Dielectron analysis in p+p collisions at 1.58 GeV beam energy with HADES

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

GSI

HADES

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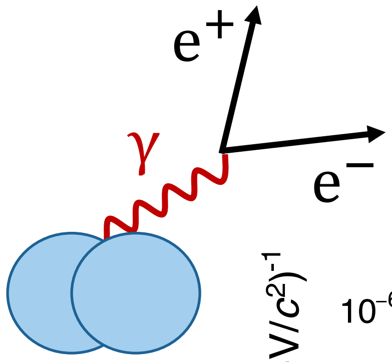
1. Motivation

- Electromagnetic probes offer direct access to all stages in heavy-ion collisions
- The slope and excess of the in-medium contribution allows for the extraction of the mean medium temperature and medium lifetime in heavy-ion collisions
- p+p(n) collisions serve as baseline for the understanding of the Ag+Ag data measured at $\sqrt{s_{NN}} = 2.55$ GeV in March 2019
- Main uncertainties of the in-medium contribution originate from the simulated NN reference spectrum

→ Provide p+p & p+n reference spectrum for the Ag+Ag measurement from 2019



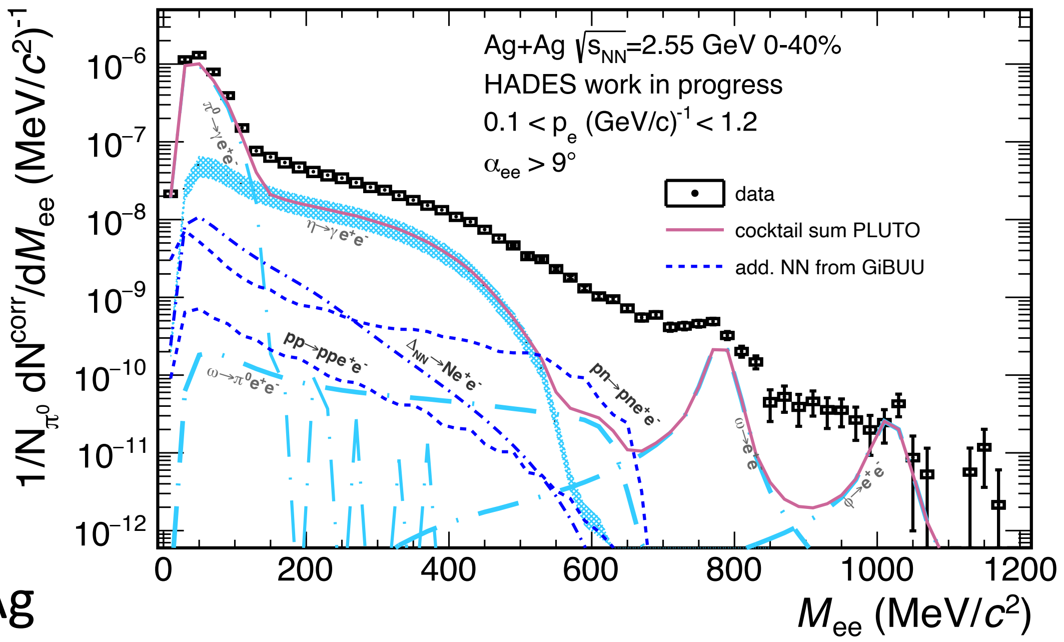


Figure 1: Ag+Ag data with hadronic cocktail and relevant NN channels from simulation [2].

2. The HADES Experiment

High **A**cceptance **D**i**E**lectron **S**pectrometer

- Fixed target experiment
- Located at GSI in Darmstadt, Germany
- Operating for more than 25 years with different kinds of hadrons and ions
- Divided into 6 identical sectors each covering $60°$ of the azimuthal angle
- High acceptance: $18° < \theta < 85°$ and full azimuthal acceptance

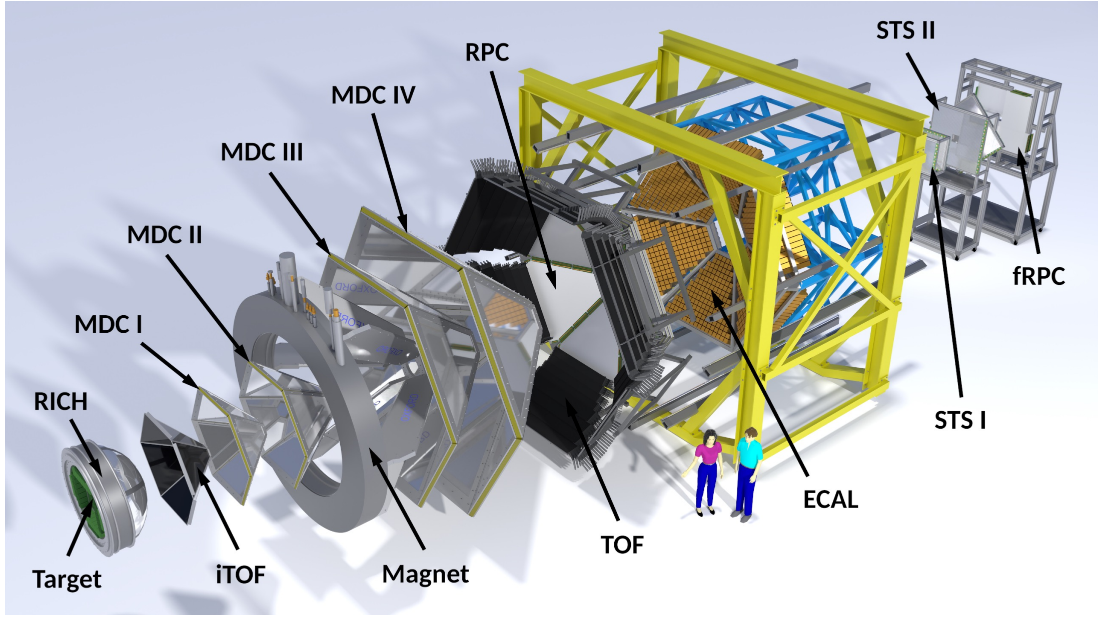


Figure 2: 3-dimensional schematic view of HADES for the p+p beamtime from 2022.

2. The HADES Experiment – The RICH detector

- Upgraded photodetection plane in 2019
  → based on MAPMTs and DiRICH readout
- Filled with isobutan (C_4H_{10})
  → refractive index $n = 1.0014$
- Thresholds for Cherenkov radiation:
  - Electrons: ≈ 9 MeV/c
  - Hadrons: > 2.5 GeV/c

→ Existence of a ring is a sufficient criterion for the identification of an electron in the RICH detector

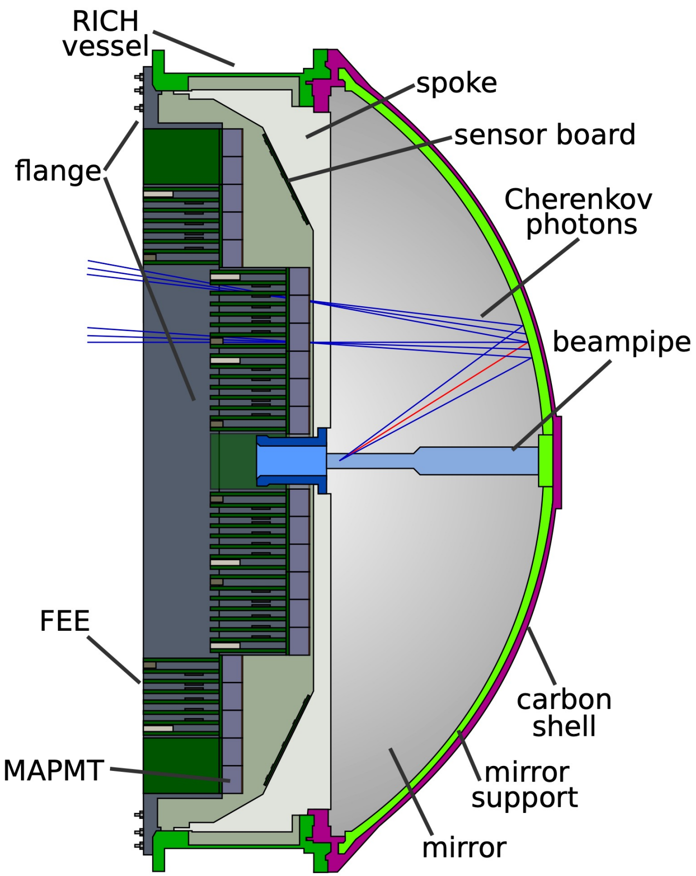


Figure 3: Schematic view of the HADES RICH detector after the upgrade in 2019 [1].

3. Data Sample

- p+p collisions at 1.58 GeV beam energy collected in February 2022 (Gen2)
- Liquid hydrogen (LH_2) target

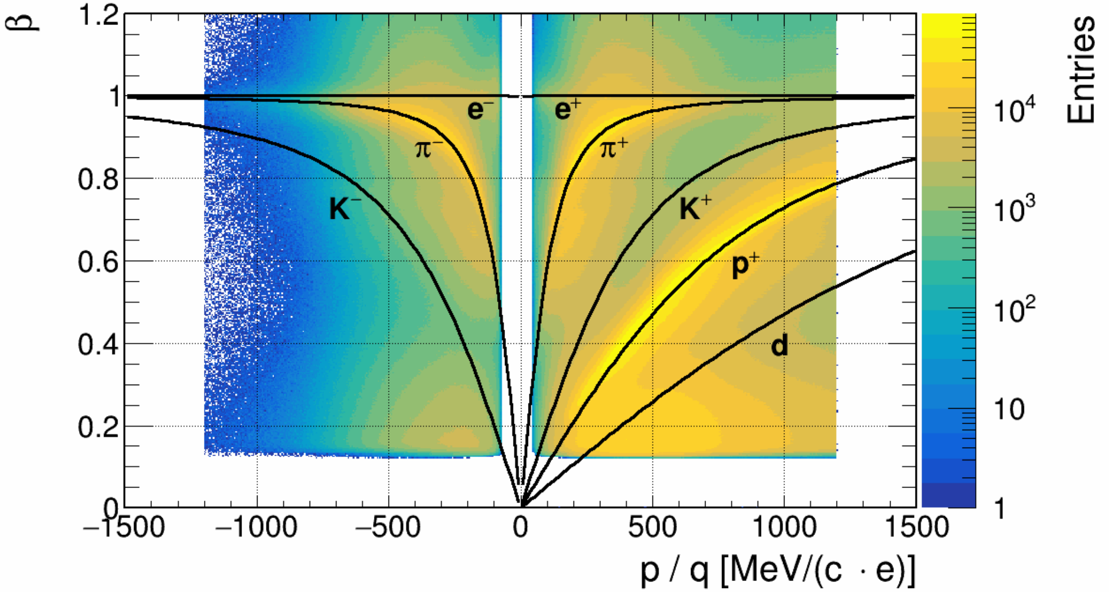


Figure 4: β-p/q-distribution for all reconstructed tracks with a certain quality.

- $380 \cdot 10^6$ events available after event selection based on trigger and vertex information
- Measurement with empty target for reconstruction of interactions with target mounting
- 10 % of all events measured with the full target originate from the target mounting (2.5 % for the blue selected area, see figure 5)

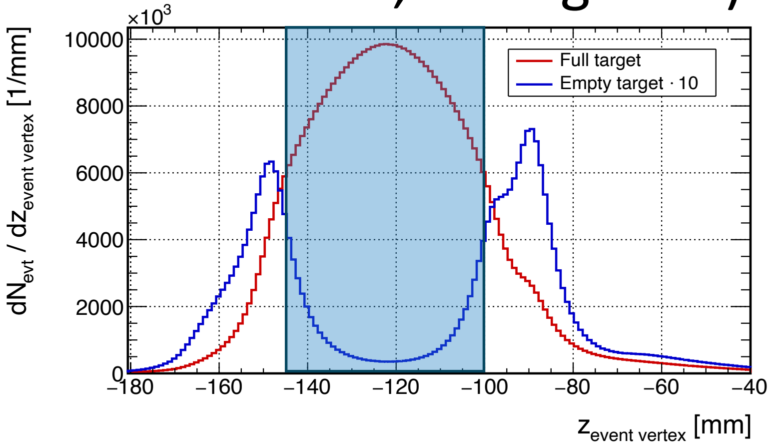


Figure 5: z-component distribution of the event vertex.

4. Identification of electrons

Identification based on

- Velocity information: $\beta > 0.8$
- Reconstructed mass: $m^2 < 15000\ (\mathrm{MeV/c^2})^2$ for $q > 0$
- RICH matching quality: $RMQ < 2°$
- Selection of high-quality rings (number of cals, radius information)

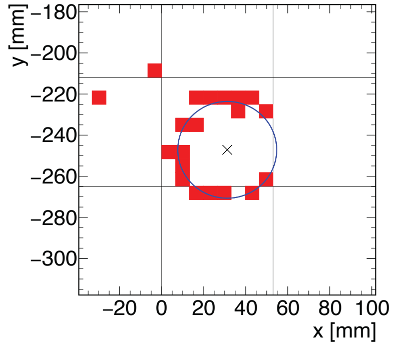


Figure 6: RICH event display (see fig. 8).

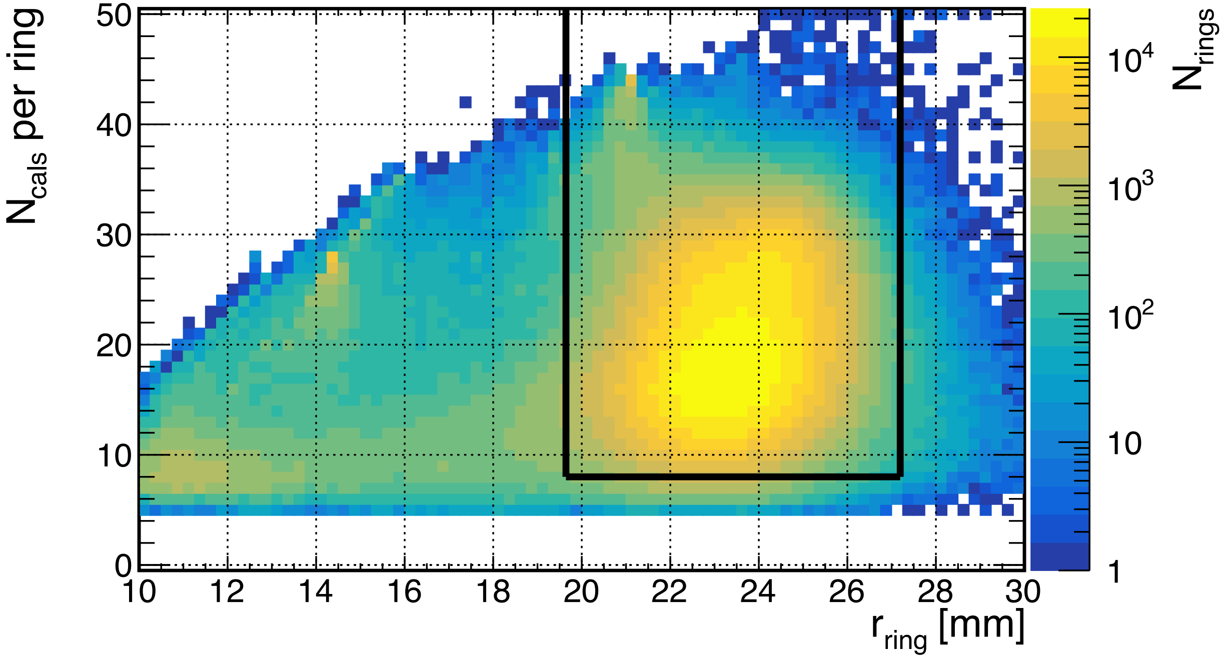


Figure 7: The correlation of N_{cals} and the ring radius is shown. Cuts applied on the ring radius and the number of cals are shown as black lines.

5. Reduction of γ conversion

- Electrons, which arise from γ **conversion**, represent the largest part of the physical background of dielectrons

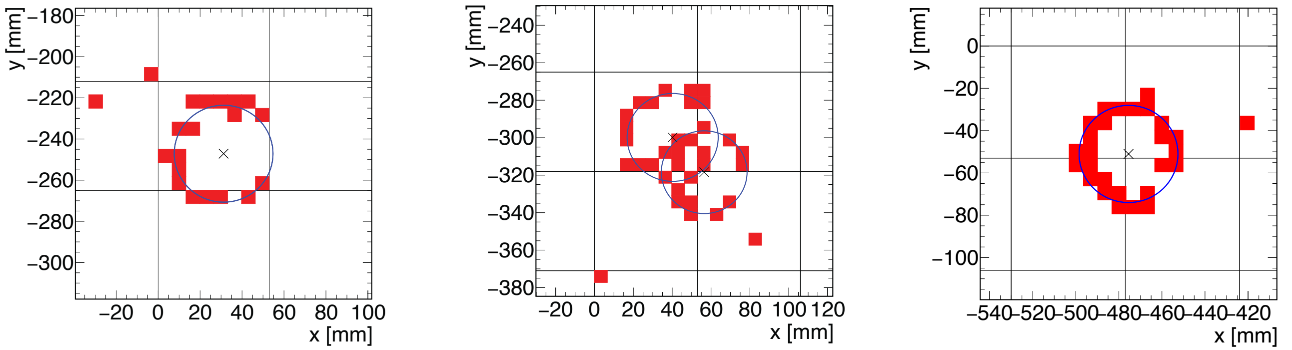


Figure 8: Event displays observed on the HADES RICH MAPMT plane [2].

- Dielectrons from conversions theoretically have an opening angle of $0°$

→ 2 methods of conversion reduction:

- Based on the opening angle for $3° < \theta < 9°$
- Based on the number of cals for $0° < \theta < 3°$

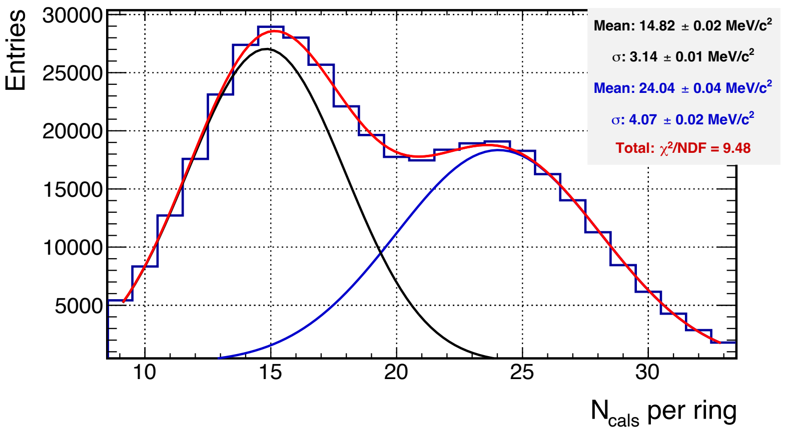


Figure 9: θ dependent cal distribution for $31° < \theta < 37°$. The structure is fitted by two Gaussian functions: isolated rings in black, double rings in blue.

6. Calculation of the dielectron signal

- Definition of acceptance based on 'white electron simulations'
- Correction for acceptance and efficiency losses based on p_t-y-distribution (further acceptance correction in π^0 mass region ongoing, $\approx$10 - 20 % increase expected for signal)
- Calculation of the combinatorial background based on like-sign pairs & event mixing:

$$\langle BG_{+-}\rangle = 2\cdot k\,\sqrt{\langle FG_{++}\rangle\langle FG_{--}\rangle}$$

$$k = \frac{\langle fg_{+-}\rangle}{2\sqrt{\langle fg_{++}\rangle\langle fg_{--}\rangle}}$$

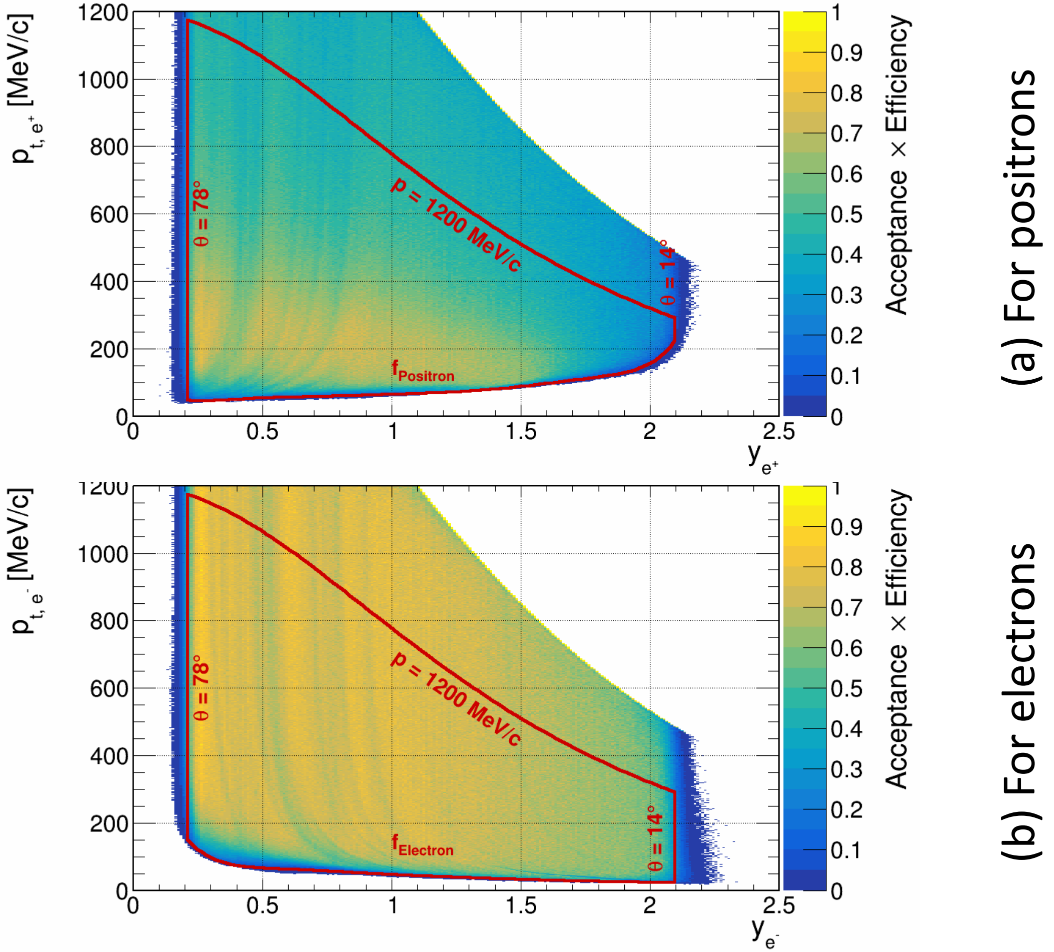


Figure 10: Product of acceptance and efficiency. Only electrons within the red cuts are used for the analysis.

6. Calculation of the dielectron signal

- Dielectron signal up to 500 MeV/c^2
- Signal to background ratio > 1
- Measured number of pairs:

M_{ee}	$\leq 140\ MeV/c^2$	$> 140\ MeV/c^2$
$N_{pairs,\,raw}$	33 025	955
$N_{pairs,\,ax\epsilon\ corr}$	87 143	1 973

Originating from π^0 dalitz decays

Dominated by η dalitz decays

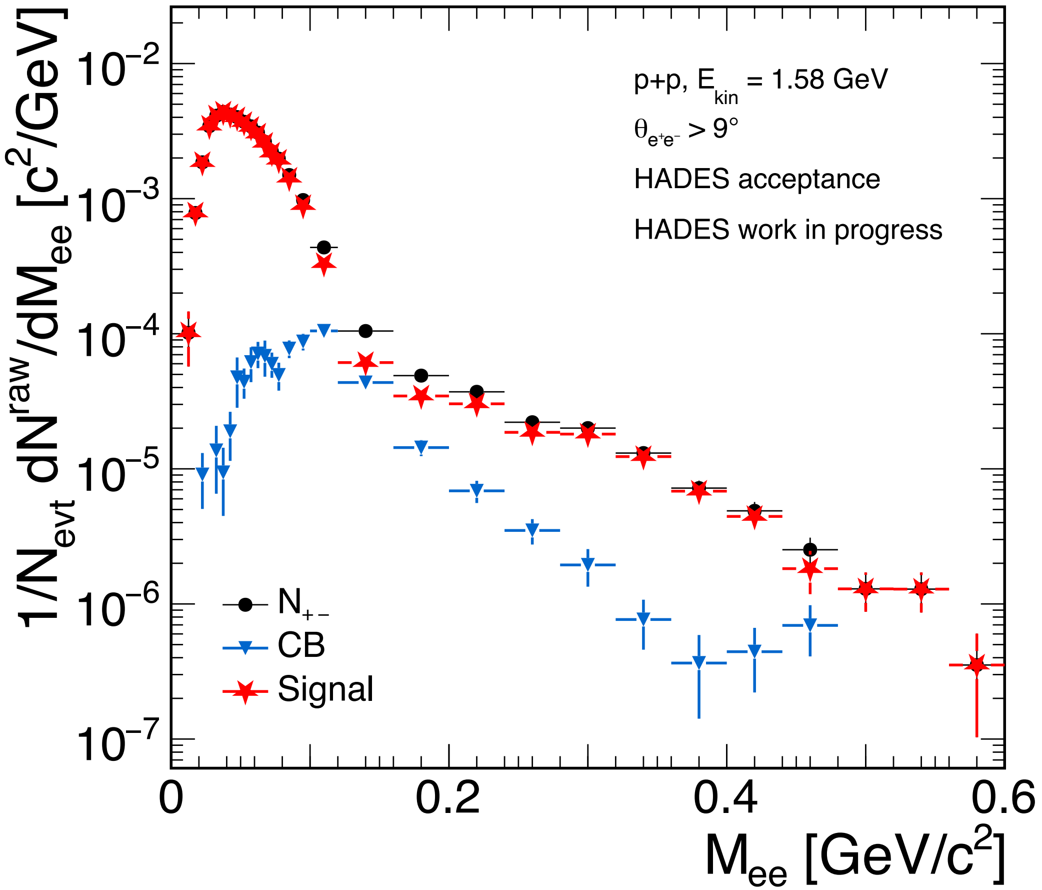


Figure 11: The signal has been calculated by subtracting the combinatorial backgound (BG) from the same event unlike-sign pairs (N_{+-}).

7. Calculation of the dielectron cross sections

- Normalization based on elastic p+p events ($L = 400$ nb^{-1})
- Introduction of a trigger bias factor to consider the influence of the event selection criteria on the number of reconstructed dileptons

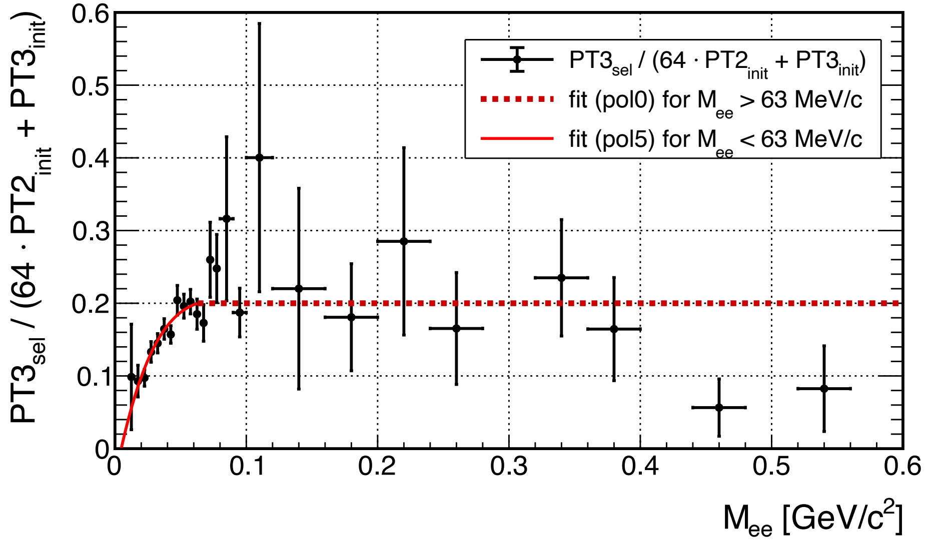


Figure 12: Calculation of the trigger bias factor for PT2 and PT3 triggered events. The distribution has been fitted (shown in red).

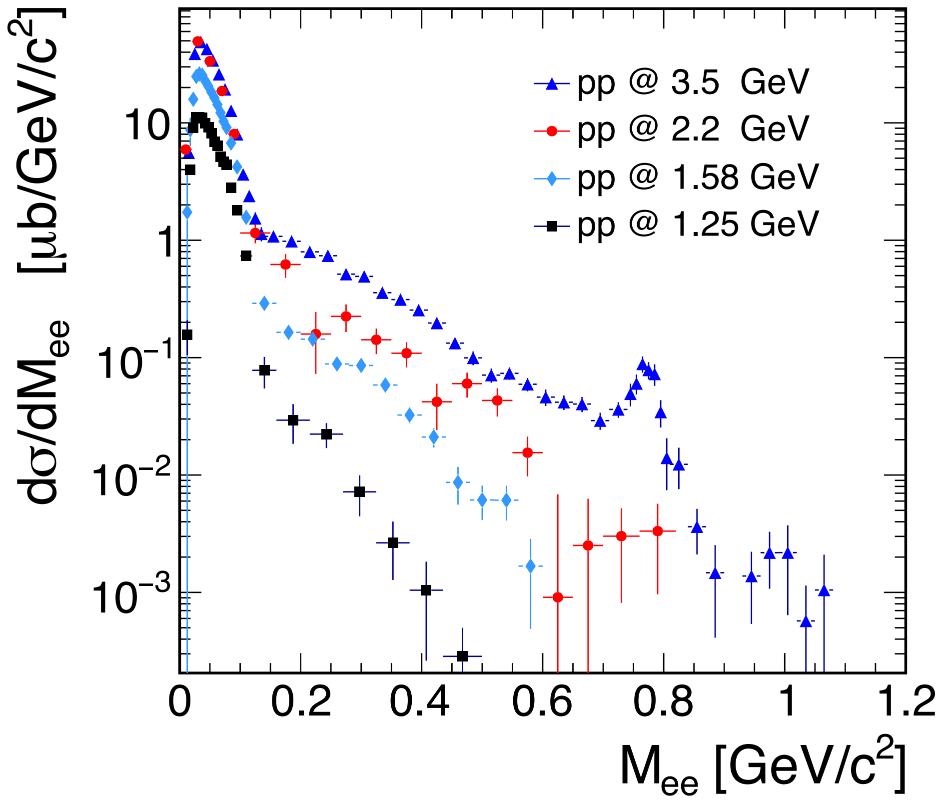


Figure 13: Differential cross sections for dielectrons in p+p collisions at various beam energies in HADES [3].

8. π^0 multiplicities from $\pi^0 \rightarrow \gamma\gamma$ channel

- Full target:

	PT3	$\geq$ 2 Tracks
No vertex$_z$ cut	0.097	0.101
With vertex$_z$ cut	0.099	0.101

- Empty target:

	PT3	$\geq$ 2 Tracks
No vertex$_z$ cut	0.057	0.058
With vertex$_z$ cut	/	/

Multi-differential analysis (in p_t, y) based on ECAL

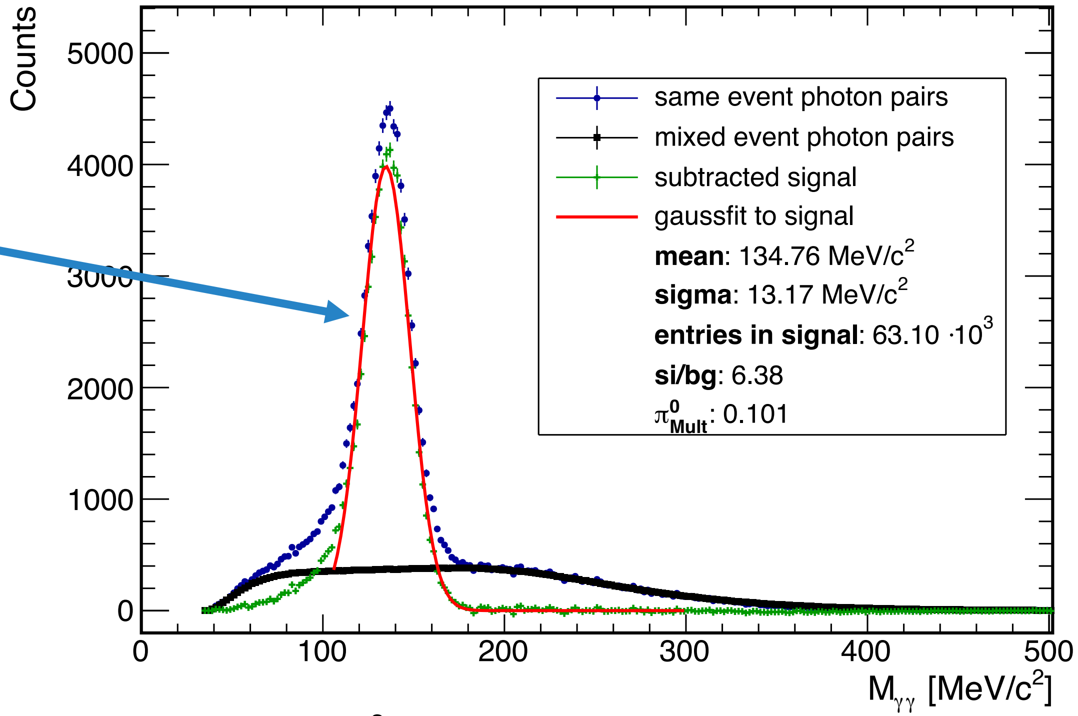
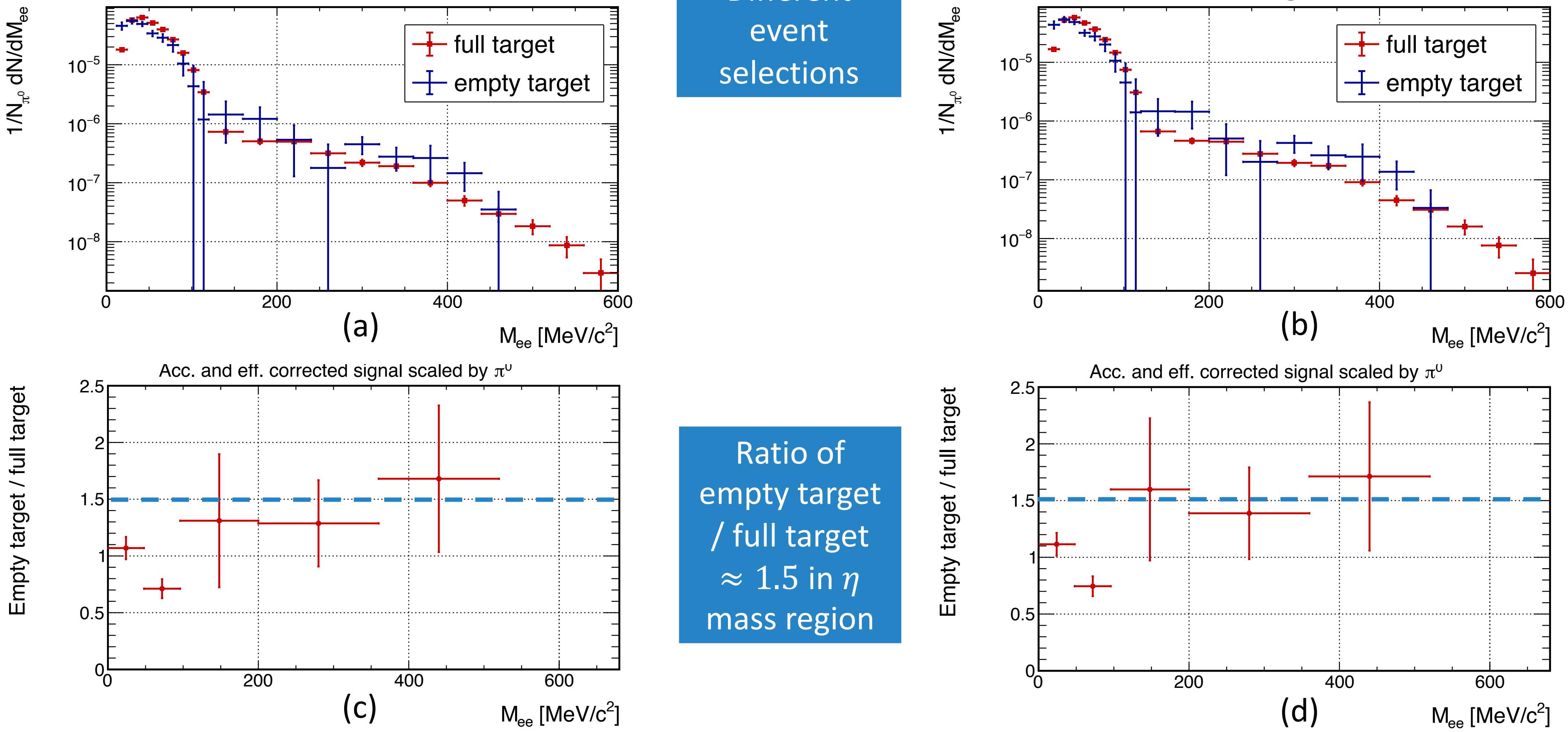


Figure 14: The π^0 signal has been calculated for the $\gamma\gamma$ channel using the ECAL and mixed event technique for BG calculation [5].

9. Comparison of empty & full target

PT3 ⟵ Different event selections ⟶ ≥ 2 charged tracks



Ratio of empty target / full target ≈ 1.5 in η mass region

Figure 15: Comparison of empty and full target (a, b) and ratios of both (c, d) for different event selections.

9. Comparisons to GiBUU

- For model comparisons use GiBUU simulations (Release 2023, patch 2)
- Channels: p+p (comparison to full target measurement)
  p+C, p+O (comparisons to empty target)
- Acceptance definition: identical to experiment (see figure 10)
- Momentum searing: extracted smearing map from experiment used as input in GiBUU (see figure 16)

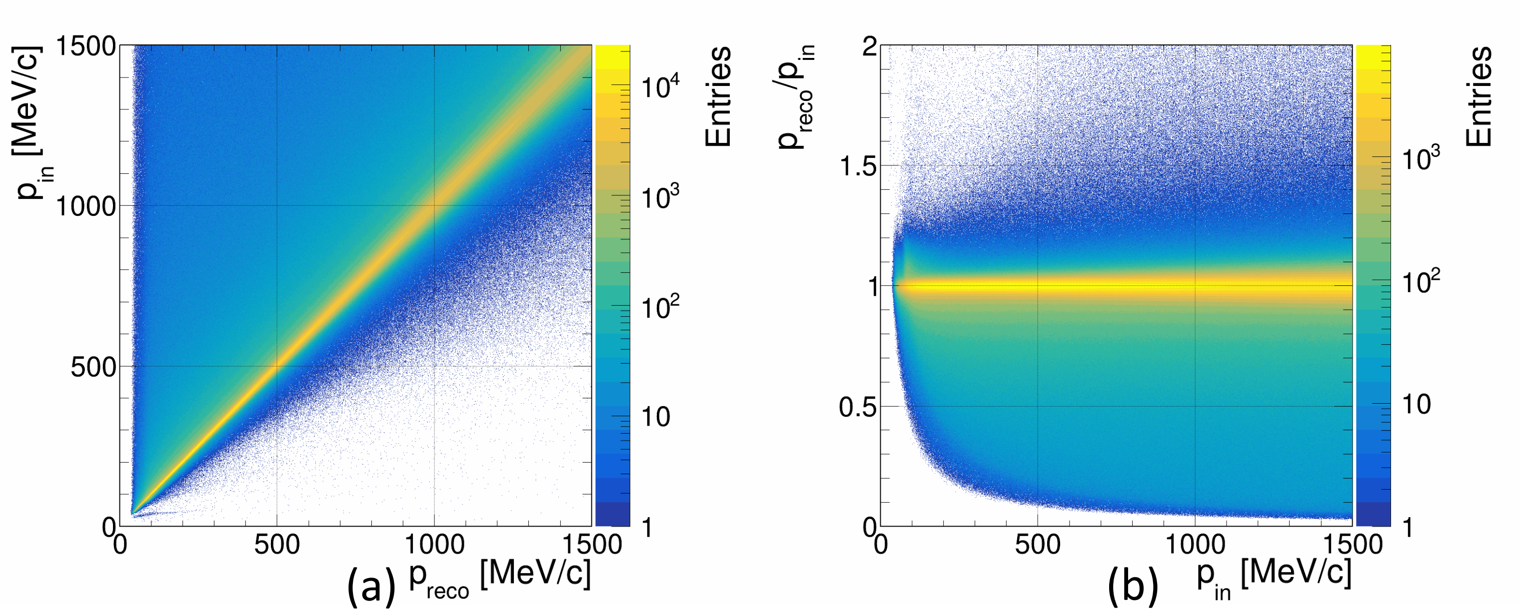


Figure 16: Extracted smearing map (a) and the ratio of ideal and reconstructed momentum (b) used for GiBUU simulations.

9. Comparisons to GiBUU

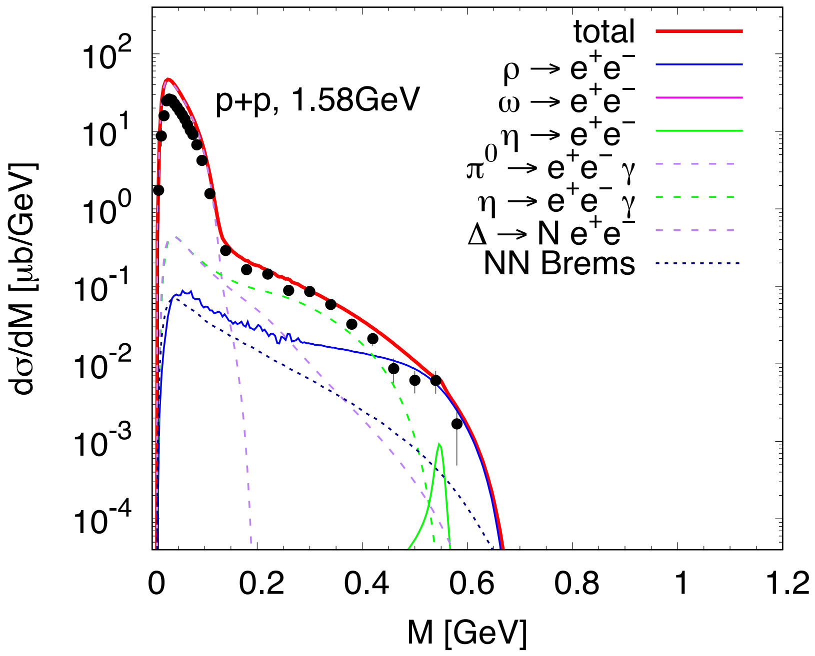


Figure 17: Comparison with GiBUU simulation for p+p at 1.58 GeV beam energy [4].

Results:

<u>Full target:</u>
- Good agreement
- Still missing efficiency correction in π^0 mass region will further improve the agreement

<u>Empty target:</u>
- Mylar = $C_{10}H_8O_4$

  → p+Mylar = $\frac{10}{22}$ p+C + $\frac{8}{22}$ p+p + $\frac{4}{22}$ p+O
- empty / full target ≈ 1.5
- p+Mylar / p+p (GiBUU) ≈ 2

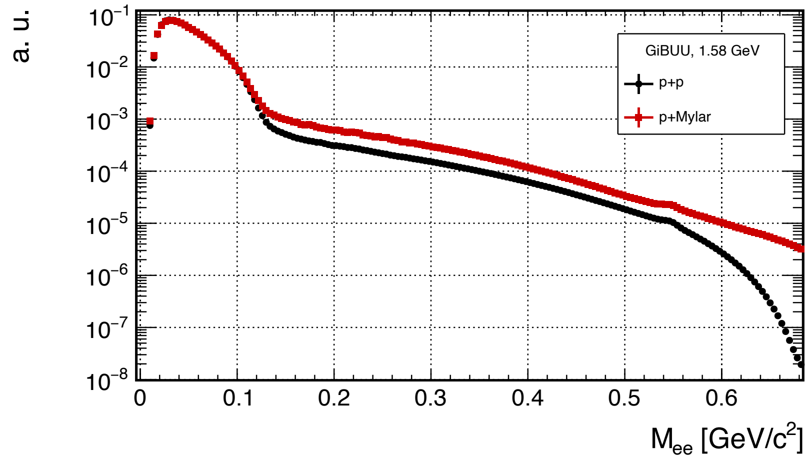


Figure 18: GiBUU simulation for p+p and p+Mylar.

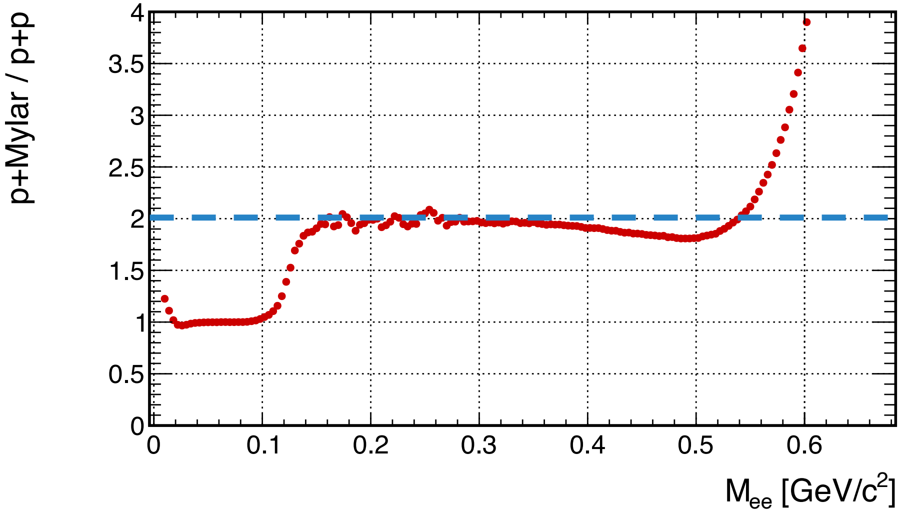


Figure 19: Ratio of p+p and p+Mylar simulation.

Summary

- Dielectron signal with signal to background ratio > 1 reconstructed
- Dielectron cross section calculated using p+p elastic collisions
- Dielectron cross section of p+p in agreement with theoretical predictions
- Ratio of empty and full target measurements calculated and compared to theory

References:

[1] Weber, Adrian Amatus (2021). Development of readout electronics for the RICH detector in the HADES and CBM experiments - HADES RICH upgrade, mRICH detector construction and analysis -. Justus Liebig University Giessen. DOI: 10.22029/jlupub-288

[2] Otto, Jan-Hendrik (2022). Dilepton reconstruction in Ag+Ag collisions at $\sqrt{s_{NN}} = 2.55\ GeV$ with HADES. Justus Liebig University Giessen. DOI: 10.22029/JLUPUB-7207.

[3] Agakishiev, G. et al. (2012). Inclusive dielectron production in proton-proton collisions at 2.2 GeV beam energy. Physical Review C 85.5. DOI: 10.1103/physrevc.85.054005.

[4] Gallmeister, Kai O. (2023). Private communication.

[5] Albohn, Lena M. (2024). Private communication.

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Outlook

- Finalize signal spectra for full and empty target
- Together with simulations from GiBUU establish p+n reference

→ Provided p+p and p+n reference allow the extraction of the medium temperature and excess yield in the Ag+Ag measurement.

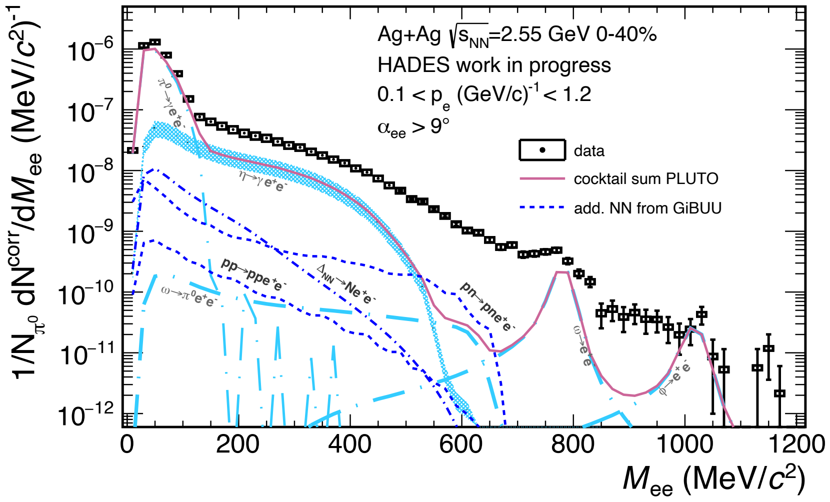

Figure 20: Ag+Ag data with hadronic cocktail and relevant NN channels from simulation [2].

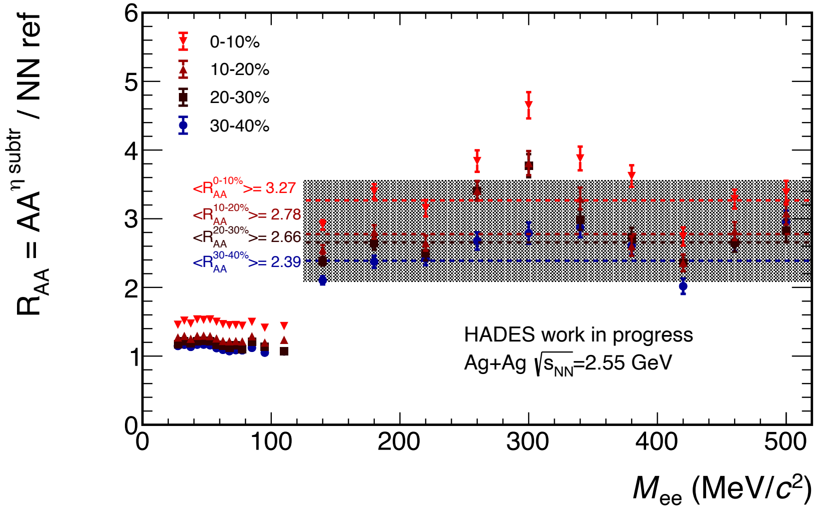

Figure 21: Centrality dependence of the dielectron excess yield from Ag+Ag measurement [2].

Thank you for your attention!