The STAR Dilepton Program

Frank Geurts (Rice University) for the STAR Collaboration
Outline

• Introduction & Motivation
• Electron Identification in STAR

• Dielectron Production at $\sqrt{s_{NN}} = 200$ GeV
  – p+p and Au+Au results
  – elliptic flow of dielectrons
• Results from Beam Energy Scan Program

• STAR Dilepton Present & Future
• Summary
Dilepton Physics

**Dileptons are excellent penetrating probes**
- very low cross-section with QCD medium
- created throughout evolution of system

**Chronological division:**
- **High Mass Range (HMR)**
  \[ M_{ee} > 3 \text{ GeV}/c^2 \]
  - primordial emission, Drell-Yan
  - \( J/\Psi \) and \( \Upsilon \) suppression
- **Intermediate Mass Range (IMR)**
  \[ 1.1 < M_{ee} < 3 \text{ GeV}/c^2 \]
  - QGP thermal radiation
  - heavy-flavor modification
- **Low Mass Range (LMR)**
  \[ M_{ee} < 1.1 \text{ GeV}/c^2 \]
  - in-medium modification of vector mesons
  - possible link to chiral symmetry restoration
Dilepton Elliptic Flow

Elliptic flow is generated very early stage
- dileptons can further probe this early stage
- possibly constrain QGP EoS

Combination of $p_T$ and $M_\parallel$ can set observational windows on specific stages of the expansion


Expect interesting structures in $p_T$-integrated $v_2(M)$:
- high-mass dileptons
  - hot early stage
  - flow is still weak
- low-mass dileptons
  - flow strong, temperature low
- modulations from the contributions of vector mesons
  - strong variations of relative weights on/off resonances
The STAR Detector

Large acceptance electron ID
- Time Projection Chamber
- Time-of-Flight detector
  - 2009: 72% completed (p+p)
  - 2010: fully commissioned
- Electromagnetic Calorimeter

*Time Projection Chamber*
$0<\phi<2\pi$, $|\eta|<1$
- Tracking
- dE/dx PID

*Time-of-Flight Detector*
$0<\phi<2\pi$, $|\eta|<0.9$
- Time resolution < 100ps
- Significantly improves PID

TOF cut removes “slow” hadrons
- improves electron purity
  - central events ~92%
  - min-bias events ~95%

Poster: K. Jung (125)
**e^+e^- Invariant Mass & Background**

**Background sources**
- combinatorial background (non-physical)
- correlated background
  - *e.g.* double Dalitz decay, jet correlation.

**Background methods**
- mixed-event method: combinatorial only
  - improve statistics
- like-sign method: combinatorial & correlated BG
  - correct for acceptance differences
- pair cuts remove photon conversions

**Other signals (meson decays)**
Remove by comparing real data with simulations for hadron contamination
- Hadron Simulation Cocktail

Combine both methods:
- \( p+p \): \( \text{LS} < 0.4 \text{ GeV}/c^2 < \text{ME} \)
- \( \text{Au}+\text{Au} \): \( \text{LS} < 0.75 \text{ GeV}/c^2 < \text{ME} \times \text{LS} \)
carefully normalized using overlap in \( M_{ee} \)

\[ S/B @ M_{ee} \sim 0.5 \text{ GeV}/c^2: \]
- 1/10 for \( p+p \)
- 1/250 for \( \text{Au}+\text{Au} \) central

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Quark Matter 2012 -- Washington D.C.
Production in p+p at 200 GeV

Understand the p+p reference

Cocktail simulation consistent with data
L. Ruan (STAR), Nucl. Phys. A855 (2011) 269

Charm contribution dominates IMR
— scaled with STAR charm cross-section

Uncertainties:
• vertical bars: statistical
• boxes: systematic
• grey band: cocktail simulation systematic
• not shown: 11% normalization
Production in Au+Au at 200 GeV

Low Mass:
- enhancement when compared to cocktail (w/o ρ meson)
- little centrality dependence

Intermediate Mass:
- cocktail “overshoots” data in central collisions
- but, consistent within errors
- modification of charm?
  - difficult to disentangle (modified) charm from thermal QGP contributions
  - future detector upgrades required

B. Huang (3C, 268) Poster: Y. Guo (153) H. Huang (6C - 142)
Compare to Rapp, Wambach, v. Hees

- STAR central 200 GeV Au+Au
- hadronic cocktail (STAR)

Ralf Rapp (priv. comm.)
R. Rapp & J. Wambach, EPJ A 6 (1999) 415

Complete evolution (QGP+HG)

- Agreement w/in uncertainties

- hadronic phase: \( \rho \) “melts” when extrapolated close to phase transition boundary
  - total baryon density plays the essential role
- top-down extrapolated QGP rate closely coincides with bottom-up extrapolated hadronic rates
Compare to Theory: PHSD Model


Parton-Hadron String-Dynamics

1. Collisional broadening of vector mesons
2. Radiation from QGP

Minimum bias collisions (0-80%):
- Generally good agreement

Central collisions (0-10%):
- PHSD roughly in line with LMR region
Elliptic Flow in Au+Au at 200 GeV

First measurements from STAR

- 700M min-bias events
  - combined 2010/2011
- Background:
  - Like-Sign $M_{ee} < 0.7$ GeV/$c^2$
  - Mixed-Event $M_{ee} > 0.7$ GeV/$c^2$
- Event-Plane method: TPC
- Cocktail contributions:

$\gamma \rightarrow ee$, $\eta \rightarrow \gamma ee$, $\pi^0 \rightarrow \gamma ee$, $\rho \rightarrow ee$, $\eta \rightarrow \gamma ee$

$\pi^0 \rightarrow \gamma ee$, $\rho \rightarrow ee$, $\eta \rightarrow \gamma ee$ - Cocktail Sum

$\pi^0$, $\eta$, $\omega$, $\phi$

Dielectron $v_2(M_{ee})$: data and simulations consistent
  - work in progress to include IMR $v_2$

Poster: X. Cui (322)
Dielectron $v_2$ $p_T$ Dependence

Au+Au $v_{sNN} = 200$GeV  0-80% centrality

Comparison with measured $v_2(p_T)$

π± (STAR) and π0 (PHENIX)

$M_{ee} < 0.14$ GeV/$c^2$

PHENIX, PRC 80 (2009) 054907

Φ → $K^+K^-$ (STAR)

0.98 < $M_{ee}$ < 1.06 GeV/$c^2$

$\mathbf{v_2(p_T)}$ consistent with simulations & measurements

Poster: X. Cui (322)
Dielectron $v_2$ Centrality Dependence

Centrality dependence $v_2(p_T)$

$M_{ee}<0.14 \text{ GeV}/c^2$
- consistent with simulations
- consistent with measurements

Can we distinguish between HG and QGP $v_2$ contributions?

Recall: need uncertainties to be <4% (compared with model differences) ... no, not yet.

- Require ~2x more Au+Au min-bias data and e-μ measurements at higher $M_{ee}$ to disentangle charm contributions
Dielectron Production at lower $v_{NN}$

Observed Low-Mass enhancement at top RHIC energy
   - in-medium modification effects?
   - indication of chiral symmetry restoration?

Explore Low Mass Range down to SPS energies
   - possible enhancement, consistent model description?

Beam Energy Scan Dielectrons:
   2010 - 2011
   Au+Au at 62.4, 39, and 19.6 GeV

STAR data samples:
   55M, 99M, and 34M min-bias events

Posters: P. Huck (113), B. Huang (269)
Comparison to SPS measurements

**STAR Au+Au at 19.6 GeV/c**
- min-bias (0 - 80%)
- $p_T > 0.2\text{GeV/c}$, $|\eta| < 1$, $|y_{ee}| < 1$

**Cocktail:**
- $\pi^0$ yield: STAR $\pi^\pm$
- other mesons: NA49-based, scaled with SPS meson/$\pi^0$ ratio

**CERES Pb+Au at 17.2 GeV/c**
- semi-central (0-28%)
- $p_T > 0.2\text{GeV/c}$, $2.1 < \eta < 2.65$, $\theta_{ee} > 35\text{mrad}$

**STAR enhancement comparable to CERES**
... and with better mass resolution

Posters: B. Huang (269)
Compare to Theory: in-medium $\rho$

Robust theoretical description top RHIC down to SPS energies
- calculations by Ralf Rapp (priv. comm.)
- black curve: cocktail + in-medium $\rho$

Measurements consistent with in-medium $\rho$ broadening
- expected to depend on total baryon density
- tool to look for chiral symmetry restoration
STAR Dileptons: Present & Future

• 2009 – 2011
  – TPC + TOF + EMC
    • dielectron continuum
    • dielectron spectra, and $v_2$ ($p_T$)
  – vector meson in-medium modifications
  – LMR enhancement
  – modification in IMR?

• 2012-2013
  – TPC + TOF + EMC + MTD (partial)
    • e-μ measurements
  – IMR: Improve our understanding of thermal QGP radiation
  – LMR: vector meson in-medium modifications

• 2014 and beyond
  – TPC + TOF + EMC + MTD + HFT
    • dimuon continuum
    • e-μ spectra and $v_2$
  – LMR: vector meson in-medium modifications
  – IMR: measure thermal QGP radiation

➢ More on HMR physics:
  Wei Xi – Heavy Flavor Results from STAR (Plenary IIB)

➢ More on MTD and HFT:
  Huan Huang – STAR Upgrade Plan for the Coming Decade (Parallel 6C)
  Poster: C. Yang (331)
Summary

- STAR detector very well suited for dilepton physics
  - recent TOF upgrade allows for large acceptance electron ID

- Dielectron in p+p and Au+Au at $\sqrt{s_{NN}}=200$ GeV: centrality and $p_T$ differentials
  - observe low mass enhancement

- Dielectron elliptic flow measurements in Au+Au at $\sqrt{s_{NN}}=200$ GeV
  - $v_2(M_{ee},p_T)$ results consistent with other measurements & cocktail simulations
  - need ~2x increase in statistics to distinguish HG and QGP contributions

- Dielectron measurements in Au+Au at $\sqrt{s_{NN}}=19.6$ – 62.4 GeV
  - low mass enhancement down to SPS energies, with comparable magnitude
  - consistent with in-medium $\rho$ broadening
  - robust and consistent description for $\sqrt{s_{NN}}=19.6$, 62.4, and 200 GeV

- Future STAR upgrades enable further exploration of the dilepton continuum
  - upcoming MTD upgrade allows for large acceptance $\mu$ ID
  - QGP thermal radiation measurements
STAR Dilepton Presentations at QM’12

- **B. Huang**  – parallel session 3C (268)
  Di-electron differential cross section in Au+Au collisions at different beam energies at STAR

- **X. Cui**  – poster 322
  Centrality, mass and transverse momentum dependence of di-electron elliptic flow in \( \sqrt{s_{NN}} = 200 \) GeV Au+Au collisions at STAR

- **K. Jung**  – poster 125
  A Study of High-pT/High-mass Dielectron Production through Trigger Combination in 200 GeV Au+Au Collisions at STAR

- **B. Huang**  – poster 269
  Low mass di-electron production in Au+Au collisions at \( \sqrt{s_{NN}} = 19.6 \) GeV at STAR

- **P. Huck**  – poster 113
  Dielectron Production in Au+Au-Collisions \( \sqrt{s_{NN}} = 39 \) & 62.4 GeV at STAR

- **M. Wada**  – poster 110
  \( \omega(782) \) and \( \phi(1020) \) mesons from di-leptonic decay channels at the STAR experiment

- **Y. Guo**  – poster 153
  Centrality and pT dependence study of Dielectron Production \( \sqrt{s_{NN}} = 200 \) GeV Au+Au collisions at STAR

- **H. Huang**  – parallel session 6C (142)
  STAR Upgrade Plan for the Coming Decade

- **C. Yang**  – poster 331
  Performance of the Muon Telescope Detector in STAR at RHIC
BACKUP
Hadronic Background Simulation

- **Hadrons:** flat $|y|<1.0$, and flat full azimuthal input distribution
  - $p_T$ distribution from Tsallis blast-wave fit to measured particle spectra

- **Heavy flavor sources:**
  - STAR measurements, and PYTHIA simulation
  - $N_{bin}$ scaled in Au-Au
  - at low energy: FONLL

- TBW fit from NA49 data
- $\pi$ yield from STAR

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Dielectron $M_{ee}$ for 39 and 62 GeV
Systematic Uncertainties

**p+p@200GeV**
- Background subtraction: 0 - 27%
- Hadron contamination: 0 - 32%
- Efficiency: ~10%

**Au+Au@200GeV**

![Graph showing systematic uncertainties for p+p and Au+Au collisions with various uncertainties labeled.]

- Background subtraction: 0 - 27%
- Hadron contamination: 0 - 32%
- Efficiency: ~10%
- Total normalization: ~11%
- Cocktail simulation: 14 - 33%

**Au+Au@19.6GeV**
- Tracking efficiency: 7%
- TOF matching: 5%
- Pair uncertainties (summed): 17%
- Cocktail uncertainties: 12-20%
Leptonic Decay of $\phi$ and $\omega$ Mesons

Lifetimes comparable to fireball
- hadronic decay daughters interact with hadronic medium
  - sensitive to lifetime of that medium
- leptonic decay daughters do not interact with QCD medium
  - look for medium modifications to resonance mass & width
  - sensitive to chiral phase transition
  - small branching ratio

➢ No evidence of $\phi$ mass shift or width broadening
  - beyond known detector effects

➢ $\phi$ yield in dilepton decay channel consistent with hadronic channel

$\omega$ $p_T$ shapes agree with light hadrons
$\omega$ mass and width are under study

Poster: M. Wada (110)
PHENIX & STAR Enhancement Factor

Enhancement factor in $0.15 < M_{ee} < 0.75$ GeV/$c^2$

<table>
<thead>
<tr>
<th></th>
<th>Minbias (value ± stat ± sys)</th>
<th>Central (value ± stat ± sys)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAR</td>
<td>$1.53 \pm 0.07 \pm 0.41$ (w/o $\rho$)</td>
<td>$1.72 \pm 0.10 \pm 0.50$ (w/o $\rho$)</td>
</tr>
<tr>
<td></td>
<td>$1.40 \pm 0.06 \pm 0.38$ (w/ $\rho$)</td>
<td>$1.54 \pm 0.09 \pm 0.45$ (w/ $\rho$)</td>
</tr>
<tr>
<td>PHENIX</td>
<td>$4.7 \pm 0.4 \pm 1.5$</td>
<td>$7.6 \pm 0.5 \pm 1.3$</td>
</tr>
<tr>
<td>Difference</td>
<td>$2.0 \sigma$</td>
<td>$4.2 \sigma$</td>
</tr>
</tbody>
</table>
Dielectron Enhancement vs. $\sqrt{s_{NN}}$

Systematic measurements of enhancement factor vs. $\sqrt{s_{NN}}$

- STAR data shows no evident beam-energy dependence
  - 150-750 MeV/$c^2$ range
    - low energy: comparable with CERES
    - high energy: discrepancy with PHENIX

- $200 < M_{ee} < 600$ MeV/$c^2$ range
  - STAR: $1.9 \pm 0.6 \pm 0.4$
  - CERES: $2.73 \pm 0.25 \pm 0.65 \pm 0.82$ [decays]

B. Huang (3C, 268) Poster: P. Huck (113)
Reproducing the PHENIX Cocktail

- Reproduce the cocktail within PHENIX acceptance by our method.

- The momentum resolutions are still from STAR.

Scaled by all the yields from PHENIX paper[1], STAR reproduces the PHENIX cocktail. [1]. Phys. Rev. C 81, 034911 (2010).
STAR with PHENIX Acceptance

- **STAR**
  - 12 sectors east and west barrel
  - $2\pi$ coverage, $|\eta|<1$

- **PHENIX**
  - 20 sectors east and west arm
  - $\pi$ coverage, $|\eta|<0.35$

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**STAR Preliminary**

Au+Au 200 GeV MinBias

$P_T>0.2$ GeV/c, $|\eta|<0.35,|y_{ee}|<0.5$

- PHENIX data
- STAR with PHENIX acc

$\pi^+, \eta, \eta', \omega, \phi$

$J/\psi, \psi', b\bar{b}, D\bar{Y}$

$e^+e^-$ PYTHIA 0.96mb

Cocktail Sum

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Data/Cocktail

Gold 200 GeV (MinBias)

$P_T>0.0-5.0$ (GeV/c)

$M_{ee}$ (GeV/c$^2$) vs

Mass($e^+e^-$) (GeV/c$^2$)

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