Fast generators of direct photons

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- Introduction
- Prompt photons
- Thermal photons in 1+1 hydrodynamics
  - Hot Hadron Gas (HHG) scenario
  - Qurk Gluon Plasma (QGP) scenario
- Summary

Introduction - definitions

- **Direct photons**: not from hadron decays
- ***Quark gluon level***:
  - qq → gγ, qg → qγ, qq(g) → qq(g)γ.

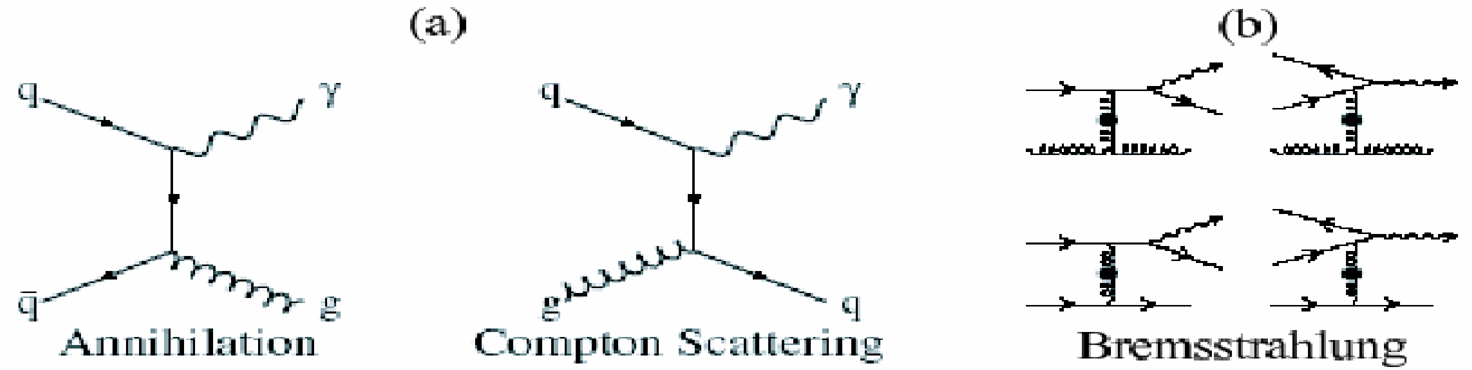


Fig. 1. Photon production in (a) leading order process, and (b) next-to-leading order process.

  - Initial hard NN collisions, pQCD → prompt γ.
  - Thermalised QGP stage → thermal γ from QGP.

Introduction – definitions

- ***Hadron level***:
  - meson scatterings: $\pi\pi \rightarrow \rho\gamma$, $\pi\rho \rightarrow \pi\gamma$, $\pi K \rightarrow K^*\gamma$, $K\rho \rightarrow K\gamma$, $KK^* \rightarrow \pi\gamma$, $\pi K^* \rightarrow K\gamma$, . . .
  - Thermalised hadron stage → thermal γ from HHG
- **Decay photons**:
  - Long lived ($c\tau \gg c\tau_{AB} \sim$ 50-100 fm)
    $\pi^0 \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\gamma$, $\eta' \rightarrow \rho\gamma/\omega\gamma/2\gamma$
  - Shot lived ($c\tau \leq c\tau_{AB} \sim$ 50-100 fm)
    $\omega \rightarrow \pi\gamma$, $\rho \rightarrow \pi\pi\gamma$, $a_1 \rightarrow \pi\gamma$, $\Delta \rightarrow N\gamma$, $K^* \rightarrow K\gamma$, $\phi \rightarrow \eta\gamma$, . . . In the dense nuclear matter can not be reconstructed in an experiment → direct photons

Prompt photons: pp data fit + binary scaling

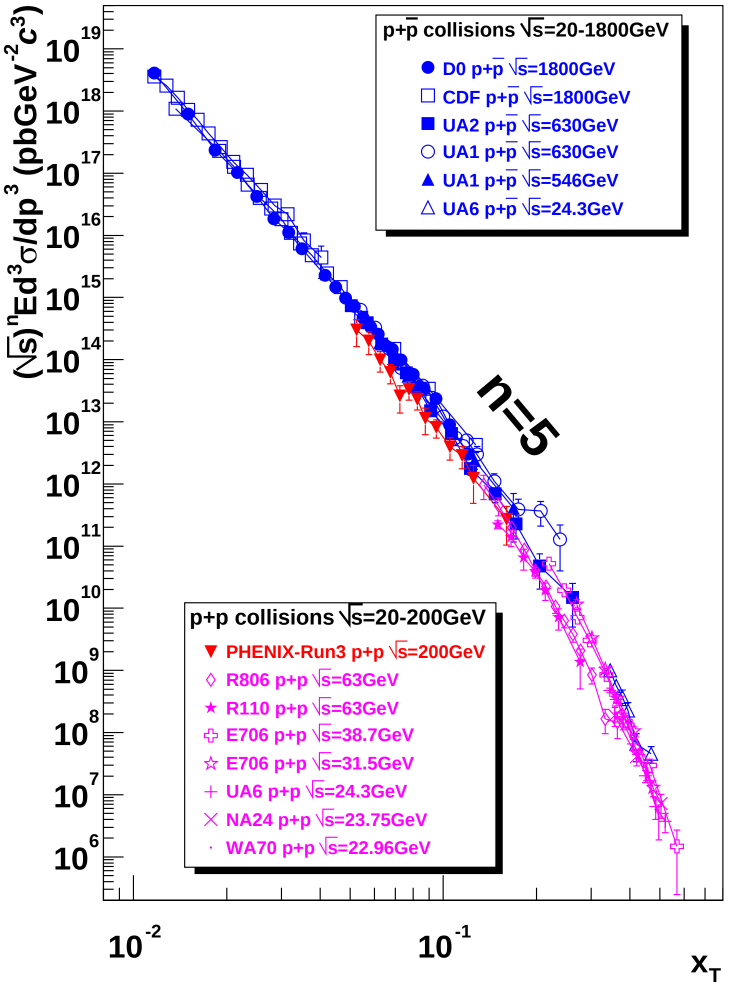
- PHENIX hep-ph/0609037
  $(\sqrt{s})^5\, Ed^3\sigma/d^3p = F(x_T,y)$
- One can use a data tabulation of the $F(x_T,y)$ to generate prompt photons.
- A+B:

$Ed^3N/d^3p(b)=$

$Ed^3\sigma_{pp}/d^3p\ AB\ T_{AB}(b)=$

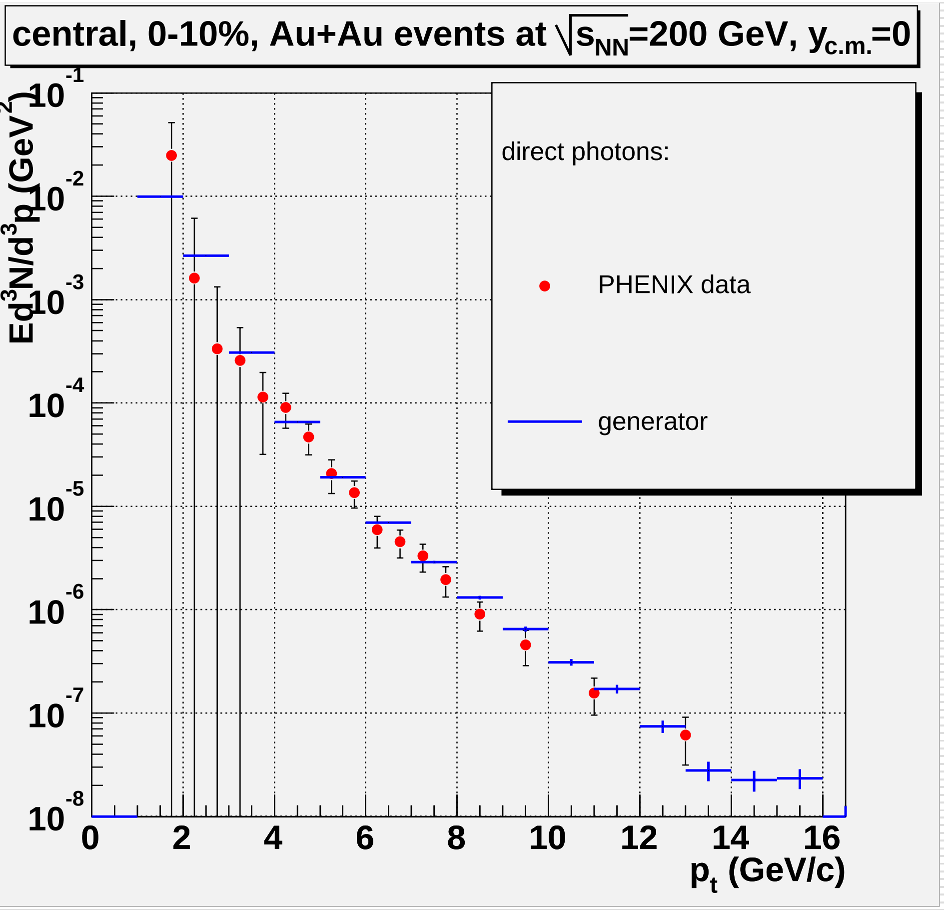
$Ed^3\sigma_{pp}/d^3p\ N_{coll}(b)/\sigma_{pp}^{in}$

- Nuclear effects (Cronin, quenching, …) are not taken into account.
- Realization: GePP.C macros for the ROOT package (http://root.cern.ch)

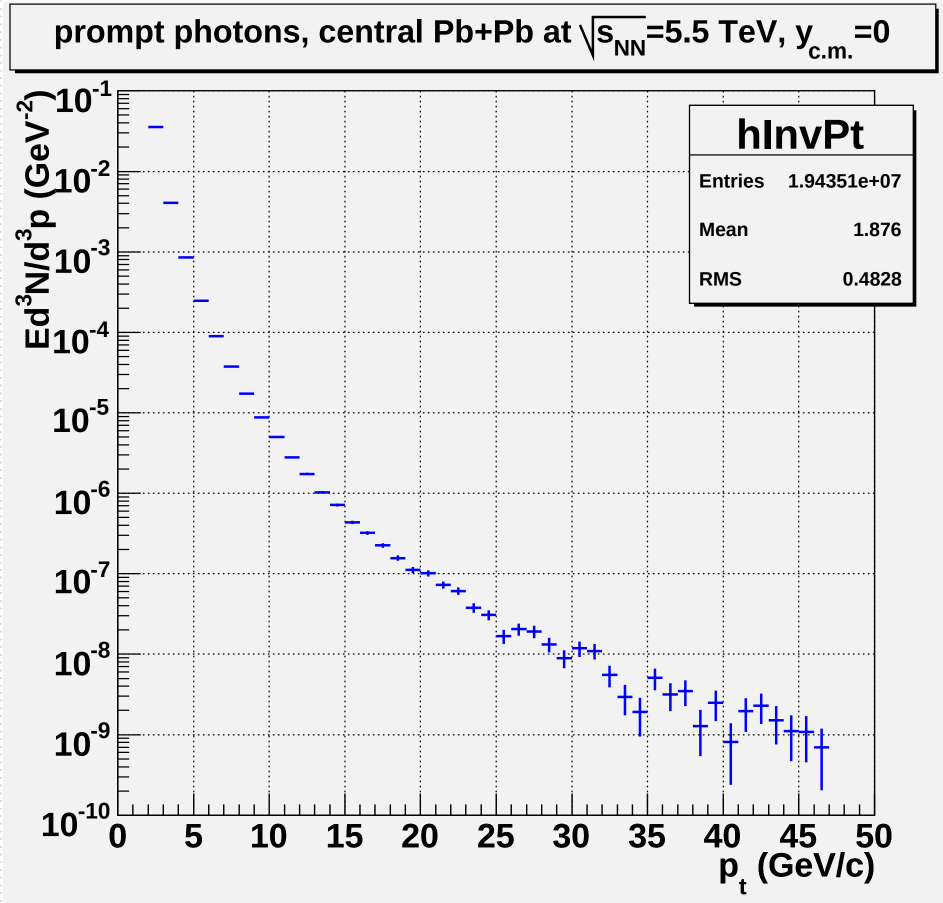


GePP: results

Comparison with RHIC data



Prediction for LHC

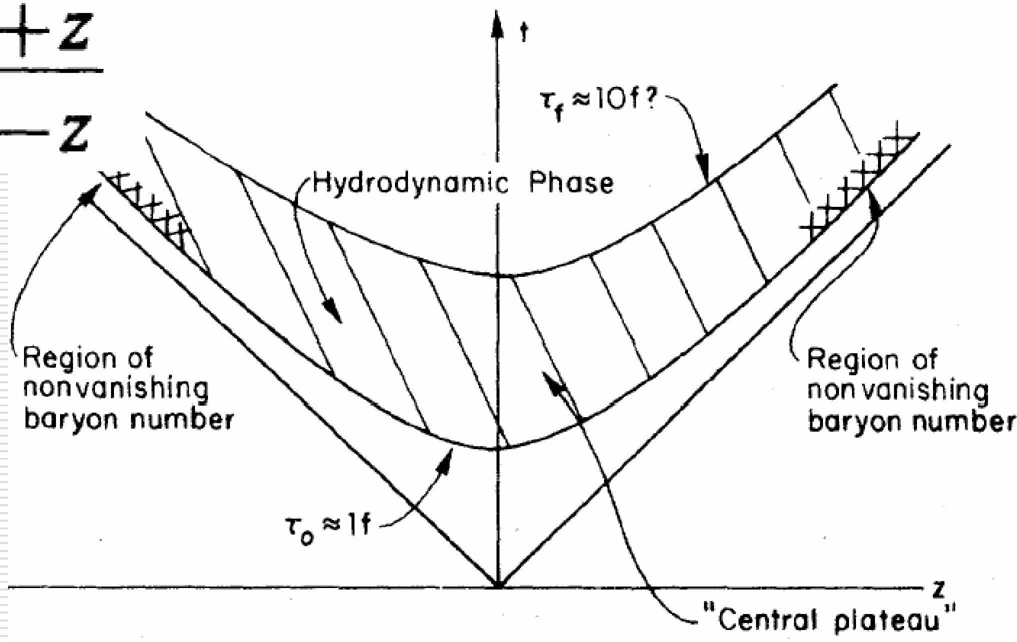


Bjorken -(1+1)-HydroDynamics (BHD)

Phys.Rev.**D27**(1983)140

Proper time τ and rapidity y

$$\tau=(t^2-z^2)^{1/2} \qquad y=\frac{1}{2}\ln\frac{t+z}{t-z}$$



There is no dependence on Lorenz boost variable y:

$$\epsilon=\epsilon(\tau)\ ,$$

$$p=p(\tau)\ ,$$

$$\beta=T^{-1}=\beta(\tau)\ ,$$

Landau hydrodynamical model, viscosity and conductivity are neglected

Photon spectrum in BHD Phys.Rep.364(2002)98

Photon spectra follow from convoluting the photon production rates with the space–time evolution

$$E\frac{dN}{d^3p} = \int d^4x E \frac{dN}{d^4x\,d^3p}$$

For a longitudinally expanding cylinder

$$\int d^4x = \pi R_A^2 \int dt\,dz$$

For proper time τ and rapidity y`

$$\int dt\,dz = \int_{\tau_0}^{\tau_f} d\tau\,\tau \int_{-y_{nucl}}^{+y_{nucl}} dy'$$

$$\frac{dN}{d^2p_\perp dy} = \pi R_A^2 \int_{\tau_0}^{\tau_f} d\tau\,\tau \int_{-y_{nucl}}^{+y_{nucl}} dy' E \frac{dN}{d^4x\,d^3p}$$

Input function – production rate $E\ dN/d^4xd^3p\ (E,T)$

Connection with the local rest frame $E = p_T \cosh(y' - y)$

For an ideal gas $T = T_0(\tau_0/\tau)^{1/3}$

Main parameters: initial τ_0 , T_0 and T_f (at freeze-out)

$\tau_0 \leftrightarrow$ yield, $T_0 \leftrightarrow$ spectrum slope

$T_f \leftrightarrow$ weak sensitivity, $T_f = 100$ MeV

HHG scenario

- C.Song, Phys.Rev.**C47**(1993)2861 an effective chiral Lagrangian with π, ρ and a_1 mesons to calculate the processes $\pi\pi \to \rho\gamma$, $\pi\rho \to \pi\gamma$, and $\rho \to \pi\pi\gamma$.
- C.Song and G.Fai, Phys.Rev.**C58**(1998)1689.

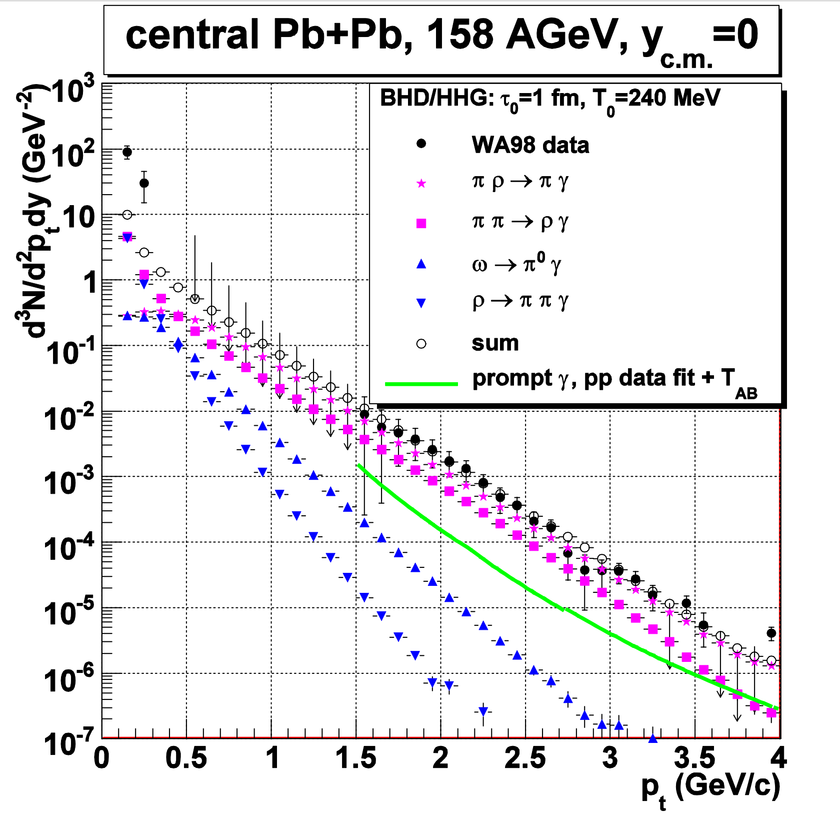
  parameterizations for photon rates.

$$E \frac{dN}{d^4x\, d^3p}\bigg|_{\text{process}} = T^2 e^{-E/T} F_{\text{process}}(T/m_\pi, E/m_\pi)$$

Realization: GeTP_HHG.C macros for ROOT

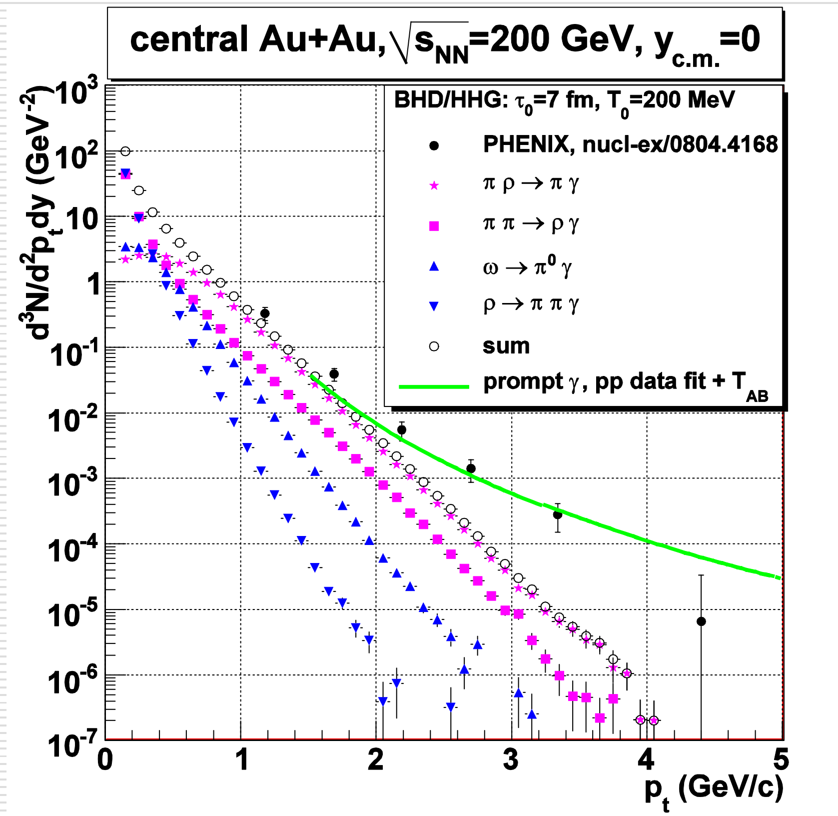
GeTP_HHG: SPS and RHIC data

SPS



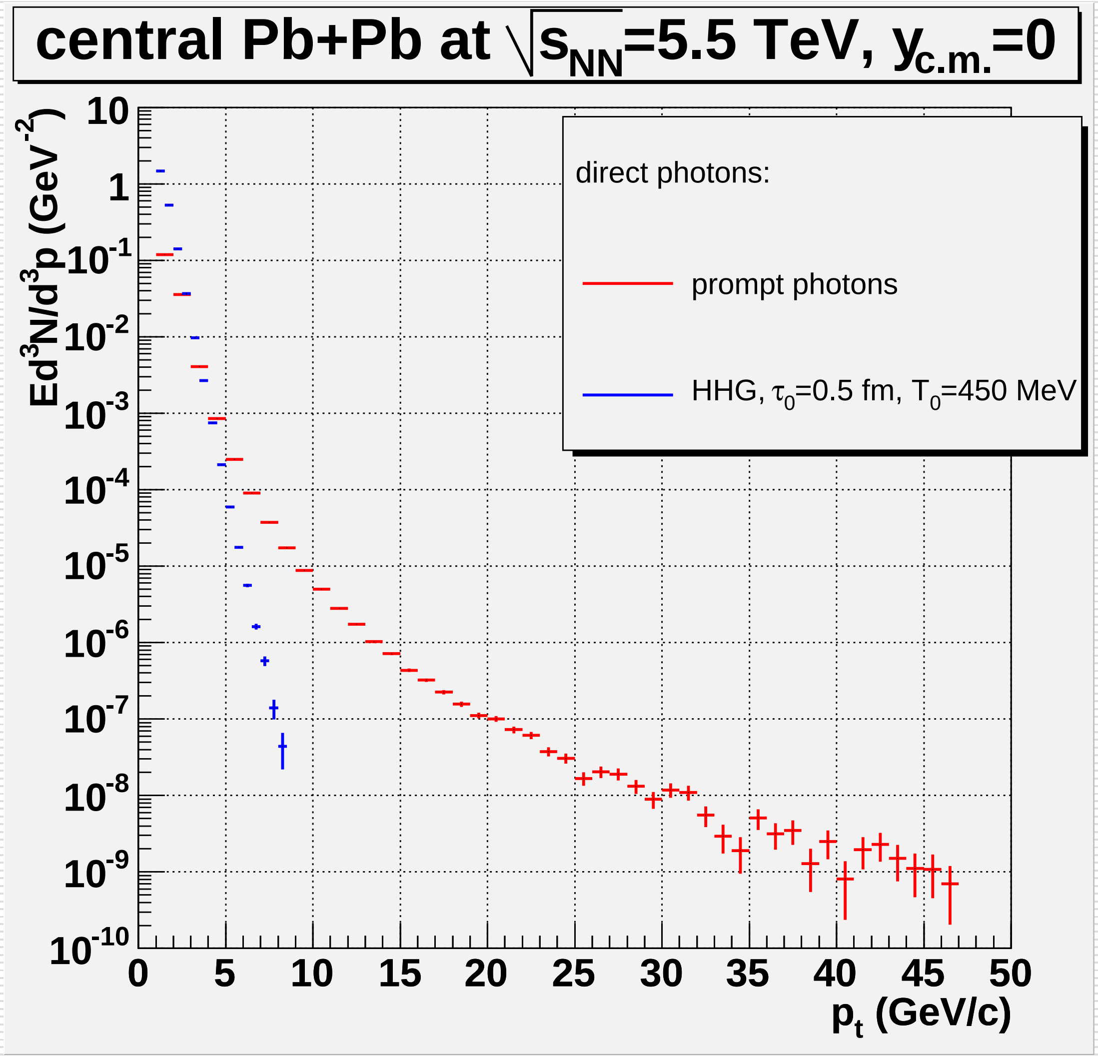
one can fit SPS data at high p_t

RHIC



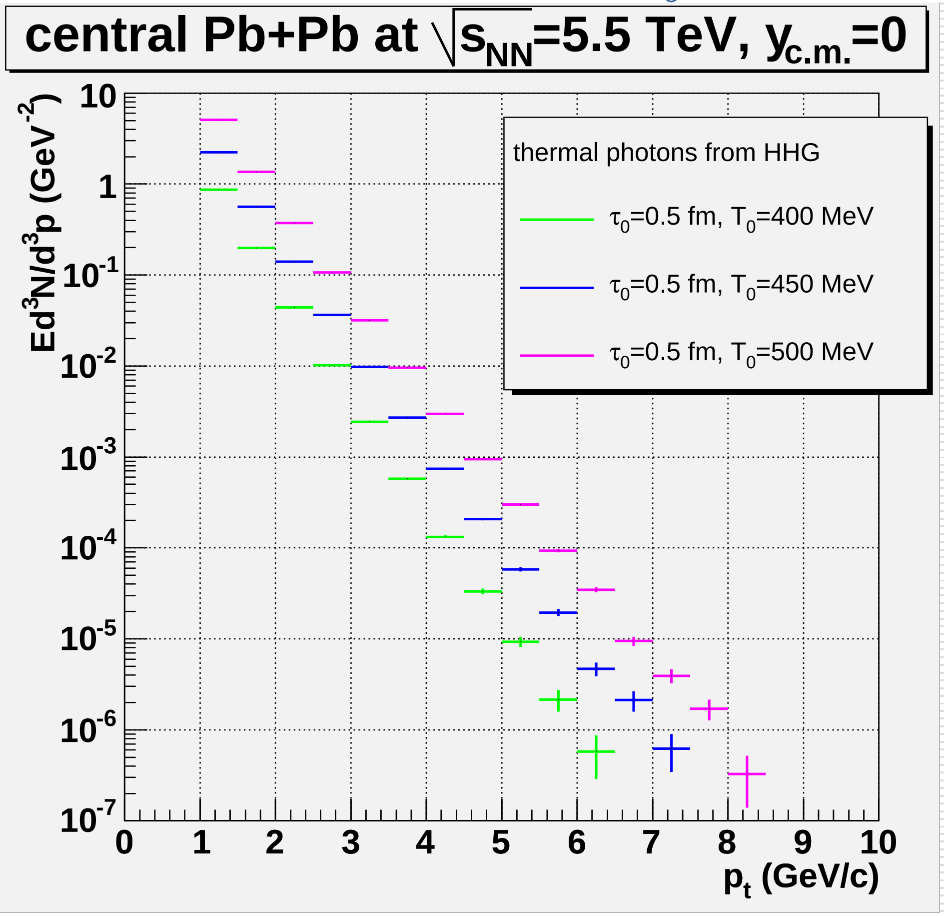
one can fit RHIC data but with not reasonable parameters

GeTP_HHG: prediction for LHC

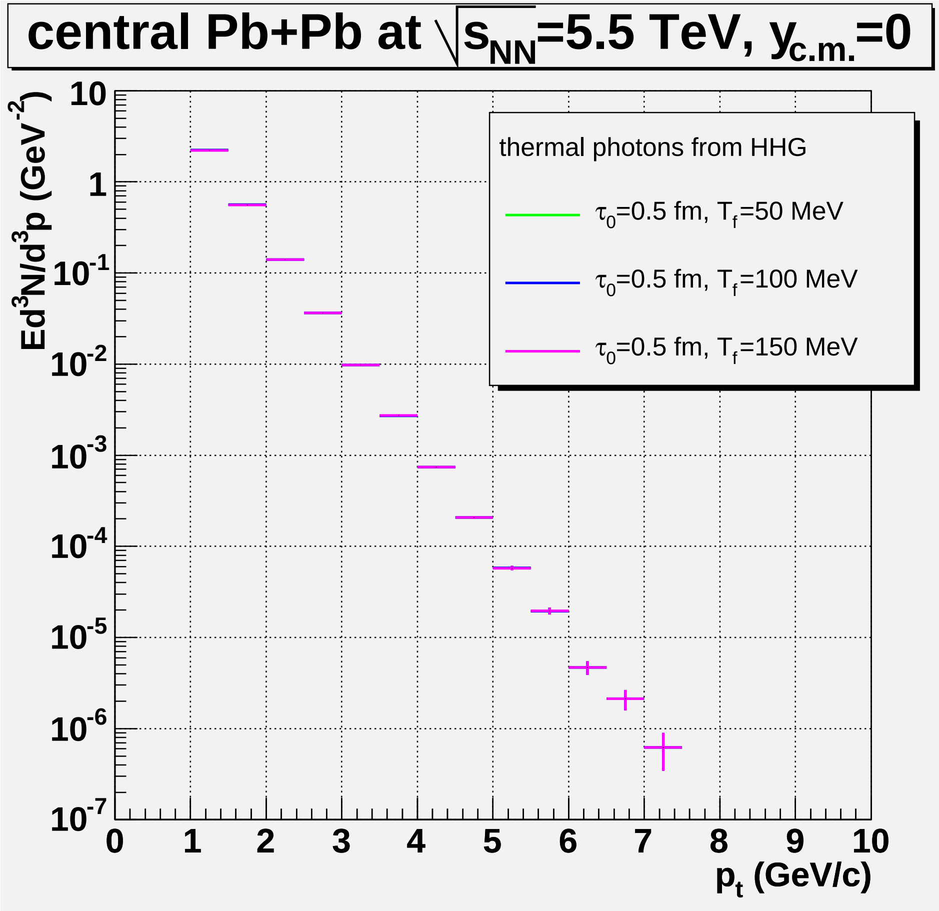


GeTP_HHG: sensitivity to the parameters

sensitivity to T_0



sensitivity to T_f



QGP scenario: QGP and HHG phases

QGP: ideal massless parton gas (μ_q =0)

$$\begin{aligned} P_q &= g_q \frac{\pi^2}{90} T^4 - B, \\ \varepsilon_q &= g_q \frac{\pi^2}{30} T^4 + B, \\ s_q &= g_q \frac{2\pi^2}{45} T^3, \end{aligned}$$

B bag constant

HHG: ideal massless pion gas

$$\begin{aligned} P_h &= g_h \frac{\pi^2}{90} T^4, \\ \varepsilon_h &= g_h \frac{\pi^2}{30} T^4, \\ s_h &= g_h \frac{2\pi^2}{45} T^3, \end{aligned}$$

g number of degrees of freedom

$$g_q = 2\,(N_c^2 - 1) + \left(\frac{7}{8}\right) 4\, N_c\, N_f$$

N_c colors
N_f flavors

$$g_h = 3.$$

$$\varepsilon_q = 3P_q + 4B.$$

$$\varepsilon_h = 3P_h.$$

First order phase transition at critical temperature T_c

$$\begin{aligned} T_c^q &= T_c^h = T_c, \\ P_c^q &= P_c^h = P_c, \end{aligned}$$

$$T_c = \sqrt[4]{\frac{90B}{(g_q - g_h)\pi^2}}.$$

QGP scenario: mixed phase

Mixed phase

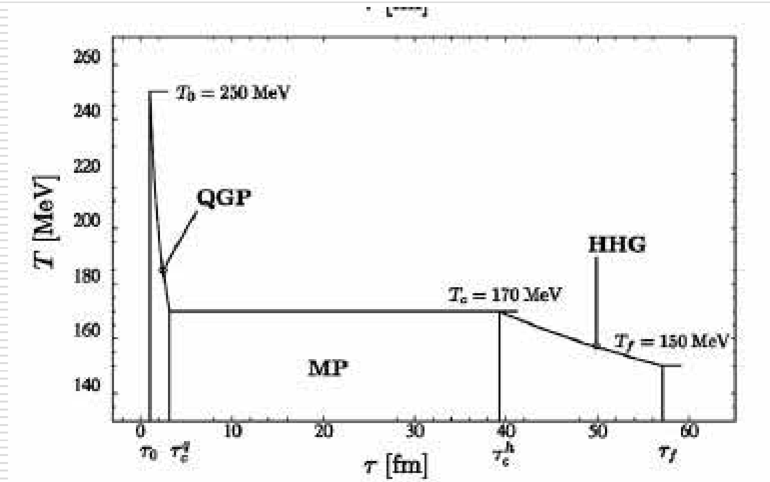
$$\left(E\frac{dN}{d^4x\,d^3p}\right)_{(LR)} = \lambda\left(E\frac{dN}{d^4x\,d^3p}\right)^{QGP}_{(LR)} + [1-\lambda]\left(E,\frac{dN}{d^4x\,d^3p}\right)^{HHG}_{(LR)}$$

$$\lambda(\tau) = \frac{V_q(\tau)}{V_{tot}(\tau)} = \frac{V_q(\tau)}{V_q(\tau)+V_h(\tau)},$$

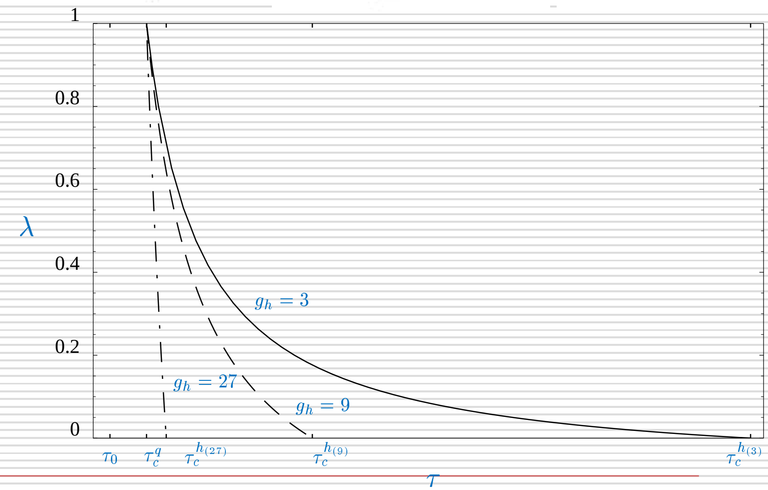
$$\lambda(\tau) = \left(\frac{g_q}{g_q-g_h}\right)\left(\frac{T_0}{T_c}\right)^3\left(\frac{\tau_0}{\tau}\right) - \left(\frac{g_h}{g_q-g_h}\right)$$

$$T_q(\tau) = T_0\left(\frac{\tau_0}{\tau}\right)^{1/3}$$

$$T_h(\tau) = T_c\left(\frac{\tau_c^h}{\tau}\right)^{1/3}$$



$$\tau_c^q = \left(\frac{T_0}{T_c}\right)^3\tau_0 \qquad \tau_c^h = \frac{g_q}{g_h}\left(\frac{T_0}{T_c}\right)^3\tau_0 \qquad \tau_f = \frac{g_q}{g_h}\left(\frac{T_0}{T_f}\right)^3\tau_0$$



Additional parameters: T_c and g_h

T_c =170 MeV, g_h = 8 (to fit SPS data)

Rates from QGP -1st order

Perturbative thermal QCD applying Hard Thermal Loop (HTL) resummation

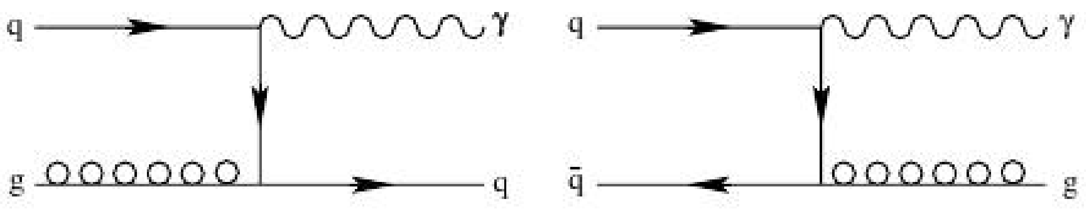


Fig. 1. Lowest order contributions to photon production from the QGP: Compton scattering (left) and quark–antiquark annihilation (right).

$$\left.\frac{dN}{d^4x\, d^3p}\right|_{1\text{-loop}} = a\alpha\alpha_s e^{-E/T}\frac{T^2}{E}\ln\frac{0.2317E}{\alpha_s T},$$

where $a = 0.0281$ for $N_F = 2$ thermalized quark flavors and $a = 0.0338$ for $N_F = 3$, respectively.

$$\alpha_s(T) = \frac{6\pi}{(33 - 2N_f)\ln(8T/T_c)}.$$

Rates from QGP -2nd order

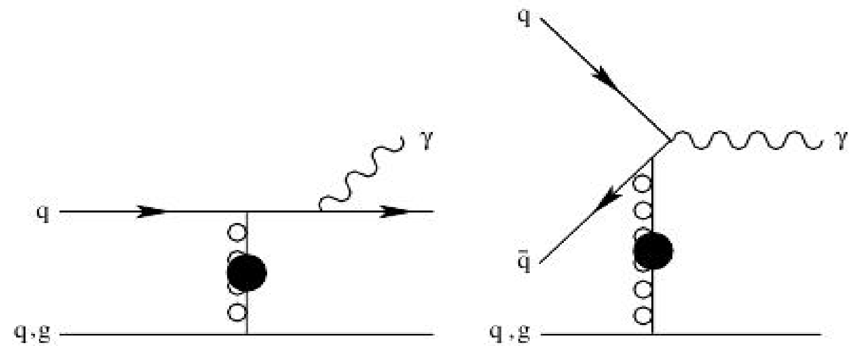


Fig. 5. Photon production processes corresponding to the 2-loop HTL contribution: bremsstrahlung (left) and annihilation with scattering (right). The filled circles indicate HTL resummed gluon propagators. The lower line indicates either a quark or a gluon.

$$\left.\frac{dN}{d^4x\, d^3p}\right|_{\text{brems}} = b\alpha\alpha_s e^{-E/T}\frac{T^2}{E},$$

where $b=0.0219$ for $N_F=2$ and $b=0.0281$ for $N_F=3$, respectively. (aws) in Fig. 5 leads to

$$\left.\frac{dN}{d^4x\, d^3p}\right|_{\text{aws}} = c\alpha\alpha_s e^{-E/T} T,$$

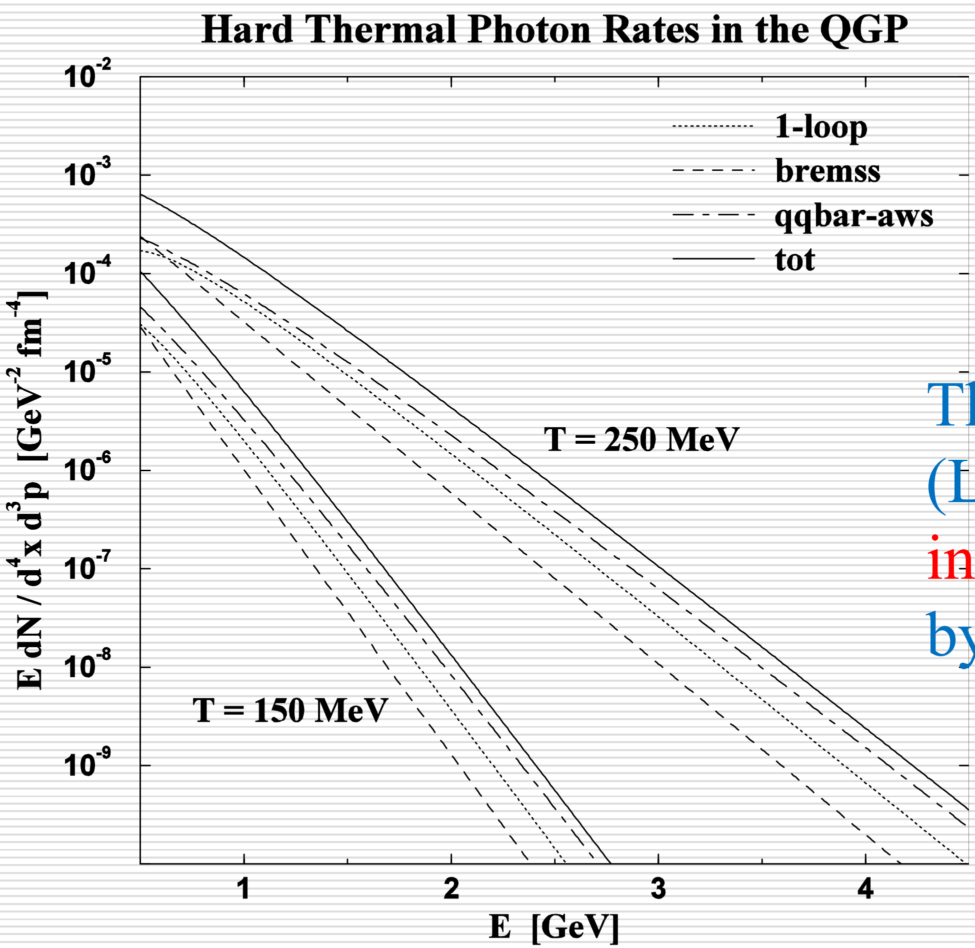
where $c=0.0105$ for $N_F=2$ and $c=0.0135$ for $N_F=3$, respectively.[7]

2-loop contribution is the same order in α_s
3-loop ….

Thermal photon production in the QGP is a non-perturbative mechanism that can not be accessed in perturbative HTL resummed thermal field theory

One must consider the QGP rates as an educated guess. PL B510(2001)98

Rates from QGP

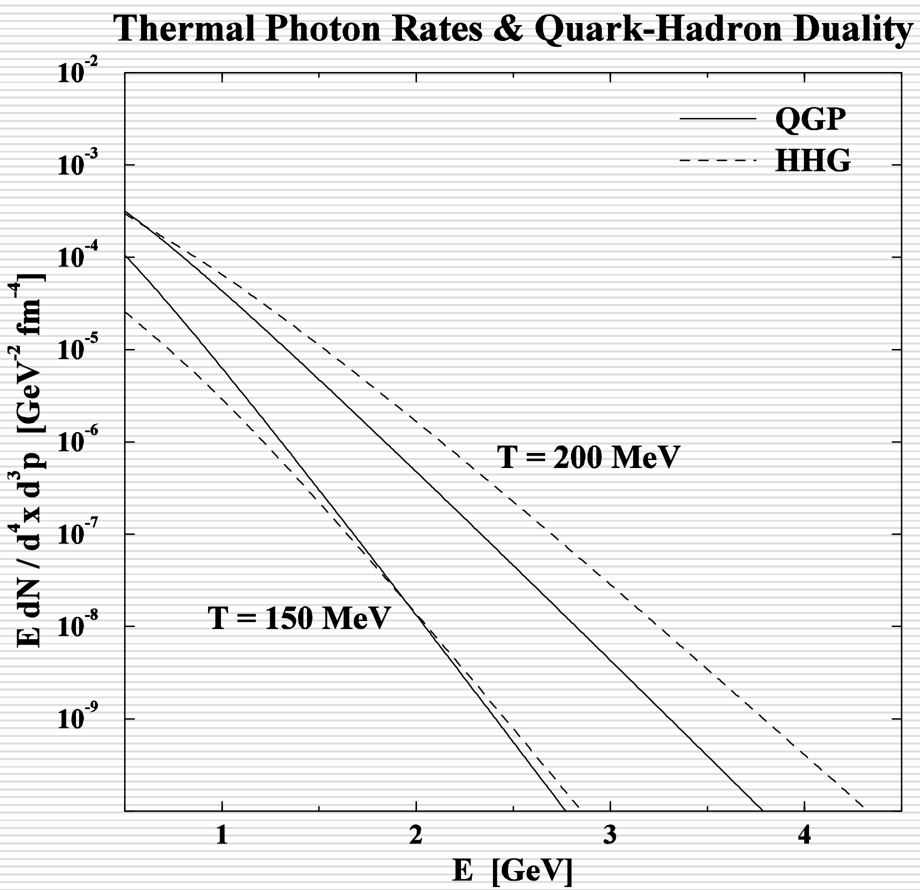


Annihilation with scattering (aws) dominates at high E

The Landau-Pomeranchuk-Migdal (LPM) effect (not taken into account in out study) reduces the 2-loop rates by ~30% in E/T > 1

Realization: GeTP_QGP.C macros for ROOT

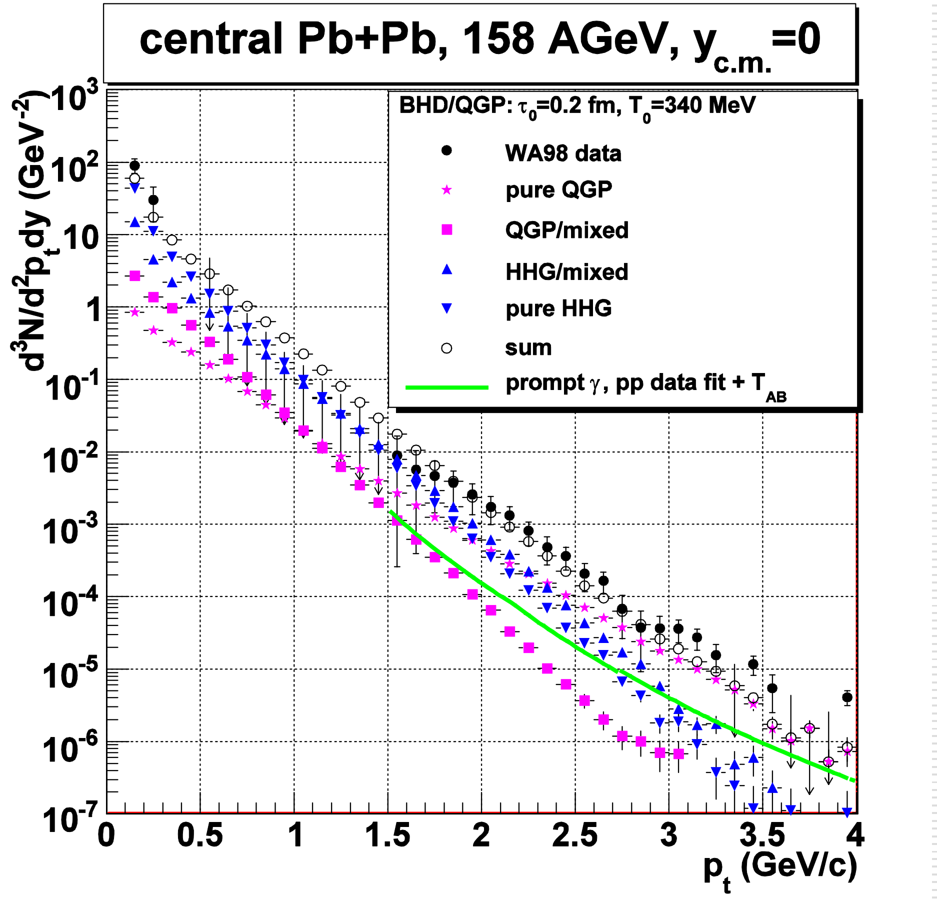
Rates: QGP vs HHG



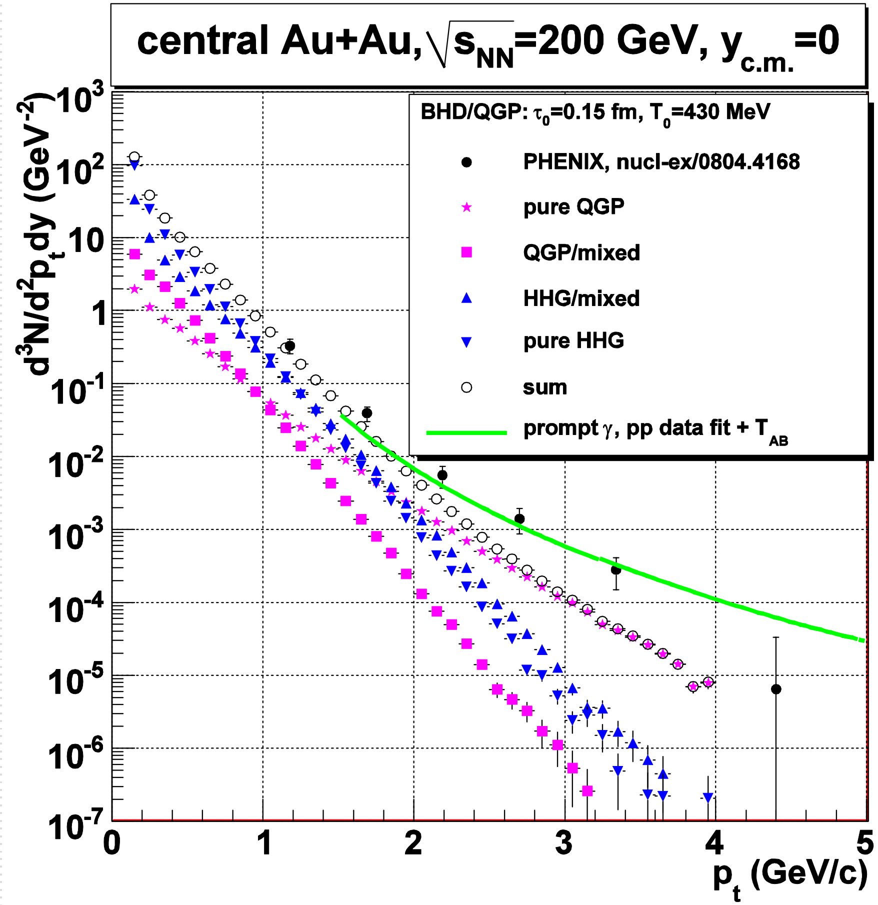
Steeper spectra from QGP

GeTP_QGP: SPS and RHIC data

SPS

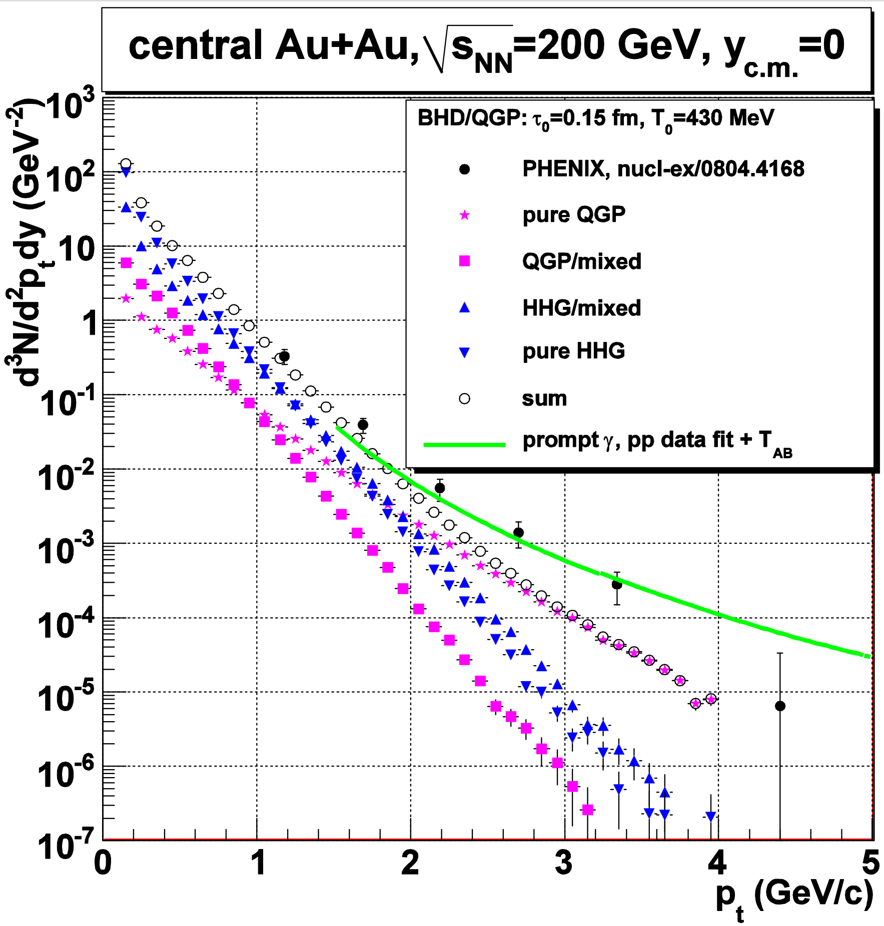


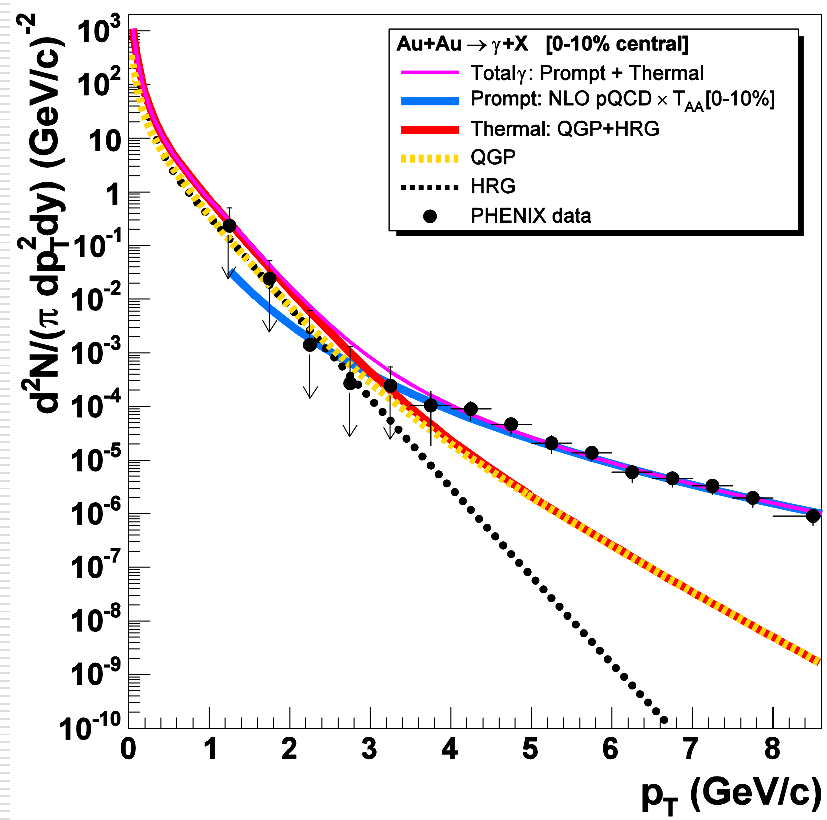
RHIC



GeTP_QGP: comparison with 2+1 hydro

D. d'Enterria and D. Peressounko, Eur. Phys. J. C **46**, 451 (2006)

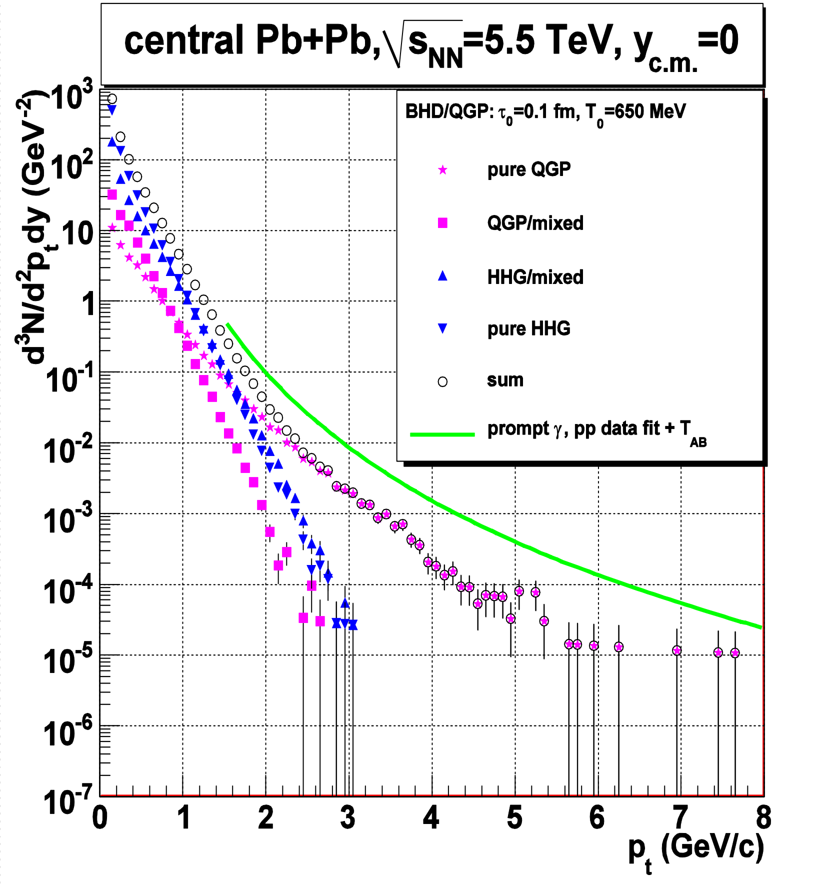


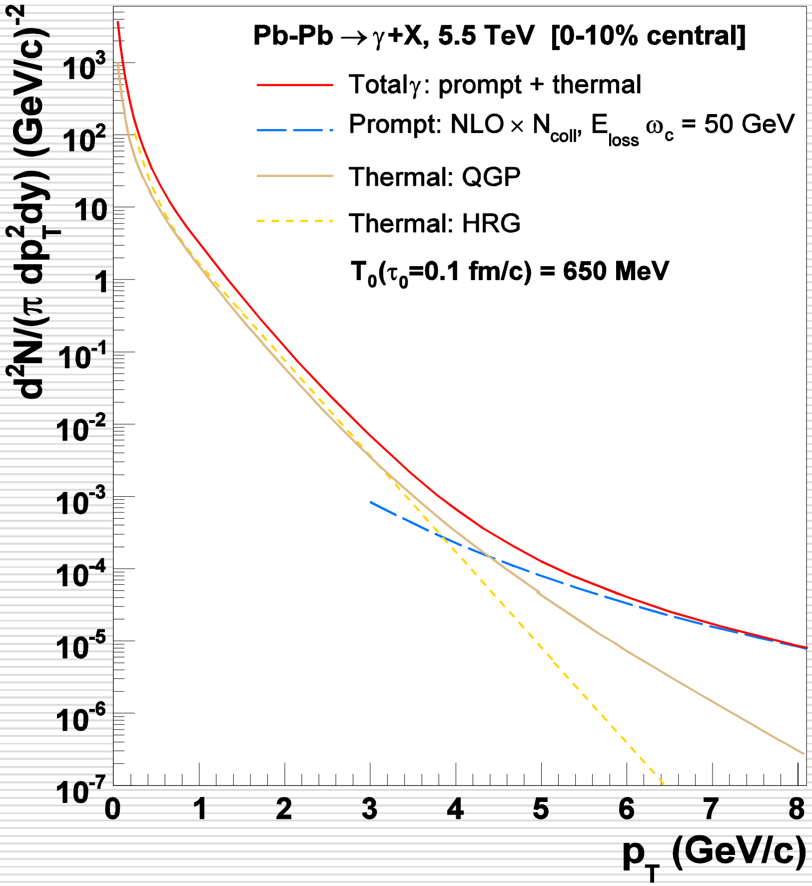


The same τ_0 , T_0: steeper HHG spectrum in 1+1 due to radial flow in 2+1

GeTP_QGP: prediction for LHC

2+1 hydro, F.Arleo, D. d'Enterria, D. Peressounko, nucl-th/0707.2357





GeTP_QGP: dN_γ/dy and …

T_c = 170 MeV, g_h = 8, T_f = 100 MeV

$\sqrt{s}$ GeV	T_0 MeV	τ_0 fm/c	τ_c^q fm/c	τ_c^h fm/c	τ_f fm/c	dN_γ/dy	INIT CPU
17	340	0.20	1.6	9.5	46.7	14	110 s
200	430	0.15	2.4	14.4	70.8	31	160 s
5500	650	0.10	5.6	33.2	163	173	390 s

Contribution of the QGP phases into dN/dy: ~ 10%

INIT CPU – CPU for initialization

Summary

- 3 fast generators of direct photons have been proposed:
  - GePP.C – prompt photons (pp data fit + binary scaling)
  - GeTP_HHG.C – thermal photons in the HHG scenario
  - GeTP_QGP.C – thermal photons in the QGP scenario

  in Bjorken (1+1) hydrodynamics

  other assumptions: ideal massless gas, $\mu_q = 0$,
  1^{st} order phase transition,
  QGP rates – educated guess
- One can fit SPS and RHIC data
- Predictions for LHC
- GePP.C, GeTP_HHG.C have been implemented, thanks to Ludmila Malinina, into the FASTMC code of the UHKM package (http://uhkm.jinr.ru).