Estimation of the photon production rate using imaginary momentum correlators

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in collaboration with:
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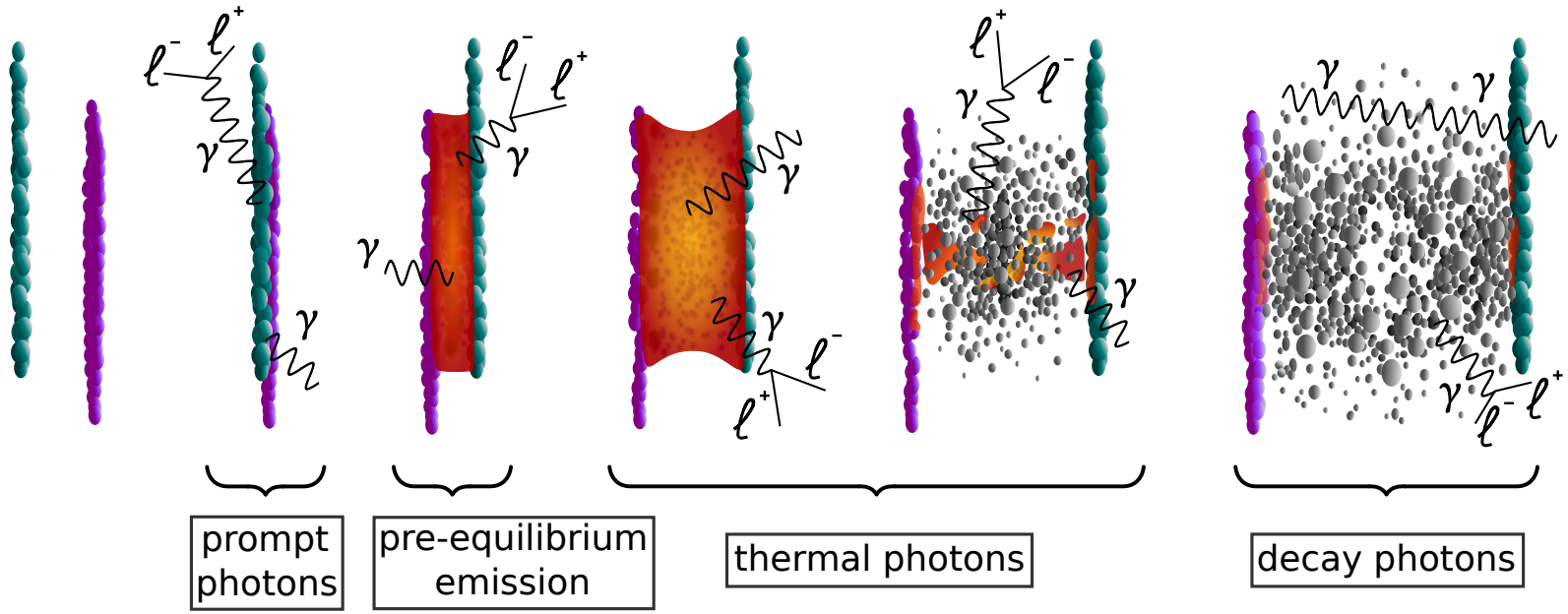
NEPhEu QCD

Motivation

- electromagnetic probes (photons, dileptons) interact weakly with the QGP medium → on-going experimental research (RHIC, LHC, GSI)



+ other small contribs.

direct photons = total - [decay photons]

- discrepancies: direct photon excess at low p_T see e.g. Gale, Paquet, Schenke, Shen '21
- dominant contribution at low p_T: **thermal photons**

Correlators at imaginary spatial momentum

- theory input: thermal photon emission rate
- model input: hydro

$\longrightarrow$ thermal photon yield

Thermal photon emission rate per unit volume of the QGP:

$$\frac{\mathrm{d}\Gamma_\gamma(\omega)}{\mathrm{d}\omega} = \frac{\alpha_{\mathrm{em}}}{\pi}\,\frac{1}{e^{\omega/T}-1}\,\omega\sigma(\omega) + \mathcal{O}(\alpha_{\mathrm{em}}^2)$$

where $\sigma(\omega) \equiv \rho_T(\omega, k=\omega)$, $\qquad \rho_T = \frac{1}{2}(\delta^{ij} - k^i k^j/k^2)\rho_{ij}(\omega, \vec{k})$

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Meyer '18

$$H_E(\omega_n) \equiv G_E^T(\omega_n, k = i\omega_n), \qquad \omega_n = 2n\pi T$$

$$= -\frac{1}{2}\sum_{i=1}^{2}\int_0^\beta \mathrm{d}x_0 \int \mathrm{d}^3x\, \mathrm{e}^{\mathrm{i}\omega_n x_0}\, \mathrm{e}^{-\mathrm{i}(\mathrm{i}\omega_n)x_3}\langle J_i(x)J_i(0)\rangle$$

Dispersion relation:

$$H_E(\omega_n) = -\frac{\omega_n^2}{\pi}\int_0^\infty \frac{\mathrm{d}\omega}{\omega}\,\frac{\sigma(\omega)}{\omega^2+\omega_n^2}$$

Lattice estimator of H_E

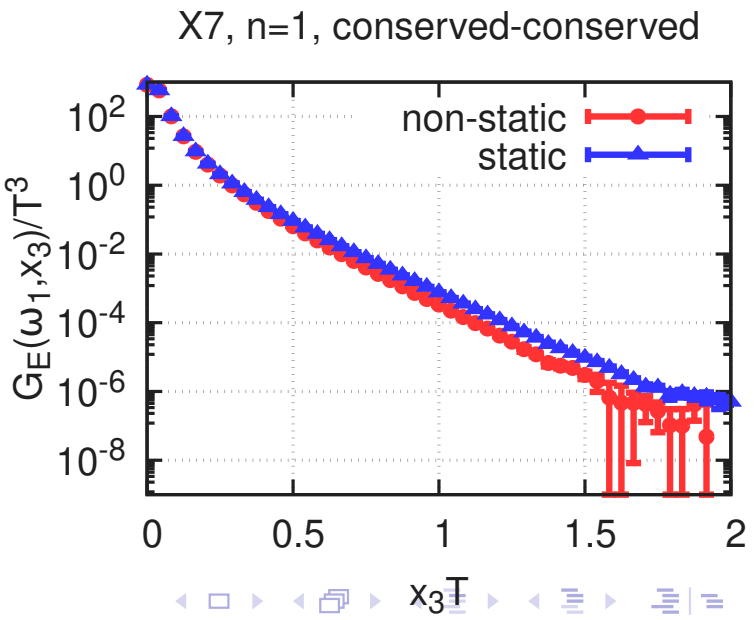
$$H_E(\omega_n) = -\sum_{i=1}^{2}\int_0^\beta \mathrm{d}x_0 \int \mathrm{d}^3x \left(\mathrm{e}^{\mathrm{i}\omega_n x_0} - \mathrm{e}^{\mathrm{i}\omega_n x_2} \right) \mathrm{e}^{\omega_n x_3} \langle J_i(x) J_i(0) \rangle$$

$$= -\int_{-\infty}^{\infty} \mathrm{d}x_3\, \mathrm{e}^{\omega_n x_3} \Big[\underbrace{G_{\mathrm{s}}(\omega_n, x_3)}_{\mathrm{static}} - \underbrace{G_{\mathrm{ns}}(\omega_n, x_3)}_{\mathrm{non-static}} \Big]$$

- subtraction term: makes the integral finite by power counting
  : vanishes in the continuum limit
- $H_E(\omega_n) < 0$

Strategy:

- measure the screening correlators G_{ns} and G_s
- fit their tails with single state fits
- model the tail of their difference



Lattice setup

ensembles:

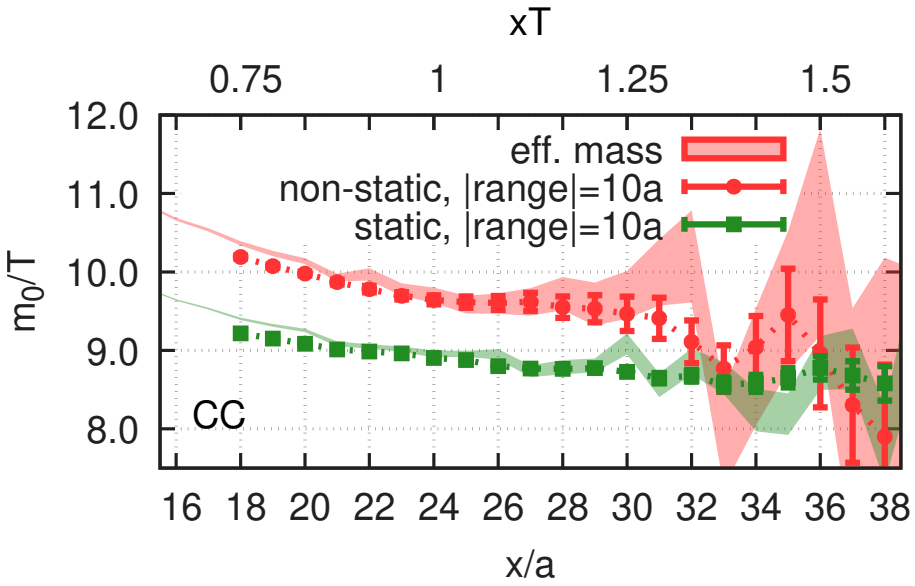
- $N_f = 2$, clover-improved Wilson fermions
- $m_\pi \approx 280$ MeV
- $T \approx 250$ MeV
- three lat. spacings: 0.05, 0.04, 0.033 fm (volume $\sim$ (3.1 fm)^3)
  $64^3 \times 16$, $80^3 \times 20$, $96^3 \times 24$
- 1500-2000 configurations with 64 point sources

observable:

- $I = 1$ contribution
- different discretizations using the local/conserved currrent
- focus on the $n = 1$ & $n = 2$ Matsubara sectors

Modelling the tail of the integrand

- single state fits on the screening correlators: $A\cosh[m_0(x - L/2)]$
- plateau regions consist of only a few points
- three representatives from AIC-based histogram



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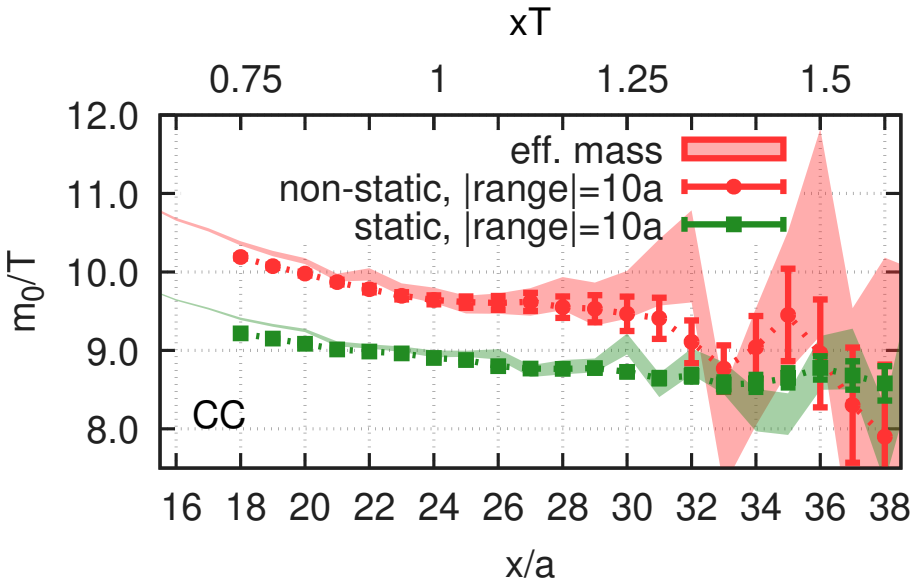
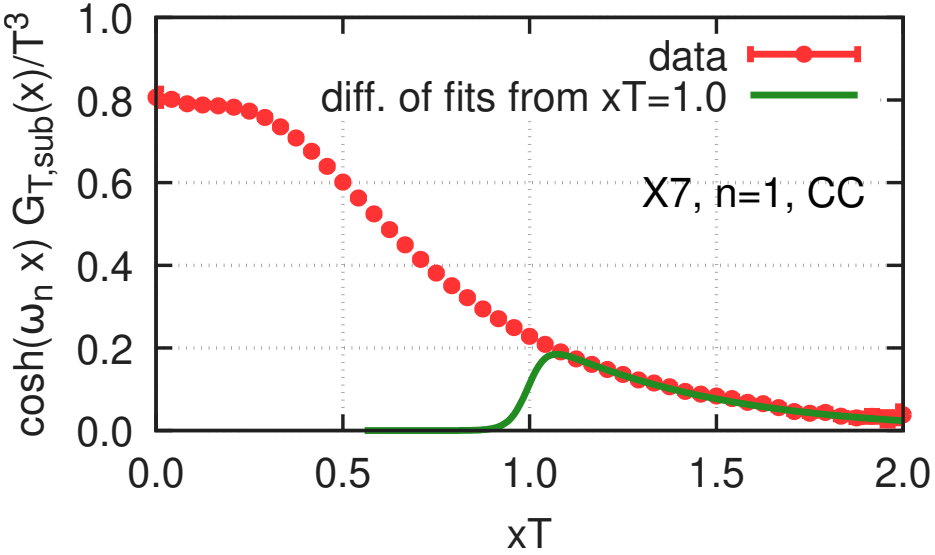
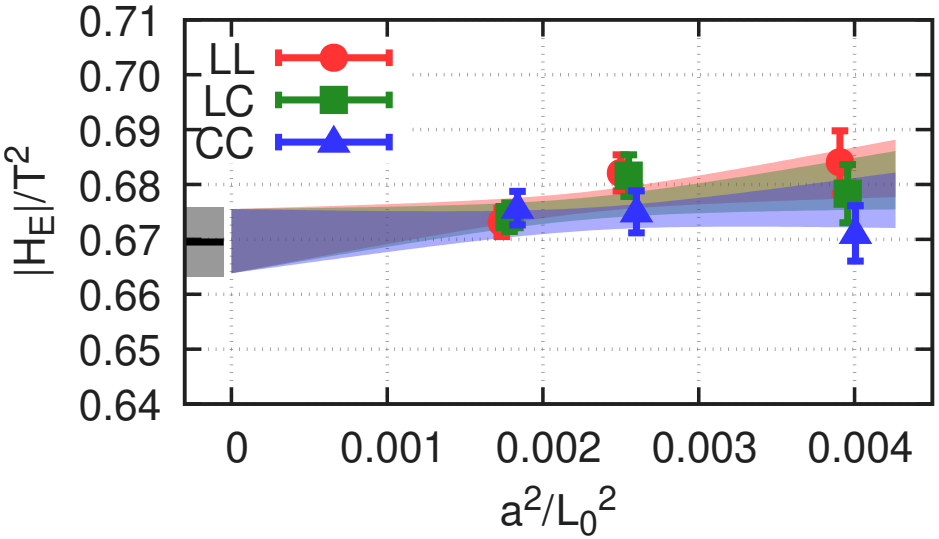
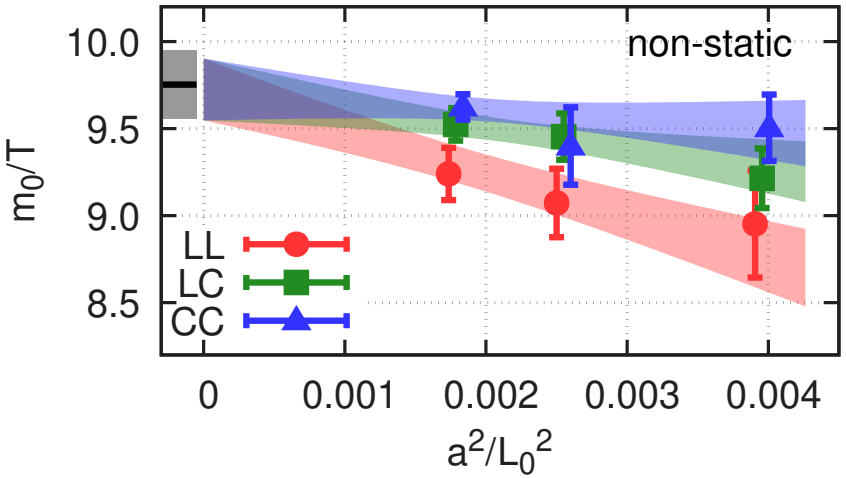


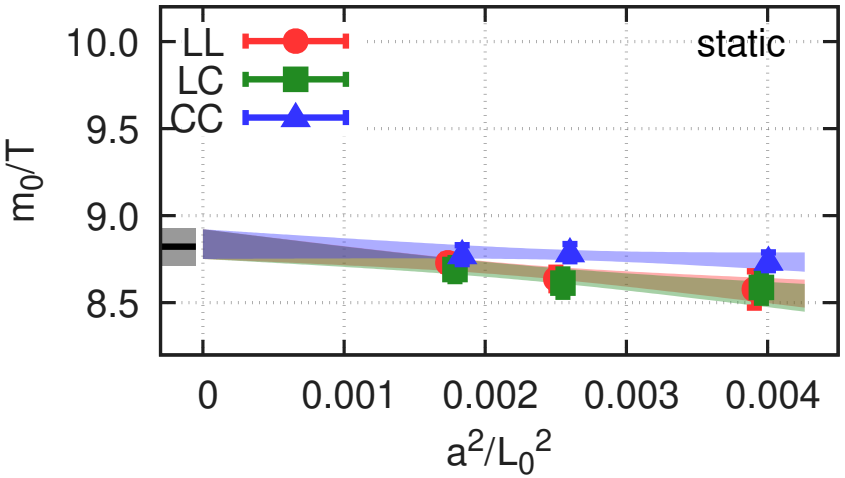
- modelling the tail reduces errors by a factor of $\sim$2.5 on the coarsest ensemble
- different switching points give consistent total integral results



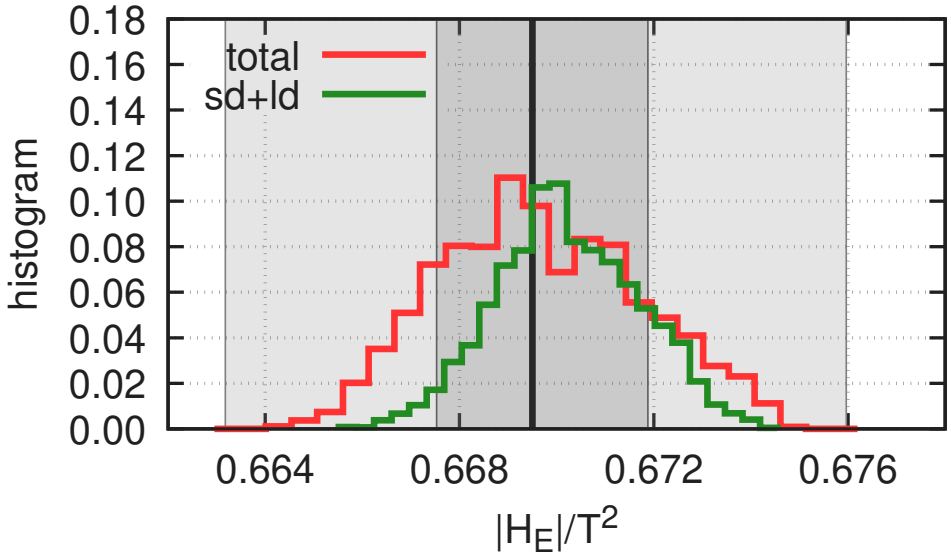
Continuum extrapolations

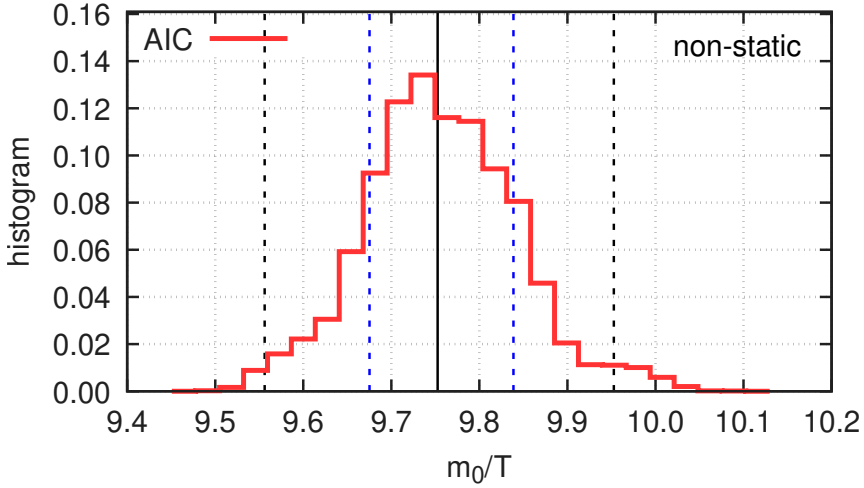


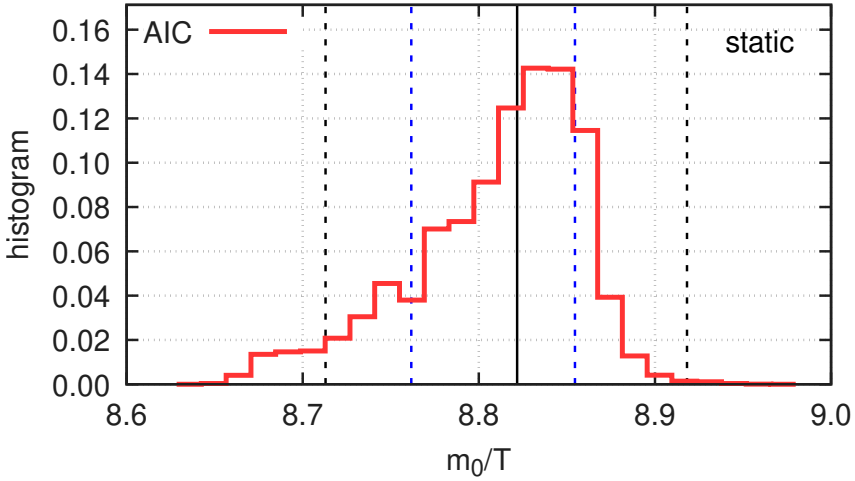




Histograms of continuum extrapolated results







Results for first Matsubara sector ($n = 1$)

observable	value at the continuum limit
$\lvert H_E \rvert / T^2$	$0.670(6)_{\rm stat}(2)_{\rm sys}$
$\mathrm{sd}(x_{\rm w} T = 1)$	$0.579(3)_{\rm stat}(1)_{\rm sys}$
$\mathrm{ld}(x_{\rm w} T = 1)$	$0.091(5)_{\rm stat}(2)_{\rm sys}$
$m_0^{\rm non-static}/T$	$9.75(18)_{\rm stat}(9)_{\rm sys}$
$m_0^{\rm static}/T$	$8.82(9)_{\rm stat}(6)_{\rm sys}$

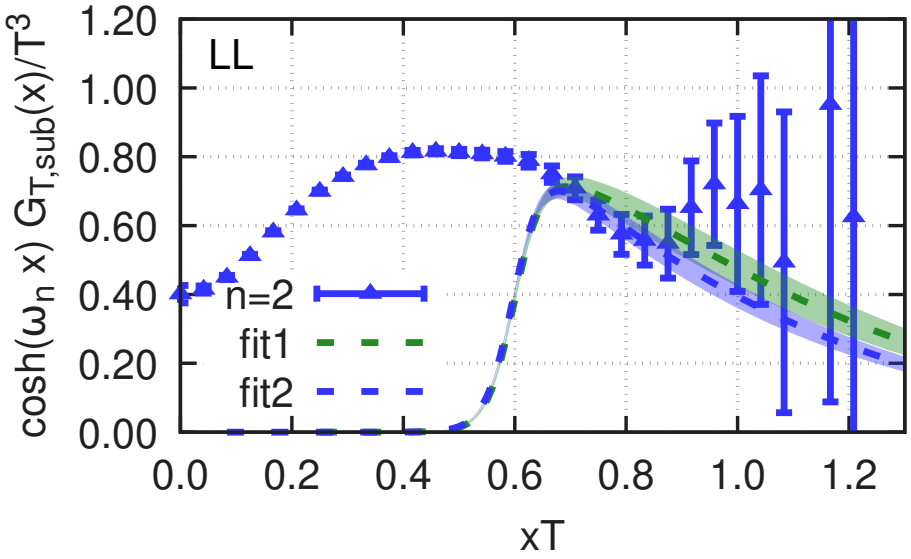
comparisons:

- free theory: $|H_E|/T^2 = 0.5$ Meyer '18
- $\mathcal{N} = 4$ SYM: $|H_E|/\chi_s^{SYM} = 0.67$ Meyer '18

  while $|H_E|^{(lat)}/\chi_s = 0.75$
- static screening mass for $n = 1$ on our coarsest ensemble using the dispersion relation $\sqrt{5.76^2 + (2\pi n)^2} = 8.52$

Brandt, Francis, Laine, Meyer '14

Similar steps for n=2: more noisy



- data is more noisy
- screening masses are large: $m_0 a \sim 1$ on the coarsest ensemble
- $n = 2$ result is compatible within errors with the $n = 1$ result
- dispersion rel., $\sigma(\omega) > 0$: $\Longrightarrow |H_E(r)| > |H_E(n)|$ if $r > n$

Summary and outlook

- first analysis of imaginary spatial momentum correlators at finite T in the $n = 1$ & $n = 2$ Matsubara sectors
- simultaneous continuum extrapolation of H_E/T^2 of different discretized correlators using three lattice spacings
- determining H_E/T^2 for $n \geq 2$ (or modelling using e.g. NLO pert. theory) might allow a more educated guess for the photon rate at this temperature

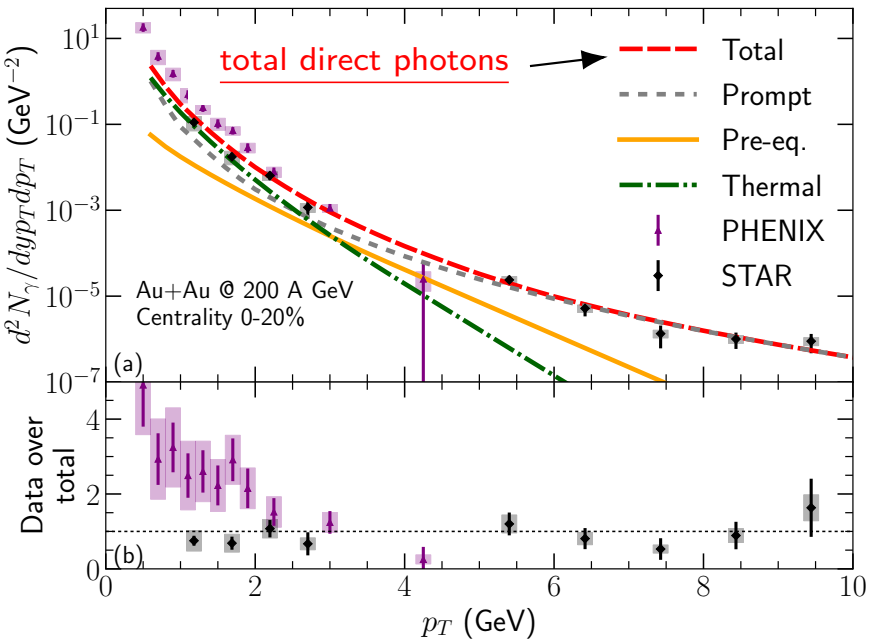
Thank you for your attention!

BACKUP

Discrepancies between experiment and theory

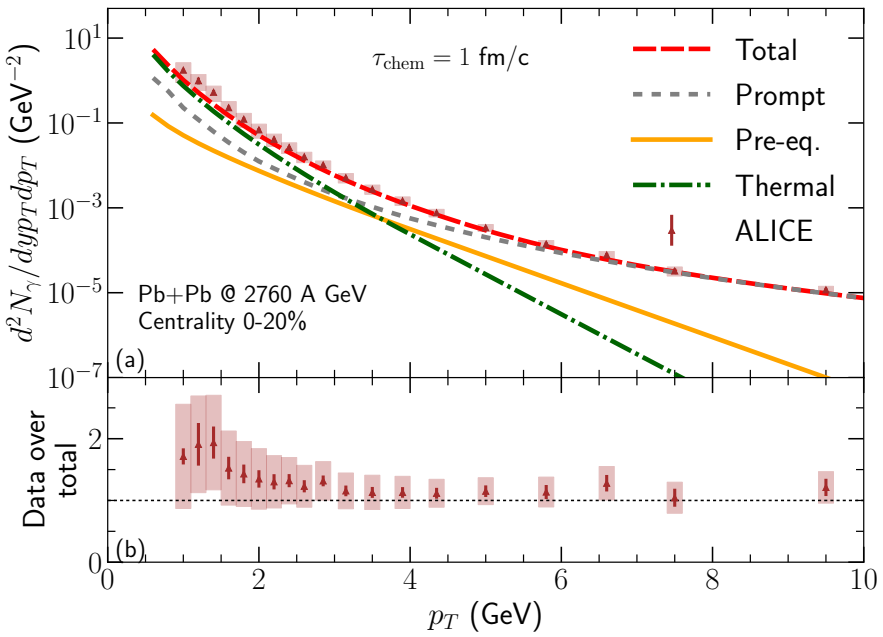
PHENIX, STAR (RHIC)

[1405.3940, 1607.01447]



ALICE (LHC)

[1509.07324]



source of figs: [2106.11216]

- discrepancy between PHENIX & STAR
- discrepancy between PHENIX & theory (/ALICE & theory)
- thermal photon yield: assuming weakly coupled plasma + hydro