Decoding the composition of QCD matter with the polarization of thermal dileptons

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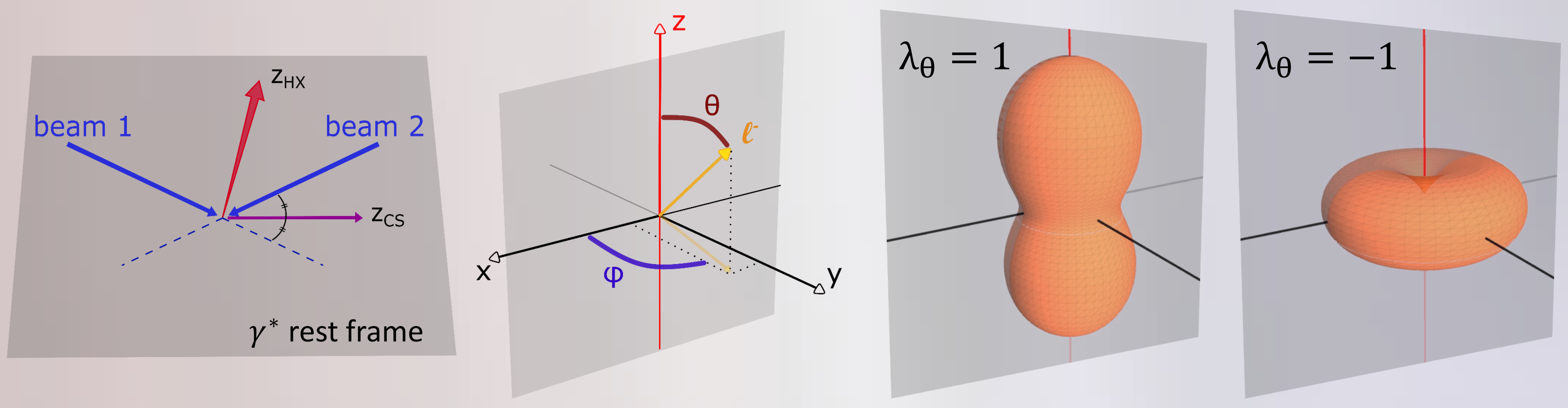
Motivation

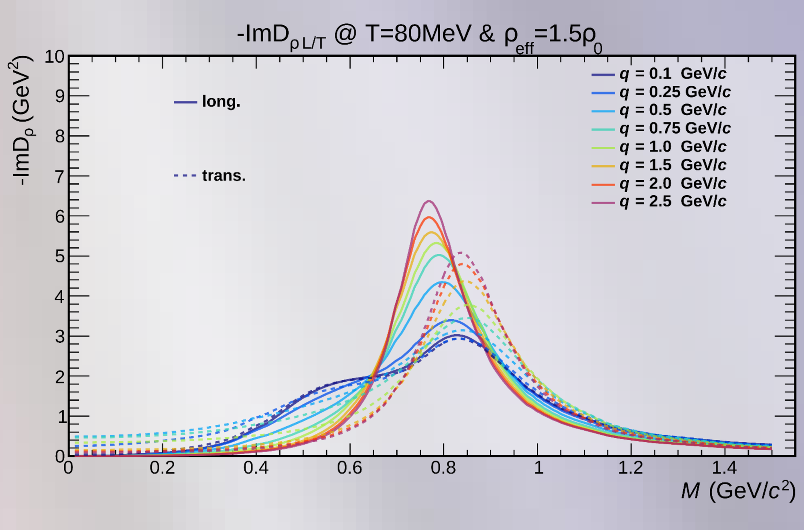
- Dilepton emission rate of thermal QCD matter
$$\frac{dN_{ll}}{d^4x\, d^4q} = \frac{\alpha^2\, L(M)}{6\,\pi^3\, M^2}\, f^B(q_0;\, T)\, g_{\mu\nu}\, \rho^{\mu\nu}_{EM}(M, |\vec{q}|;\, T, \mu_B) \text{ with } \rho^{\mu\nu}_{EM} = -2\,\mathrm{Im}\,\Pi^{\mu\nu}_{EM}$$
- Decomposition of spectral function (SF) with projectors for a spin-1 particle $P^{\mu\nu}_{L,T}$: $\rho^{\mu\nu}_{EM} = \rho_L\, P^{\mu\nu}_L + \rho_T\, P^{\mu\nu}_T$ with $g_{\mu\nu}\,\rho^{\mu\nu}_{EM} = \rho_L + 2\rho_T$
- Invariant mass spectra related to sum of longitudinal and transverse components of the spectral function
  - medium lifetime, temperature, electrical conductivity, EoS at high baryon densities
- Angular distribution of single lepton in γ^* rest frame depends on polarization of γ^*:
$$\frac{dN}{d^4x\, d^4q\, d\Omega} = \mathcal{N}\,(1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi)$$

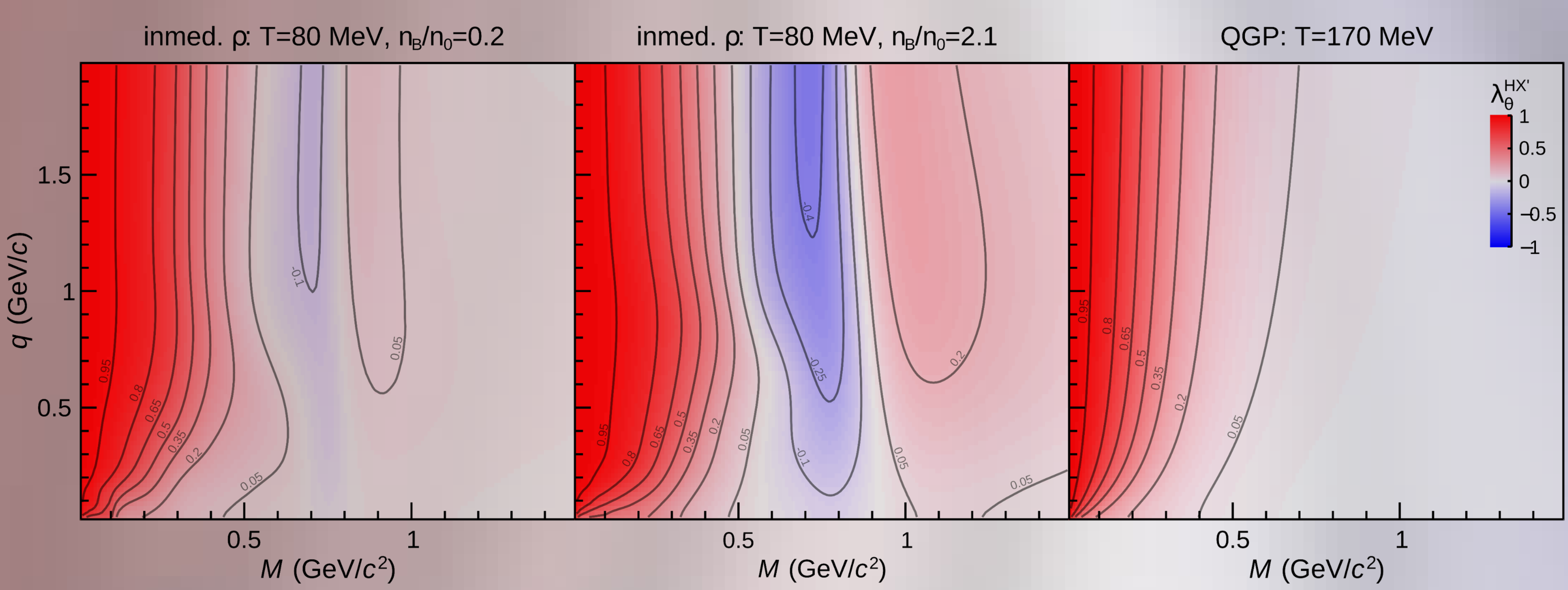


- λ coefficients related to the **difference** between longitudinal and transverse SF components
  - Rotational symmetry of the medium broken by finite momentum $|\vec{q}|$ of the virtual photon
  - for a static thermal medium in the helicity frame: $\lambda_\theta = \frac{\rho_T - \rho_L}{\rho_T + \rho_L}$
- Spin polarization allows to distinguish between different sources of thermal dileptons
  - Access **production mechanism**

Polarization for static medium

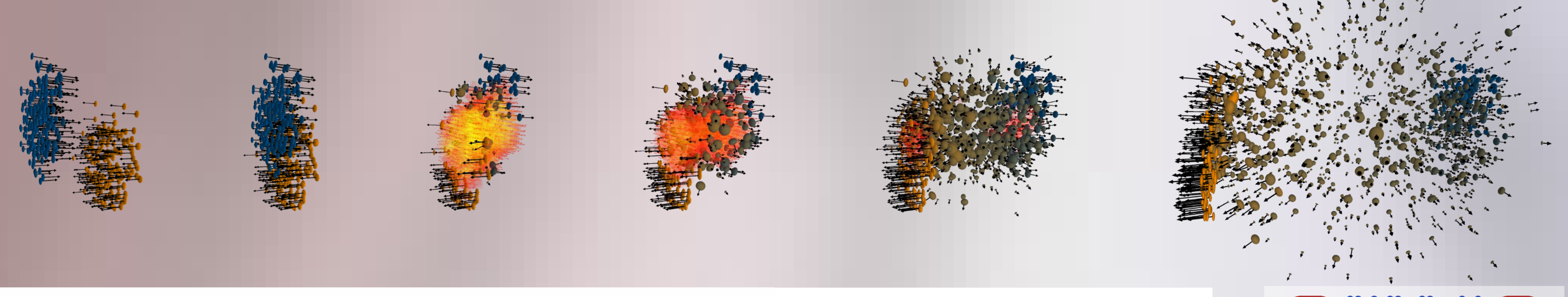
- Employ realistic in-medium SF
- Strong dependence on mass, momentum and baryon density for hadronic medium
- Rather small polarization for QGP except for $M_{ee} < 0.5$ GeV/c^2



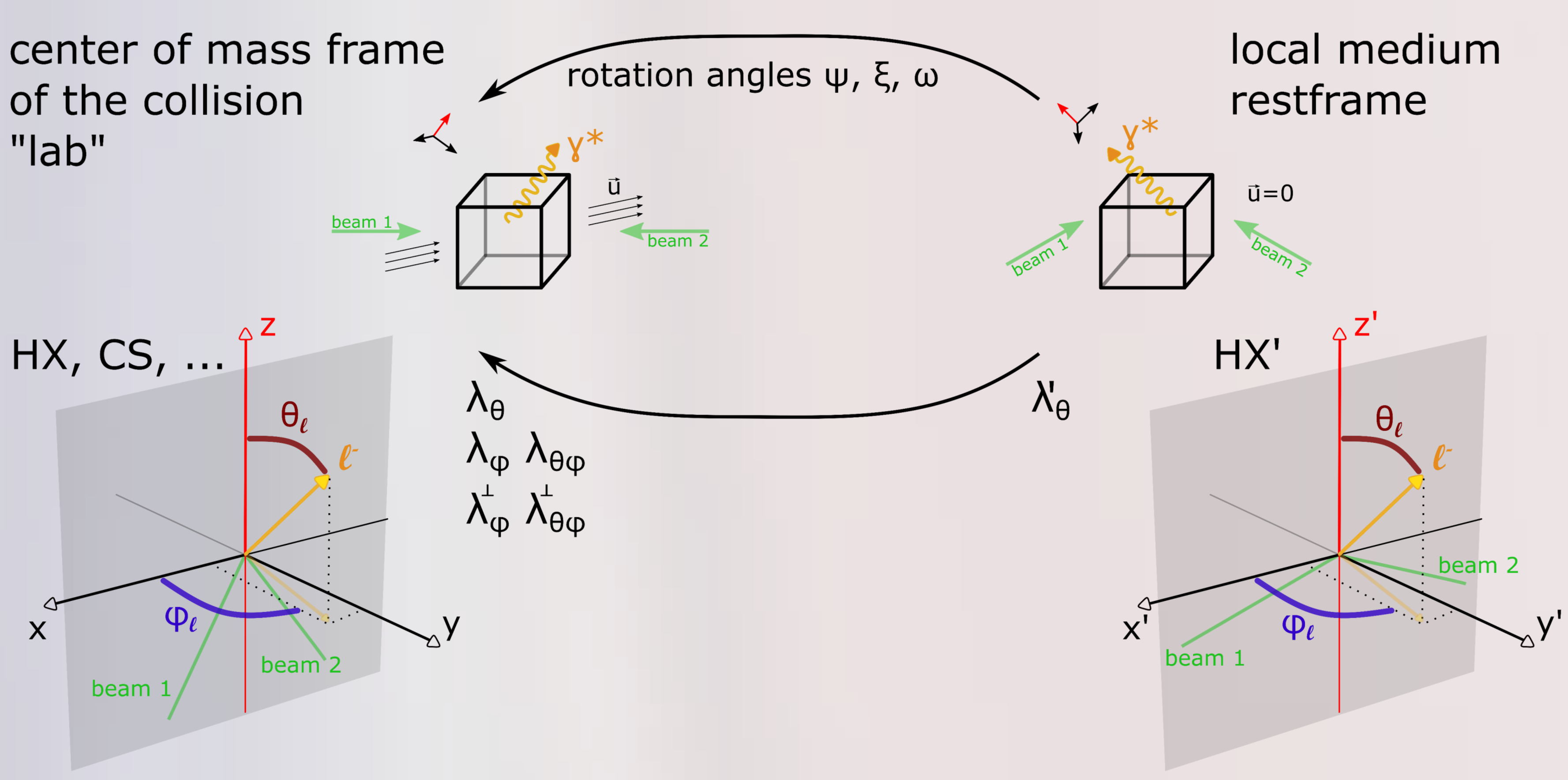


Dynamic medium in heavy-ion collisions

- Space-time evolution modeled via small fluid cells: coarse-grained UrQMD or fireball model
- Helicity frames (HX') of individual local fluid cells misaligned

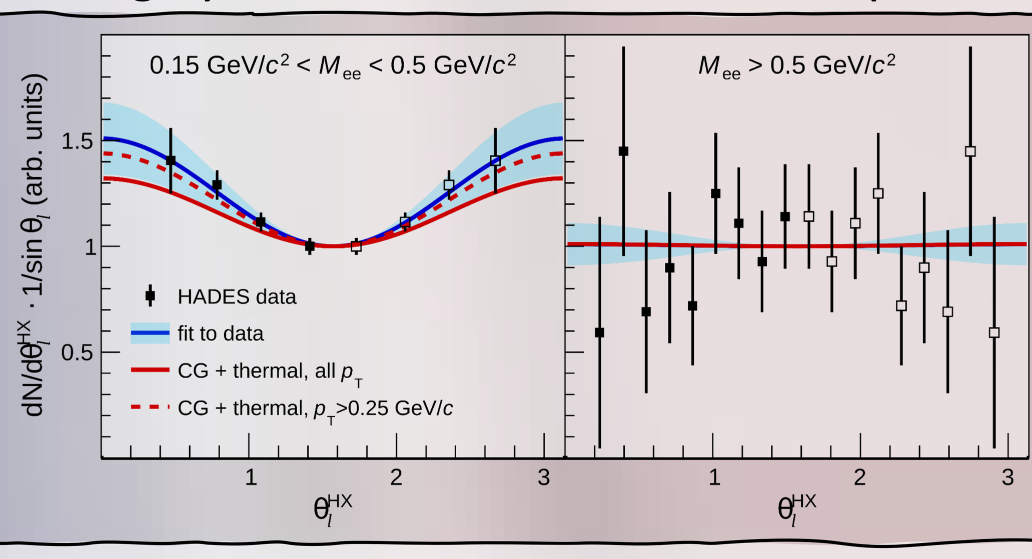


Transform coefficients into a global frame accessible in experiment



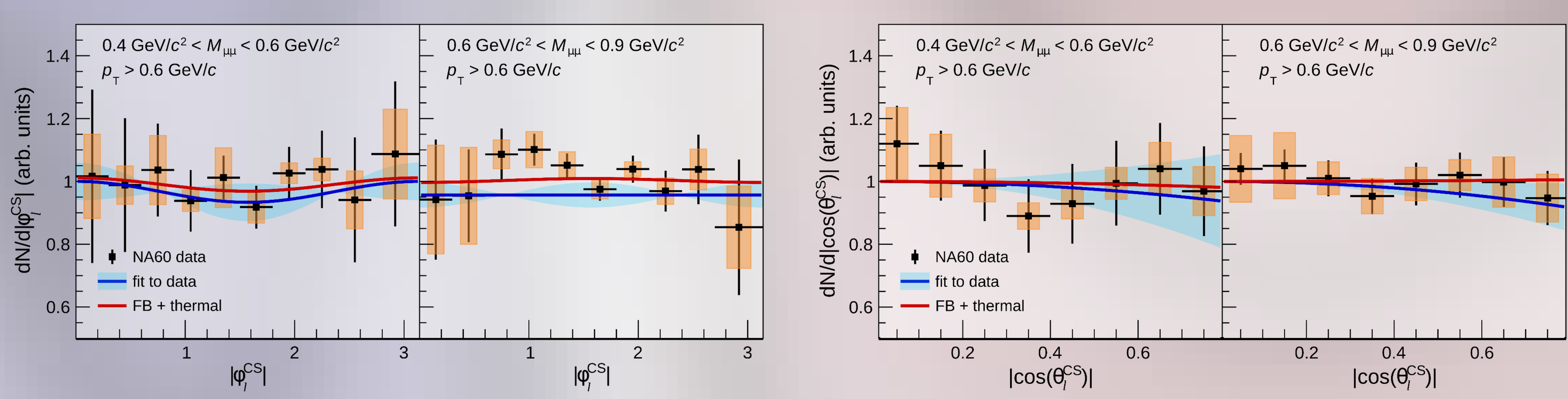
Comparison with HADES data

- Measurement of λ_θ of excess radiation in the HX frame in Ar+KCl collisions at 1.76 AGeV beam energy
  - Space-time evolution via coarse-grained UrQMD
  - Polarization largely survives evolution of the expanding medium



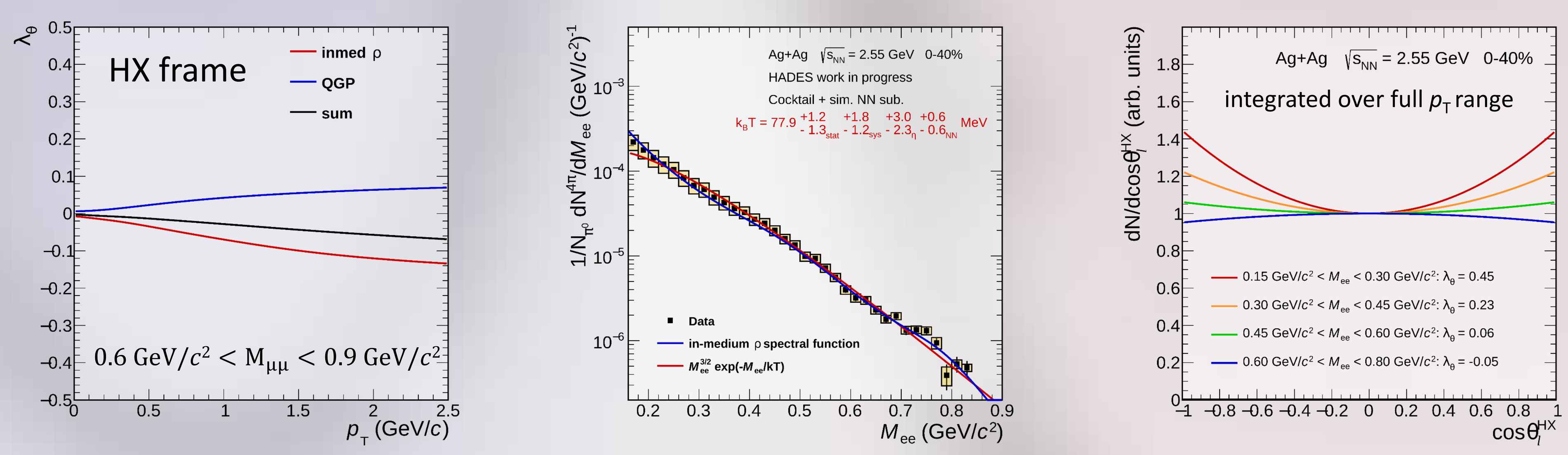
Comparison with NA60 data

- Measurement of λ_θ, λ_φ and $\lambda_{\theta\varphi}$ of excess radiation in the CS frame in In+In collisions at 158 AGeV beam energy
  - Space-time evolution via isentropic fireball model with transition from QGP to hadronic rates at T=170 MeV
  - Near absence of a net polarization due to properties of the EM spectral function
- Strong dependence on the polarization frame as a function of invariant mass and momentum
- Good agreement between data and theory → size and trend



Perspective for future measurements

- Polarization observables play an important role in exploring the mechanisms underlying EM emission spectra in heavy-ion collisions
- Multi-differential measurements of the virtual photon polarization
  - Search for onset of QGP
  - ρ-a_1 mixing vs. QGP around $M_{ee} \simeq 1.1$ GeV
- Large datasets needed: CBM, NA60+ and ALICE 3
- Predictions for polarization in Ag+Ag at $\sqrt{s_{NN}} = 2.55$ GeV with HADES



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