Measurements of dielectron production in \( \text{Au+Au} \) collisions at \( \sqrt{s_{\text{NN}}} = 27, 54.4 \) and 200 GeV with the STAR experiment

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for the STAR Collaboration
**SOURCES OF LEPTON PAIRS**

- Different sources of correlated lepton pairs contribute at different stages of the collision.
- Relative strength of sources depends on collision energy, species, centrality.

[Diagram showing time flow with LMR and IMR regions, and mass distribution with peaks at different masses including p, o, D, D, J/ψ, ψ'.]

MAPPING THE QCD PHASE STRUCTURES WITH DILEPTONS

Excess yield in low mass window tracks fireball lifetime

Search for "extra radiation" around phase transition (& critical point?)

Invariant mass slope measures radiating source temperature (no blue shift)

Flattening of caloric curve (T vs $\sqrt{s_{NN}}$) → evidence for a phase transition

- Ongoing
  - STAR
  - HADES
  - ALICE

- In addition
  - CBM
  - MPD
  - NA60+
  - J-PARC HI

FS et al.: EPJ A 52 (2016) 131

COMPONENTS OF EM PROBES

- Phenomenological tools $\rightarrow$ excitation functions
  - $T_{\text{slope}}$, excess yield and shape, $T_{\text{eff}}$ vs. mass,
  - $v_2$ vs. mass, polarization
COMPONENTS OF EM PROBES

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  - $T_{\text{slope}}$, excess yield and shape, $T_{\text{eff}}$ vs. mass, $v_2$ vs. mass, polarization

- **Degrees of freedom** of the medium
  - Spectral function merges into QGP description → Direct evidence for transition from hadrons to quarks & gluons

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H. Ding, et. al: PRD 94 (2016) 034504
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- **Restoration of chiral symmetry**
  - $\int \frac{ds}{\pi s} \left( \text{Im} \Pi^\gamma_\gamma - \text{Im} \Pi^\alpha_\alpha \right) = -m_q \langle 0 | q \bar{q} | 0 \rangle$
  - Mixing of vector and axial-vector correlators

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- Transport properties
  - $\sigma_{EM}(T) = -e^2 \lim_{q_0 \to 0} \left[ \frac{1}{q_0} \Im \Pi_{EM}(q_0, q = 0; T) \right]$
  - Electric conductivity → probes soft limit of EM spectral function

STAR – SOLENOIDAL TRACKER AT RHIC

- **27 GeV**
  - Larger data set compared to submitted BES-I results
- **54.4 GeV**
  - New energy for dielectron excitation function
- **200 GeV with HFT**
  - Suppress $c\bar{c}$ contribution to the IMR
  - DCA resolution better than 50μm at $p_T = 1$ GeV/c

<table>
<thead>
<tr>
<th>Year</th>
<th>$\sqrt{s_{NN}}$ (GeV)</th>
<th>Analyzed events (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>27</td>
<td>500</td>
</tr>
<tr>
<td>2017</td>
<td>54.4</td>
<td>875</td>
</tr>
<tr>
<td>2014</td>
<td>200</td>
<td>860</td>
</tr>
</tbody>
</table>

TPC – TOF – VPD

- **HFT** (2014-2016)
- IST – Intermediate Silicon Tracker
- PXL – Pixel Detector
RAW SPECTRA

- Raw spectra in 0-80% centrality (MinBias) at 27, 54.4 and 200 GeV

- For 200 GeV:
  - Additional material close to beam pipe
  - Increased photon conversion background
  - Utilizing HFT data on the tracks gives similar S/B ratio as 2010/11 data without HFT
Decay topology cuts show strong effect on the IMR

- Slope change → hint to $c\bar{c}$ contribution
- MC studies of topological selections to reduce semi-leptonic charm decay contribution ongoing
- Unfolding with DCA resolution & momentum
- More Au+Au data with HFT (2016) on tape
**BES-I DATA COMPARISON TO THEORY**

- Data / cocktail ratio in STAR acceptance
  - $\omega$ and $\phi$ subtracted from data and cocktail
  - Theory calculations consistent with data

- Reduce data uncertainties with new measures at 27 and 54.4 GeV
  - Factor $\sim 10$ more data compared to BES-I in 2010/11

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EFFICIENCY CORRECTED SPECTRA: 54.4 GeV

- 54.4 GeV: first $e^+e^-$ measurement at this energy
  - Excess over the cocktail in the LMR with increased significance compared to 62.4 GeV
  - IMR consistent with cocktail
- Enough statistics for differential measurements vs $p_T$, centrality, etc.

STAR Preliminary

Poster 329 (EM8) by Zhen Wang
EFFICIENCY CORRECTED SPECTRA: 27 GeV

  - Lower charm cross section hint of excess in the IMR at 1.7 σ level
  - Correlated $c\bar{c}$ gives upper limit on charm contribution

Poster 387 (EM10) by Zaochen Ye
Constrain cocktail with direct measurement of \( \omega, \phi, (J/\Psi) \) in \( e^+e^- \) channel

Poster 387 (EM10) by Zaochen Ye
FILLING IN THE EXCITATION FUNCTION

- Excess yield scaled by \( dN/dy \mid_{\pi^+\pi^-} \) from SIS to top RHIC energy
- Expected statistical precision for new measurements at 27 & 54.4 GeV added
- Projections for BES-II program

BES-II in full swing

- Measurement of $e^+e^-$ spectra at $\sqrt{s_{NN}}$ between 7.7 GeV and 19.6 GeV
- Reduced charm cross section enhances sensitivity to thermal radiation
- Data from 19.6 & 14.6 GeV already on tape
- Enhanced tracking & particle identification capabilities due to iTPC and eTOF upgrades
  - Change the rapidity window
  - Study total baryon density dependence

SUMMARY & OUTLOOK

- New measurements for $e^+e^-$ at 27 & 54.4 GeV
  - High statistics will allow differential studies
  - Constrain contribution of thermal radiation to the spectrum

- 200 GeV $e^+e^-$ with HFT
  - Comparable S/B to previously published data without HFT
  - Decay topology cuts increase sensitivity to the thermal QGP radiation in the IMR

- BES-II has started
  - Fill in excitation function of dielectron production between 7.7 and 19.6 GeV

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200 GeV: PRC 92 (2015) 024912
19.6 GeV: PLB 750 (2015) 64
BACKUP
HFT PERFORMANCE

- Heavy Flavor Tracker
- SSD – Silicon Strip Detector
- IST – Intermediate Silicon Tracker
- PXL – Pixel Detector
  - First application of MAPS technology in collider experiments
  - Pitch size 20x20 μm²
  - Thickness of first layer 0.5%X₀ (2014)

- Acceptance
  - -1 < η < 1
  - 0 < φ < 2π

- Good DCA resolution of particle track to collision point

Tracking inwards with gradually improved resolution

\( \sigma \approx 1 \text{ mm} \)

\( \sigma \approx 300 \mu \text{m} \)

\( \sigma \approx 250 \mu \text{m} \)

\( \sigma \approx 30 \mu \text{m} \)

TPC

SSD  \( r=22 \text{ cm} \)

IST  \( r=14 \text{ cm} \)

PXL  \( r = 8 \text{ cm} \)

\( r = 2.8 \text{ cm} \)
PARTICLE IDENTIFICATION

- High purity electron sample via
- Mean ionization energy loss

\[ n \sigma_e = \frac{1}{R_{dE/dx}} \log \left( \frac{\langle dE/dx \rangle_{\text{measured}}}{\langle dE/dx \rangle_{\text{theory}}} \right) \]

- Time of flight \( \frac{1}{\beta} \)
PAIRING OF LEPTONS

- Combine all electrons/positrons in an event into pairs
  - Signal contained in unlike-sign pairs
  - Combinatorial background estimated via like-sign pairs
  - $k$ corrects for acceptance difference between unlike and like-sign pairs
  - Event mixing with several event pools
    - Vertex Z, centrality, event plane angle

- Photon conversion removal
  - Cut on pair opening angle w.r.t. the magnetic field $\phi_V$
  - Decay length cut in case of HFT analysis

Mathematical expression:

$$S = N_+ - N_{++x-}$$

$$N_{++x-}^{\text{corr}} = 2 \sqrt{N_{++}(M,p_T) \cdot N_{--}(M,p_T)} \times k$$

$$k = \frac{N_{+-}^\text{mix}(M,p_T)}{2 \sqrt{N_{++}^\text{mix}(M,p_T) \cdot N_{--}^\text{mix}(M,p_T)}}$$
COMPARISON DATA / COCKTAIL: 27 & 54.4 GeV

STAR Preliminary