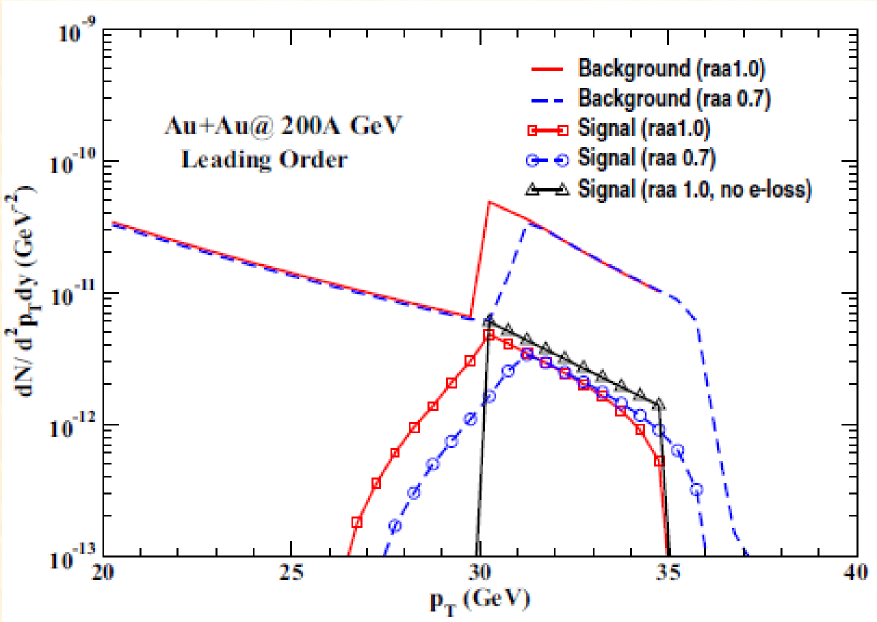
$$\times \int d^3p\, f_g(p)[1 - f_q(p)]\sigma^{(C)}(s) \frac{s-m^2}{2E_\gamma E} + (q \leftrightarrow \bar{q})$$

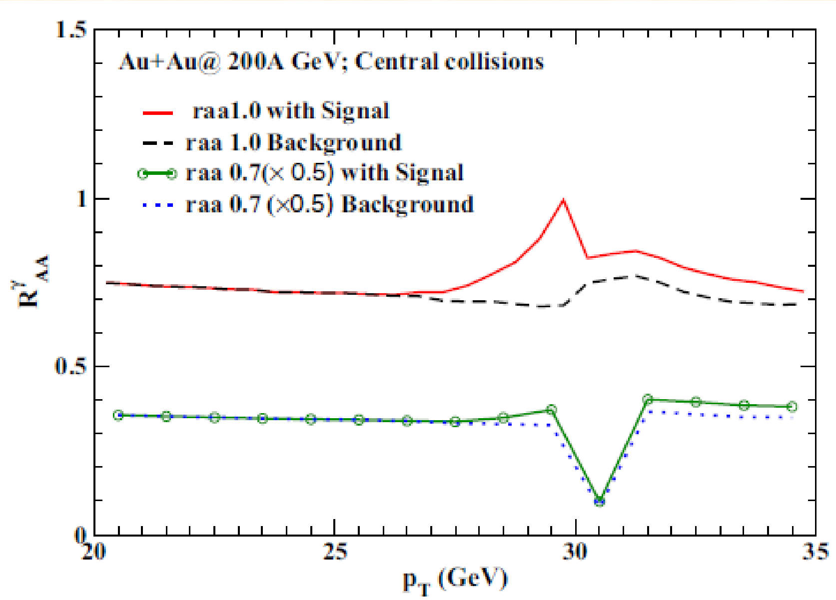
$$f^q(p) = f^{jet}(p) + f^{th}(p)$$

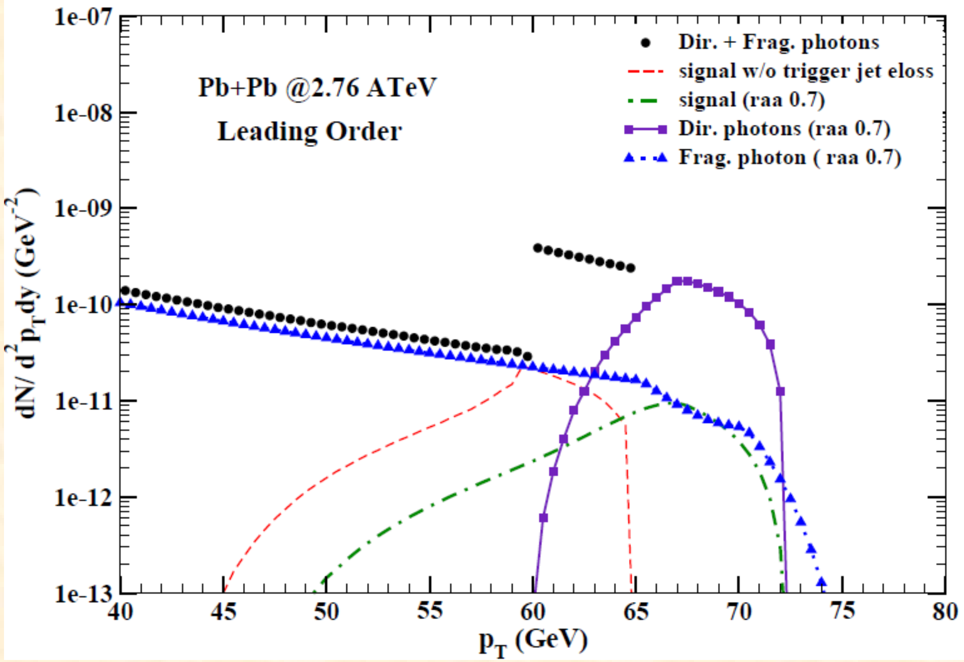
$$dN^\gamma = f_{th} \otimes f_{th} + f_{th} \otimes f_{jet} + \ldots.$$

Jet-converted photons

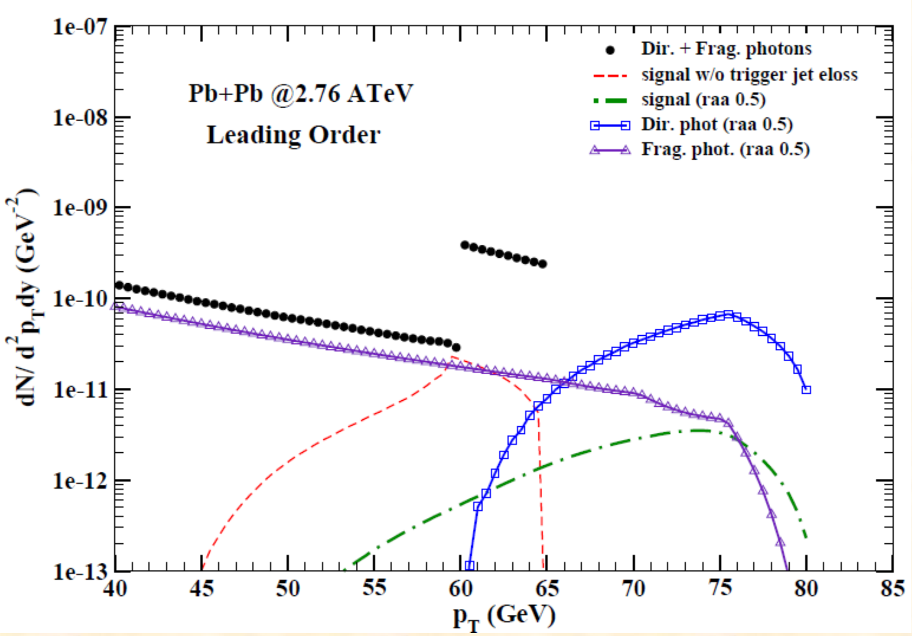
Results at RHIC energy







Pb+Pb @2.76 ATeV
Leading Order
Dir. + Frag. photons
signal w/o trigger jet eloss
signal (raa 0.7)
Dir. photons (raa 0.7)
Frag. photon (raa 0.7)
dN/ d^2p_T dy (GeV^-2)
p_T (GeV)



Pb+Pb @2.76 ATeV
Leading Order
Dir. + Frag. photons
signal w/o trigger jet eloss
signal (raa 0.5)
Dir. phot (raa 0.5)
Frag. phot. (raa 0.5)
dN/ d^2p_T dy (GeV^-2)
p_T (GeV)