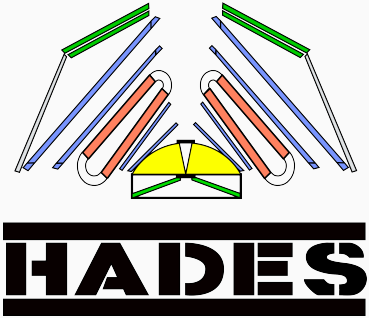
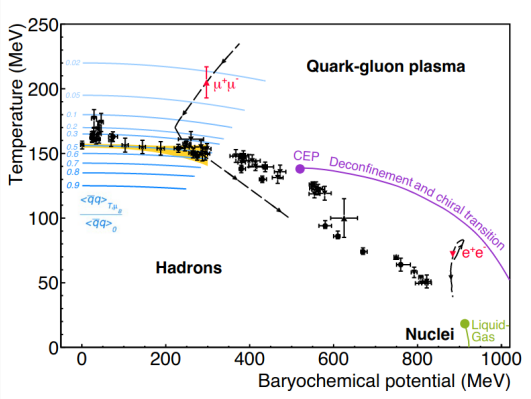


Dielectron measurements with the HADES at GSI

Quark Confinement and the Hadron Spectrum, 01.08.-06.08.2022

Jan-Hendrik Otto for the HADES collaboration, JLU Gießen
05/08/2022

HADES Physics Program



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

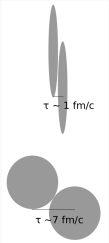
- Explore high-μ_B region of the QCD phase diagram
- Focus on rare and penetrating probes

  → **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

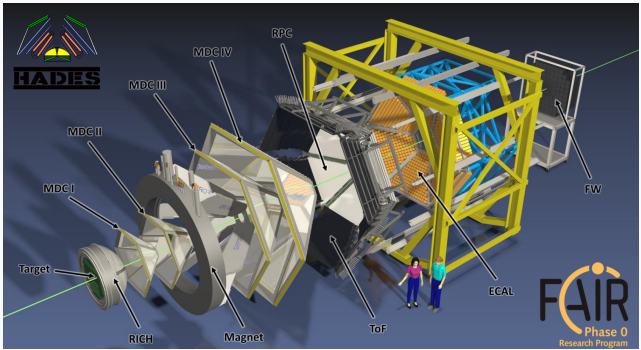
→ **Heavy ion collisions at** $\sqrt{s_{NN}} = 2 - 3\ GeV$

- HADES collision dynamics strongly differs from high energy collisions

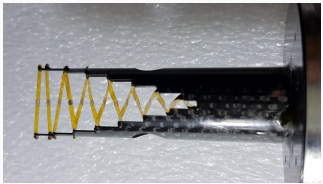
→ **Pion and nucleon beams** e.g. for reference



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



Dielectron measurements with the HADES

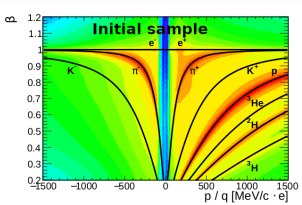
→ $Ag + Ag$ at $\sqrt{s_{NN}} = 2.55\,GeV$

→ $Au + Au$ at $\sqrt{s_{NN}} = 2.42\,GeV$ (Nat. Phys. V15, p 1040–1045 (2019))

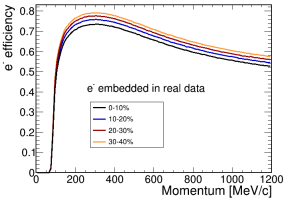
→ $\pi^- + CH_2$ at $\sqrt{s_{\pi^- p}} = 1.49\,GeV$ (arXiv:2205.15914v2 (Jun 2022))

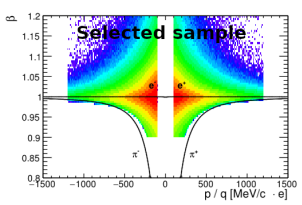
→ $p + p$ at $\sqrt{s_{NN}} = 3.46\,GeV$

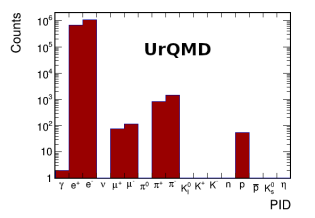
Detector performance - electron identification

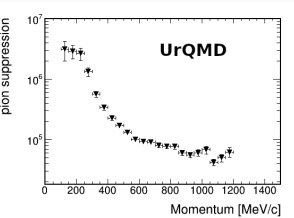


- HADES (RICH) combines high efficient electron identification with high pion and conversion suppression
- Electron efficiency derived embedding single $e^{\pm}$ in real data
- $\rho \rightarrow \pi\pi$ ($\sim 100\%$) vs. $\rho \rightarrow ee$ ($\sim 4.72 \cdot 10^{-5}$)
- Electron purity of $P > 99\%$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

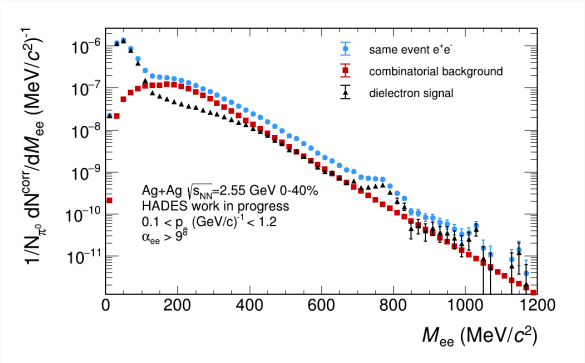








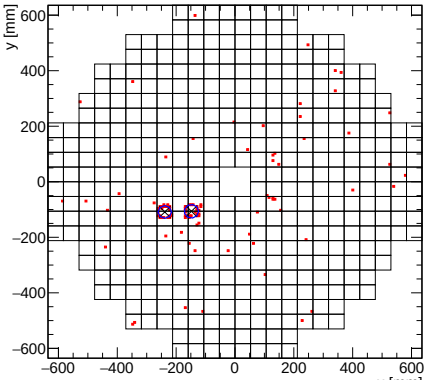
Pair invariant mass distribution

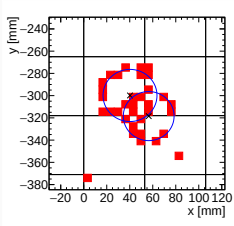


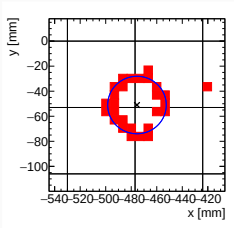
M_{ee} [MeV/c^2]	0 -150	150 - 450	450 - 750	750 - 1200
N^{raw}_{pairs}	$1.20 \cdot 10^6$	$1.59 \cdot 10^5$	$1.23 \cdot 10^4$	617
$N^{corr.}_{pairs}$	$2.57 \cdot 10^6$	$3.21 \cdot 10^5$	$2.48 \cdot 10^4$	1432

- 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

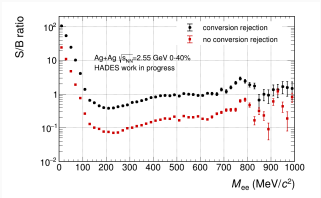




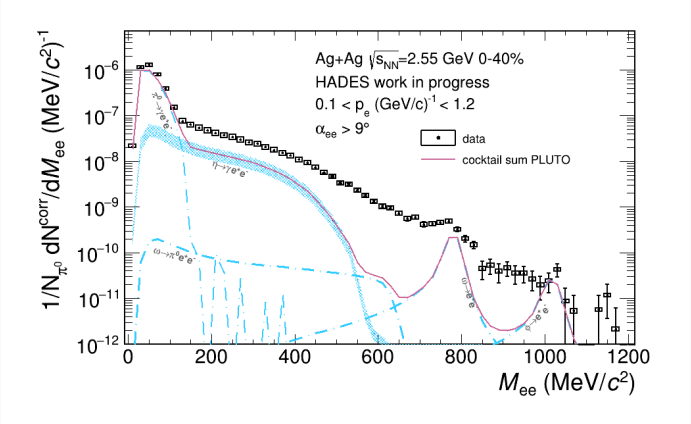


Upgrade of the HADES RICH (in co-operation with CBM)

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

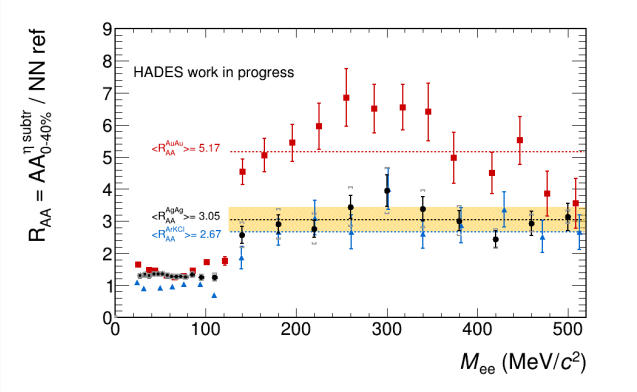


Cocktail simulation



- 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)

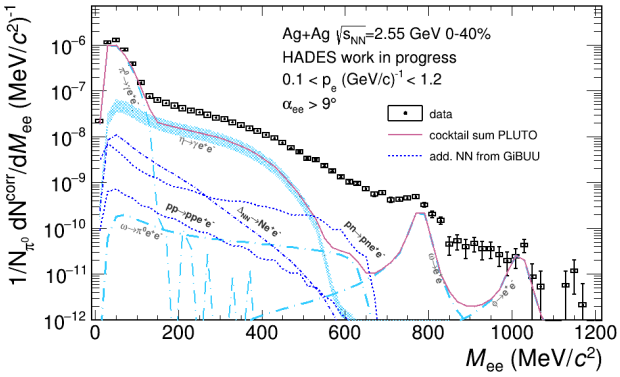
The dielectron excess ratio R_{AA}



- R_{AA}: Dielectron yield in AA collisions normalized to elementary reactions
- 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

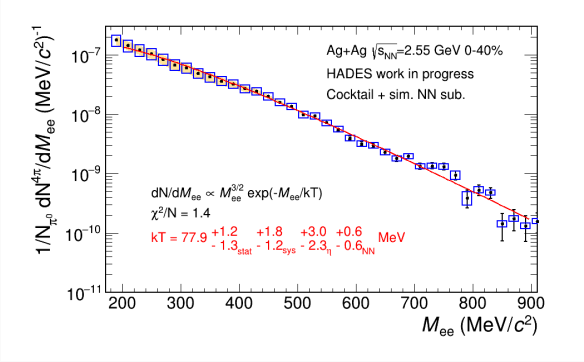
AuAu, ArKCl data published in Nature Physics volume 15, pages 1040–1045 (2019)

Towards in-medium contribution

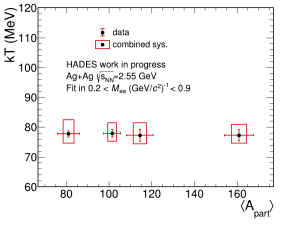


- Use model calculations to compensate for currently missing NN reference to reveal in-medium contribution
- pp and pn simulated using GiBUU 2021 release (Phys. Rept. 512 (2012) 1-124) modeling $NN = 0.54\,pp + 0.46\,pn$ (analogue to Physical Review C, 6, 102.064913)
- Usage of initial NN channels from GiBUU (bremsstrahlung, Δ-resonance)

Temperature of the medium

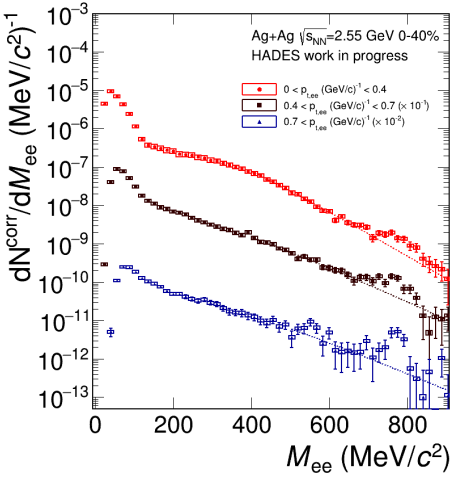


- Subtraction of hadronic cocktail and simulated initial NN contributions reveals excess radiation (Fireball radiation)
- Acceptance corrected medium radiation reveals mean temperature of the fireball; performed based on PLUTO simulation
- Uncertainties in η multiplicity dominant
- Minor temperature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



p_t dependent dielectron spectra

- Perform analysis in bins of transverse pair momentum
- Broad excess over continuum in low momentum data develops into peak structure in high momentum data at $M_{ee} \sim 770\,MeV/c$
- High p_t data shows also an enhancement above the continuum at around $M_{ee} \sim 550\,MeV/c^2$
  - Currently under investigation



Dielectron measurements with the HADES

- $\rightarrow$ $Ag + Ag$ at $\sqrt{s_{NN}} = 2.55\,GeV$
- $\rightarrow$ $Au + Au$ at $\sqrt{s_{NN}} = 2.42\,GeV$ (Nat. Phys. V15, p 1040–1045 (2019))
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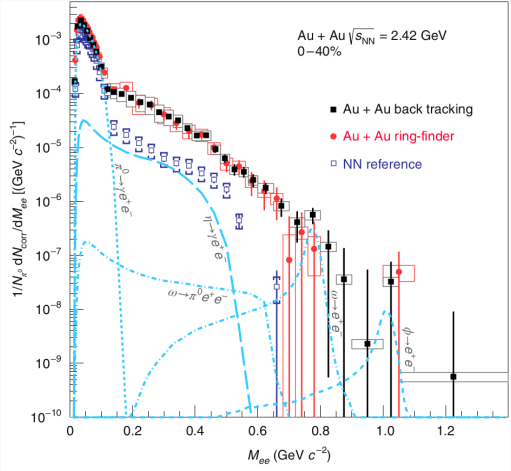
- $\rightarrow$ $p + p$ at $\sqrt{s_{NN}} = 3.46\,GeV$

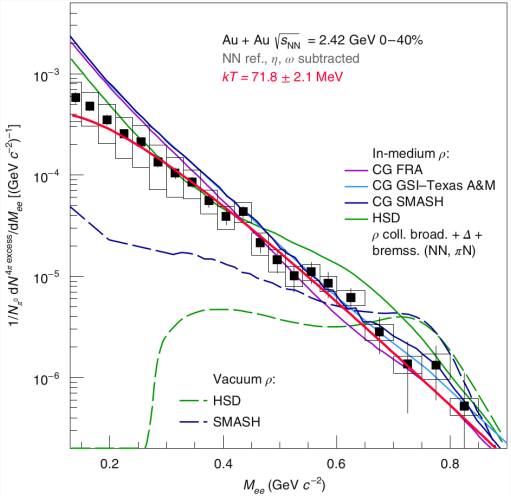
HADES Au+Au measurement

- Analysis performed similarly to presented $Ag + Ag$ data, but data was taken before the RICH upgrade ($S/B \sim 0.1 - 0.2$ instead of $S/B \sim 1$)
- NN reference measured at the same energy by HADES
  $\longrightarrow$extraction of the in-medium contribution straight forward



HADES Au+Au measurement

- Subtraction of NN reference, η (sub-threshold production in A+A) and ω reveals in-medium contribution
- Structureless, near exponential falling spectrum indicates a strong medium modification of the ρ meson required in theory to describe the data



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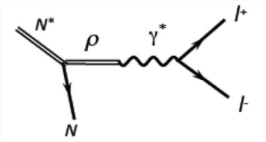
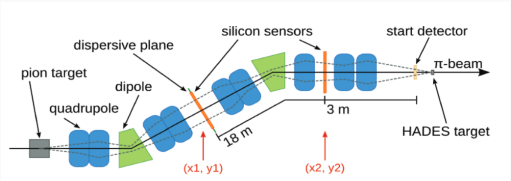
Dielectron measurement in pion induced reactions

- In-medium modification of the ρ potentially caused by strong coupling to baryonic resonance states
- To further test this approach, an experiment of the type $\pi + N \rightarrow Ne^+e^-$, where such resonances are directly formed is ideal
- HADES has initiated a dedicated pion beam program allowing for a resolution of 0.1% to 0.3% in pion momentum





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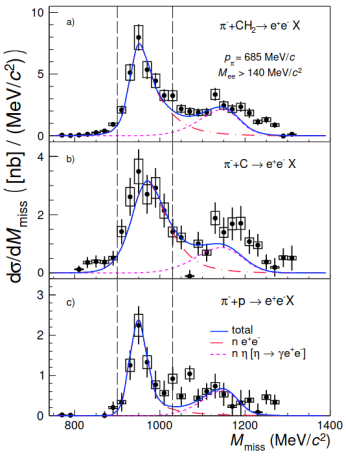
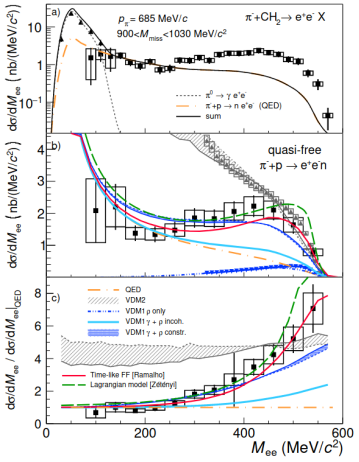
Dielectron measurement in pion induced reactions

- Measurement of dielectron production in $\pi^- + CH_2$ and $\pi^- + C$ allows extraction of $\pi^- + p$ data
- Missing mass requirement of $m(n)$ triggers selection of $\pi^- + p \rightarrow ne^+e^-$ events
- Cross section measured of $\sigma = (2.97 \pm 0.38)\mu b$
- First time measurement at this energy provides necessary input to theory





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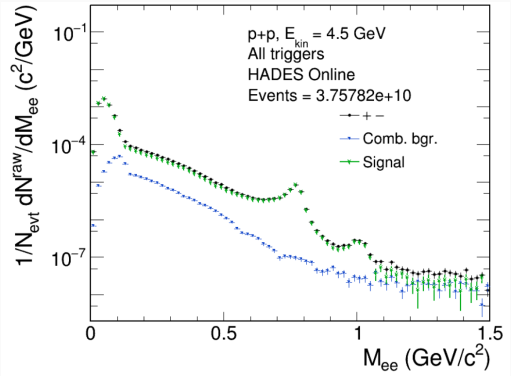
p+p measurement

- HADES FAIR phase 0
- ”Online” spectrum, analysis is ongoing
- Study electromagnetic decays of hyperons
- Dielectron data as reference for $p + A$ and $A + A$ future CBM measurements
- Additionally: Study hadronic decays of hyperons (also double and hidden strangeness)



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, quantified by the dielectron excess ratio R_{AA}
- Thermal-like excess spectrum: $T \sim 78$ MeV/k
- Pair momentum dependent differences in the line-shape in the $\rho - \omega$ mass region
- The versatile HADES allows to study pion induced reactions for further investigation of the $\rho - N$ coupling
  $\rightarrow$First time measurement of $\pi^- + p \rightarrow ne^+e^-$ cross section at the corresponding energy
- Recently taken $p + p$ data currently analyzed

The HADES collaboration