Virtual Photon measurement with the HADES in Ag+Ag collisions at 1.56 AGeV

Theory Lunch Seminar

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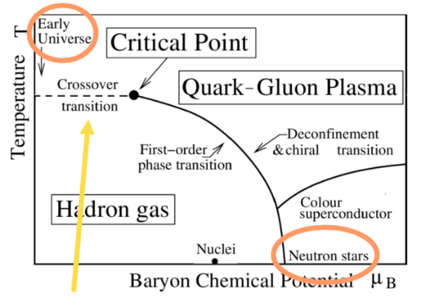
Outline

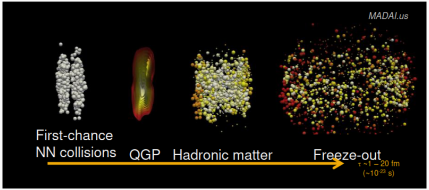
- Introduction and motivation to experimental measurements
- The HADES and electromagnetic probes
- DiElectrons in Ag+Ag collisions at 1.56 AGeV
    - Understanding of the signal contributions
    - System size dependence
    - Momentum dependence

Heavy ion collisions

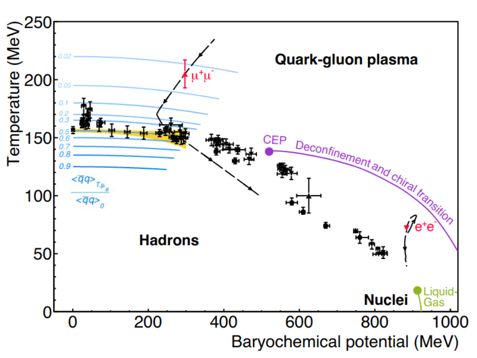
- Understand and classify the properties of strongly interacting matter at extreme temperatures and densities
  →equation of state
  →phase structure



- Features predicted by theory need to be experimentally proven
- use heavy ion collisions to heat up and compress bulk hadronic matter
- μ_B describes density of baryons - anti-baryons
- with varying collision energy, different regions of the QCD phase diagram are accessible



Physics at HADES



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

- Explore high-μ_B region of the QCD phase diagram
- Focus on rare and penetrating probes
- Address various aspects of baryon-meson coupling

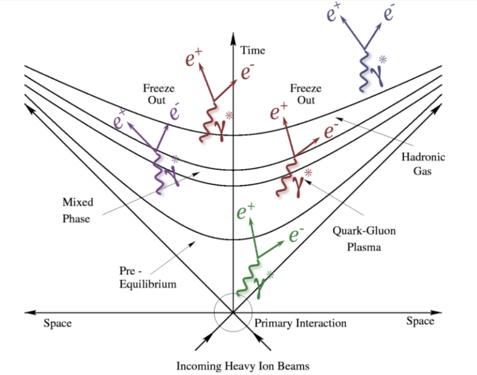
Heavy ion collisions at $\sqrt{S_{NN}} = 2 - 3\,GeV$:

- Microscopic properties of baryon dominated matter
- Equation of state
  - Event-by-event fluctuations
  - Flavor production and collective effects
  - DiLeptons

Pion and nucleon beams

- Reference measurements (cold matter, vacuum)
- Electromagnetic structure of baryons and hyperons

Electromagnetic probes



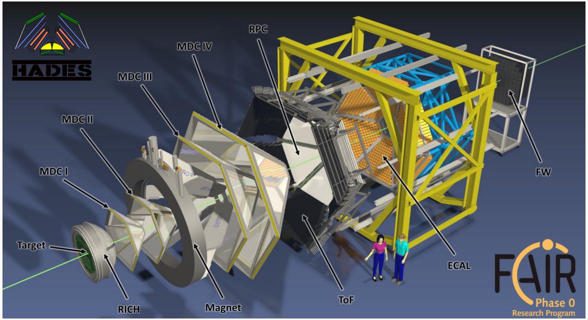
Virtual and real photons probe all different stages of heavy ion collision

- Intitial NN collisions
- Fireball
- Decay of hadronic resonances

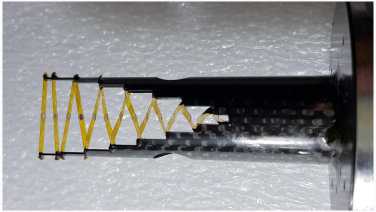
Virtual photons serve e.g. as

- Thermometer
- Chronometer
- Baryometer

The High Acceptance DiElectron Spectrometer

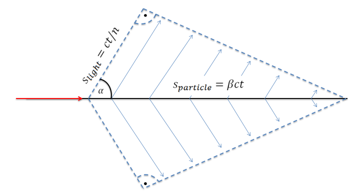


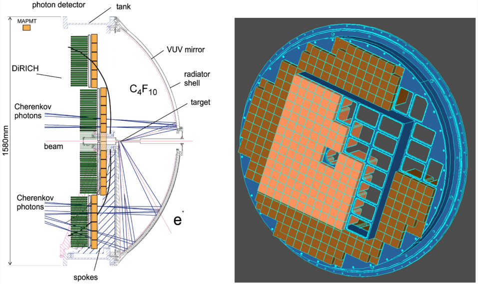
- Fixed target experiment at SIS18 (GSI, Germany)
- Magnet spectrometer
- Low mass Mini-Drift-Chambers (MDCs)
- Time of flight walls RPC and ToF
- Upgraded RICH detector and new ECal for electron and photon detection
- Almost full azimuth angle coverage and polar angles between 18° — 85°
- 15-fold (25 μm, $\Delta z = 3.7$ mm) segmented target



The upgraded HADES RICH detector

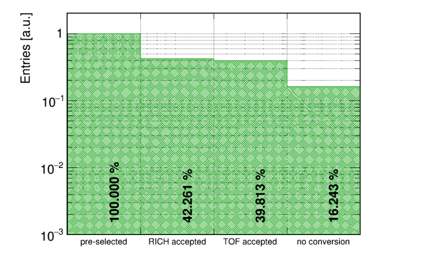
- Cherenkov radiation emitted in a 'Mach cone' in case of $v_{particle} > c_{medium}$
- HADES RICH radiator gas: C_4F_{10} with $n = 1.0014$
  - $p_{thresh,e} = 9.65\,MeV$
  - $p_{thresh\pi} = 2636.70\,MeV$
- operation as threshold detector: Only electrons produce Cherenkov photons

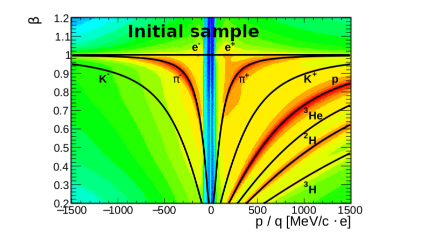


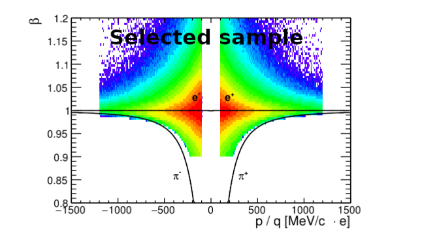


- Cherenkov cone reflected onto the PMT plane to form a ring (**R**ing **I**maging)
- 428 PMTs, 8 × 8 pixels each, individual pixel readout
- Timing information (LE, ToT) provide high level noise rejection (unfortunately no double hit recognition)

Electron identification

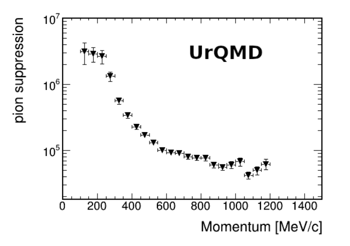


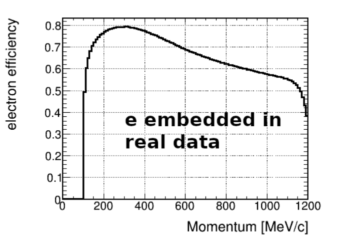




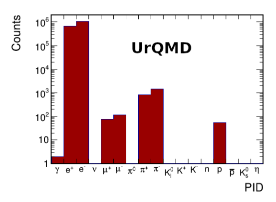
- $4.55 \cdot 10^9$ Ag+Ag collisions analysed (0 – 40% centrality)
- RICH (and TOF) criteria for lepton identification
- New: Highly efficient physical background (conversion) rejection based on the RICH

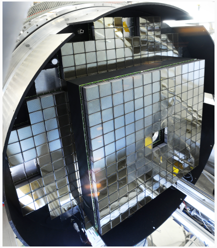
Electron identification





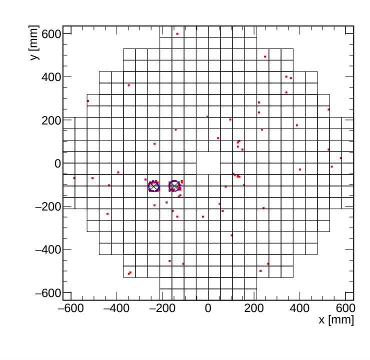
- HADES (RICH detector) combines high efficient electron identification with high pion and conversion suppression
- $\rho \to \pi\pi$ ($\sim 100\%$) vs. $\rho \to ee$ ($\sim 4.72 \cdot 10^{-3}\%$)
- Electron purity of $P > 99\%$ at low momenta; $P \sim 90\%$ at high momenta (UrQMD simulation, RICH rotation technique)
- Efficiency calculation based on $e^{\pm}$ embedded in real data
- HADES electromagnetic calorimeter might even further improve



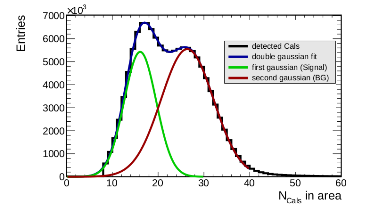


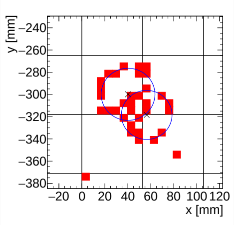
The HADES RICH - conversion suppression

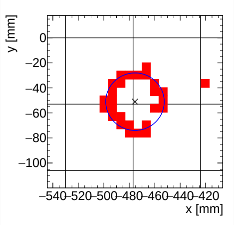
Upgrade of the HADES RICH (in cooperation with CBM)



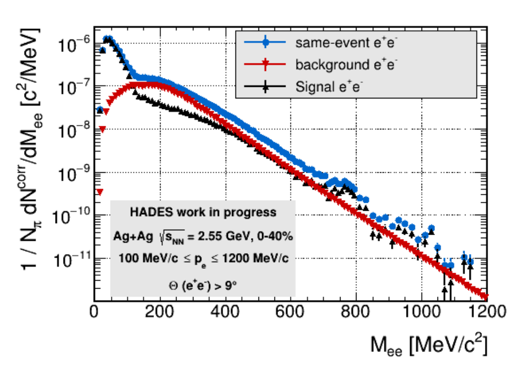
- On average 16 photons/ring
- Negligible background level - timing cuts enable high level noise rejection
- Excellent conversion recognition even at vanishing opening angles by counting converted Cherenkov photons (Cals)





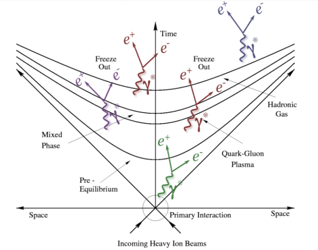


DiElectron formation

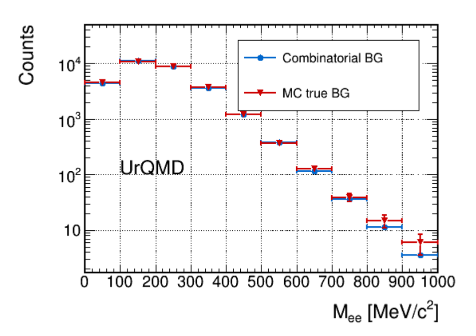


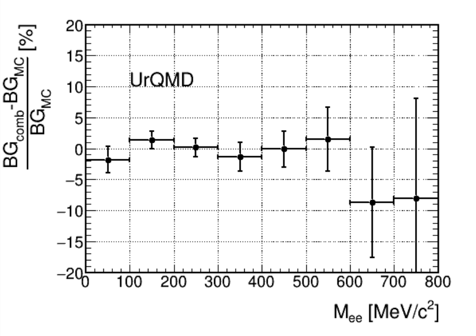
M_{ee} [MeV/c^2]	0 -150	150 - 450	450 - 750	750 - 1200
N^{raw}_{pairs}	$0.141 \cdot 10^6$	$0.607 \cdot 10^5$	$0.590 \cdot 10^4$	556
$N^{corr., CB sub.}_{pairs}$	$1.546 \cdot 10^6$	$1.752 \cdot 10^5$	$1.318 \cdot 10^4$	1500

- 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 $M_{ee} > 300\ MeV/c^2$
- $S/B\,(M_{ee} = m_\omega) \approx 3$
- $S/B > 1$ for $M_{ee} > 400\ MeV/c^2$

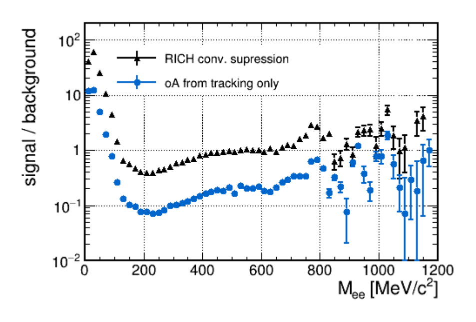


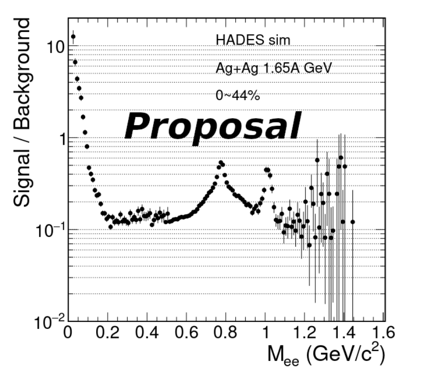
On CB - Comparison to MC true in UrQMD





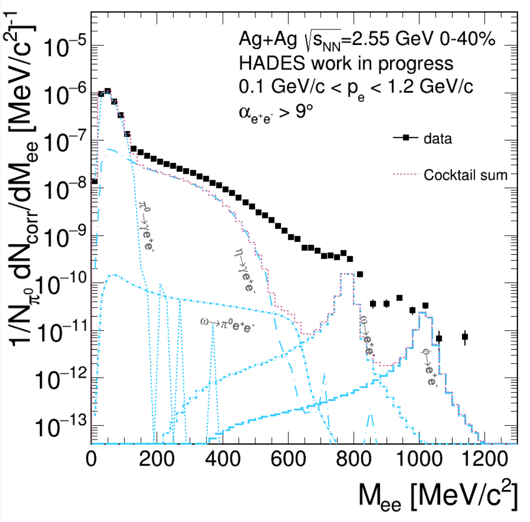
Signal/BG





- Conversion suppression using the upgraded RICH detector improves S/B by a factor of about 5
- The same improvement is reached comparing to idealistic simulation from the proposal

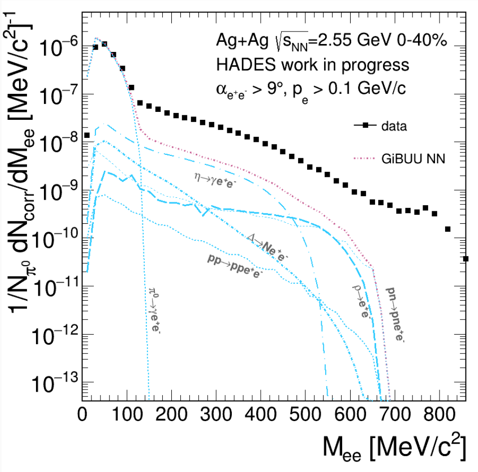
Cocktail simulation



- π^0 extrapolated from π^+ and π^- measurement; π^0 analysis in $\pi^0 \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma \to 4e$ currently performed (see later slide)
- η from TAPS systematics (Phys. Rev. C84(1 2011)); analysis via conversion channel also currently performed
- ω and ϕ from thermal models; good agreement with extrapolation from high momentum data to full phase space in ω
- Clear excess above final freezeout hadrons

	Mult/ $\langle A_{part}\rangle$	0 — 40 % centrality
$\langle A_{part}\rangle$		102
$Mult_{\pi^0}$	0.08	8.01
$Mult_{\eta}$	$2 \cdot 10^{-3}$	0.20
$Mult_{\omega}$	$3.50 \cdot 10^{-5}$	$3.57 \cdot 10^{-3}$
$Mult_{\phi}$	$3.00 \cdot 10^{-7}$	$3.06 \cdot 10^{-5}$

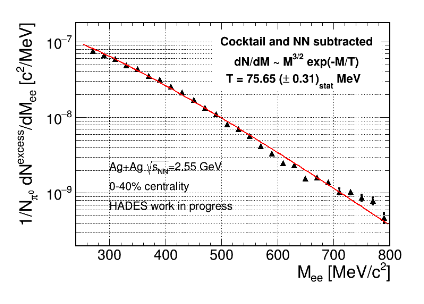
NN Reference



- No NN reference measured by HADES at $\sqrt{s_{NN}} = 2.55\,GeV$
- pp and pn simulated using GiBUU 2021 release (analogue to Physical Review C, 6, 102.064913) modeling $NN = 0.54\,pp + 0.46\,pn$
- Uncertainties especially in the pn-bremsstrahlung contribution dominant for $M_{ee} > 500\,MeV/c$

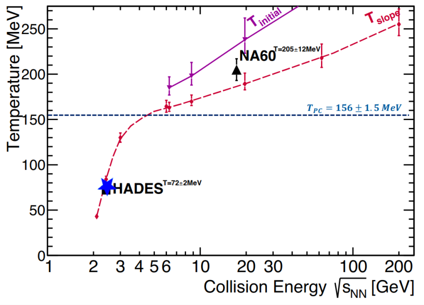
Excess radiation

- Subtraction of hadronic cocktail and GiBUU NN reference (bremsstrahlung) reveals fireball radiation
- Acceptance correction based on PLUTO simulation
- Only statistical errors shown



Rapp and v. Hess, *PLB* 753 (2016) 586

TG et al. : *EPJA* 52 (2016) 131

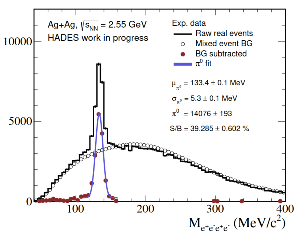


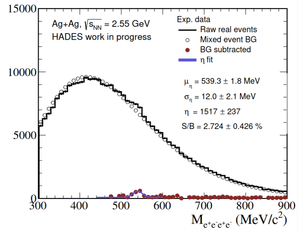
[NA60] *Chiral* 2010, *AIP Conf.Proc.* 1322 (2010)

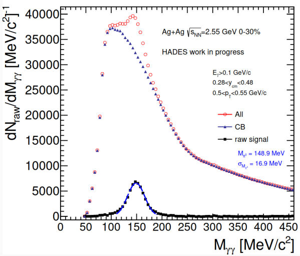
[HADES] *Nature Phys.* 15(2019) 1040

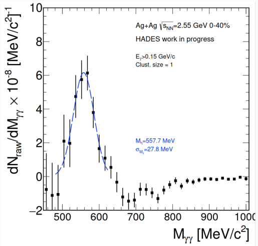
On systematics

- All physics quantities heavily rely on a precise knowledge on π^0 and η production
- Major differences in hadron multiplicities assumed for cocktail compared to model calculations (e.g. GiBUU, 40% less in η yield)
- Upcoming HADES results will significantly improve here
- Preliminary (HADES Colaboration meeting two weeks ago): 5-6 π^0 per event

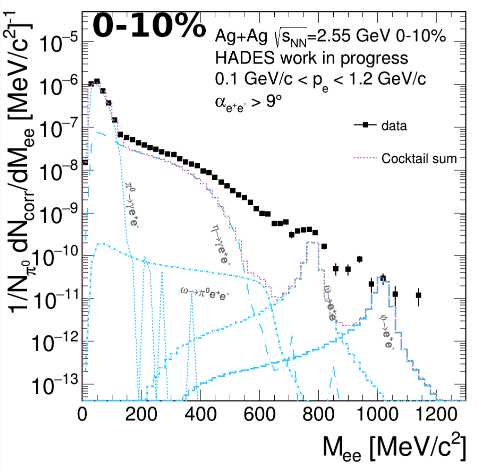




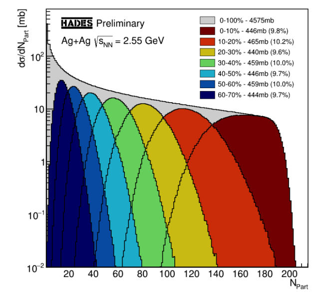




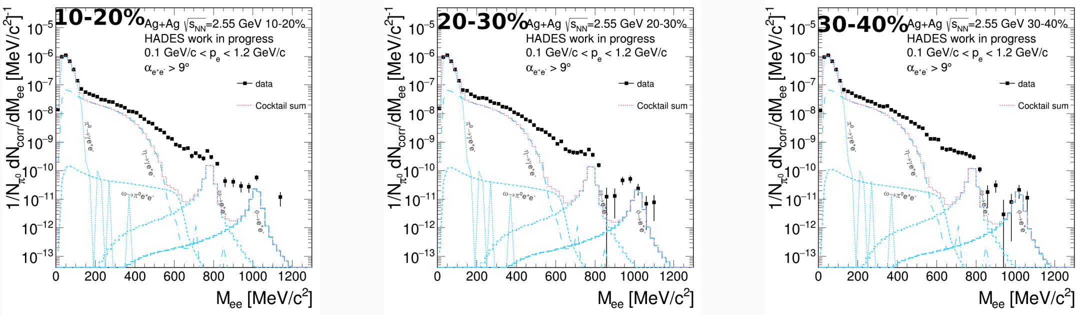
Centrality dependent analysis



- Centrality estimation based on the Glauber MC model (analogue to published AuAu data, Eur. Phys. J. A 54, 1434-601X)
- Linear scaling with $\langle A_{part} \rangle$ assumed for π^0 and η
- $\langle A_{part} \rangle^{4/3}$ scaling assumed for ω and ϕ

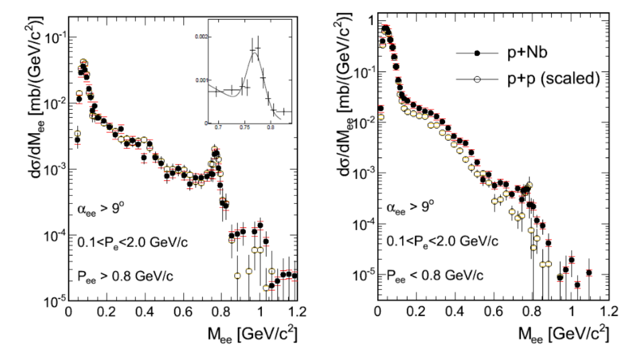


Centrality dependent analysis



- All centrality classes compare well → assumptions on scaling of hadron production seem reasonable

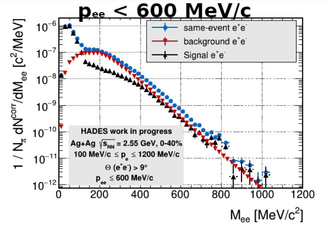
Pair momentum dependent analysis with HADES

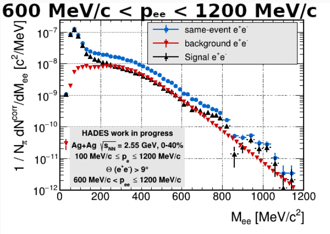


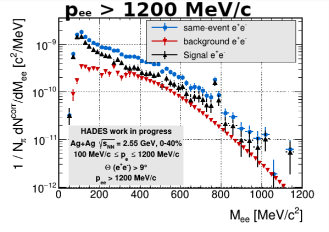
HADES p+Nb analysis, Phys.Lett.B 715 (2012) 304-309

- no hints for in-medium broadening of the ω in the high momentum case ($p_{ee} > 800\,MeV/c$); fitted width of $13 - 19\,MeV/c$
- in low momentum data ($p_{ee} < 800\,MeV/c$) no peak structure is observed, but therefore a strong excess yield below the ω pole mass
- strong modification of the spectrum with momentum

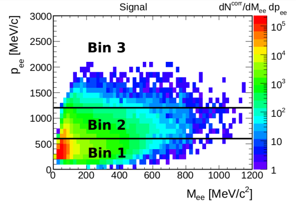
Pair momentum dependent analysis



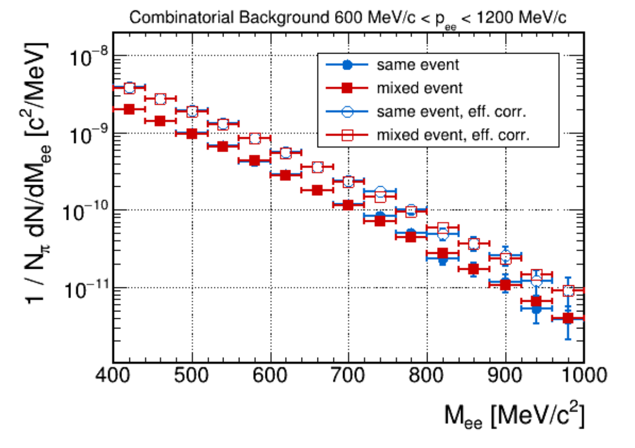




- Change of the line shape with momentum at the ω pole mass observed (similar to previous HADES p+Nb measurement, *Phys. Let. B 8 (2012), 10.1016*)
- ω multiplicity estimation possible for high momenta

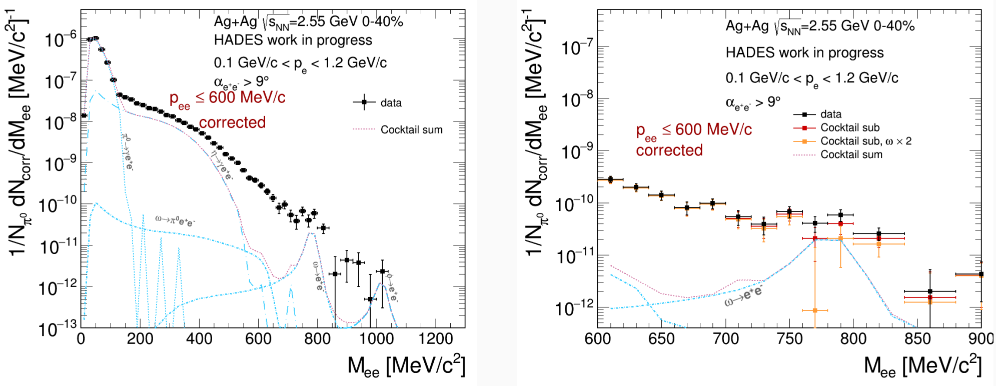


On systematics

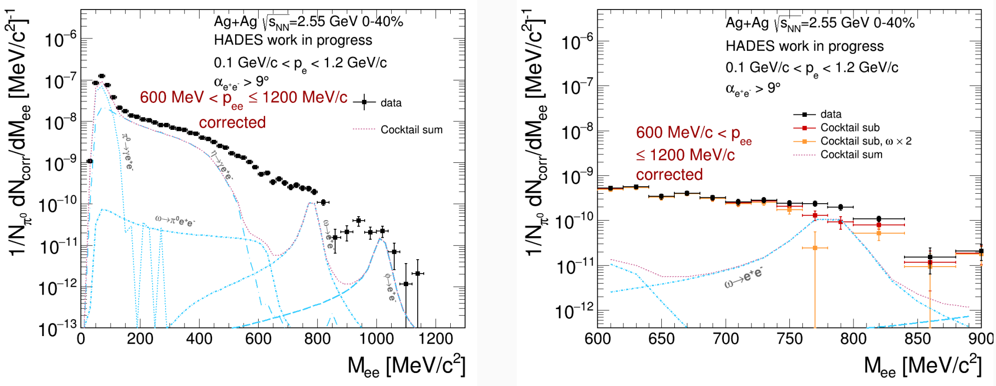


- perfect agreement between same-event and mixed event distributions
- efficiency correction is a constant up-scaling of the spectrum, although performed on single electron basis ⟶small systematic error (from those sources)

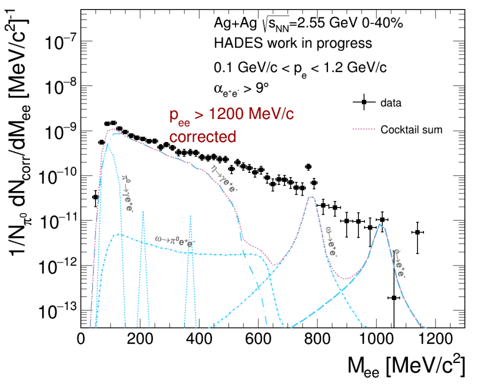
Cocktail simulation, $p_{ee} \leq 600 MeV/c$

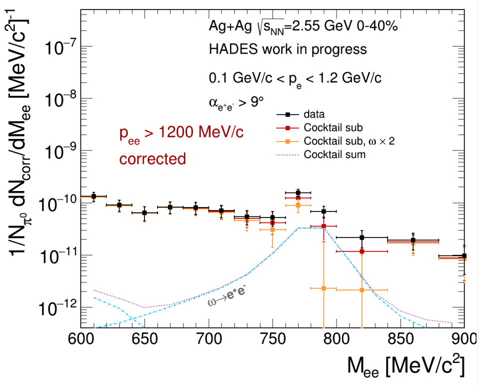


Cocktail simulation, $600 MeV/c < p_{ee} \leq 1200 MeV/c$

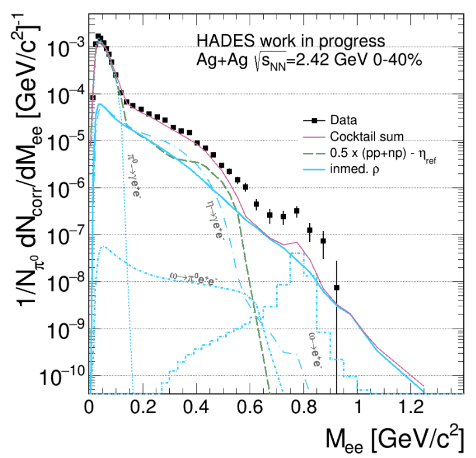


Cocktail simulation, $p_{ee} > 1200 MeV/c$





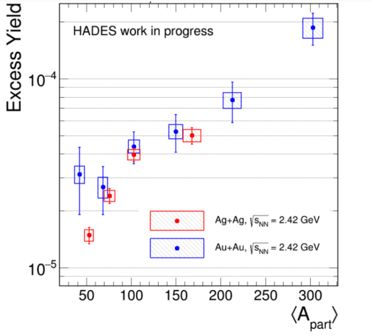
Ag+Ag at $\sqrt{s_{NN}} = 2.42\,GeV$



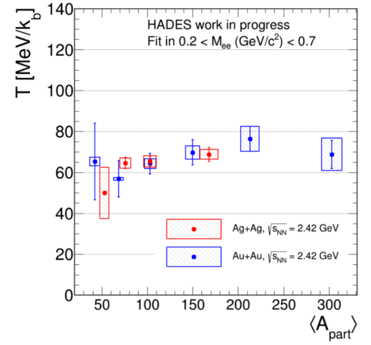
- In only three days of beamtime, HADES measured AgAg at $\sqrt{s_{NN}} = 2.42\,GeV$
- DiElectron statistics similar to same energy measurement in AuAu in 2012
- Here, we have measured NN reference available!

Ag+Ag at $\sqrt{s_{NN}} = 2.42\ GeV$

- Integrated DiElectron yield mirrors lifetime of the system ⟶DiElectrons as chronometer

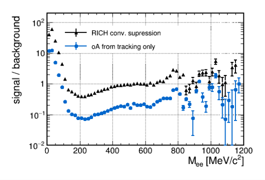


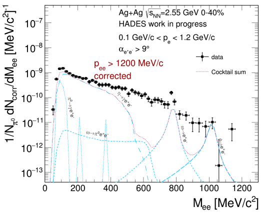
- Slope of the excess yield reveals medium temperature ⟶DiElectrons as thermometer
- Measurements in both systems agree

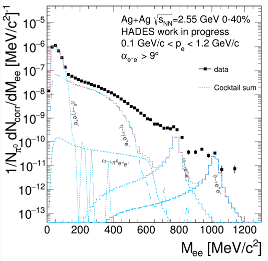


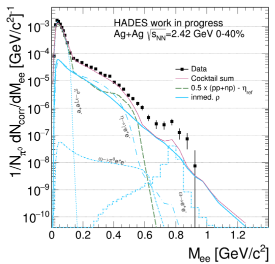
Summary

- High quality AgAg data at $\sqrt{s_{NN}} = 2.55\,GeV$ and $\sqrt{s_{NN}} = 2.42\,GeV$ taken by HADES
- The upgraded spectrometer allows for high efficient electron identification paired with high pion suppression and conversion recognition: Unprecedented quality of DiElectron spectra
- Hints for in-medium modification of the ω meson comparing low and high momentum data
- Decomposition of the DiElectron spectrum and comparison to NN reference (GiBUU) enables temperature estimation (as in AuAu, Nature Physics volume 15, pages 1040–1045 (2019))









The HADES collaboration