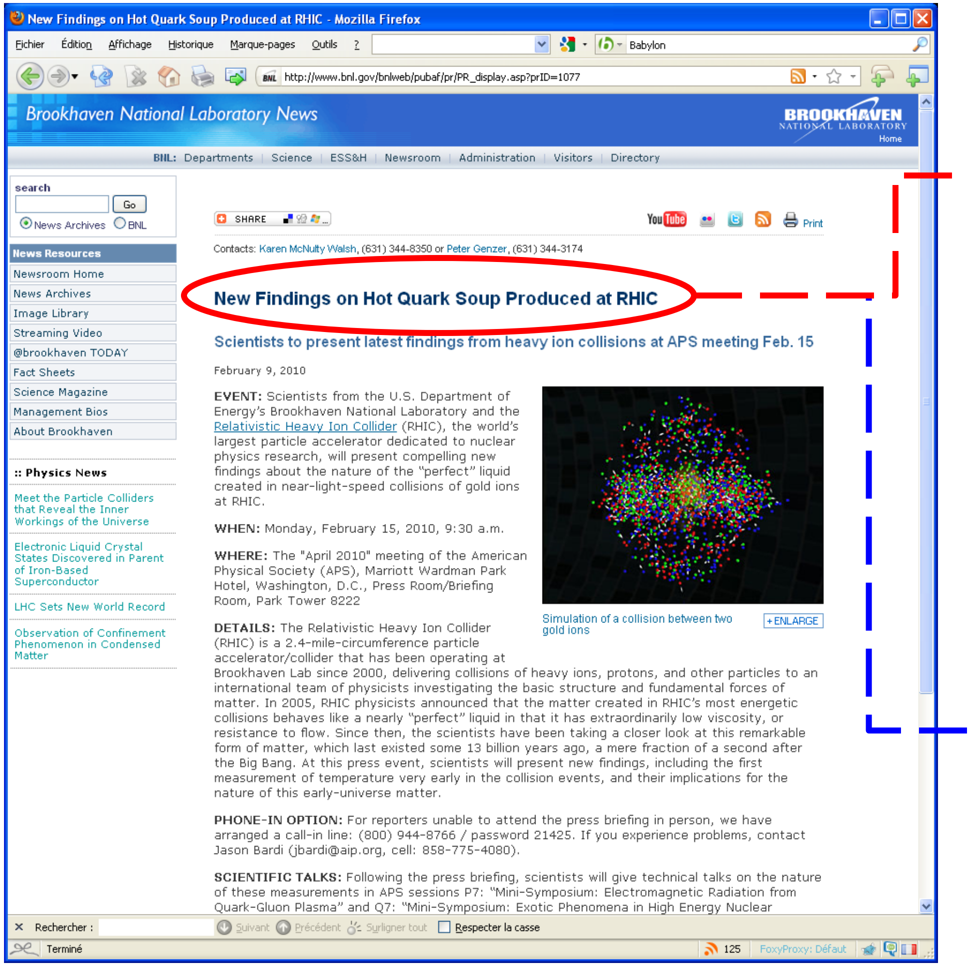
Latest results on direct photon from Phenix

BY A PEDESTRIAN

Related publications

direct photon in Au+Au	→	PRL94, 232301 (2005)
direct photon in p+p	→	PRL98, 012002 (2007)
e+e- in p+p and Au+Au	→	arXiv:0912.0244 (PRC)
Direct (virtual) photon in Au+Au	→	arXiv:0804.4168 (PRL)

New findings on Hot Quark Soup



Contacts: Karen McNulty Walsh, (631) 344-8350 or Peter Genzer, (631) 344-3174

New Findings on Hot Quark Soup Produced at RHIC

Scientists to present latest findings from heavy ion collisions at APS meeting Feb. 15

February 9, 2010

EVENT: Scientists from the U.S. Department of Energy's Brookhaven National Laboratory and the Relativistic Heavy Ion Collider (RHIC), the world's largest particle accelerator dedicated to nuclear physics research, will present compelling new findings about the nature of the "perfect" liquid created in near-light-speed collisions of gold ions at RHIC.

Simulation of a collision between two gold ions

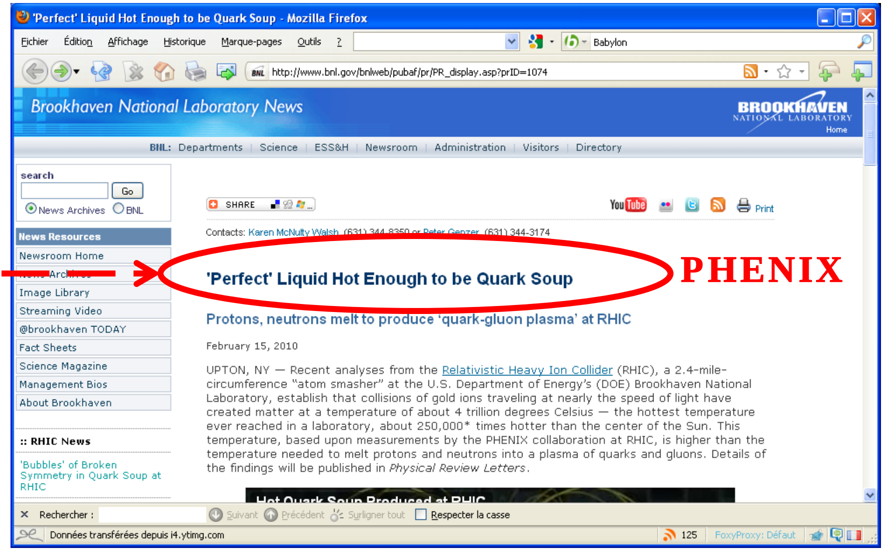
WHEN: Monday, February 15, 2010, 9:30 a.m.

WHERE: The "April 2010" meeting of the American Physical Society (APS), Marriott Wardman Park Hotel, Washington, D.C., Press Room/Briefing Room, Park Tower 8222

DETAILS: The Relativistic Heavy Ion Collider (RHIC) is a 2.4-mile-circumference particle accelerator/collider that has been operating at Brookhaven Lab since 2000, delivering collisions of heavy ions, protons, and other particles to an international team of physicists investigating the basic structure and fundamental forces of matter. In 2005, RHIC physicists announced that the matter created in RHIC's most energetic collisions behaves like a nearly "perfect" liquid in that it has extraordinarily low viscosity, or resistance to flow. Since then, the scientists have been taking a closer look at this remarkable form of matter, which last existed some 13 billion years ago, a mere fraction of a second after the Big Bang. At this press event, scientists will present new findings, including the first measurement of temperature very early in the collision events, and their implications for the nature of this early-universe matter.

PHONE-IN OPTION: For reporters unable to attend the press briefing in person, we have arranged a call-in line: (800) 944-8766 / password 21425. If you experience problems, contact Jason Bardi (jbardi@aip.org, cell: 858-775-4080).

SCIENTIFIC TALKS: Following the press briefing, scientists will give technical talks on the nature of these measurements in APS sessions P7: "Mini-Symposium: Electromagnetic Radiation from Quark-Gluon Plasma" and Q7: "Mini-Symposium: Exotic Phenomena in High Energy Nuclear



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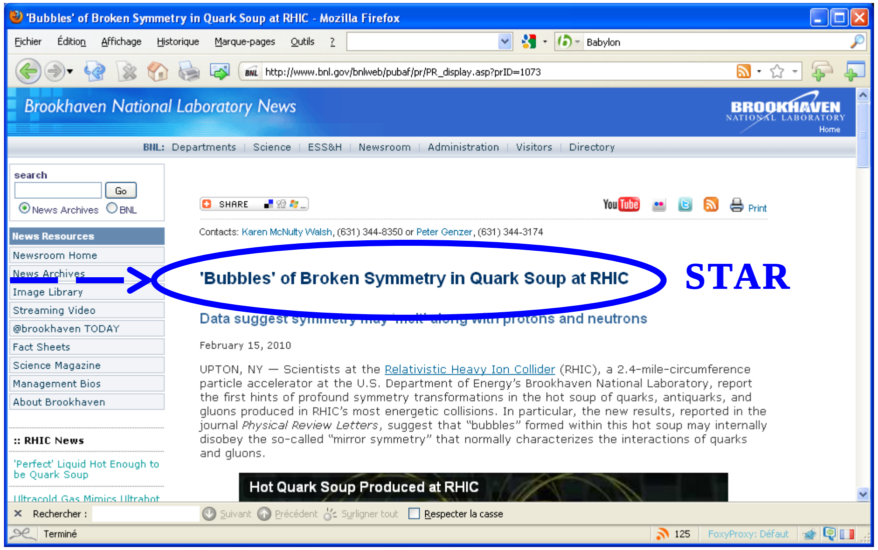
'Perfect' Liquid Hot Enough to be Quark Soup

PHENIX

Protons, neutrons melt to produce 'quark-gluon plasma' at RHIC

February 15, 2010

UPTON, NY — Recent analyses from the Relativistic Heavy Ion Collider (RHIC), a 2.4-mile-circumference "atom smasher" at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory, establish that collisions of gold ions traveling at nearly the speed of light have created matter at a temperature of about 4 trillion degrees Celsius — the hottest temperature ever reached in a laboratory, about 250,000* times hotter than the center of the Sun. This temperature, based upon measurements by the PHENIX collaboration at RHIC, is higher than the temperature needed to melt protons and neutrons into a plasma of quarks and gluons. Details of the findings will be published in *Physical Review Letters*.



Contacts: Karen McNulty Walsh, (631) 344-8350 or Peter Genzer, (631) 344-3174

'Bubbles' of Broken Symmetry in Quark Soup at RHIC

STAR

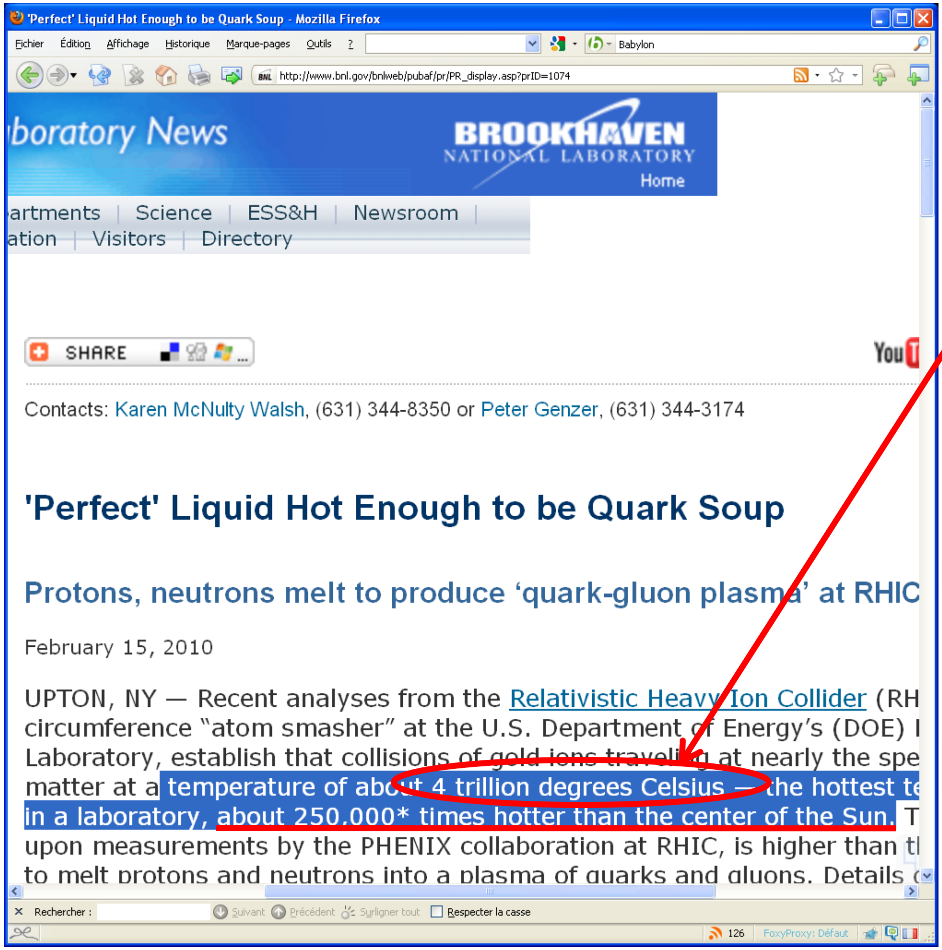
Data suggest symmetry may 'melt' along with protons and neutrons

February 15, 2010

UPTON, NY — Scientists at the Relativistic Heavy Ion Collider (RHIC), a 2.4-mile-circumference particle accelerator at the U.S. Department of Energy's Brookhaven National Laboratory, report the first hints of profound symmetry transformations in the hot soup of quarks, antiquarks, and gluons produced in RHIC's most energetic collisions. In particular, the new results, reported in the journal *Physical Review Letters*, suggest that "bubbles" formed within this hot soup may internally disobey the so-called "mirror symmetry" that normally characterizes the interactions of quarks and gluons.

Perfect liquid hot enough to be quark soup

(Arxiv:0804.4168)



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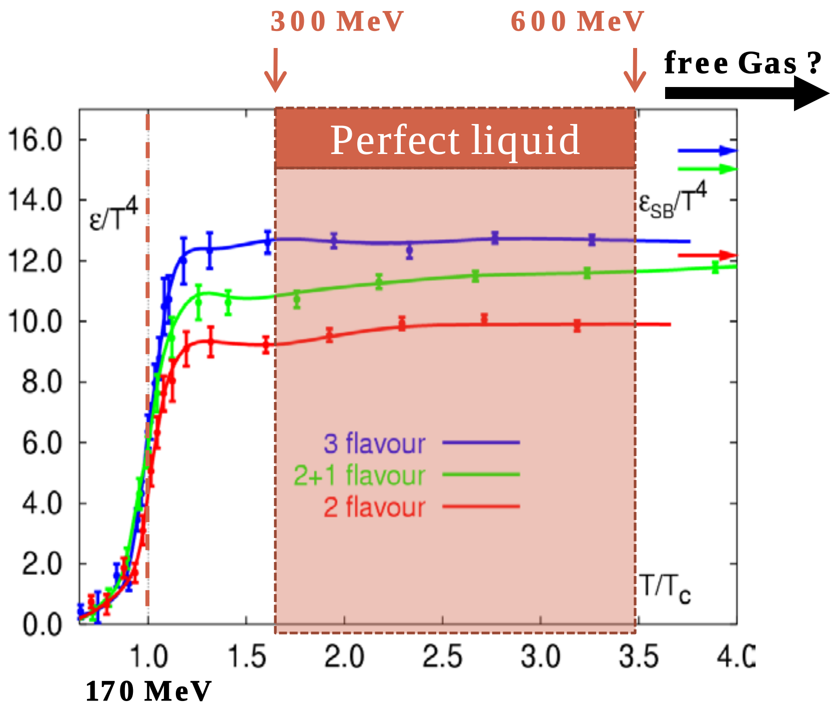
Hydro fits ➔ T_{ini} ~ 300 – 600 MeV

$(k_BT \sim 8.6\ 10^{-5}$ eV $K^{-1})$

$T \sim 4 – 8\ 10^{12}$ K

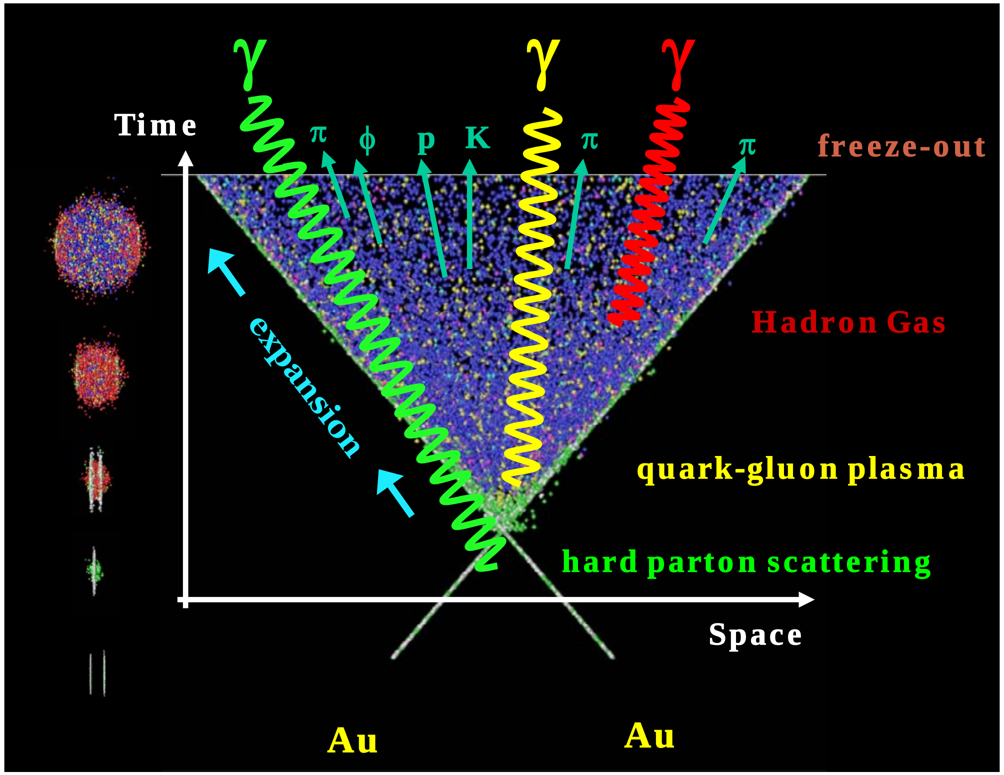


How to measure the temperature ?

- **Looking at photons**
  - Hot matter emits thermal radiation
  - Temperature can be measured from the emission spectrum

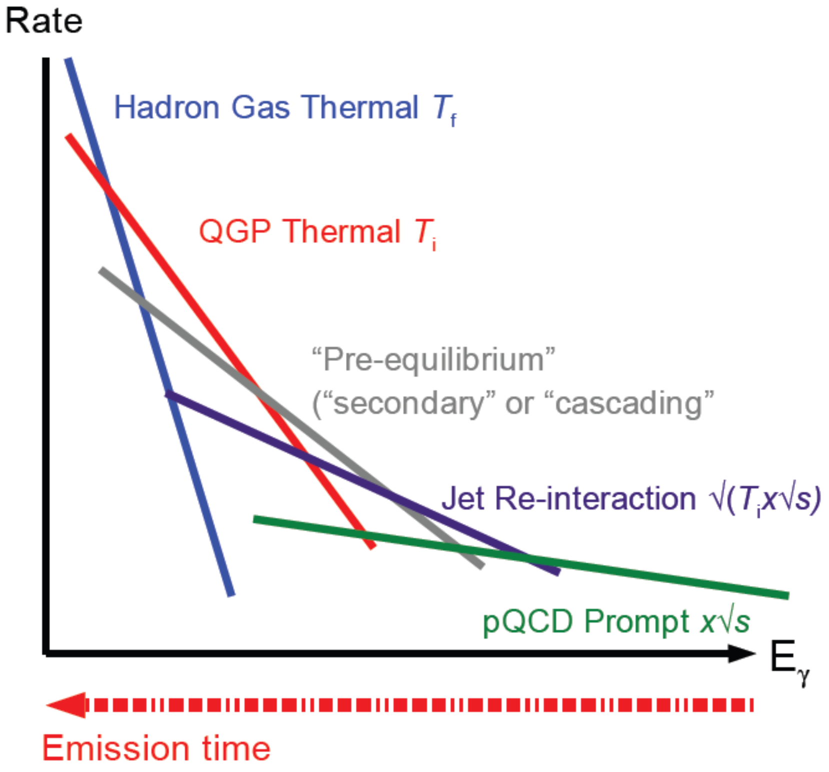
- **Hard parton scattering**
  - High pT photons (> 6 GeV)
- **QGP photons**
  - Low pT photons (1 – 3 GeV)
- **Hadron gas photons**
  - Very low pT photons (<2 GeV)

- **Measuring the photons**
  - In p+p : get the baseline
  - In Au+Au : get the temperature

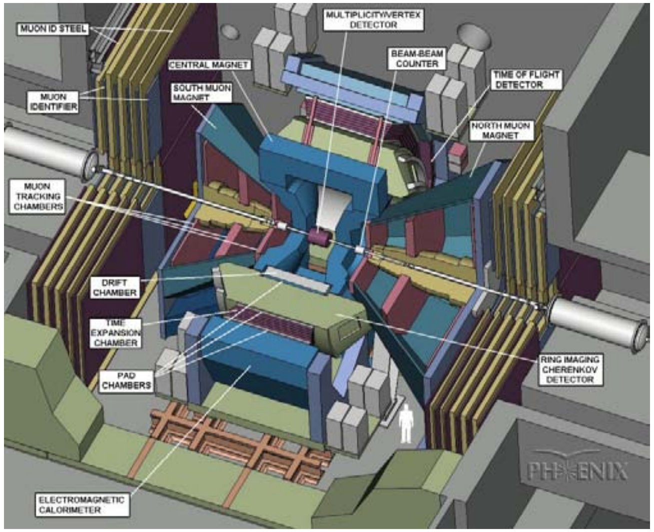


Sources of photons in A+A

- **In A+A collisions**
  - High pT photons (pT> 6 GeV): **non thermal**
    - **Initial parton-parton scattering**: as in p+p
    - not affected by Hot and Dense Matter ➔ test the theoretical description of A+A collisions with pQCD
  - Low pT photons (pT < 3 GeV) : **thermal**
    - **Come from the thermalized medium**
    - Carry information about the initial temperature of the Quark Gluon Plasma
    - Thermal photons are created in the QGP as well as in the hadron gas over the entire lifetime of these phases ➔ test hydro models
  - Low and intermediate pT photons (up to 6 GeV)
    - **Interaction of the quarks and gluons** from the hard scattering processes **with the QGP**
      - $q_{hard} + g_{QGP} \rightarrow q + \gamma$
      - γ get a large fraction of the momentum of q_{hard}



Phenix detector

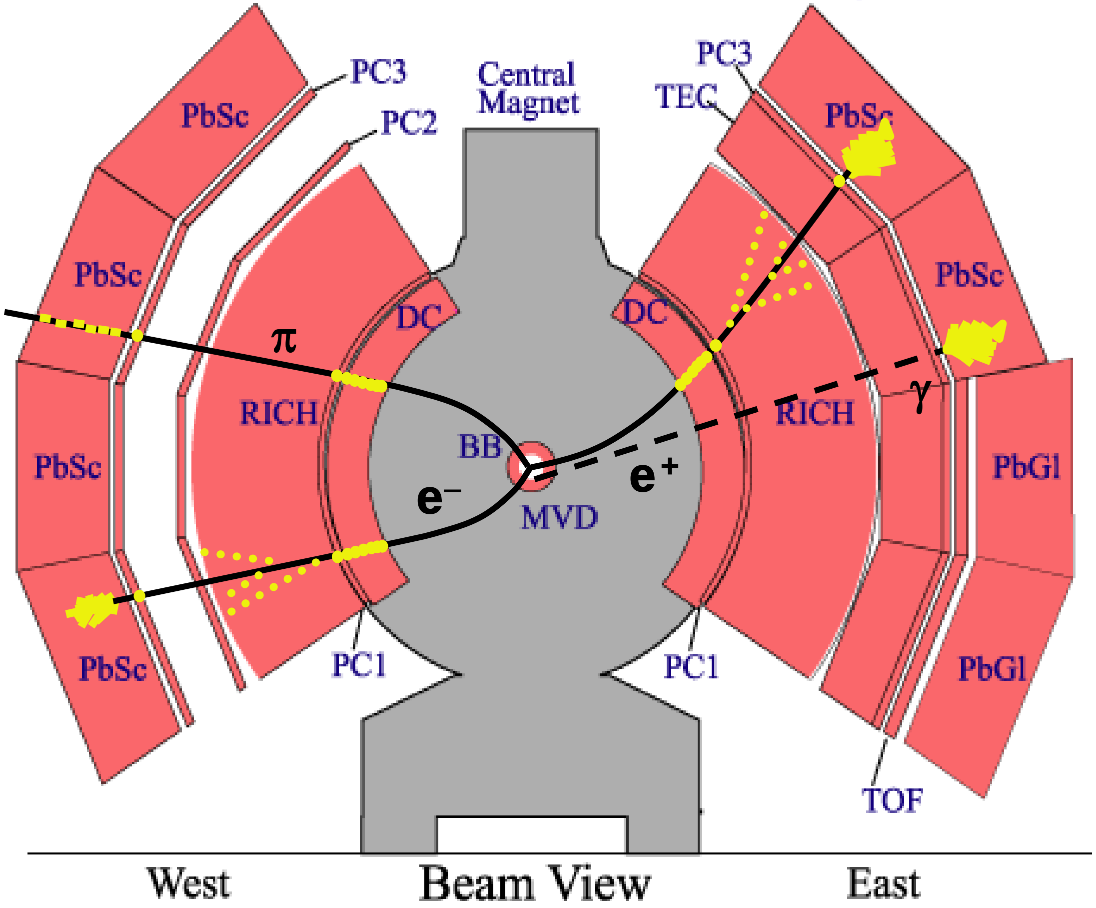


- 2 central arms:

  electrons, photons, hadrons

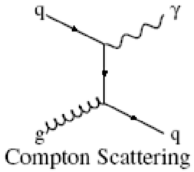
  - charmonium J/ψ, ψ' → e^+e^-
  - vector meson ρ, ω, ϕ → e^+e^-
  - high p_T π^o, π^+, π^-
  - direct photons
  - open charm
  - hadron physics

$|y|<0.35$

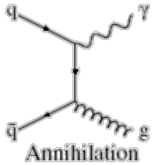


Direct photons in p+p : the baseline

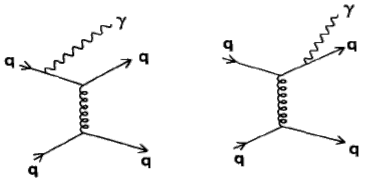
- **In p+p collisions**
  - **Direct photons**
    - Compton scattering
      - $q + g \rightarrow q + \gamma$



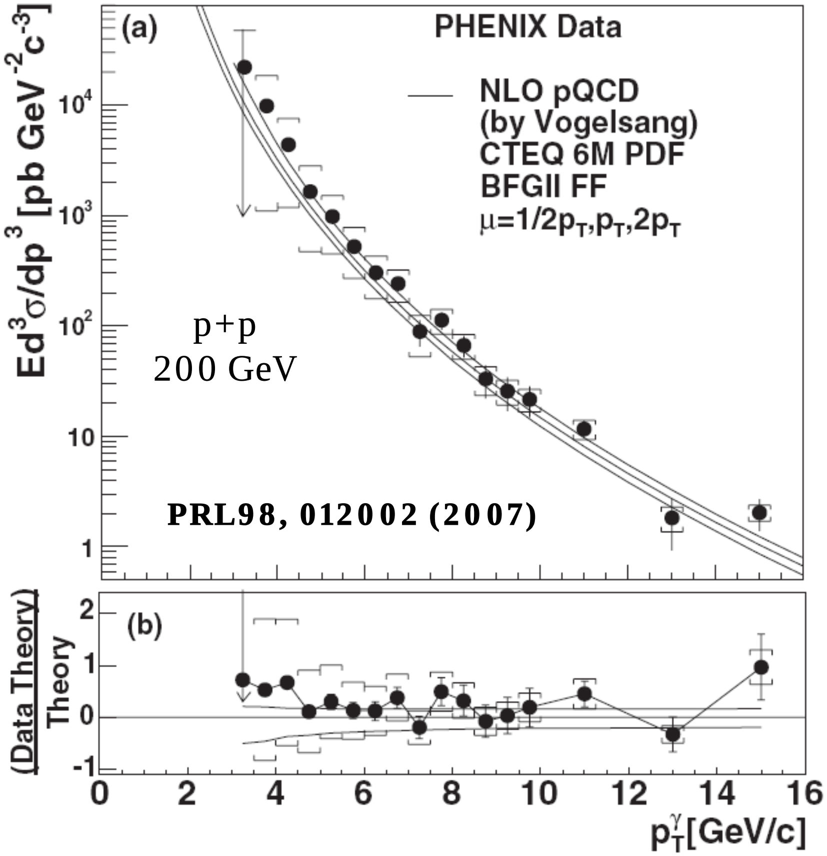
    - $q\bar{q}$ annihilation
      - $q + \bar{q} \rightarrow g + \gamma$



    - Bremsstrahlung (intial state)



  - **Fragmentation photons**
    - Brem. From final state partons
  - Final state **hadron decay** (background)
    - π^0, η, K^0,… $\rightarrow \gamma + \gamma$



p+p
200 GeV

PRL98, 012002 (2007)

Measured p+p yield compatible with NLO pQCD calculations

Thermal photons

direct photons are measured as « excess » above hadron decay photons

$$R_{\gamma}=\frac{\left(\frac{\gamma}{\pi^0}\right)_{\text{measured}}}{\left(\frac{\gamma}{\pi^0}\right)_{\text{background}}} \approx \frac{\gamma_{\text{measured}}}{\gamma_{\text{background}}}$$

Direct photons candidates : obtained after rejecting photons pairs falling within 110<$M_{\gamma\gamma}$<170 MeV/c² (π^0) and 500<$M_{\gamma\gamma}$<620 Mev/c² (η)

$$\left(\frac{\gamma}{\pi^0}\right)_{\text{measured}}$$

γ ← Direct photons candidates (from data)

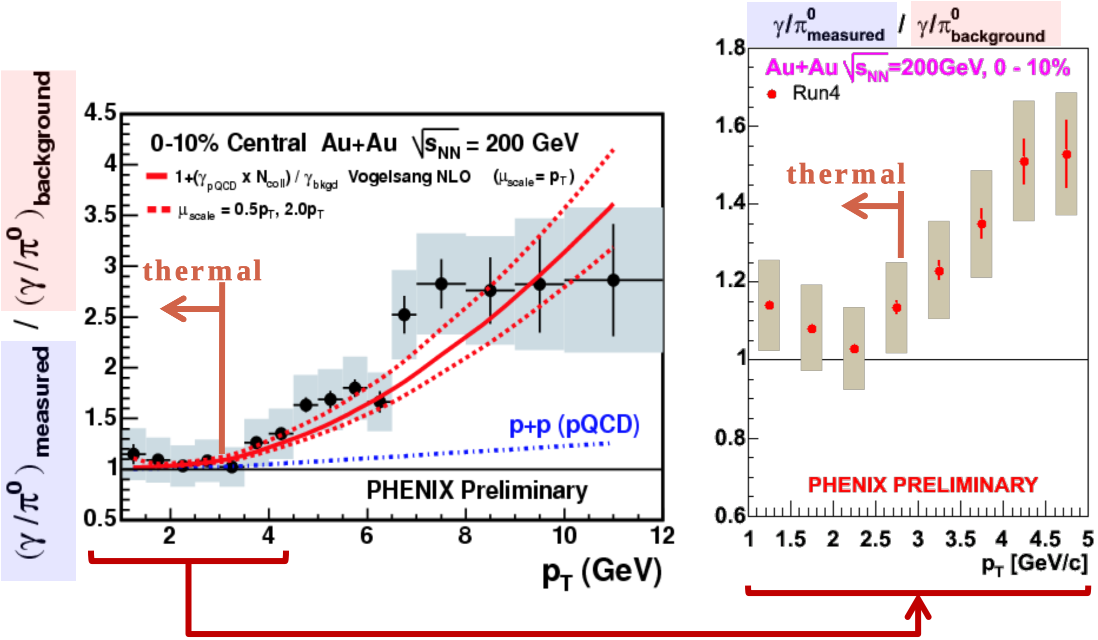
π^0 ← π^0 from data

$$\left(\frac{\gamma}{\pi^0}\right)_{\text{background}}$$

γ ← background photons

π^0 ← π^0 from MC

From Monte Carlo : take a parametrization of measured π^0 as input and propagate the particles through detectors
background photons = remaining photons (from π^0) after all cuts

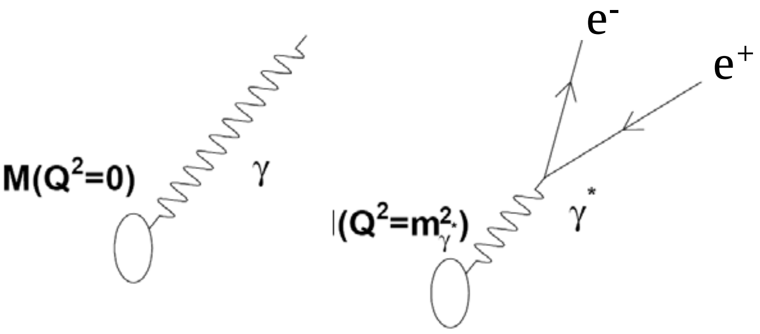


Difficult to measure below p_T<3 GeV/c

(the yield of thermal photons is only 1/10 of that of hadron decay photons)

Alternative: « quasi real » virtual photons

Source of real photon should also be able to emit virtual photon



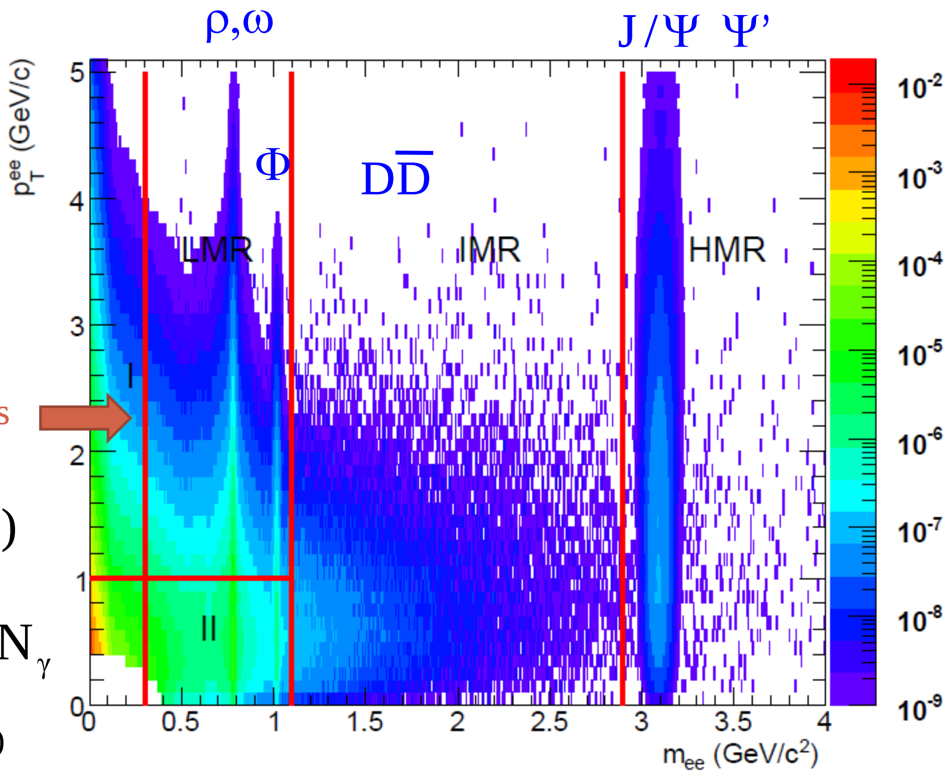
LMR I (Low Mass Region I)

$(M_{ee} \rightarrow 0)\ p_T^{ee} >> M_{ee}$ → « quasi real » photons

$$\frac{d^2N_{ee}}{dM} \approx \frac{2\alpha}{3\pi}\frac{1}{M}dN_\gamma \qquad (\text{When } M << E_\gamma)$$

$$\Rightarrow dN_{ee}\left(m_1 < M < m_2\right) \approx \frac{2\alpha}{3\pi}\log\frac{m_1}{m_2}dN_\gamma$$

(See arXiv : 0912.0244 (appendix B) for more details)



Advantages : π^0 decay photons are removed → reduce the bkg by ~80%

Signal/Background improved by a factor 5

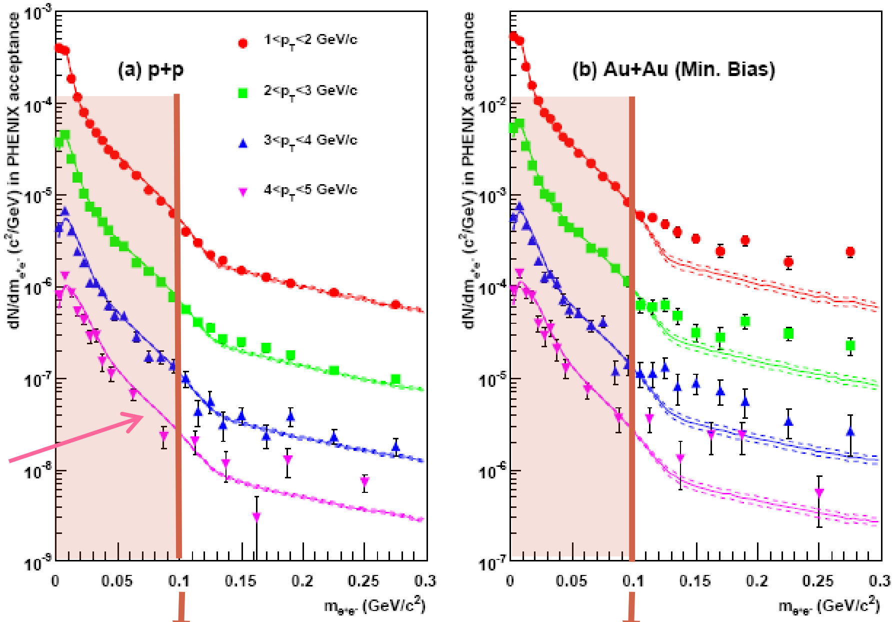
Measuring lepton (electron) pairs

Look at $100<M_{ee}<300$ MeV

Several p_T bins

Remove (dalitz) $\pi^0 \rightarrow e^+e^-\gamma$ ➔ $M_{ee} > 100$ MeV/c²

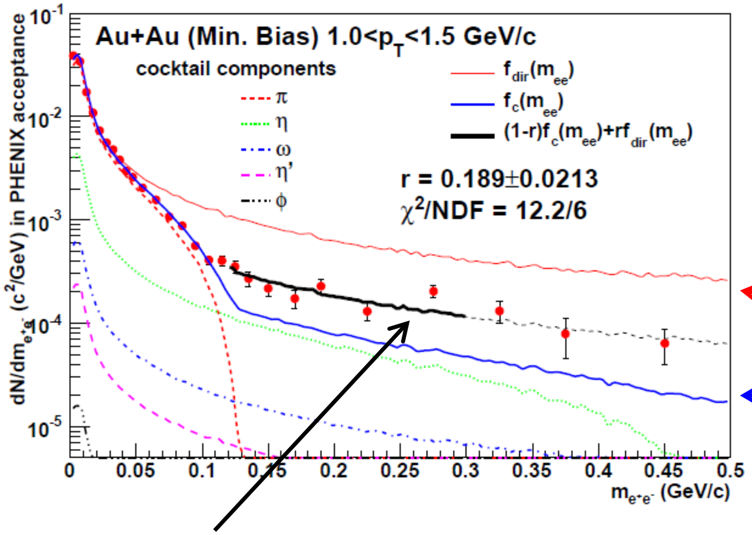
Remove other sources of bkg ➔ $M_{ee} < 300$ MeV/c²



Cocktail $(\pi,\eta,\omega,\rho,..)$

π_0 **cut-off**

π_0 **cut-off**



$f_{dir}(M_{ee})$ = expected shape from direct photon spectrum normalized to the data for mee<30 MeV/c²

$f_c(M_{ee})$ = cocktail mass distribution normalized to mee<30 MeV/c²

(Note : identical shape for f_{dir} and f_c for m_{ee}<30 MeV/c²)

$f_{tot}=(1-r)\, f_c(M_{ee}) + r\, f_{dir}(M_{ee})$ ⟶ **r** = fraction of direct photons = direct/inclusive

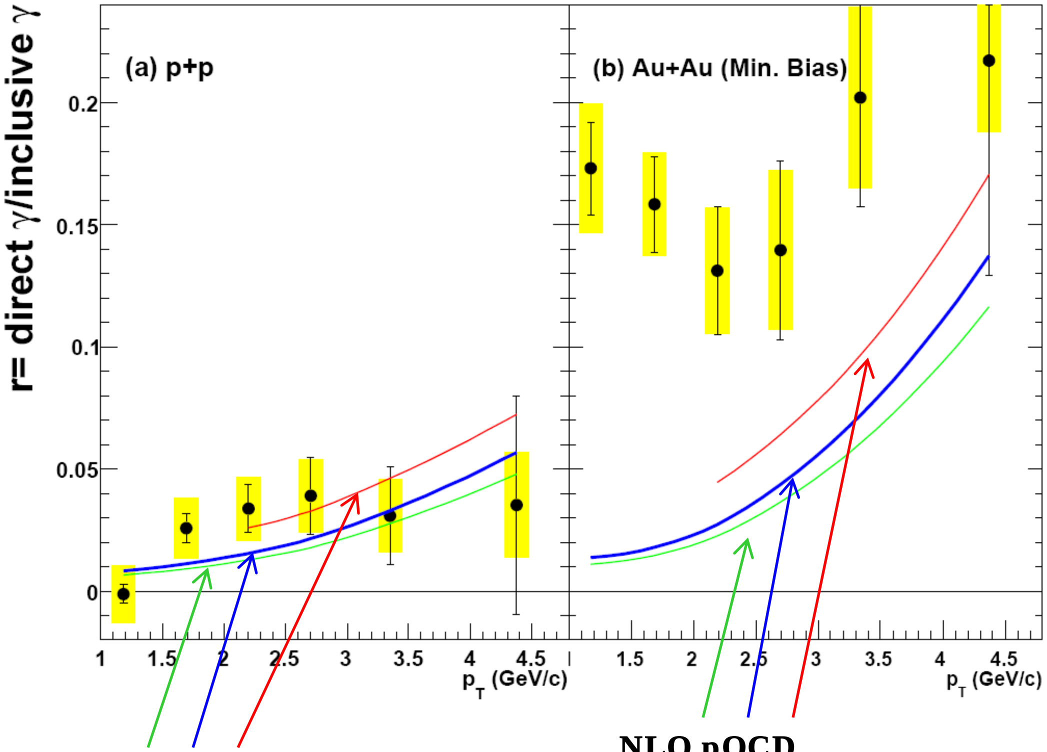
Fraction of direct photons

Several pT bins:

- $1.0 < p_T < 1.5$ GeV/c
- $1.5 < p_T < 2.0$ GeV/c
- $2.0 < p_T < 2.5$ GeV/c
- $2.5 < p_T < 3.0$ GeV/c
- $3.0 < p_T < 4.0$ GeV/c
- $4.0 < p_T < 5.0$ GeV/c

p+p consistent with NLO pQCD

Au+Au : large excess above NLO pQCD



NLO pQCD calculations

NLO pQCD calculations $\times T_{AA}$

T_{AA} = glauber nuclear overlap function

Direct photon spectrum : the final plot

Starting from $r = \dfrac{\gamma^{dir}}{\gamma^{incl}}$

$$dN_\gamma^{dir} = r \times dN_\gamma^{incl} = r \times N_{ee}^{data} \times \frac{dN_\gamma^{c}}{dN_{ee}^{c}}$$

Measured e+e- yield for m_{ee} < 30 MeV/c²

Photon yield from normalized cocktail

Normalized cocktail e+e- yield For m_{ee} < 30 MeV/c²

(identical shape for f_{dir} and f_c for m_{ee}<30 MeV/c²)

$$\text{Fit} = \text{exponential} + (\text{MPLF}\times T_{AA})$$
$$= Ae^{-p_T/T} + (\text{MPLF}\times T_{AA})$$

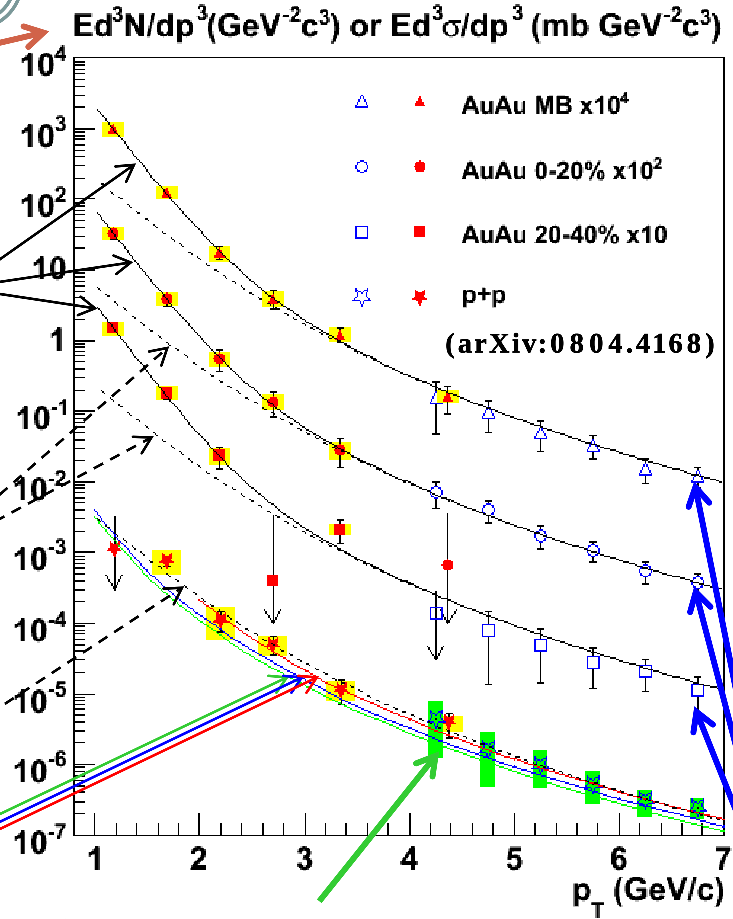
T = 221 ±23±18 MeV

Exponential + MPLF on p+p × T_{AA}

MPL Fit on p+p × T_{AA}

Modified Power Law Fit on p+p

NLO pQCD calculations



Au+Au Min bias

central

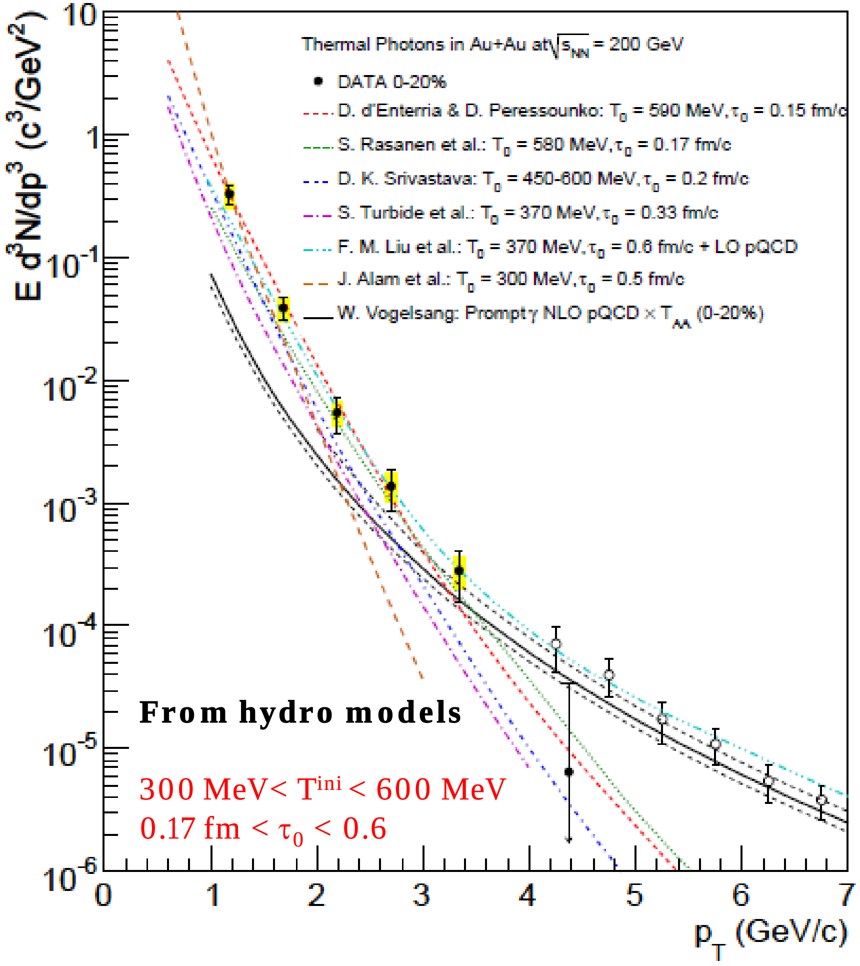
mid

p+p

Direct (real) photons in p+p
Phys. Rev. Lett. 98, 012002 (2007)

Direct (real) photons in Au+Au
Phys. Rev. Lett. 94, 232301 (2005)

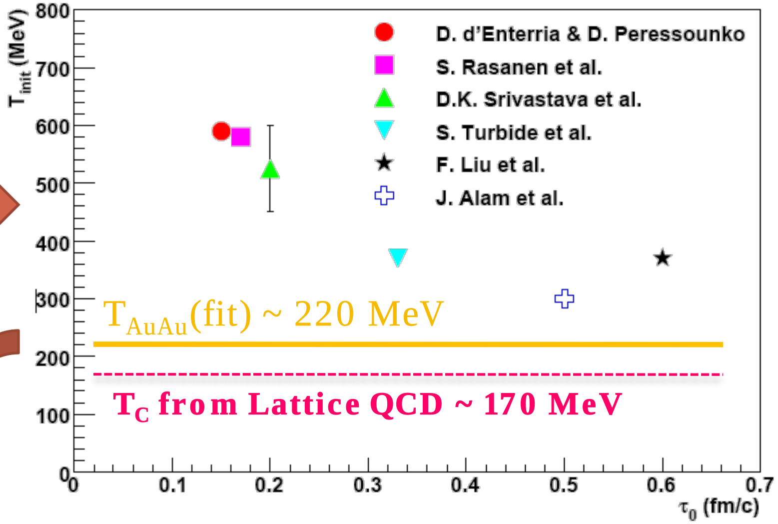
Comparison with hydro models



From hydro models

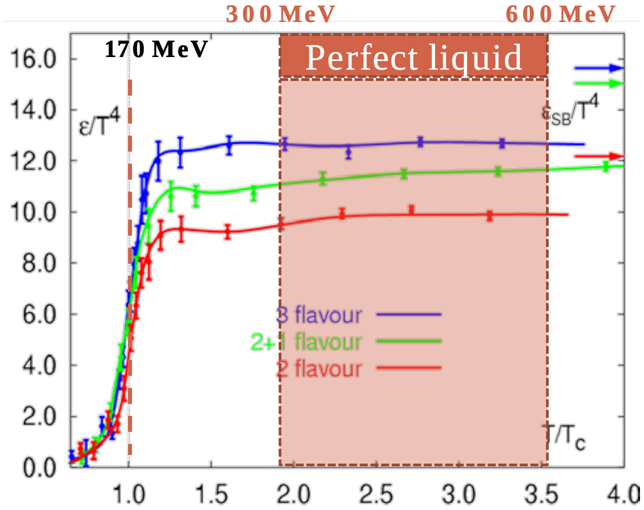
300 MeV< T^{ini} < 600 MeV

0.17 fm < τ_0 < 0.6



T_{AuAu}(fit) ~ 220 MeV

T_C from Lattice QCD ~ 170 MeV



Conclusion

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