Dilepton and Direct Virtual Photon Results at RHIC-STAR

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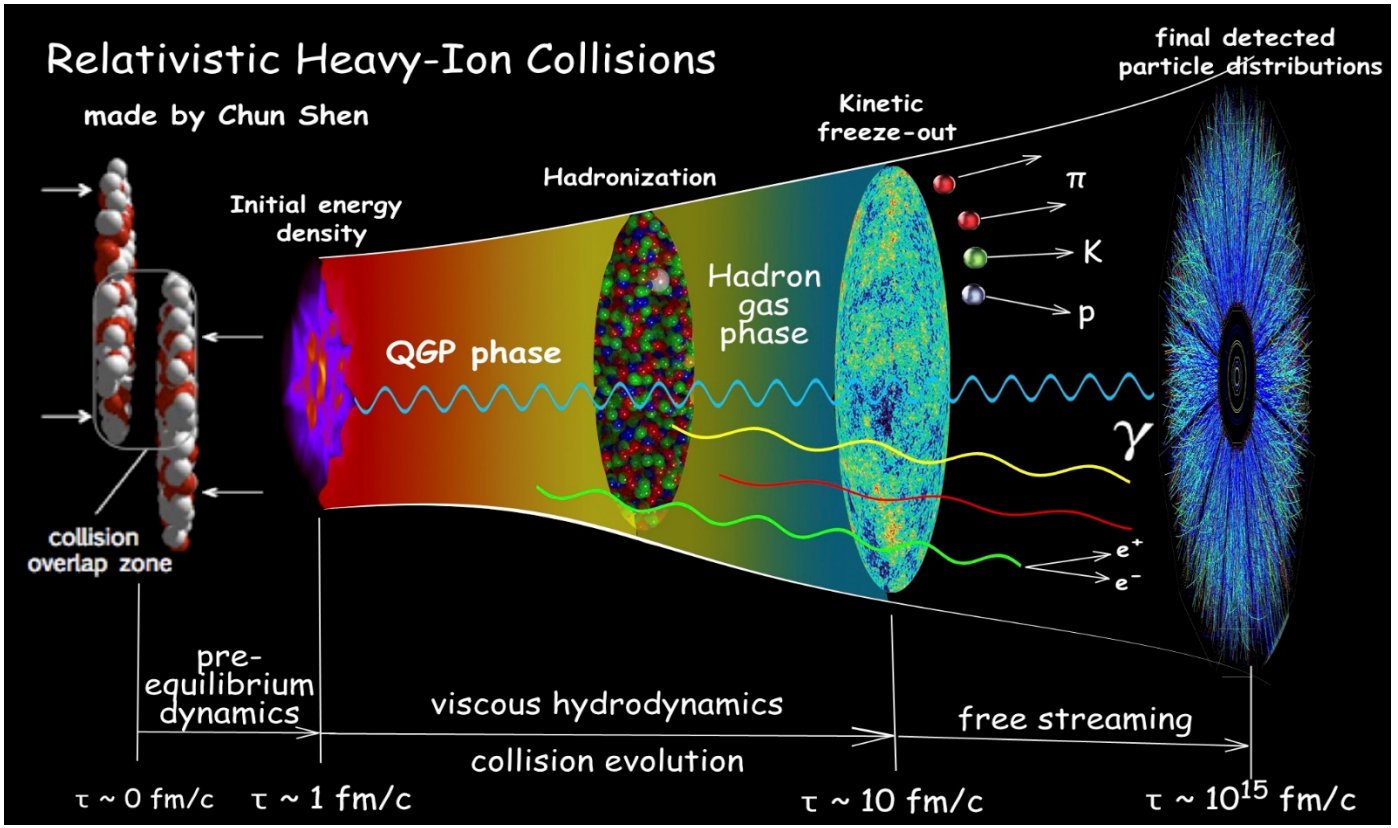
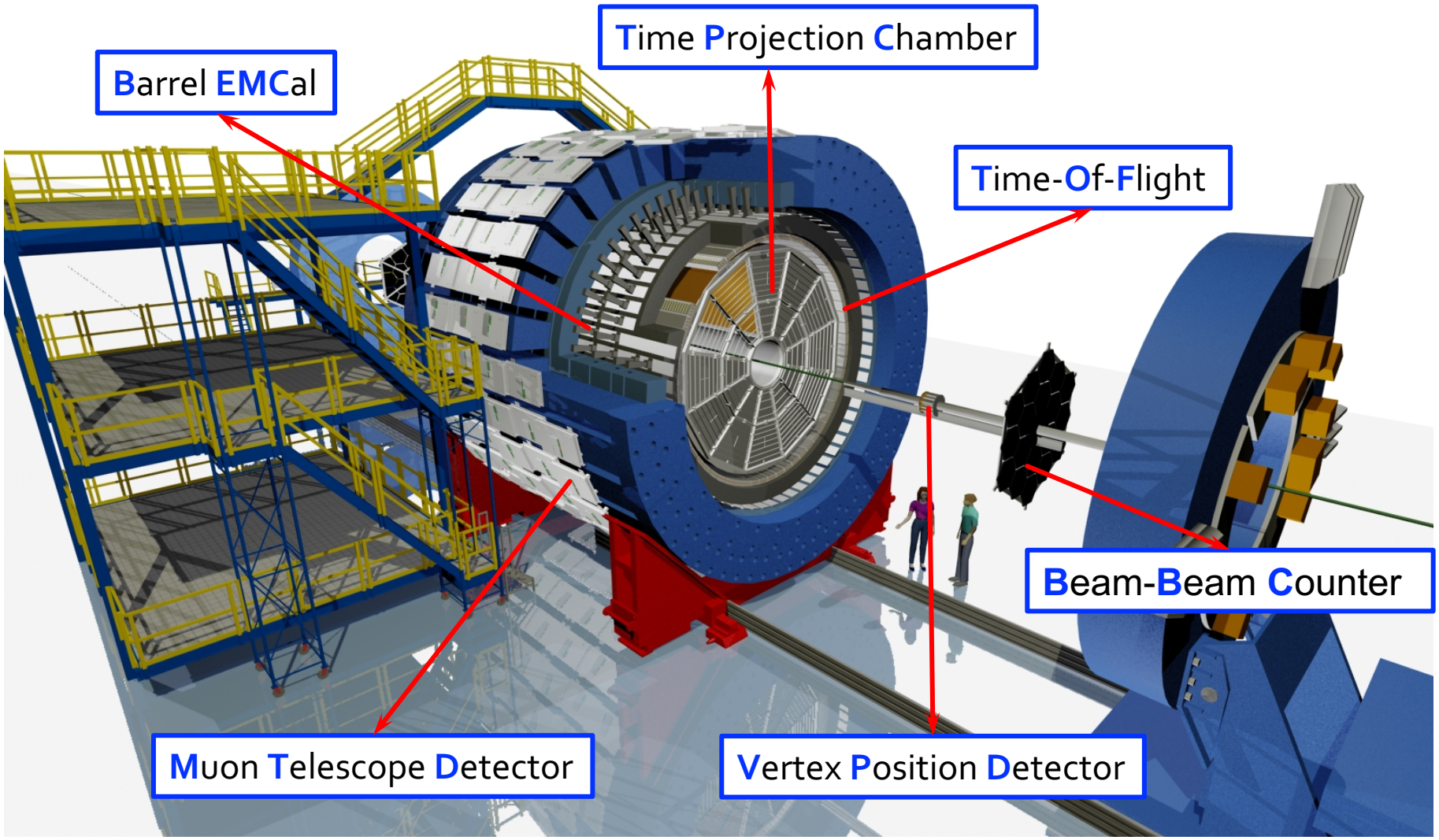
Electromagnetic Probes in HIC



Dileptons and real photons —— ideal electromagnetic probes

- Suffer no strong interaction
- Produced at all stages of the system evolution
- Bring production information to final state
- Sensitive to electromagnetic processes
- Can probe temperature of the system during its hottest phases

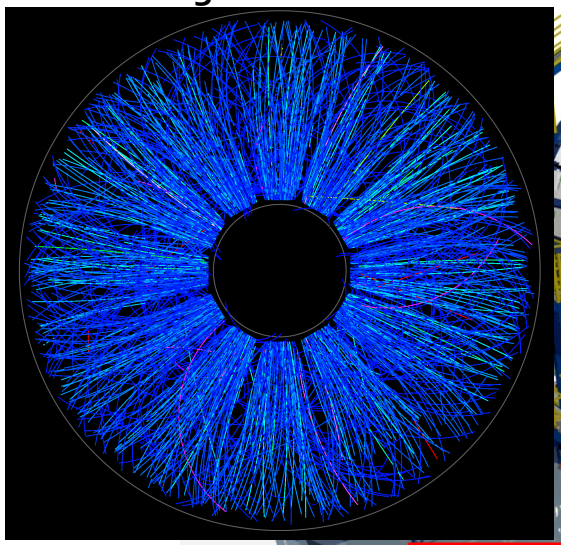
The RHIC-STAR Detector



Good particle identification, uniform acceptance over collision energies

Detector Upgrades for Beam Energy Scan Phase II at RHIC

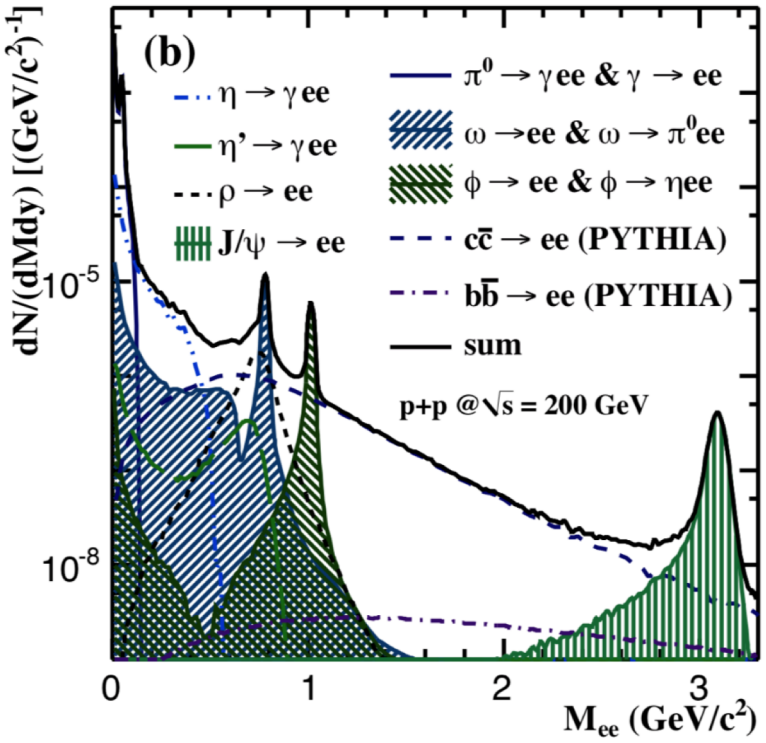
2019 Event Display : Au+Au 19.6 GeV
Full tracking with all iTPC sectors



iTPC upgrade	EPD upgrade	eTOF upgrade
Continuous pad rows Replace all inner TPC sectors	**Replace Beam Beam Counter**	**Add CBM TOF modules and electronics (FAIR Phase 0)**
$\|\eta\|<1.5$ (was 1.0)	**$2.1<\|\eta\|<5.1$**	**$-1.6<\eta<-1.1$**
p_T >60 MeV/c (was 150MeV/c)	Better trigger & b/g reduction	Extend forward PID capability
Better dE/dx resolution Better momentum resolution	Greatly improved Event Plane info (esp. 1st-order EP)	Allows higher energy range of Fixed Target program
Fully operational in 2019	**Fully operational in 2018**	**Fully operational in 2019**

Dileptons in Heavy Ion Collisions

STAR, PRC 86 (2012) 024906



Higher M_{ll} -> Earlier produced

Low Mass Region ($M_{ee} < M_{\varphi}$):

Vector meson in-medium modification

ρ broadening: *link to* **χSR**

Intermediate Mass Region ($M_{\varphi} < M_{ee} < M_{J/\psi}$):

Thermal probe of QGP $dN/dm_{ee} \sim e^{-m/T}$

Dominant contribution from semi-leptonic decays

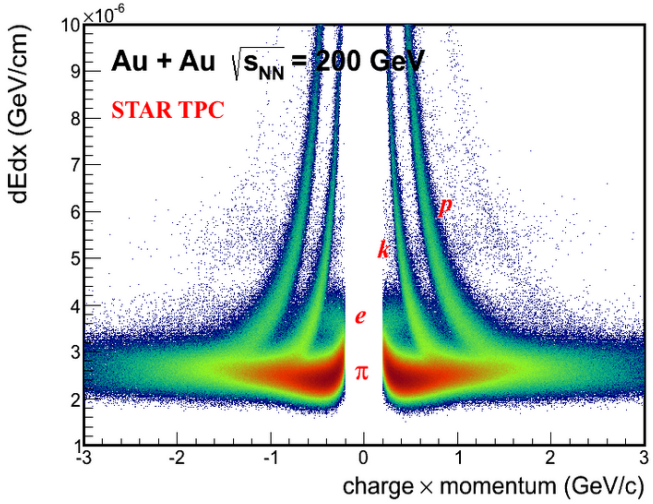
High Mass Region ($M_{ee} > M_{J/\psi}$)

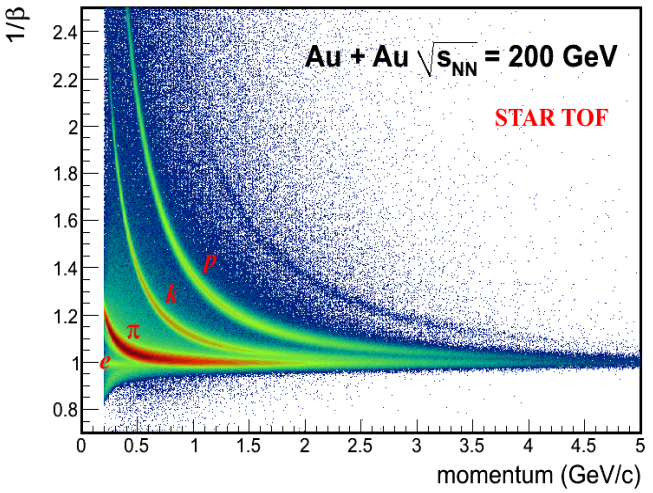
Primordial emission

Drell-Yan process

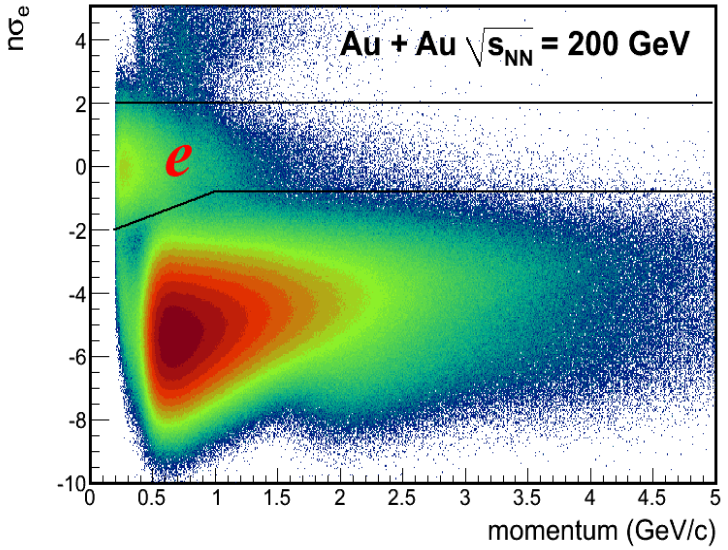
J/ψ and Upsilon

Particle Identification





Require β close to speed of light



Electron identification: TPC+TOF

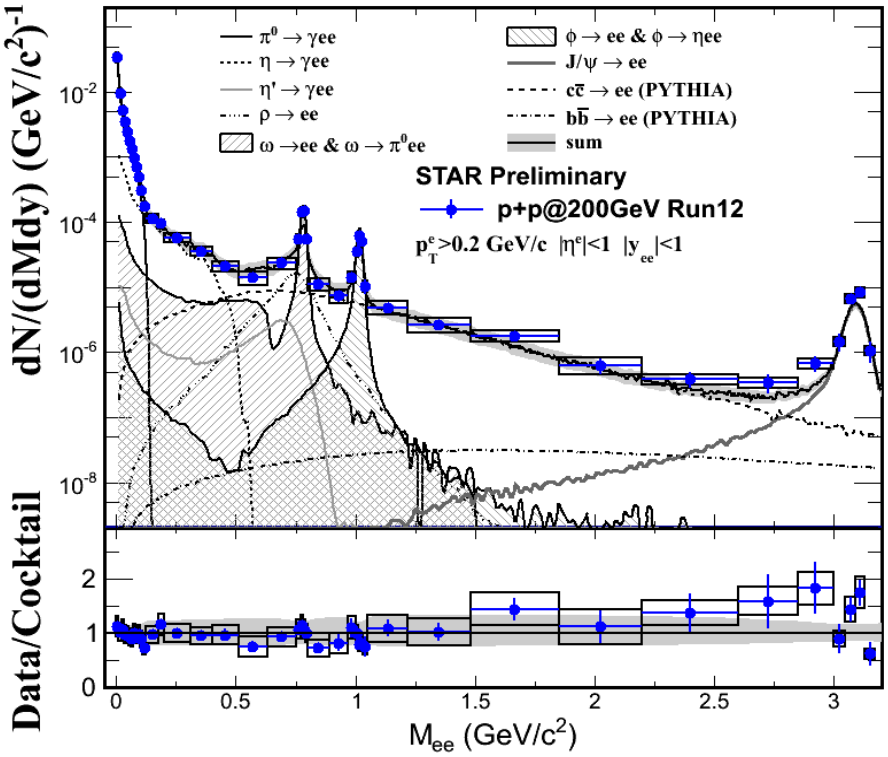
STAR, PRL 94 (2005) 062301

Muon identification: TPC or TPC+MTD

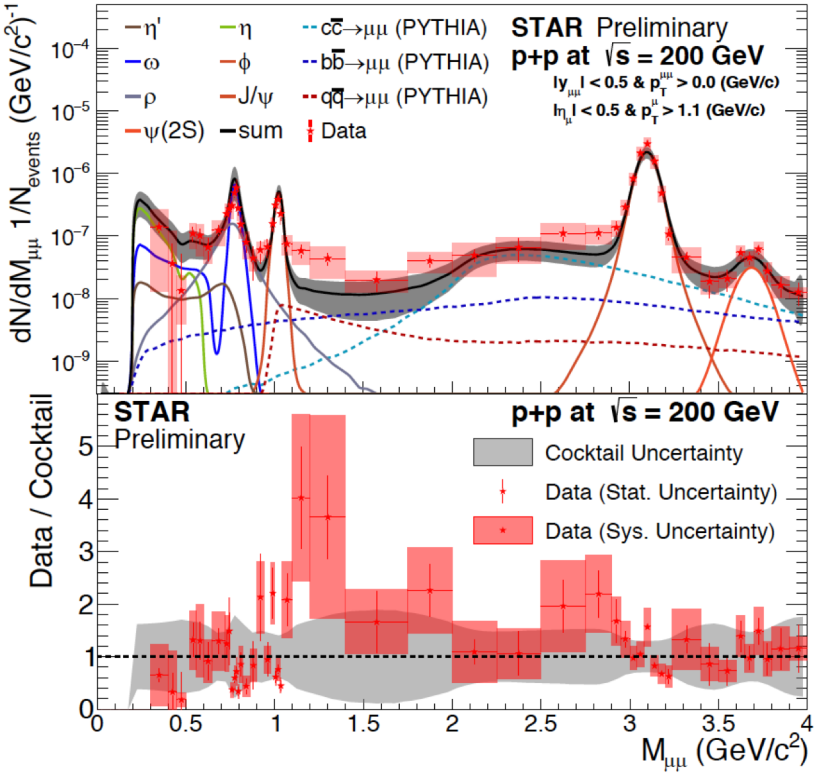
J.D.Brandenburg, NPA 982 (2019) 192
T.C.Huang, et.al., NIM.A 833 (2016) 88-93

Dilepton in p+p – Baseline

Dielectron



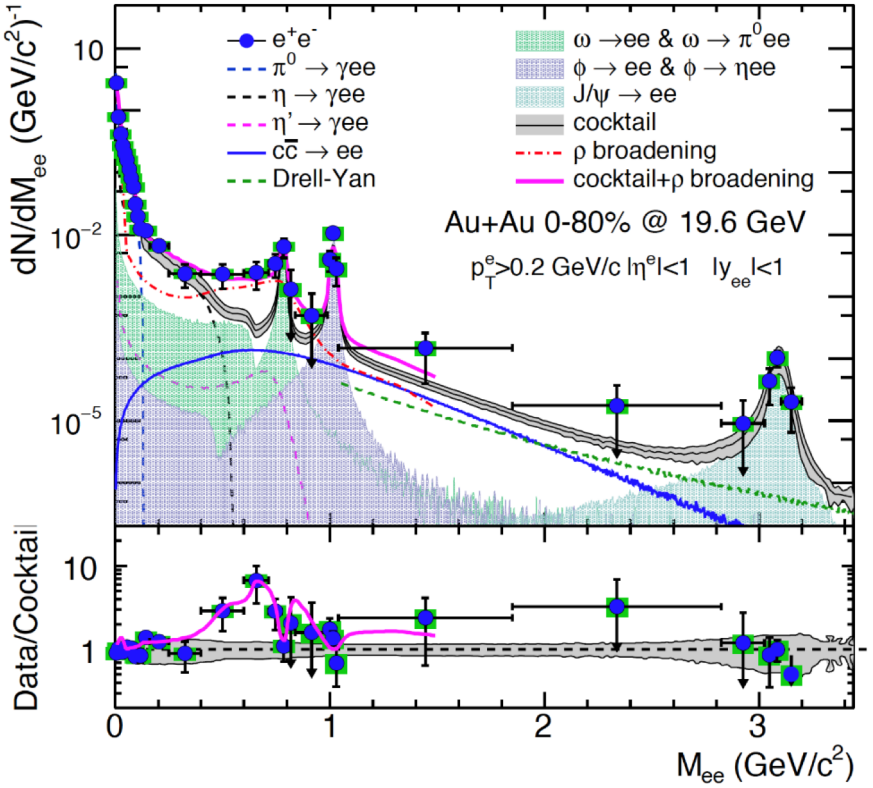
Dimuon



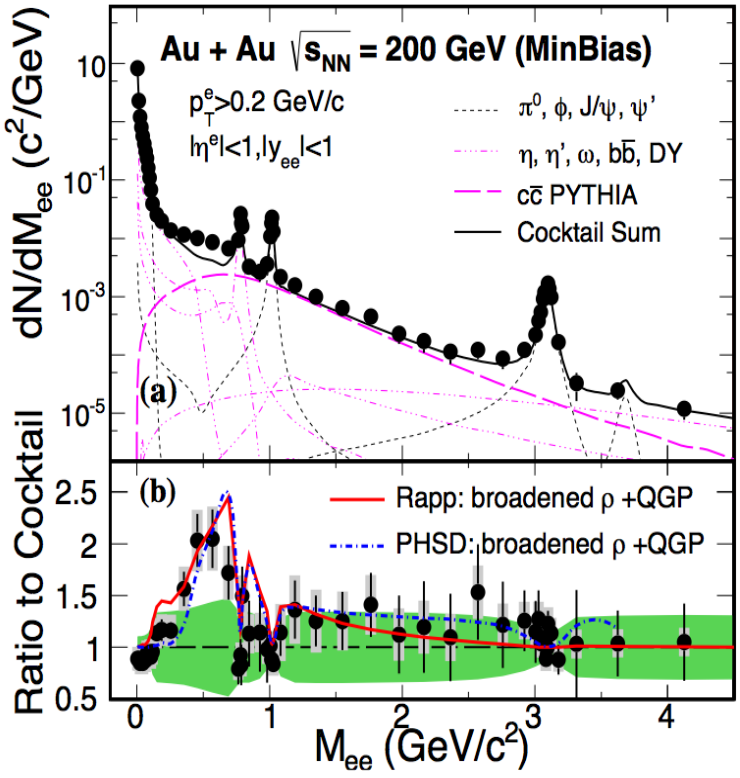
- In p+p collisions, the data are consistent with vacuum ρ distribution
- Hadronic cocktail simultaneously describe data at all mass regions
- Consistent with our understanding for p+p collisions – no "hot" contribution
- Cocktail simulation can be trusted

Dielectron in Au+Au – Low Mass Excess

Au+Au 19.6GeV



Au+Au 200GeV



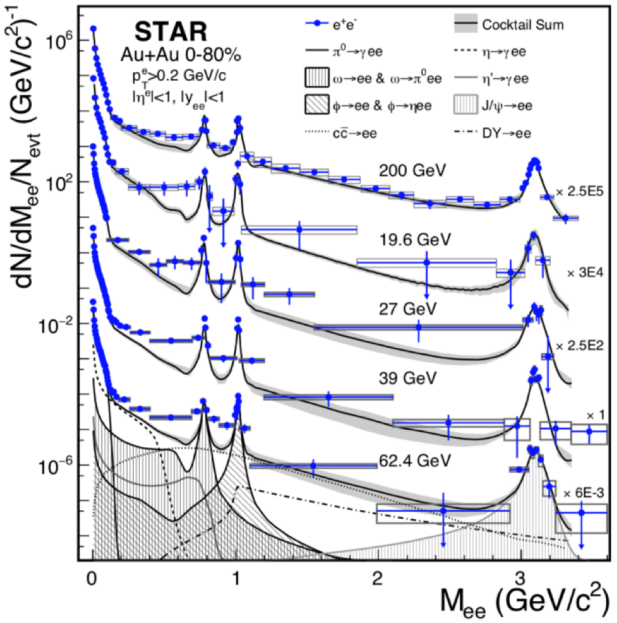
STAR, PLB 750 (2015) 64-71
STAR, PRL 113 (2014) 022301

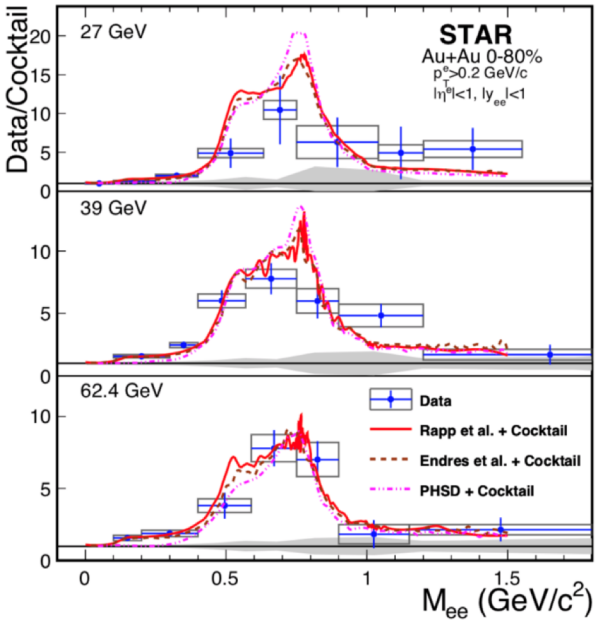
- In ρ-like region, clear excesses are observed from RHIC top energy to low energy
- Consistent with ρ broadening scenario within uncertainties

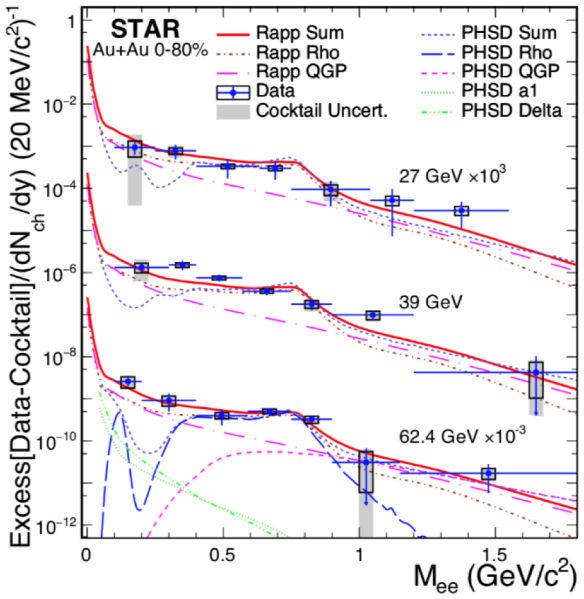
Dielectron in Au+Au – Low Mass Excess

STAR, arXiv:1810.10159

In Beam Energy Scan Phase I



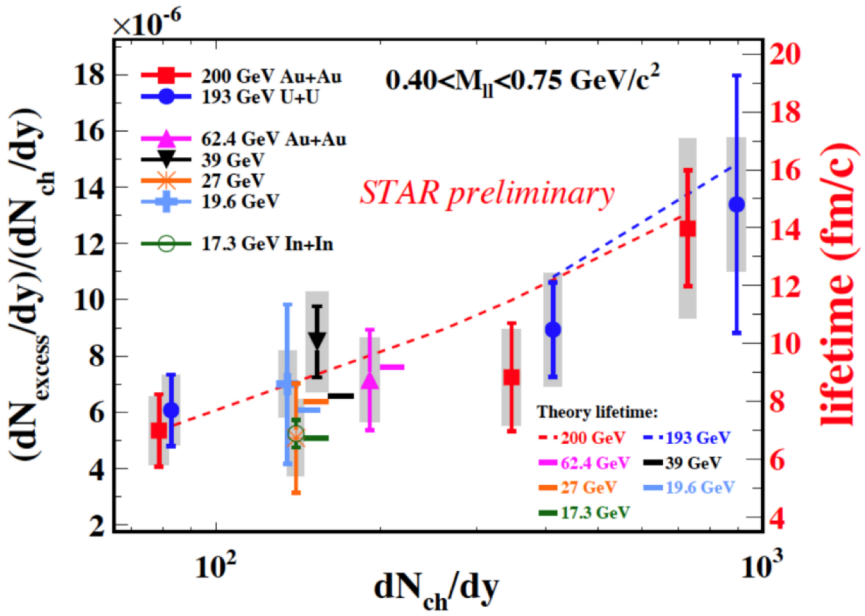


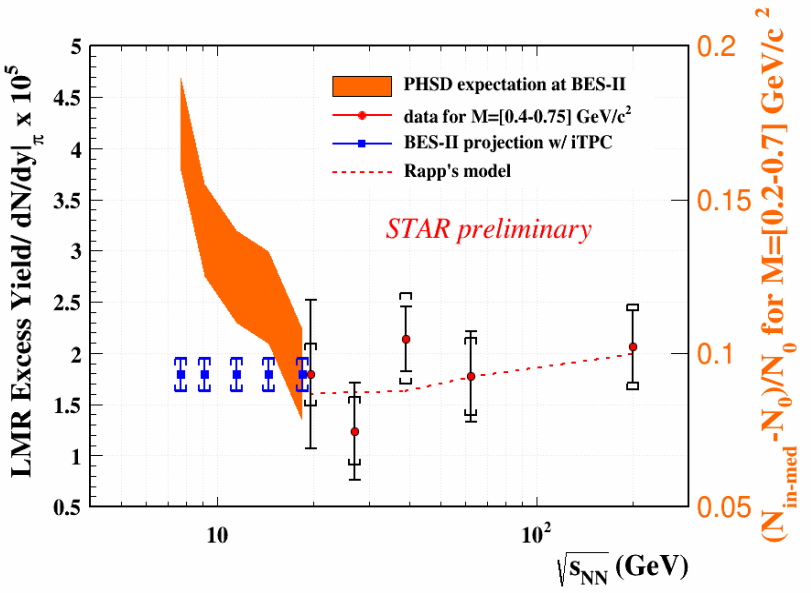


Low mass excesses are consistent with ρ broadening scenario within uncertainties from RHIC top energy down to 19.6GeV

Dielectron in Beam Energy Scan

Low-mass e^+e^- emission is effected by T, total baryon density, lifetime





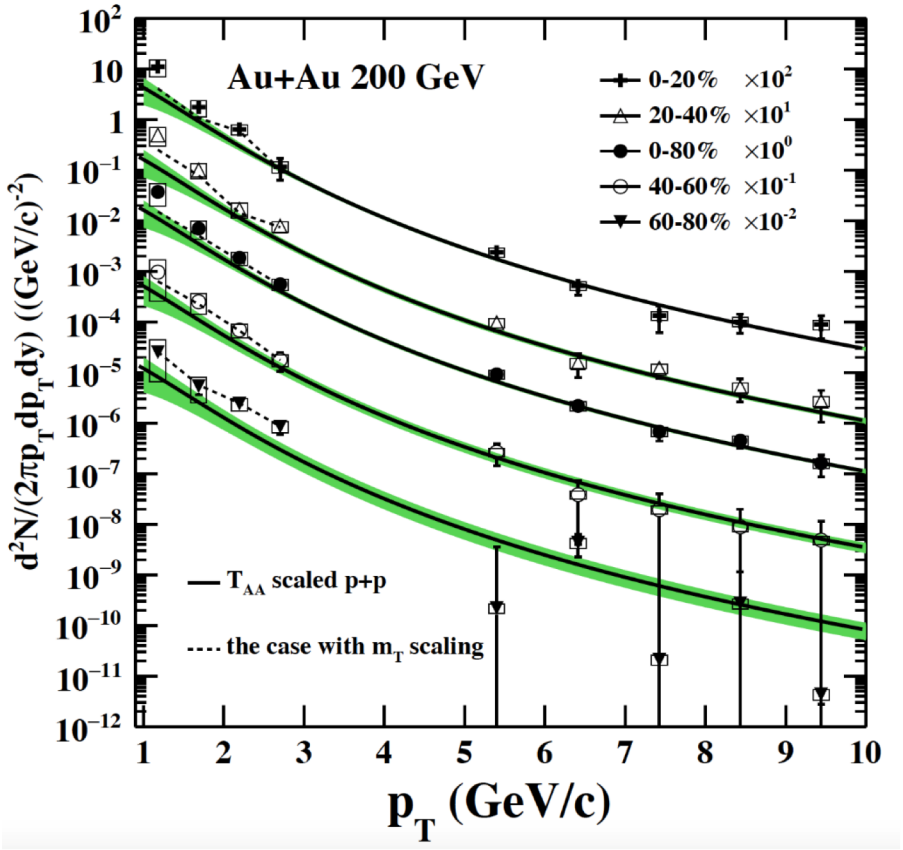
Total baryon density increases

Constant total baryon density

- Excess yield normalized by dN_{ch}/dy is proportional to lifetime of the medium
- Constant excess along constant total baryon density
- Emission rate is dominant in the T_c region
- More clear pictures of the excess versus lifetime and total baryon density in BES-II

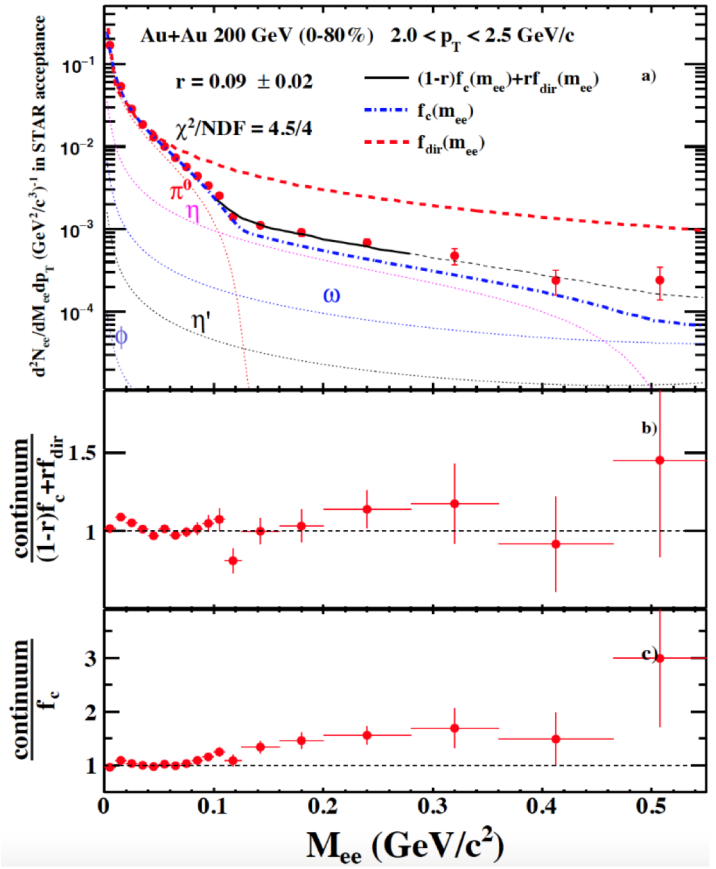
Direct Virtual Photon Yield

STAR, PLB 770 (2017) 451-458



Via internal conversion method

Two-component fitting on dielectron continuum

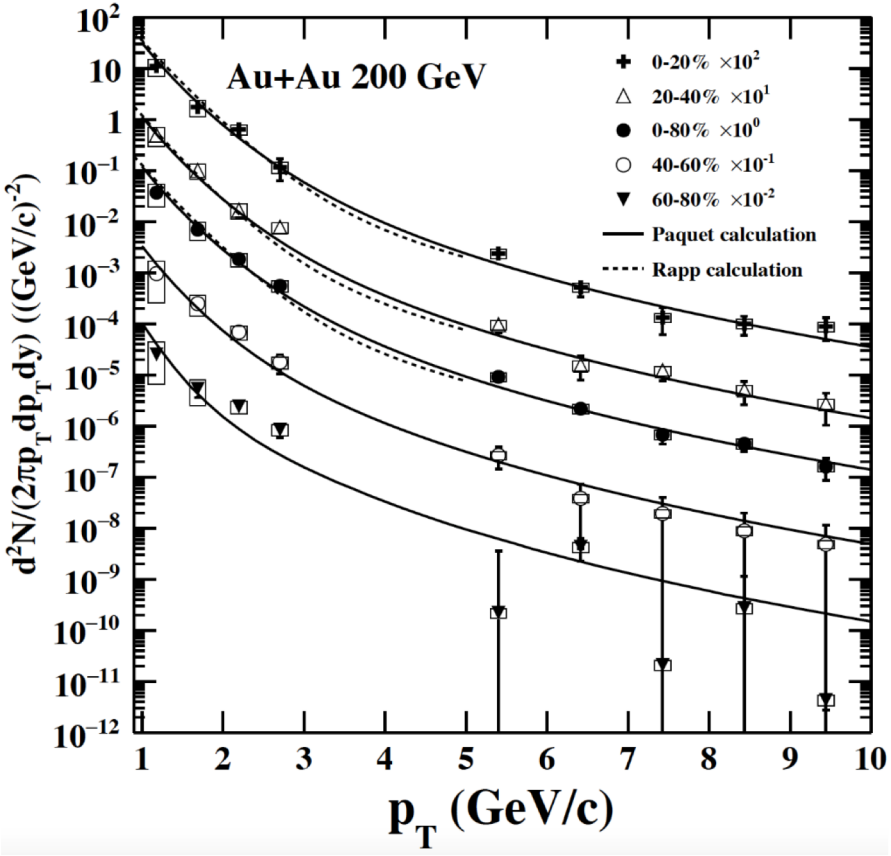


Thermal photons can be observed

Compared to p+p reference (from PHENIX collaboration)

Direct Virtual Photon Yield

STAR, PLB 770 (2017) 451-458



Model predictions considering:

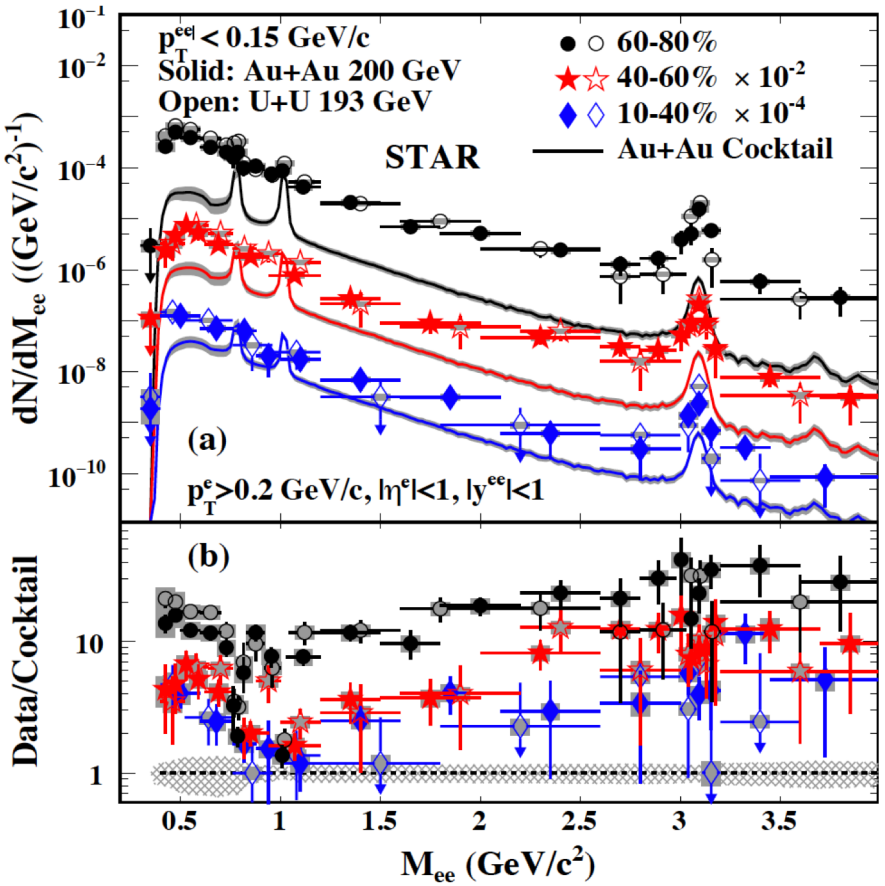
- *thermal radiation*
- *in-medium ρ meson*
- *other mesonic interactions in the hadronic gas*
- *primordial contributions from the initial hard parton scattering*

Model calculations:

- **Consistent with the yield within uncertainties except some bins in 60-80%**
- **Simultaneously describe both dielectron and direct virtual photon yields**

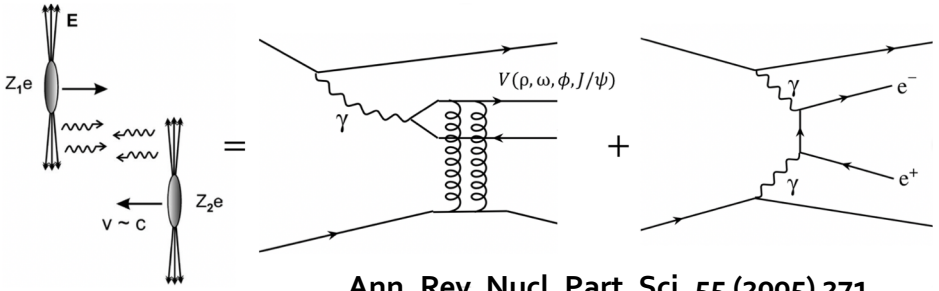
Coherent Low p_T e^+e^- in Au+Au and U+U

STAR, PRL 121 (2018) 132301



Photon-photon and Photon-nucleon Interactions

From Ultra-Peripheral Collisions (UPC) to Hadronic Heavy Ion Collisions (HHIC)

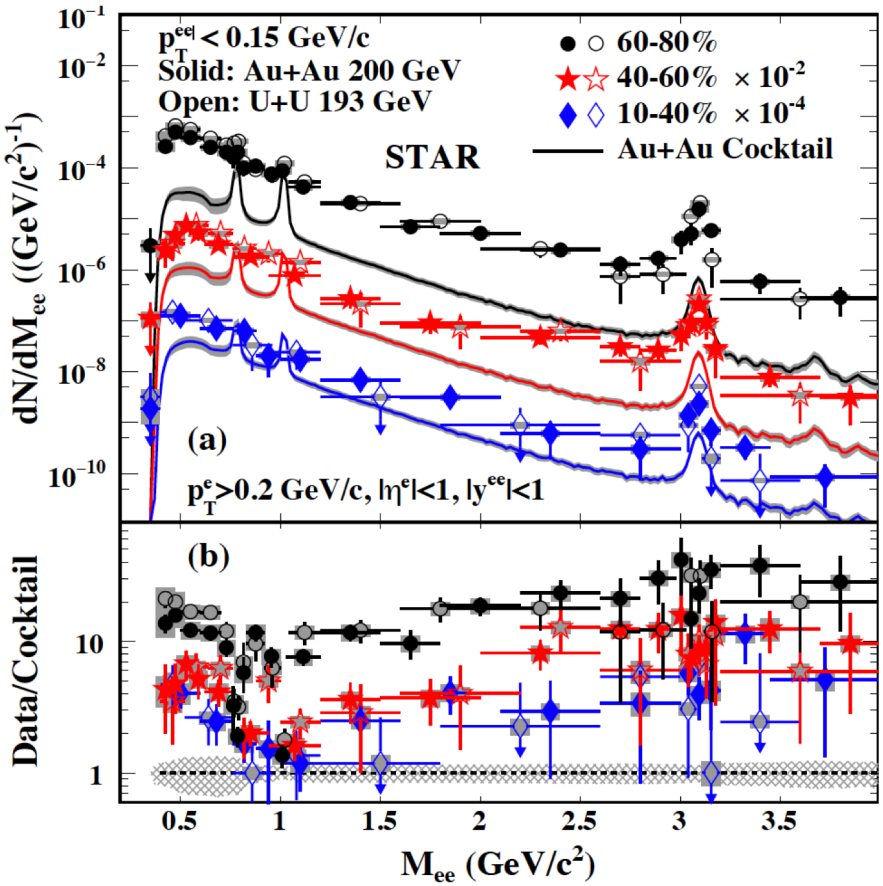


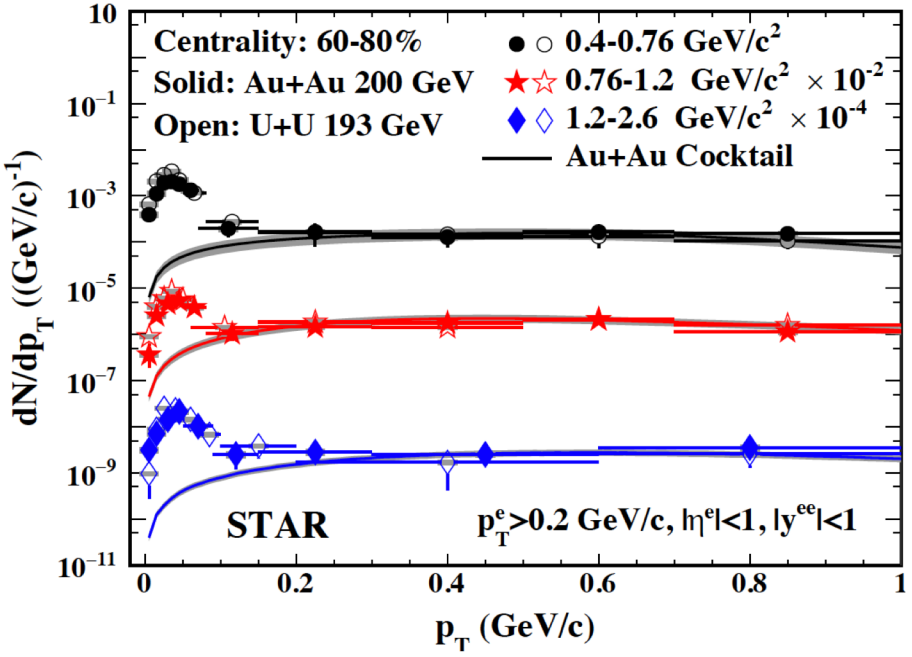
Ann. Rev. Nucl. Part. Sci. 55 (2005) 271

- Significant enhancement
- Excesses concentrate below $p_T \approx 0.15$ GeV/c
- Data are consistent with hadronic expectation when $p_T > 0.15$ GeV/c

Coherent Low p_T e^+e^- in Au+Au and U+U

STAR, PRL 121 (2018) 132301





- Coherent photon-photon and photon-nucleon interactions in HHIC!
- A new topic in dilepton analysis, challenge to theory on the understanding of coherent photon-photon and photon-nucleon interactions
- May also be observed in dimuon channel

To Go Further

In UPC

- Provide baseline
- Exclusive and clean e^+e^- detection *(STAR ultra-peripheral collisions provide opportunities)*
- Individual e should be preferentially aligned longitudinally and the azimuthal angle between the e^+e^- pair momentum and the individual e momenta should display modulations *(Polarized photon-photon collisions, C. Li, J. Zhou, Y. Zhou, PLB 795 (2019) 576–580 predicted 10~20% 4-th order modulation at STAR)*

In HHIC

- Study extreme magnetic field and potential medium effect
- Different centralities and species *(d+Au, isobaric data)*
- Kinematics WRT B-field (reaction plane), mass, p_T

Current and Future Opportunities on EM Probes at STAR

1.2 B Au+Au 54 GeV and 1.5 B Au+Au 27 GeV data collected in Run17

-- Smaller heavy flavor semi-leptonic decay in IMR

3.1 B isobaric collision data collected in Run 18

-- Same A, different Z – similar hadronic interaction, different initial magnetic field

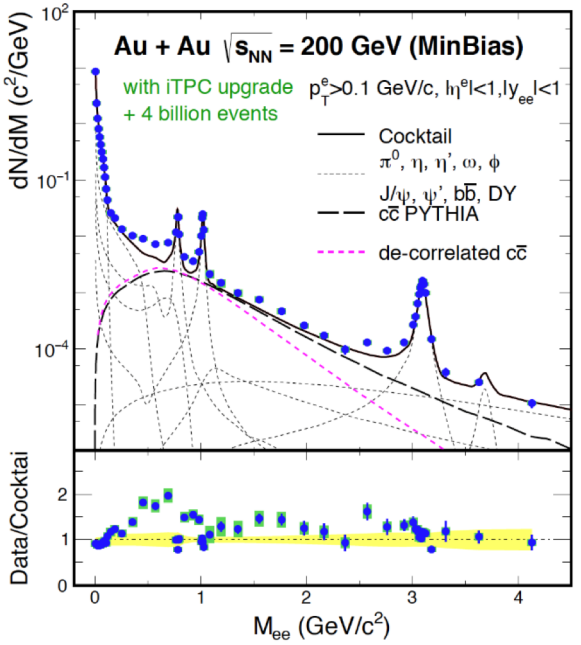
BES-II in Run 19, Run 20 and Run 21

-- Different total baryon densities, scan in high total baryon density region

Beyond 2020+

-- Mid-rapidity: e^+e^- measurement at μ_B~0

- Link to chiral symmetry restoration
  - -- Precise ρ spectra
- Thermal radiation from QGP
  - -- IMR slope
- Direct virtual photon at RHIC top energy
  - -- Thermal photon slope



Uncertainty prediction with iTPC + 4 billion events

Summary

Electromagnetic probes provide unique ways to study the hot and dense medium over the whole evolution:

Dilepton:

- **ρ broadening scenario describes the excesses in LMR**
  - *-- Measurements are from RHIC top energy down to 19.6 GeV in BES-I*
- **Coherent low p_T dielectron production observed in HHIC**
  - *-- Need further study in both UPC and HHIC*

Direct virtual photons:

- **Thermal photons observed in Au+Au collisions**
  - *-- Model calculations simultaneously describe both dielectron and direct virtual photon results*
  - *-- Need to further study the thermal photon slope and collision system dependence*

Lots of excellent opportunities on EM probes research at STAR, keep tuned!

Backup

Electron-positron Pairs from Internal Conversion

- Relation between real photon yield and the associated e^+e^- pairs:

$$\frac{d^2N_{ee}}{dM} = \frac{2\alpha}{3\pi}\frac{L(M)}{M}S(M,q)dN_\gamma$$

✓ *pass STAR acceptance*
✓ *normalize to 0-30 MeV/c²*

$$L(M) = \sqrt{1-\frac{4m_e^2}{M^2}}\left(1+\frac{2m_e^2}{M^2}\right)$$

$$S(M,q) = \frac{dN_{\gamma^*}}{dN_\gamma}$$

cocktail normalized to 0-30 MeV/c²

$(1-r)\,f_c$ + $r\,f_{dir}$

cocktail component

direct virtual photon component

Direct photons can be measured by the associated dielectron production.

S = 1 => direct virtual photon ($p_T \gg M$, $M \gg m_e$)

: two-component fit to dielectron continuum.

$$r = \frac{yield\ of\ direct\ virtual\ photon}{yield\ of\ inclusive\ photon}$$