Dielectron Production in Au+Au Collisions at BES Energies
and its energy dependence from SPS to top RHIC energies

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Fundamental Questions for HIC’s

1) thermally equilibrated matter produced through sufficient rescattering?
magnitude of collective expansion indicates $\tau < 1$-2 fm/c characterize medium by bulk thermodynamic variables

2) distinctive footprint of individual partons? $v_2$ NCQ scaling: collectively expanding partonic source

3) deconfinement? chiral restoration? spectroscopy via short-lived resonances due to inaccessible order parameter

Beam Energy Scan Program
consistently combine various signatures over a wide range of beam energies

- access hadronic spectral functions via EM probes ($\gamma / l^+ / l^-$) negligible FS interactions due to $\lambda_{mfp} > \tau_{FB}$
- additional dynamic information about HIC stages encoded in invariant mass
Dielectron Physics @ STAR

**Low-Mass-Region (M_{ee} < 1.1 \text{ GeV/c}^2)**

- distinct features of fireball radiation from hadronic phase hidden by direct decays
- ~50% reduction in $\rho/\omega$ region
- factor 2 enhancement at ~0.5 GeV/c^2
- $\omega/\phi$ less susceptible to in-med. modifications
- possibly connected to $\chi_{SR}$ through analogy with reduced duality threshold

R. Rapp, arXiV:0901.3289 & PRC 63 054907

**Intermediate-Mass-Region (1.1 < M_{ee} < 3 \text{ GeV/c}^2)**

- measure initial QGP temperature from IMR $m_T$ spectra
  - however, with contributions from correlated charmed decays unknown, large systematic uncertainties arise even at 200 GeV.
  - thus, BES analyses presented here concentrate on LMR physics

STAR in unique position to study energy dependent dielectron production and study/confirm medium consequences on spectra w.r.t to their energy dependence
installation of TOF completed in 2010 enables pure eID combined with energy loss in TPC

- photon conversion sources: beam pipe, SVT support cones and inner TPC field cage
- >98% conversion rejection via $\phi_V$ cut
Background Subtraction Methods

$e^+e^-$ created in pairs

$\Rightarrow$ unlike-sign BG is geometric mean of the like-sign BGs independent of primary probability/multiplicity distribution

$$\langle \text{BG}_{+-} \rangle = 2\sqrt{\langle \text{BG}_{++} \rangle \langle \text{BG}_{--} \rangle}$$

1) Like-Sign Same Event Method

- All like-sign pairs of one event are combined and averaged.
- Method reproduces the background from all correlated sources.
- Acceptance difference of like-sign to unlike-sign pairs is corrected using the ME Technique.

2) Unlike-Sign Mixed Event Method

- Charges from two different events within same event class are combined (event vertex, reference multiplicity & event plane).
- Method describes uncorrelated BG only.
Efficiency Correction

**TPC Selection Efficiency & Purity**

- **Contamination**:
  - K⁻
  - π⁻
  - p/\bar{p}

- **Efficiency & Purity**
  - e⁺⁻ Efficiency
  - e⁺⁻ Purity

**Systematic Uncertainty of Track Quality Cuts**

- Estimated uncertainties reflect reproducibility of track quality distributions in embedding.

- \(10-15\%\)

**Dielectron Production in Au+Au Collisions at BES Energies**

- **39 GeV**
  - TPC Tracking + TOF Matching + eID Selection
Dielectron Production in Au+Au Collisions at BES Energies

Cocktail Simulation

- flat $\eta \ [\ -1,1\ ]$ & $\phi \ [0,2\pi\ ]$, Kroll-Wada for Dalitz decays & according form-factors from measurements (PDG)

- $\text{AuAu@19.6 GeV}$:
  - Tsallis fits to meson spectra from SPS PbPb@17.3GeV
  - meson/$\pi^0$ ratio from SPS & $\pi^0$ yield from STAR
  - Conversion included via full STAR GEANT simulation

- $\text{AuAu@39 & 62.4 GeV}$:
  - $\pi^0$ $p_T$ spectra from $\pi^{+/−}$ @STAR, K spectra used for $\eta$
  - Unknown $p_T$ distributions taken from AMPT
  - According yields extrapolated from 200 GeV based on AMPT’s $\sqrt{s}$-dependence
  - conversion rejected via $\phi$ cut

- Contributions due to correlated charmed decays simulated using PYTHIA and scaled to Au+Au by $N_{\text{bin}}$

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**Input $p_T$ Spectra**

- $\pi^0$
- $\phi \times 0.05$
- $\eta$ (K)
- $J/\psi$
- $\rho \times 0.3$
- $39 \text{ GeV}$
- $\omega \times 0.2$
- $62 \text{ GeV}$

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**STAR Preliminary**

- $dN/dp_T/d\eta$ [GeV/c]^2

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**Comparison**

- STAR Preliminary $D^0 + D^0$ in $p+p$
- STAR Preliminary $D^0$ in Au+Au 0-80%
- $\Delta$ STAR $D^0 + e$ in $d+Au$
- PHENIX $e$
- SPS/FNAL
- Pamir/Muon
- UA2

- FONLL
- NLO pQCD
- PYTHIA
• $e^+e^-$ production below 3.5 GeV/c$^2$ systematically studied in STAR from $\sqrt{s_{NN}} = 19.6$ GeV up to top RHIC energy.

• correlated charm adjusted to observed dielectron yield
  FONLL predictions are used as lower and
  $\chi^2$ fits to the IMR data as upper limits

• vacuum-$\rho$ does not account for the excess yield in the LMR
LMR Enhancement

- visible LMR excess over hadronic cocktail observed for all energies. (excl. $\rho \to e^+e^-$)
- systematic measurement of the LMR enhancement factor (agreement with CERES result)
  [ $M_{ee}$-dep. energy overlay see backup ]

- LMR enhancement at 19.6 GeV comparable with CERES at 17.3 GeV
  (note: different experimental acceptances)

- increasing enhancement with decreasing energy w.r.t. the cocktail?
  “any energy dep. in X-Factor might be physics directly related to dielectrons from earlier creation times due to $\rho_{B}^{tot} \sim$ const” Z. Xu
Within systematic uncertainties, in-medium modifications of the $\rho$ spectral function consistently describe the LMR enhancement from SPS to top RHIC energies.
Dielectron spectra from Au+Au collisions measured in STAR at $\sqrt{s_{NN}} = 19.6, 39, 62.4$ & 200 GeV and compared to cocktail calculations.

LMR excess yield can be accounted for by in-medium modifications to the $\rho$ spectral function across a wide range of energies.

Enhancement increasing with decreasing energy w.r.t. the cocktail?

Measurements will provide comprehensive data for the better understanding of the LMR enhancement ($p_T$, centrality and energy dependence)

Work in progress
- complete BES data set
- $p_T$ spectra for $M_{ee}$ regions
- detailed systematic uncertainty studies
- cocktail improvements

Outlook
- IMR: Charm continuum contribution and its possible in-medium modification need better understanding in Au+Au to possibly access QGP radiation in the future
  ⇒ study energy dependence of initial temperature
  ⇒ STAR HFT & MTD upgrades

Thank you for your attention
BACKUP SLIDES
- absence of baryonic resonances with $\phi N$ decay channels due to OZI-rule *  
  * $\bar{s}$ annihilation into excitation energy strongly suppressed

<table>
<thead>
<tr>
<th>$\sqrt{s_{NN}}$ (GeV)</th>
<th>Vector Meson Yields (30% uncertainty assigned)</th>
<th>$\sigma_{pp}^{cc}$ (mb) $\pm$ sys.</th>
<th>$N_{\text{coll}}$ bin</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>$\pi^0$ 57, $\eta^+$ 9.37, $\omega$ 4.42, $\phi$ 1.39</td>
<td>$4.8 \times 10^{-4}$</td>
<td>243</td>
</tr>
<tr>
<td>62.4</td>
<td>$\pi^0$ 72.9, $\eta^+$ 11.4, $\omega$ 5.38, $\phi$ 1.79</td>
<td>$1.2 \times 10^{-3}$</td>
<td>253</td>
</tr>
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Vector Meson Signals & S/N

- \( \rho/\omega \) region exhibiting a S/N ratio of \( \sim 1/100 - 1/250 \)
- background subtraction crucial
- prominent vector meson signals after background subtraction
define $\phi_V$ as the orientation of the dilepton plane w.r.t. the magnetic field
Cocktail w/ Vacuum-Rho