Virtual Photon Measurements with the HADES at GSI

Dielectron reconstruction in Ag+Ag collisions at $\sqrt{s_{NN}} = 2.55\,GeV$

Quark Matter, 04.04.-10.04.2022

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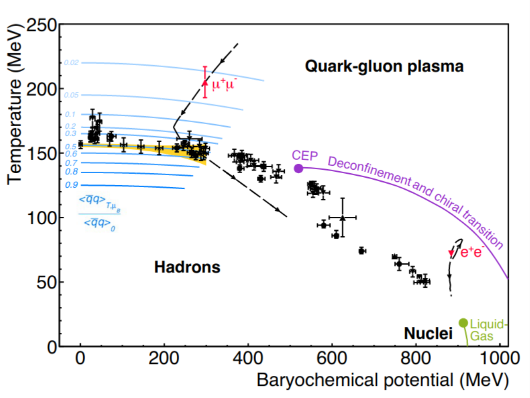
07/04/2022

HADES Physics Program



Nature Physics volume 15, pages 1040–1045 (2019)

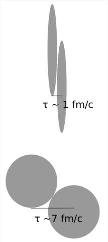
- Explore high-μ_B region of the QCD phase diagram
- Focus on rare and penetrating probes

  → **Virtual and real photons**, that probe all different stages of heavy ion collisions: Initial NN collisions → Fireball → Decay of hadronic resonances
- Address various aspects of baryon-meson coupling

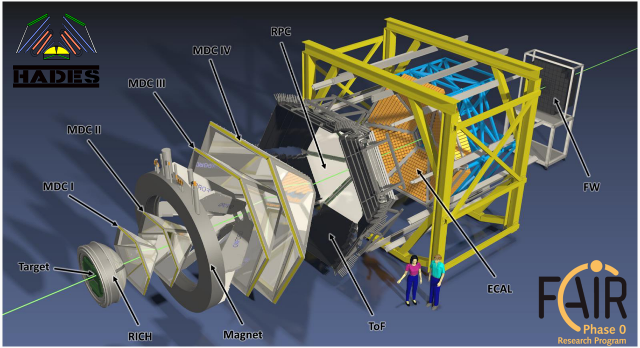
→ **Heavy ion collisions at** $\sqrt{s_{NN}} = 2 - 3\,GeV$

- HADES collision dynamics strongly differs from high energy collisions

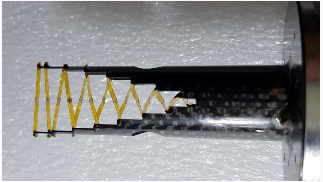
→ **Pion and nucleon beams** e.g. for reference



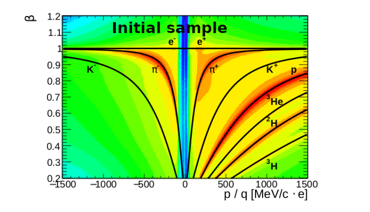
The High Acceptance DiElectron Spectrometer



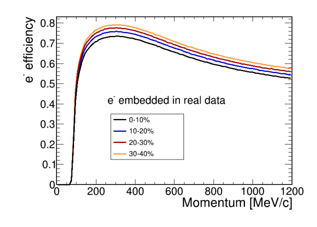
- Fixed target experiment at SIS18 (GSI, Germany)
- Magnet spectrometer
- Low mass Mini-Drift-Chambers (MDCs)
- Time of flight walls RPC and ToF
- Upgraded RICH detector and new ECal for electron and photon detection
- Almost full azimuth angle coverage and polar angles between $18^\circ - 85^\circ$
- 15-fold ($25\ \mu m$, $\Delta z = 3.7\ mm$) segmented target
- Accepted trigger rate 16 kHz for HIC, 50 kHz for elementary reactions

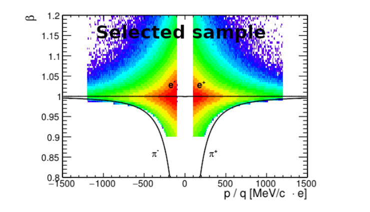


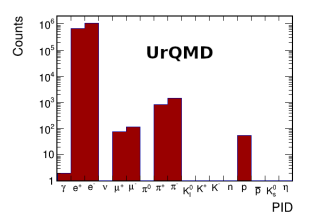
Detector performance - electron identification

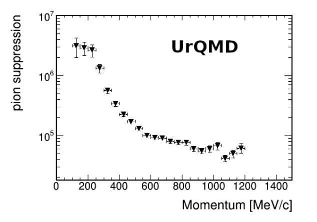


- HADES (RICH) combines high efficient electron identification with high pion and conversion suppression
- Electron efficiency derived embedding single $e^{\pm}$ in real data
- $\rho \to \pi\pi$ ($\sim$ 100%) vs. $\rho \to ee$ ($\sim 4.72 \cdot 10^{-5}$)
- Electron purity of $P > 99\%$ at low momenta; $P \sim 90\%$ at high momenta

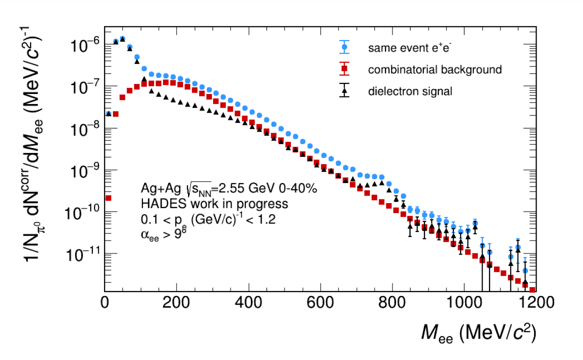








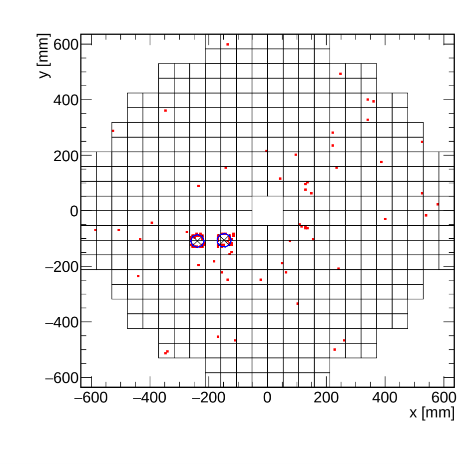
Pair invariant mass distribution

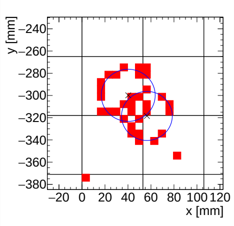


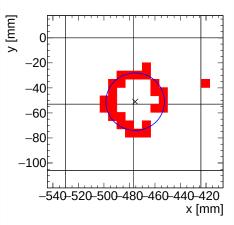
M_{ee} $[MeV/c^2]$	0 -150	150 - 450	450 - 750	750 - 1200
N^{raw}_{pairs}	$1.20 \cdot 10^6$	$1.59 \cdot 10^5$	$1.23 \cdot 10^4$	617
$N^{corr.}_{pairs}$	$2.57 \cdot 10^6$	$3.21 \cdot 10^5$	$2.48 \cdot 10^4$	1432

- Efficiency correction based on single electron simulation embedded into real data (in p, θ, ϕ)
- $< BG_{+-} >= 2k\sqrt{< FG_{++} >< FG_{--} >}$
- BG from mixed-event technique for $M_{ee} > 400\ MeV/c^2$
- $S/B\,(M_{ee} = M_{\omega}) \approx 3$
- $S/B > 1$ for $M_{ee} > 500\ MeV/c^2$

The HADES RICH - conversion recognition

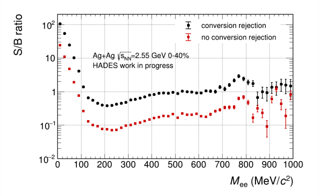




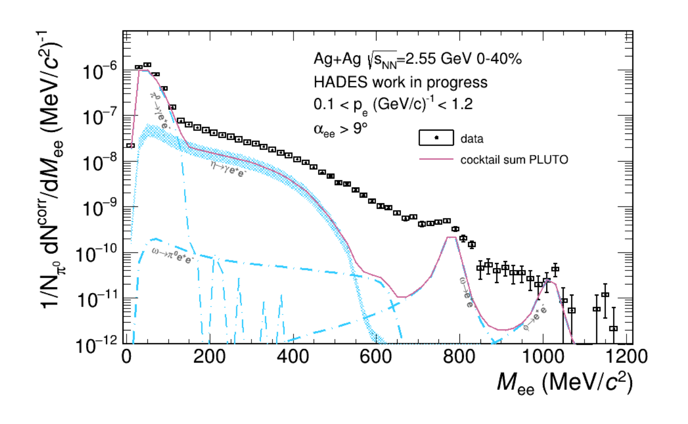


Upgrade of the HADES RICH (in co-operation with CBM)

- Allows for high efficient electron identification in clean environment
- Recognition of conversion pairs even with opening angle $\alpha = 0°$

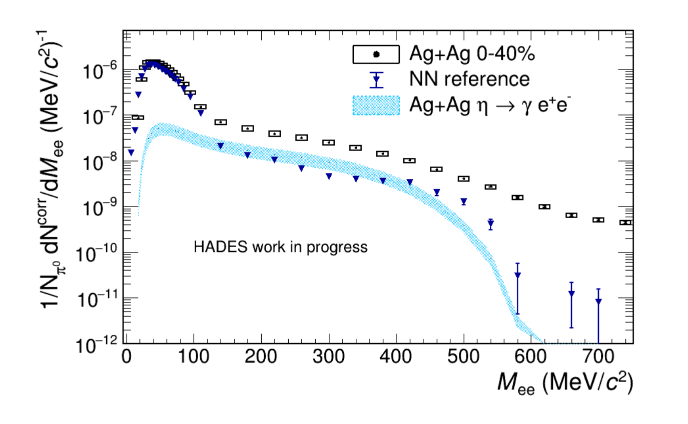


Cocktail simulation



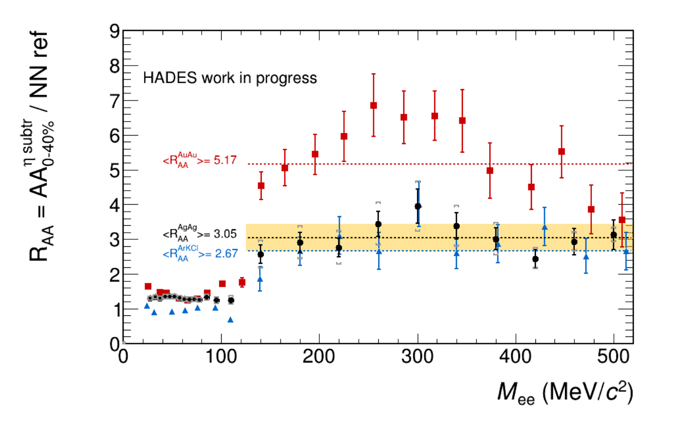
- Hadron multiplicities extracted from the same data
  - Multiplicities of pseudoscalars extracted from 4-electron analysis ($\pi^0/\eta \to \gamma\gamma^{(\star)} \to 4e$)
  - $\omega \to e^+e^-$ signal allows for multiplicity estimation
  - ϕ from K^+K^- and e^+e^-
- Clear excess above final freeze-out hadrons over the full invariant mass region (Fireball + initial NN collisions)

Towards the dielectron excess ratio R_{AA}



- R_{AA}: Dielectron yield in AA collisions normalized to elementary reactions
- NN reference measured at $\sqrt{s_{NN}} = 2.42\,GeV$
  $\rightarrow$ Subtraction of η yield in both data sets to remove energy dependence
  $\rightarrow$ Normalization of AA spectra to N_{π^0} to remove system size dependence
- NN data at $\sqrt{s_{NN}} = 2.55\,GeV$ taken in Feb22 - currently analyzed

The dielectron excess ratio R_{AA}

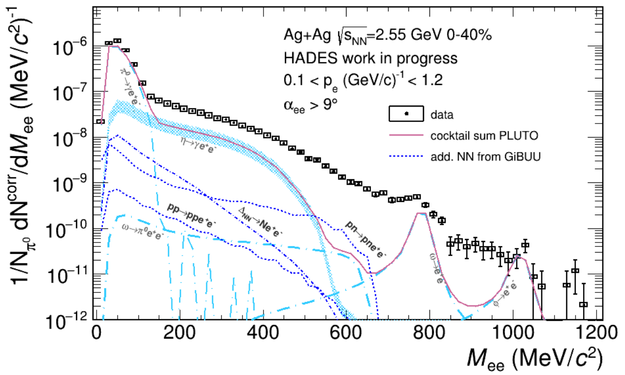


AuAu, ArKCl data published in Nature Physics volume 15, pages 1040–1045 (2019)

- At small M_{ee} the π^0 Dalitz yield dominates
  $\rightarrow$ slight excess only
- Excess of $< R^{AgAg}_{AA} >= 3.05$ observed beyond the π^0 region
- Systematic uncertainties dominated by meson multiplicities (η, yellow band)
- The excess ratio aligns in between of ArKCl and AuAu HADES data

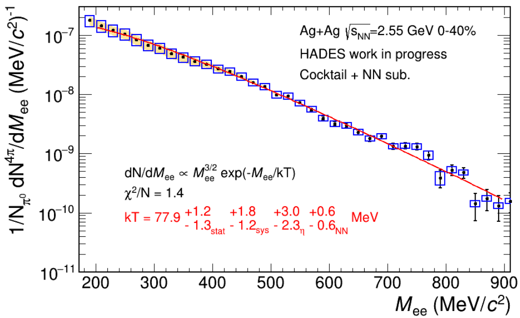
system	$< A_{part} >$
ArKCl	38.5
AgAg	102
AuAu	173

Towards in-medium contribution

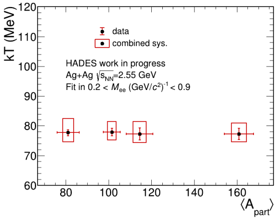


- Use model calculations to compensate for currently missing NN reference to reveal in-medium contribution
- pp and pn simulated using GiBUU 2021 release modeling $NN = 0.54\,pp + 0.46\,pn$ (analogue to Physical Review C, 6, 102.064913)
- Usage of initial NN channels from GiBUU (bremsstrahlung, Δ-resonance)

Temperature of the medium

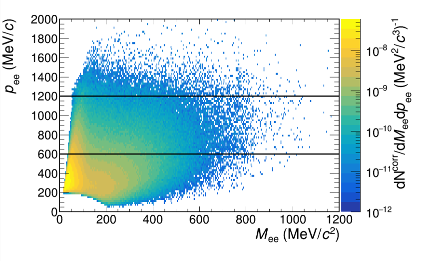


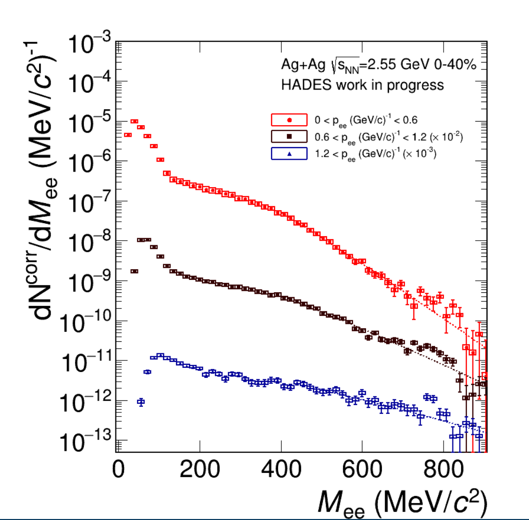
- Subtraction of hadronic cocktail and simulated initial NN contributions reveals excess radiation (Fireball radiation)
- Acceptance corrected medium radiation reveals mean temperature of the fireball; performed based on PLUTO simulation
- Uncertainties in η multiplicity dominant
- Minor temperature dependence on centrality



Momentum dependent dielectron spectra

- Perform analysis in bins of pair momentum
- Broad excess over continuum in low momentum data develops into peak structure in high momentum data at $M_{ee} \sim 770$ MeV/c
- Two possible scenarios:
  (i) ω peak is hidden under broad excess in low momentum data
  (ii) ω itself is broadened (calculation for ρ line-shape needed for ω line-shape analysis)

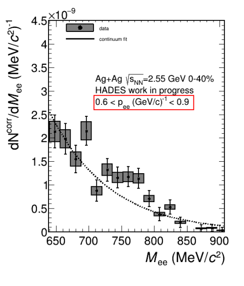


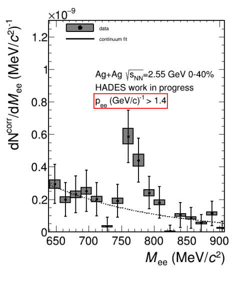


Momentum dependent dielectron spectra

Assuming scenario (i)

- Move to 5-momentum-bin analysis
- The continua of the signal spectra are fitted by a thermal function in the range 500 $MeV/c^2 < M_{ee} < 700MeV/c^2$ to quantify the excess

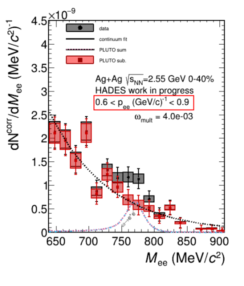


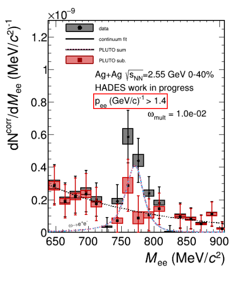


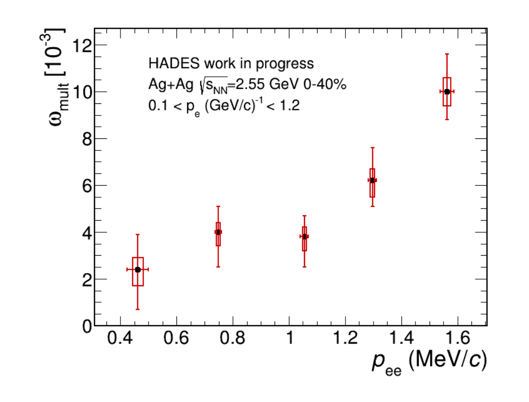
Momentum dependent dielectron spectra

Assuming scenario (i)

- A thermal momentum dependence of the $\omega \rightarrow e^+e^-$ signal is simulated using PLUTO ($T_{eff} = 100\ MeV/k$)
- The spectrum is smoothed by tuning the ω multiplicity in each momentum bin accordingly
- Pair momentum dependence of the such extracted ω multiplicity reveals a significant increase towards high momenta







Summary

- The upgraded HADES spectrometer allows for high efficient electron identification paired with high pion suppression and conversion recognition
  $\rightarrow$ High quality of dielectron spectra
- Hadronic cocktail simulations reveal a clear excess of virtual photons over the full invariant mass region
  $\rightarrow$ Quantified by the dielectron excess ratio R_{AA} aligning in between of AuAu and ArKCl data
- Thermal-like excess spectrum: $T \sim 78$ MeV$/k$; comparable to HADES Au+Au data
- Pair momentum dependent differences in the line-shape in the $\rho - \omega$ mass region
  $\rightarrow$ calculations for ρ line-shape needed to perform ω line-shape analysis

The HADES collaboration