# RHIC

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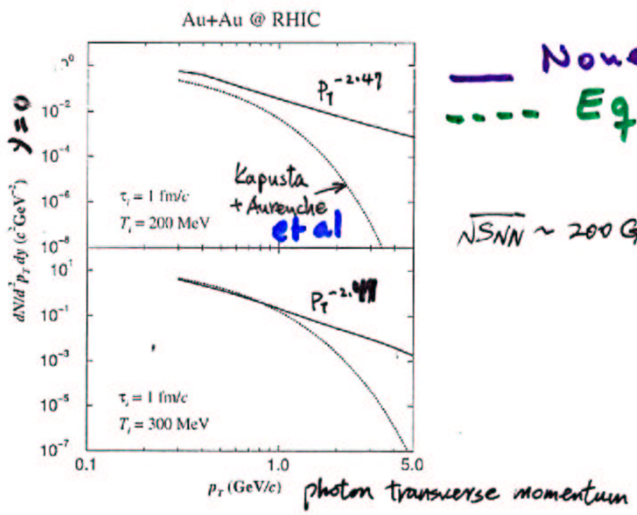
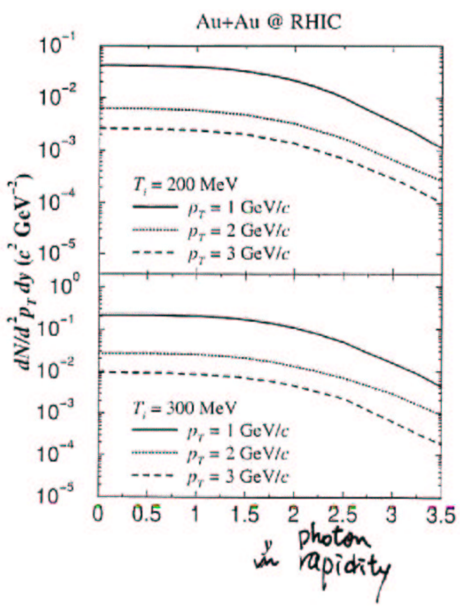
$R_A \approx 7\,fm$

$\eta_{cen} = 2$

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

$= 2$




10

Input in Hydro: Long. BJ.

Initialize at $\tau_i = 1\ fm/c$

go! Compute Yield at

$T(\tau) = 150$ MeV

Crank...

9

## CAVEAT:

Computed rate in $t - t_i \to \infty$ lim (several contribs. vanish!) BUT INPUT IN HYDRO and evolved during 10 - 20 fm/c !!

Proposal: DO NOT TAKE $t - t_i \to \infty$! KEEP EVERYTHING! (in P.T. in $\alpha_s$...)

$$k\frac{dN}{d^3k\,d^4x} = \alpha_{em}\int_{-\infty}^{\infty} \rho(\omega)\,\frac{\sin(\omega-k)(t-t_i)}{(\omega-k)}\,d\omega$$

$\rho(\omega) \propto \mathrm{Im}\{$  $+ \cdots\}$



$t_i = 1$ fm/c (depends on $t - t_i$)

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## ENTER HYDRO:

Fluid cell in LTE

The eq. result is valid in each cell in LTE with local $T(\tau)$.

INVARIANT RATE from each cell "boosted" to C.M.

Total yield: Integrate inv. rate thru space-time history from $\tau_i \sim 1$ fm/c to $\tau_{had} \sim 10\text{-}20\ \frac{fm}{c}$ and $\eta_{min} < \eta < \eta_{max}$

$T(\tau_{had}) \sim 150$ MeV

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$$\rho(\omega,k) \propto \mathrm{Im}\,\Pi(\omega,k) =$$

Im {  }

$\alpha_s^0$ $\qquad$ $\alpha_s(\ln\alpha_s)$

. The usual calculation takes

$$t - t_i \longrightarrow \infty$$

$$\Rightarrow k\frac{dN}{d^3k\,d^3x} \xrightarrow[t-t_i\to\infty]{} \alpha_{em}\,\mathrm{Im}\,\Pi(\omega,k)\Big|_{\omega=k}(t-t_i)$$

$$\Rightarrow k\frac{dN}{d^3k\,d^4x} \rightarrow \alpha_{em}\,\mathrm{Im}\,\Pi(\omega,k)\Big|_{\omega=k}$$

This is The USUAL result!

6

$$|\langle f\,1_\gamma|\,U(t,t_i)\,|i\,0\rangle|^2 =$$

$$e^2\left|\langle f\,1_\gamma|\int_{t_i}^{t} J.A\,|i\,0_\gamma\rangle\right|^2 = T_{fi}(t)$$

i) Sum over intermediate states $\sum_f$

ii) Thermal average over initial states:

$$k\frac{dN(t)}{d^3k\,d^3x} = k\sum_f\sum_i e^{-\beta E_i}\,T_{fi}(t) \equiv$$

$$\alpha_{em}\int_{-\infty}^{\infty} d\omega\,\rho(\omega,k)\left[\frac{1-\cos(\omega-k)(t-t_i)}{(\omega-k)^2}\right]$$

## Revisiting Thermal Produc: 5

- At an initial time $t_i$ the Q.G.P in Eq. and no-photons:

$$\hat{\rho}(t_i) = \sum_i e^{-\beta E_i} |i\rangle\langle i| \otimes |0\rangle_\gamma \langle 0|$$

Exact QCD

- Time Evolution

$$|i\rangle|0\rangle_\gamma \rightarrow U(t,t_i)\,|i\rangle|0\rangle_\gamma$$

$$U(t,t_i) = e^{-iH(t-t_i)} = e^{-i(H_{QCD}+H^0_{EM})(t-t_i)}\; T\, e^{-i\int_{t_i}^{t} e\, J.A\, dt'}$$

$$\simeq 1 - ie\int_{t_i}^{t} J.A$$

- Transition Prob. to $\langle f\, 1\gamma|$ ($f$: QCD)

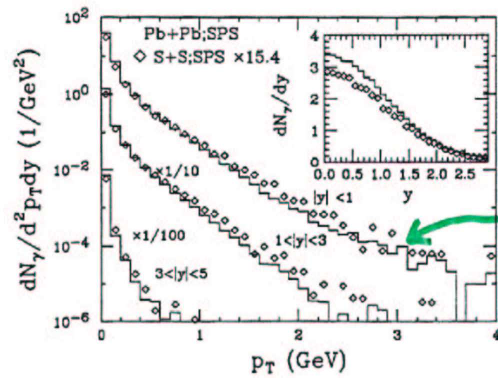
## Pre-Equilibrium: $\tau \lesssim 1$ fm/c (4)

Parton Cascade: $q\bar{q} \rightarrow g\gamma\ (\gamma\gamma)$

$q \rightarrow q\gamma$

VA AND KLAUS GEIGER PRC 58, 1734 (98)

D.K. Srivastava + K. Geiger




$\approx p_T^{-\nu}$

$2 \lesssim \nu \lesssim 3$

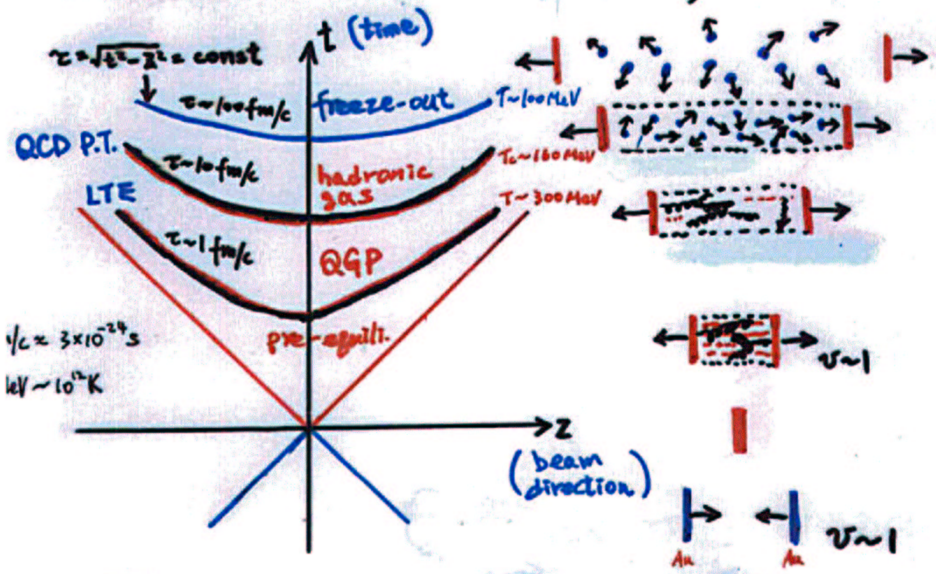
FIG. 2. The radiation of single photons from S+S (200 GeV/nucleon) and Pb+Pb (158 GeV/nucleon) collisions in different rapidity bins. The inset shows the rapidity distribution of the radiated photons. The results for the S+S collisions have been scaled by the ratio $T_{Pb\text{-}Pb}/T_{S\text{-}S} \approx 15.4$ for central collisions. $\mu_0$ for the quark branching $q \rightarrow q\gamma$ is taken as 0.01 GeV.

①

## How to create a QGP?

- Colliding GOLD nuclei at relativistic energy $\sqrt{S_{NN}} \sim 200$ GeV
- The space-time picture of an event

**Au+Au central collision** $dN_{ch}/dy \sim 500-1500$




- Signatures of QGP

onic: J/ψ suppression, strangeness enhancement

ematic: collective flow, identical-particle interferometry (ππ)

n: dileptons, direct photons ⟵ Clean (?)

t No single unique & unequivocal signal of QGP!

②

WA 98: AA ⟹ excess of γ at $p_T \gtrsim 1.5$ GeV as compared to PA (and PP)

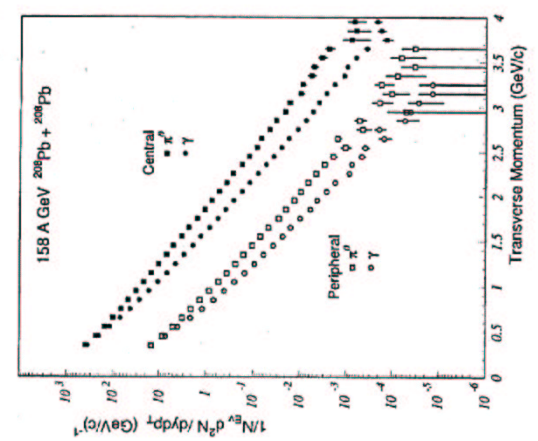



FIG. 1. The inclusive photon (circles) and $\pi^0$ (squares) transverse momentum distributions for peripheral (open points) and central (solid points) 158 A GeV $^{208}$Pb+$^{208}$Pb collisions. The data have been corrected for efficiency and acceptance. Only statistical errors are shown.

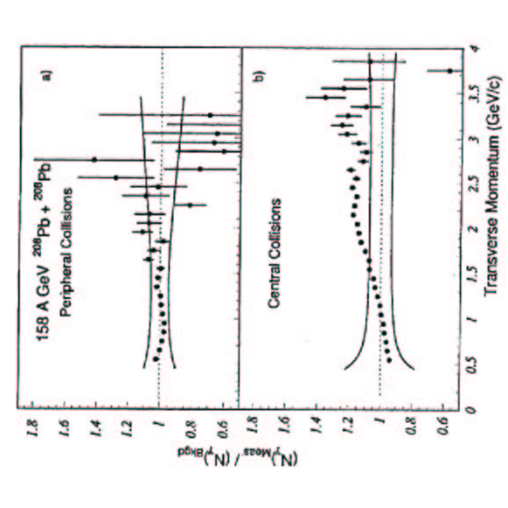



FIG. 2. The $\gamma_{Meas}/\gamma_{Bkgd}$ ratio as a function of transverse momentum for peripheral (part a)) and central (part b)) 158 A GeV $^{208}$Pb+$^{208}$Pb collisions. The errors on the data points indicate the statistical errors only. The $p_T$-dependent systematical errors are indicated by the shaded bands.

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VOLUME 85, NUMBER 17 PHYSICAL REVIEW LETTERS 23 OCTOBER 2000

### Observation of Direct Photons in Central 158*A* GeV $^{208}$Pb + $^{208}$Pb Collisions @ CERN SPS

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A measurement of direct photon production in $^{208}$Pb + $^{208}$Pb collisions at 158*A* GeV has been carried out in the CERN WA98 experiment. The invariant yield of direct photons in central collisions is extracted as a function of transverse momentum in the interval $0.5 < p_T < 4$ GeV/$c$. A significant direct photon signal, compared to statistical and systematical errors, is seen at $p_T > 1.5$ GeV/$c$. The result constitutes the first observation of direct photons in ultrarelativistic heavy-ion collisions. It could be significant for diagnosis of quark-gluon-plasma formation.

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# Photons From QGP of Finite Lifetime

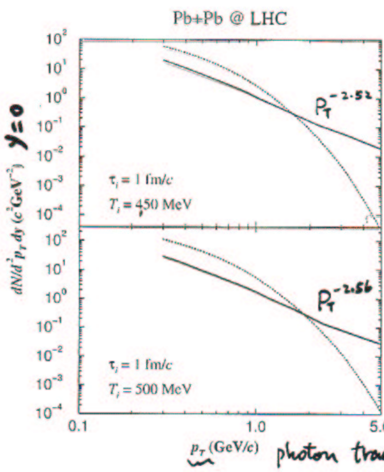
S. Y. WANG

D. B.

(10

$R_A \approx 7$ fm
$\eta_{can} = 5$

# LHC




$\sqrt{S_{NN}} \sim 5500$ GeV

photon transverse momentum

(11

# Results:

- Enhancement over usual result for $P_T \gtrsim 2$ GeV
- Prediction:* Power law $2 < \nu < 3$ for $2 \lesssim P_T \lesssim 5$ GeV (hydro not valid beyond)

* CAN and WILL be tested!

- The QGP shines even brighter!
- Dileptons?
- MUST include finite lifetime effects!
- MUST understand INITIAL STATE