Dileptons and direct photons in heavy-ion collisions at STAR

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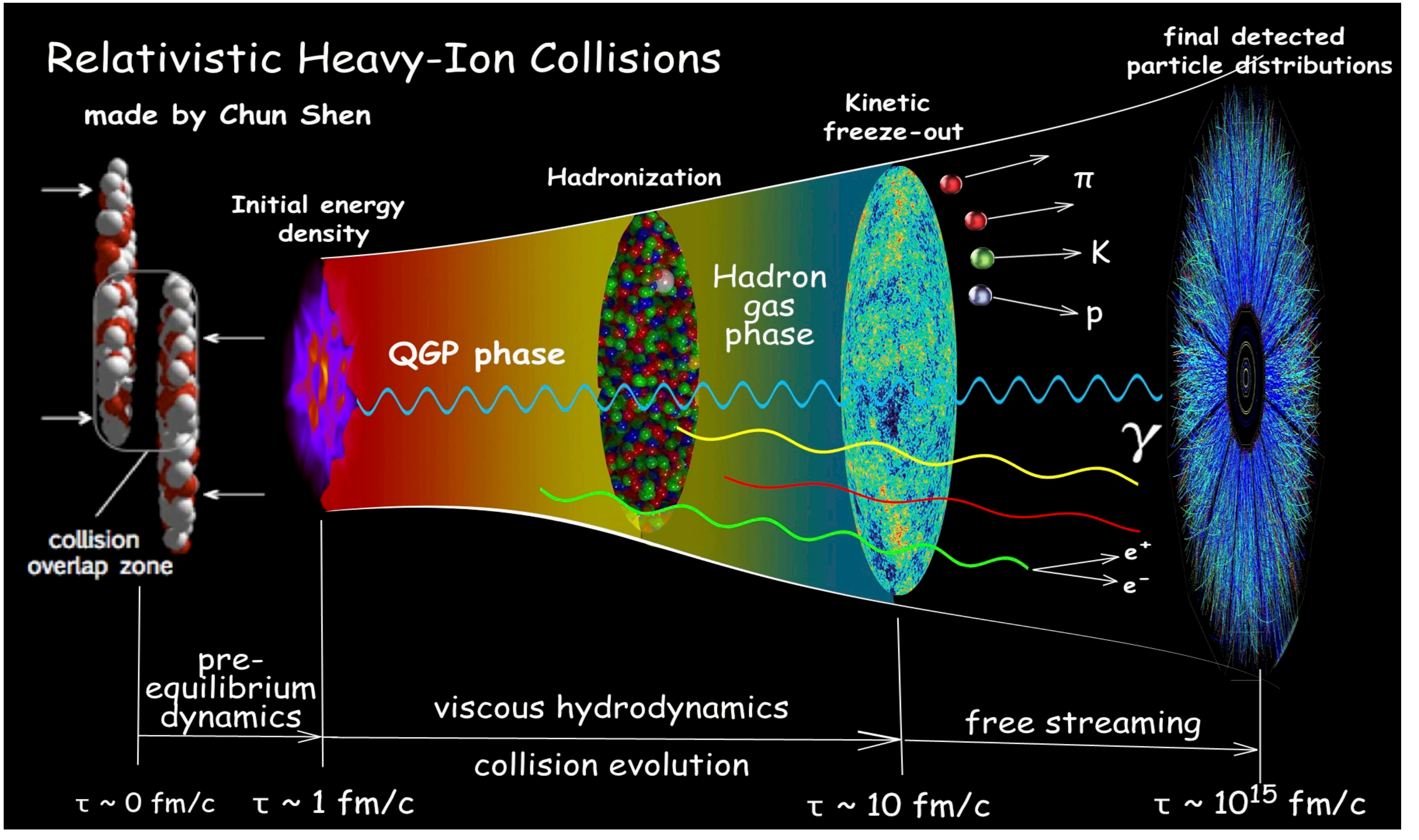
- ✓ Introduction
- ✓ Dilepton results
- ✓ Direct photon results
- ✓ Summary and outlook

NN2018
SAITAMA, JAPAN
NUCLEUS-NUCLEUS COLLISIONS

NSFC
National Natural Science Foundation of China

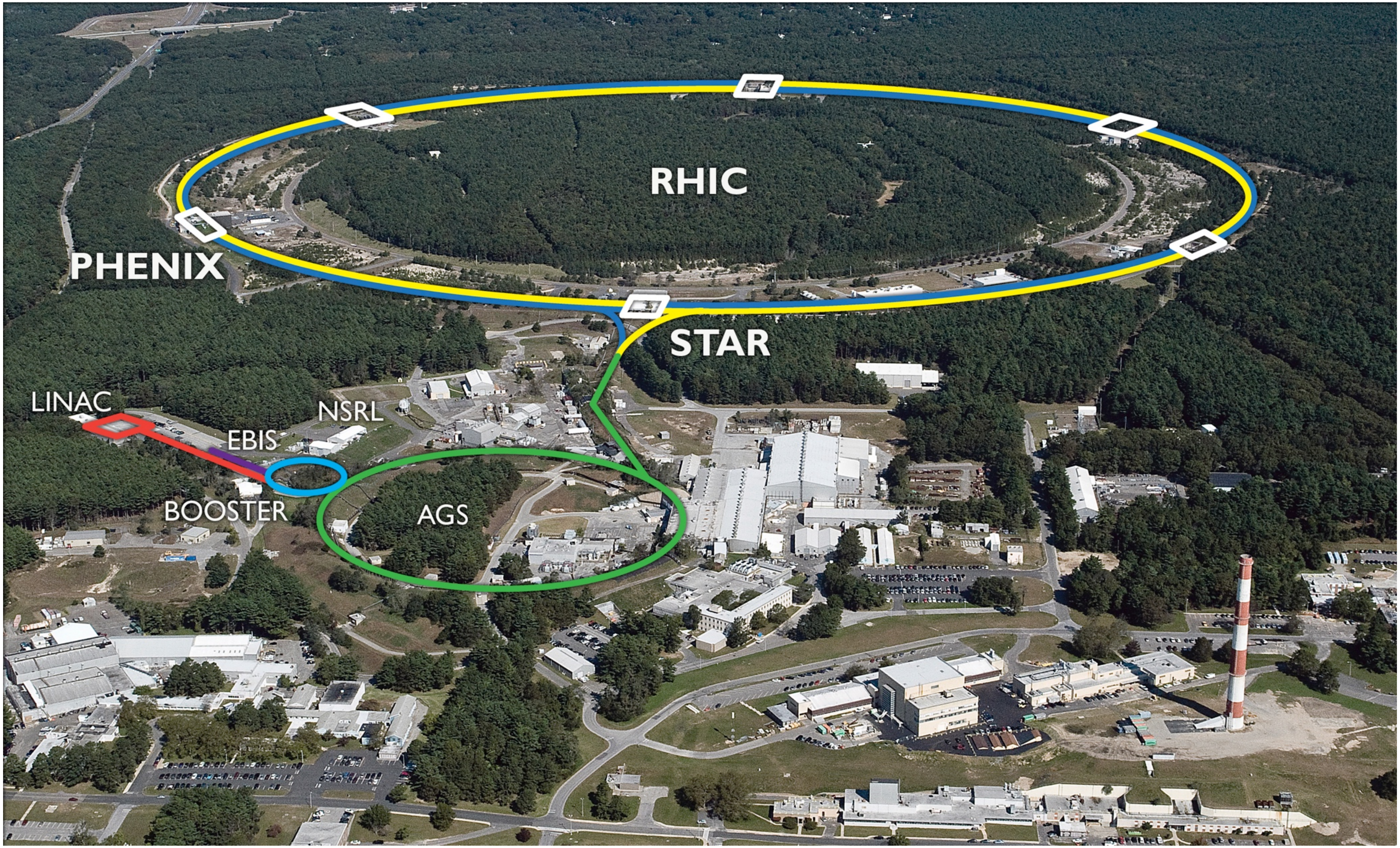
Electromagnetic probes in HIC



Dileptons and real photons —— ideal electromagnetic probes

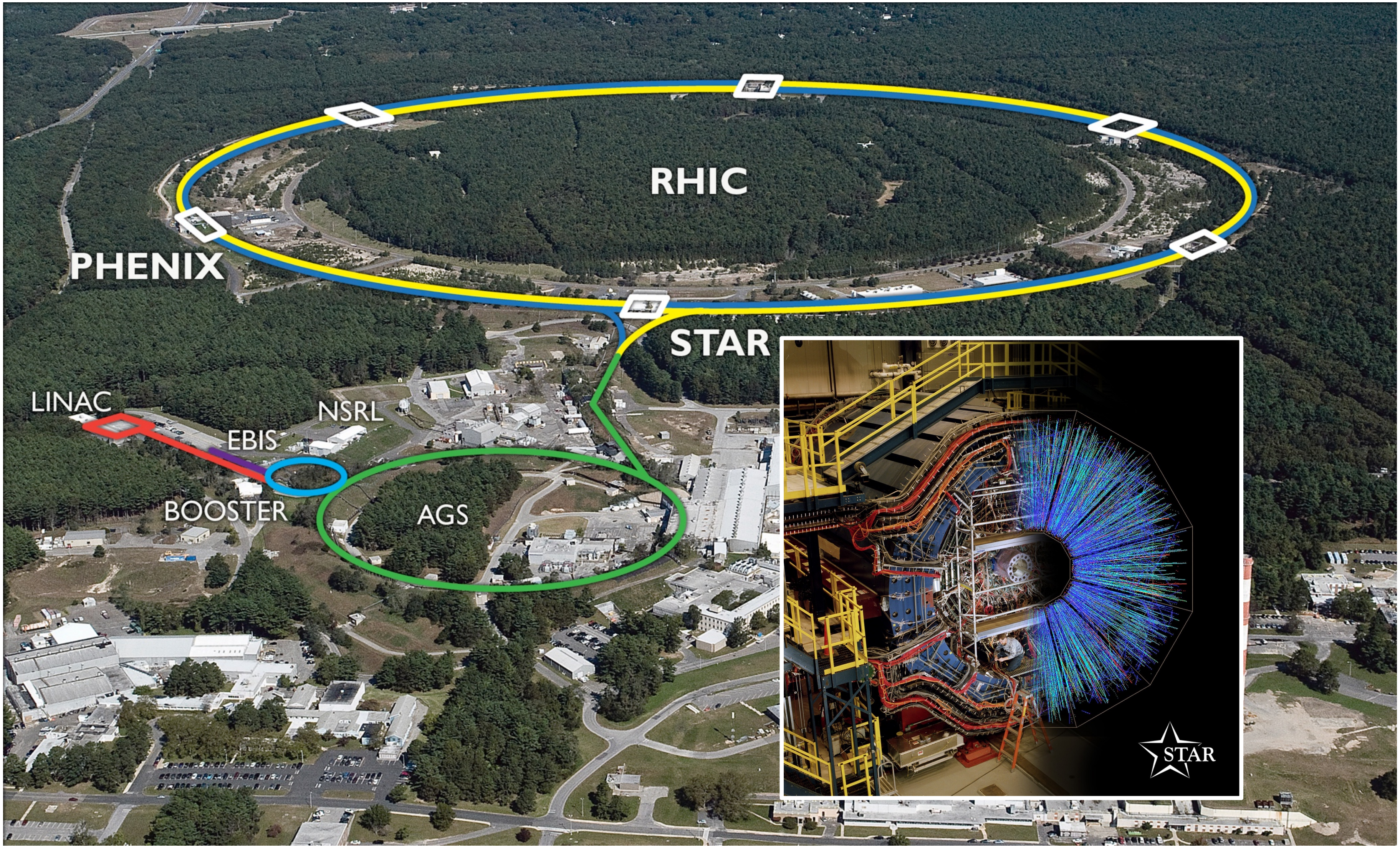
- ✓ Suffer no strong interaction
- ✓ Produced at all stages of the system evolution
- ✓ Bring production information to final state
- ✓ Sensitive to electromagnetic processes

STAR ☆ Relativistic Heavy Ion Collider



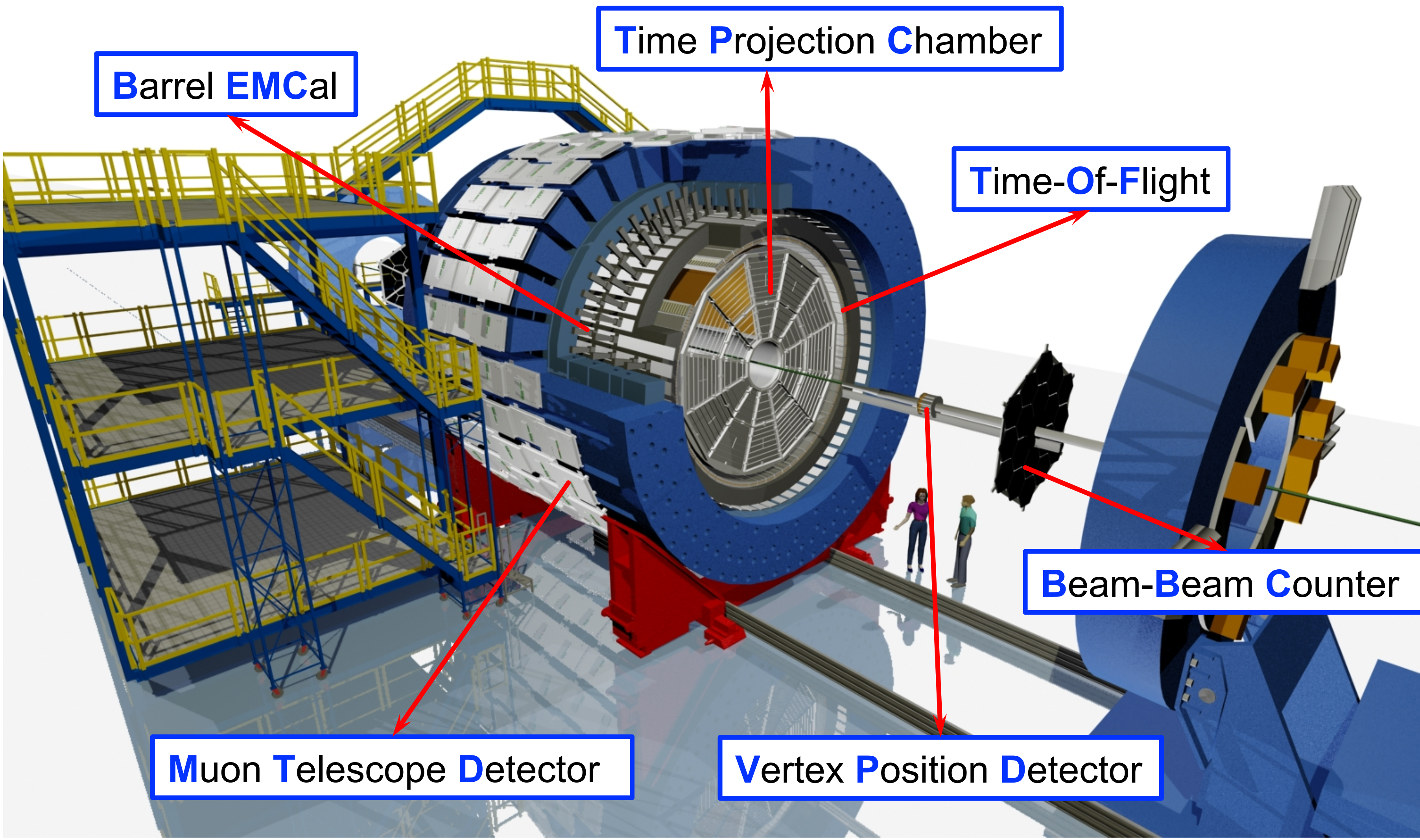
Located in Brookhaven National Laboratory, Upton, New York, USA

STAR ☆ Solenoidal Tracker At RHIC



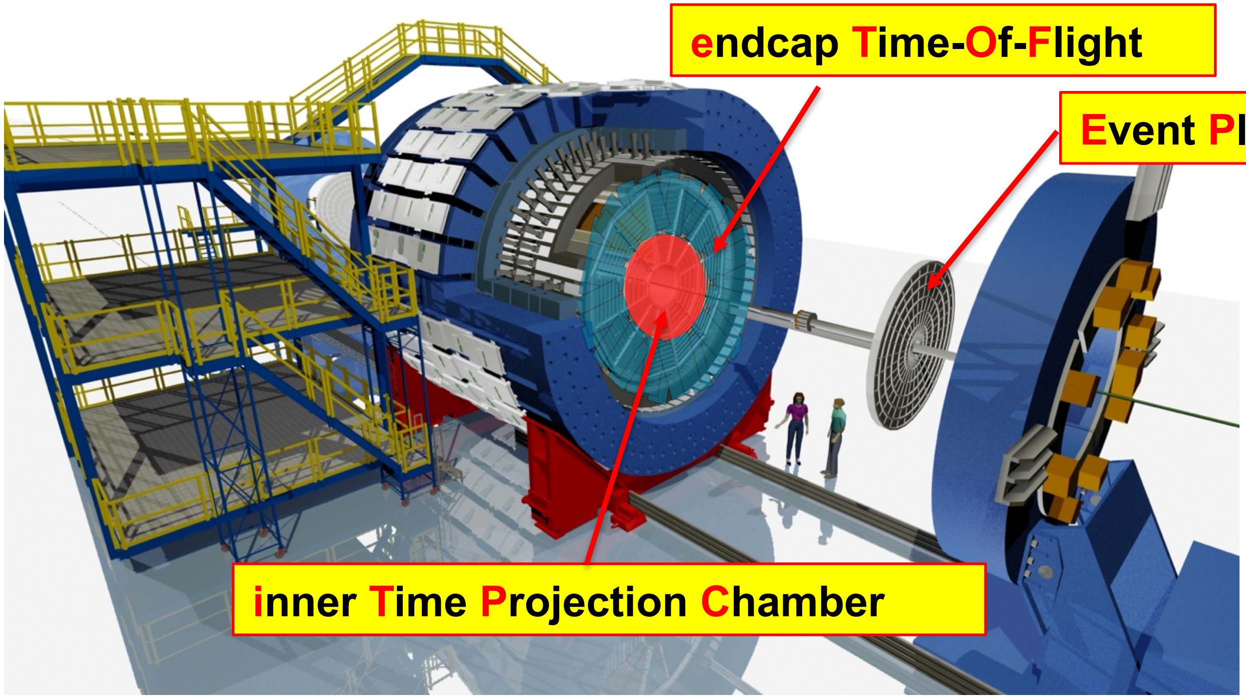
Located in Brookhaven National Laboratory, Upton, New York, USA

The current STAR detector layout



Large acceptance, good particle identification
Plenty of interesting physics results over years

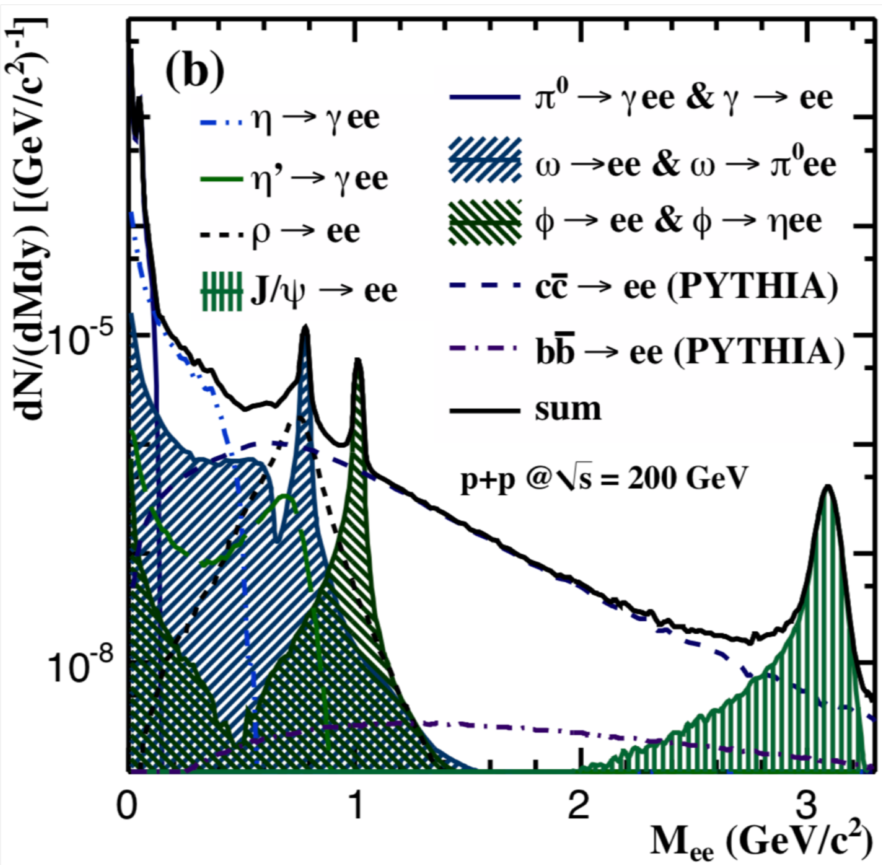
Ongoing detector upgrades



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. 1^{st}-order EP)	Allows higher energy range of Fixed Target program
Fully operational in 2019	**Fully operational in 2018**	**Fully operational in 2019**

Dileptons

STAR, PRC, 86 (2012) 024906



Higher M_{ll} -> Earlier produced

Low Mass Region (<1.1 GeV/c^2):

- ✓ vector meson in-medium modification
- ✓ link to chiral symmetry restoration

Intermediate Mass Region (1.1-3.0 GeV/c^2):

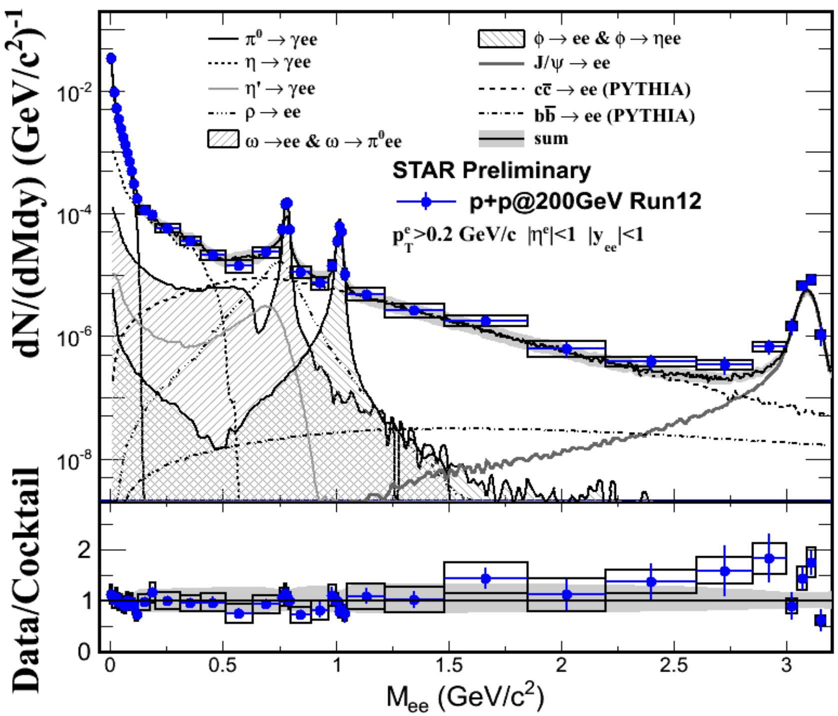
- ✓ thermal probe of QGP $dN/dm_{ll} \sim e^{-m/T}$
- ✓ dominant contribution from semi-leptonic decays

High Mass Region (>3.0 GeV/c^2)

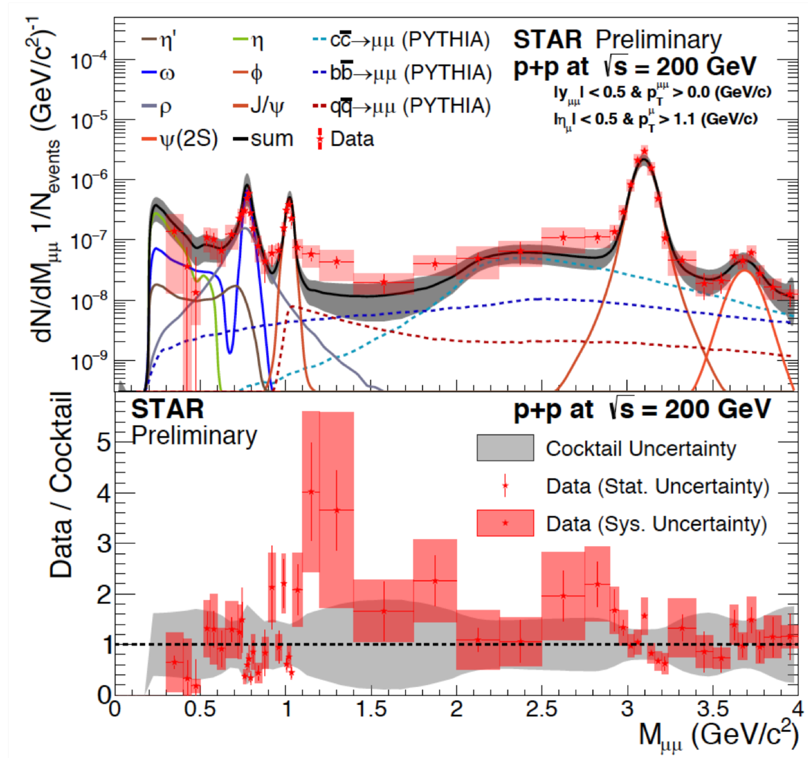
- ✓ Primordial emission
- ✓ Drell-Yan process
- ✓ J/ψ and Upsilon

Dilepton in p+p – baseline

Dielectron



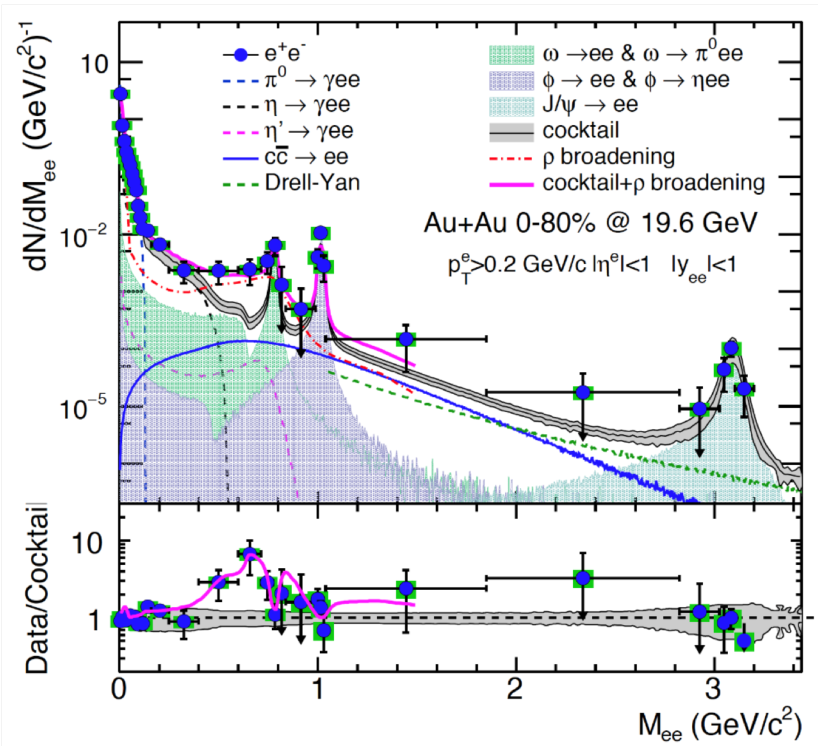
Dimuon



- ✓ 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

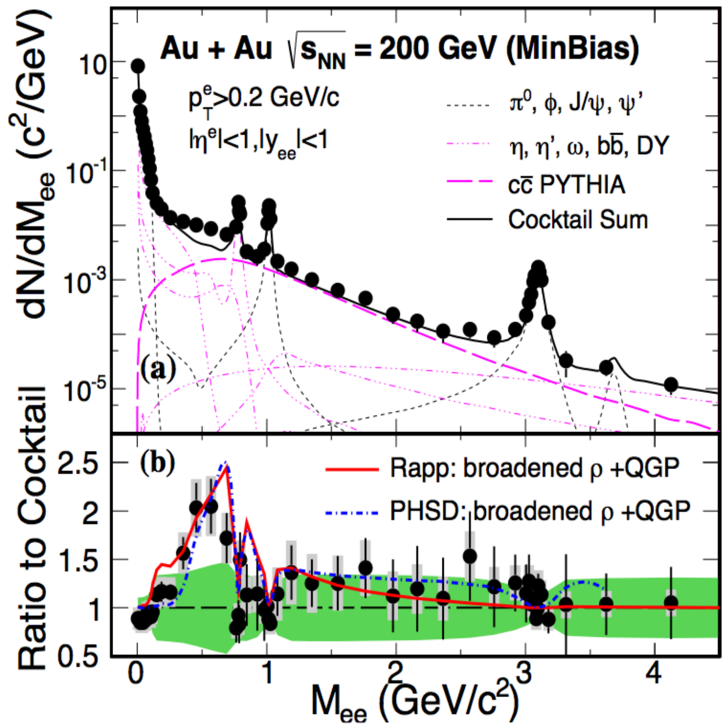
Dielectron in heavy-ion collisions

Au+Au 19.6GeV



STAR, PLB, 750 (2015) 64-71

Au+Au 200GeV

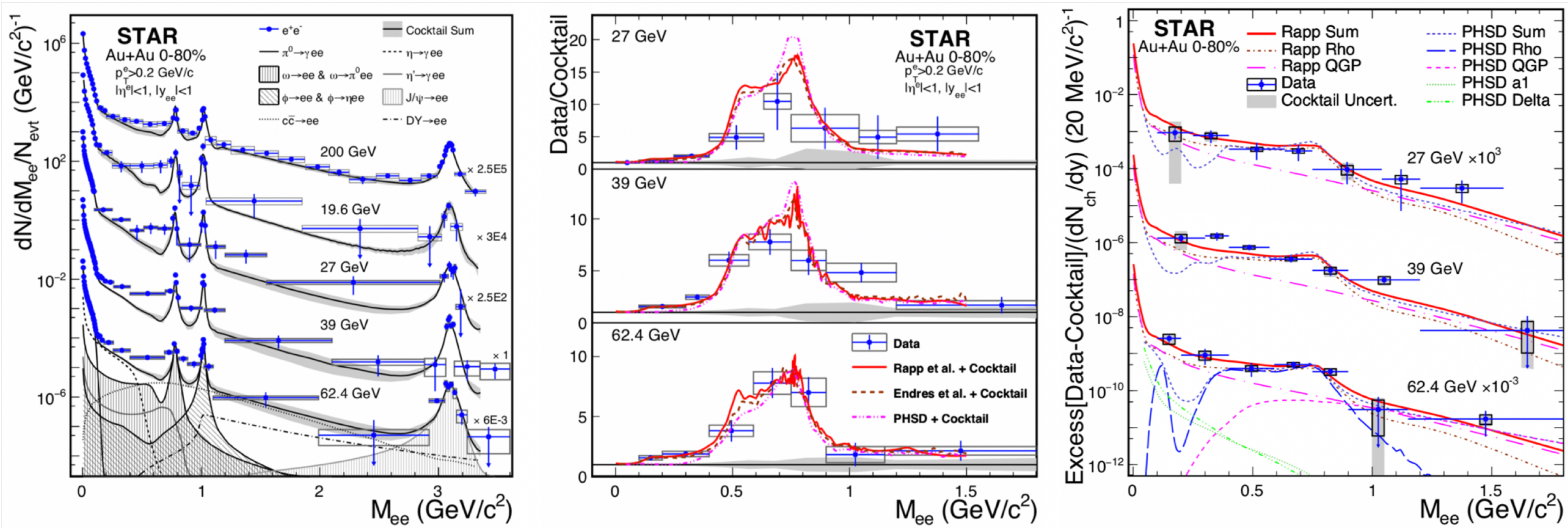


STAR, PRL, 113 (2014) 022301

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

STAR ☆ Dielectron in Beam Energy Scan Phase I

STAR, arXiv:1810.10159



- ✓ **Low mass excesses are consistent with ρ broadening scenario within uncertainties**
- ✓ **Low-mass e^+e^- emission is affected by T, total baryon density, lifetime**

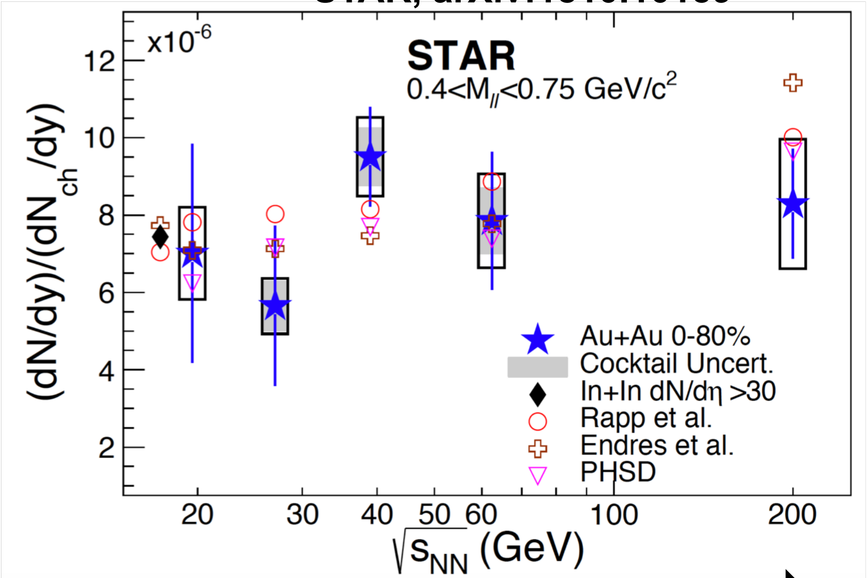
Future in Beam Energy Scan Phase II

BES-II:

In 2019-2021, scan from 19.6 GeV down to 7.7 GeV Au+Au.

Detector upgrades will reduce the systematic uncertainties and extend the acceptance.

STAR, arXiv:1810.10159



Total baryon density increases ← | → **Almost constant total baryon density**

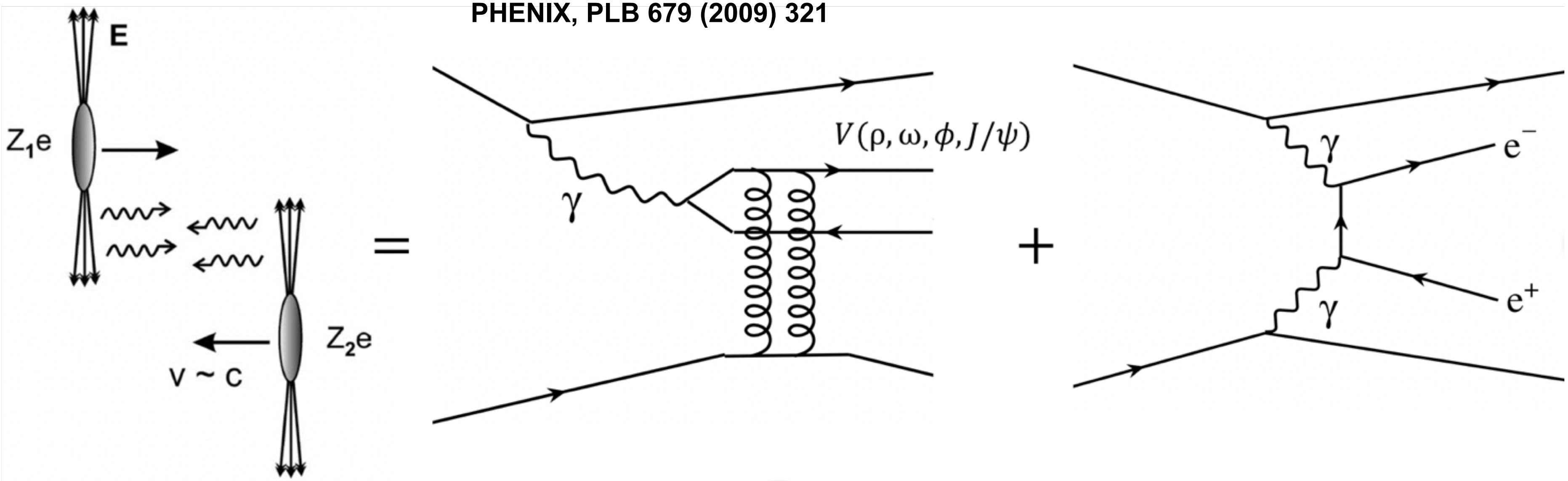
Current measurements:

- ✓ **Excess yield normalized by dN_{ch}/dy might be proportional to the lifetime of the medium**
- ✓ **Constant excess along constant total baryon density**

In BES-II:

More clear pictures of the excesses versus lifetime and total baryon density

Ann. Rev. Nucl. Part. Sci. 55 (2005) 271
PHENIX, PLB 679 (2009) 321

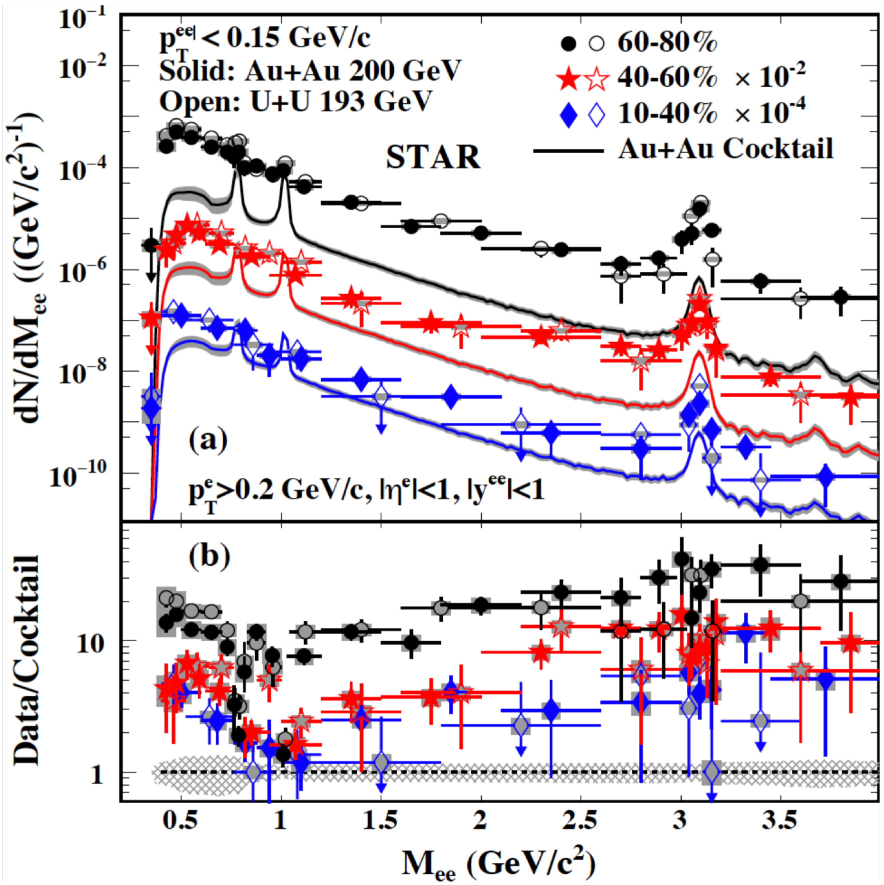


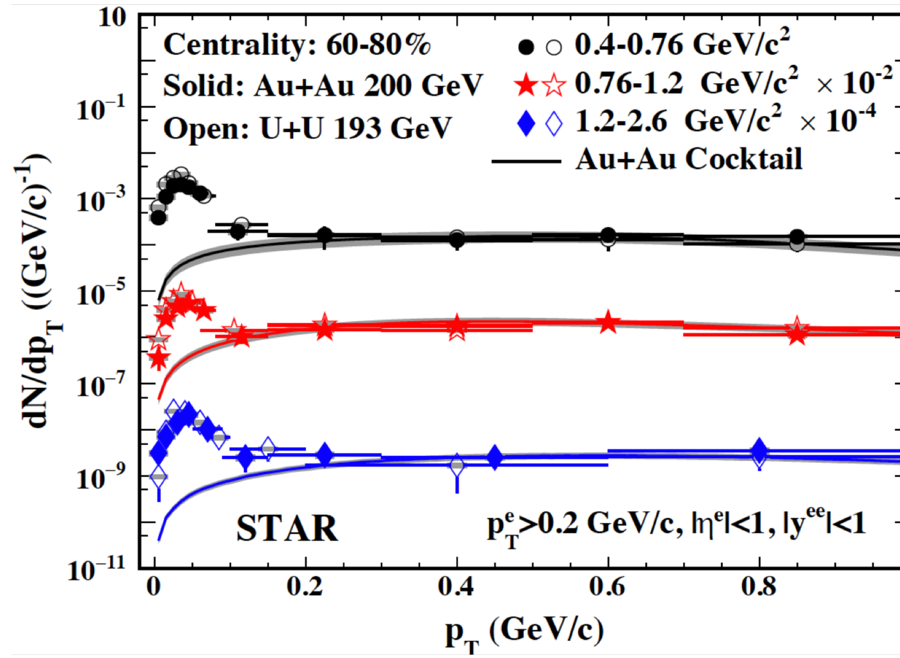
Coherent:

- ✓ Emitted photon/pomeron interacts with the nucleus as a whole
- ✓ Strong coupling results in large cross sections
- ✓ Photon wavelength $\lambda = h/p > R_A$
- ✓ $p_T < h/R_A \sim 30$ MeV/c for heavy ions
- ✓ No overlapping for two colliding nuclei

STAR ☆ Coherent low p_T e^+e^- in Au+Au and U+U

STAR, PRL, 121 (2018) 132301

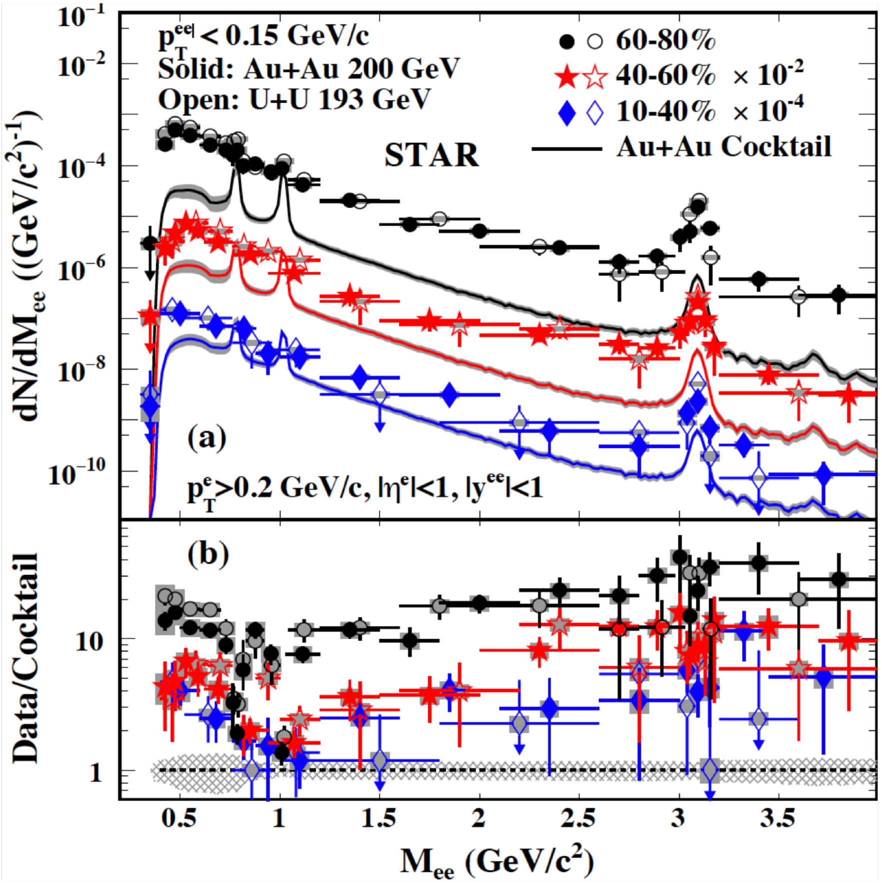


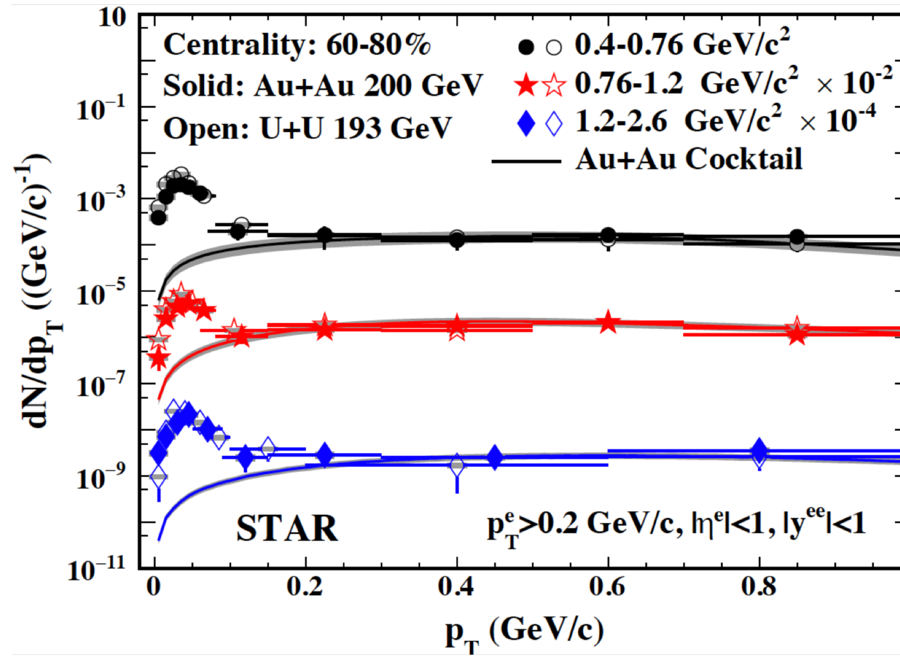


- ✓ **Significant enhancement**
- ✓ **Excesses concentrate below $p_T \approx 0.15$ GeV/c**
- ✓ **Data are consistent with hadronic expectation when $p_T > 0.15$ GeV/c**

STAR ☆ Coherent low p_T e^+e^- in Au+Au and U+U

STAR, PRL, 121 (2018) 132301

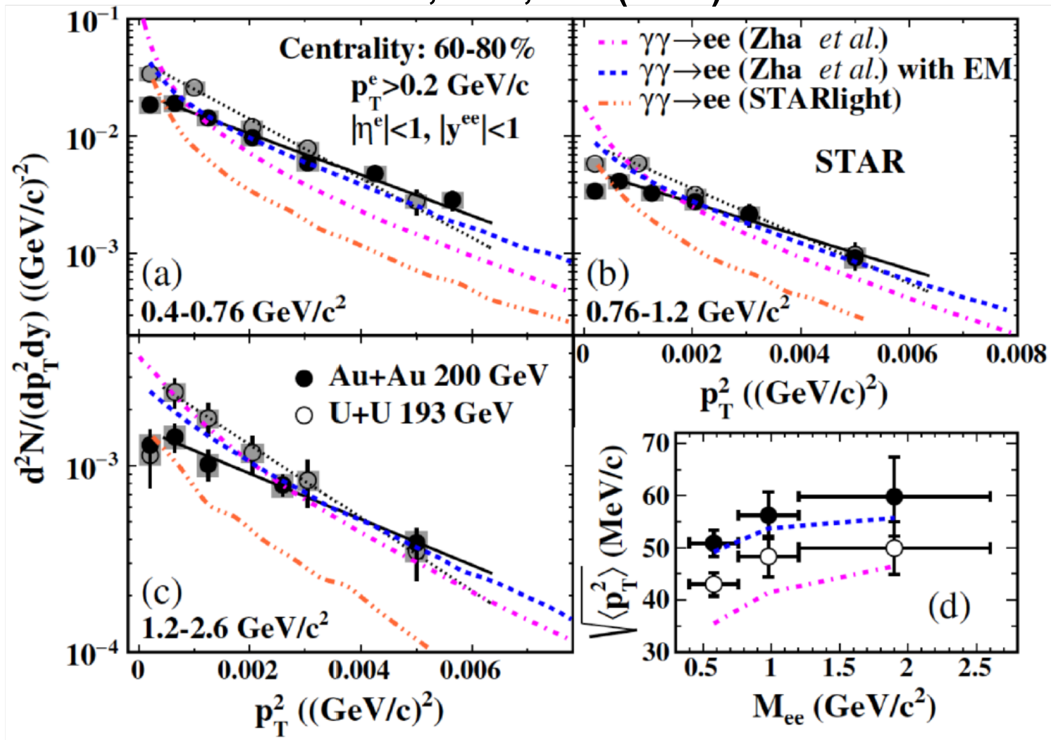




- ✓ Coherent photon-photon and photon-nucleon interaction in HHIC!
- ✓ A new topic in dilepton analysis, challenge to theory on the understanding of coherent photon-photon and photon-nucleon interactions
- ✓ May also be observed in dimuon channel

p_T^2 distribution for low p_T dielectron

STAR, PRL, 121 (2018) 132301



- ✓ **Initial produced dilepton tracks can be bent by the magnetic field**
- ✓ **The effect is large enough to see, if magnetic field last long (trapped in QGP)**
- ✓ **Theoretical calculation with magnetic field effect matches data better**

The model assumes that all the e^+e^- pairs traverse 1 fm through a magnetic field of 10^{14} T perpendicular to the beam line, the net effect of this approach is like $\int eB(t)cdt = e\bar{B}L = 30\ MeV/c$ *for one track*

Direct photons

Direct photons:

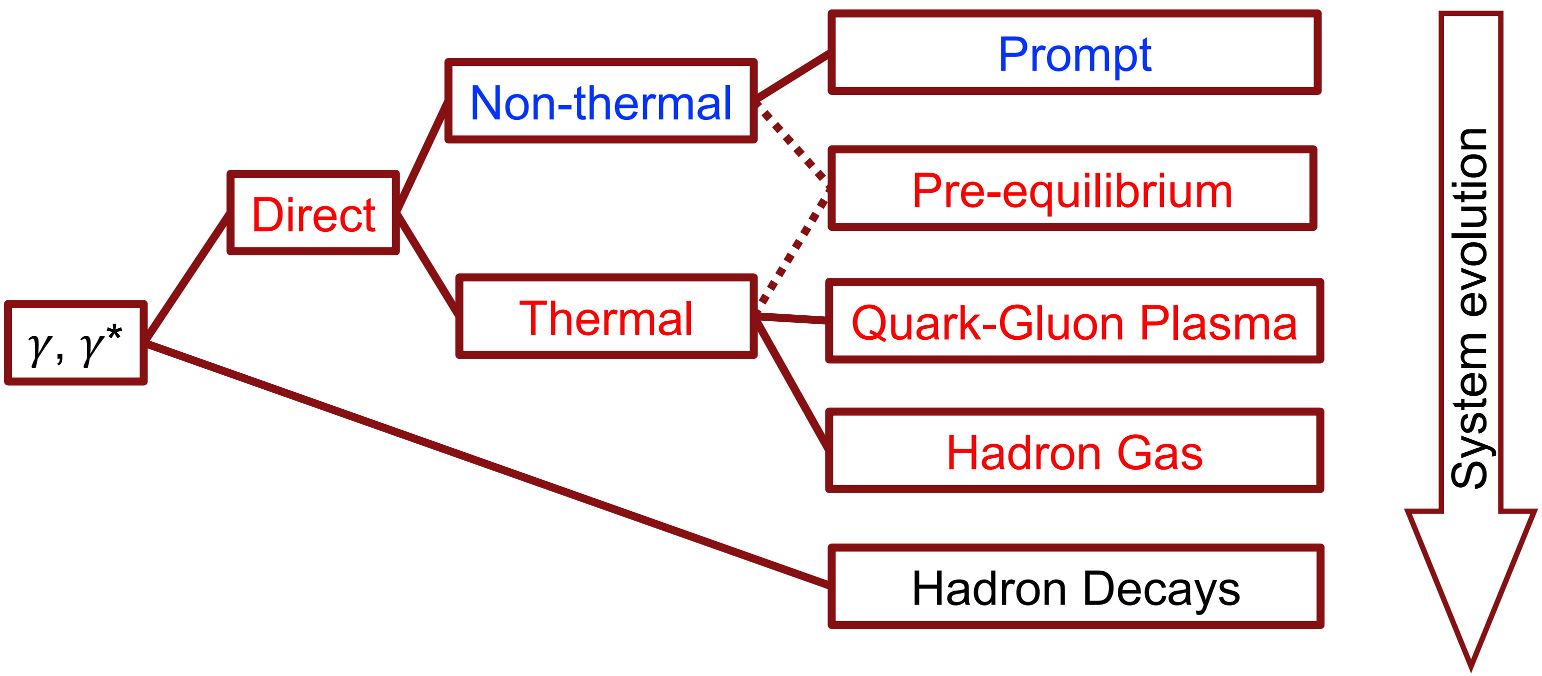
all photons which DO NOT come from hadron decay

Unique probe:

- ✓ Charge neutral
- ✓ Can probe the whole time evolution

Higher p_T -> Earlier produced

- ✓ high p_T : initial hard scattering
- ✓ low p_T : QGP thermal + hadron gas



STAR ☆ e^+e^- pairs from internal conversion

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

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

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

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

✓ pass STAR acceptance
✓ normalize to 0-30 MeV/c^2

Direct photons can be measured by the associated dielectron production.

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

cocktail normalized to 0-30 MeV/c^2

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

cocktail component

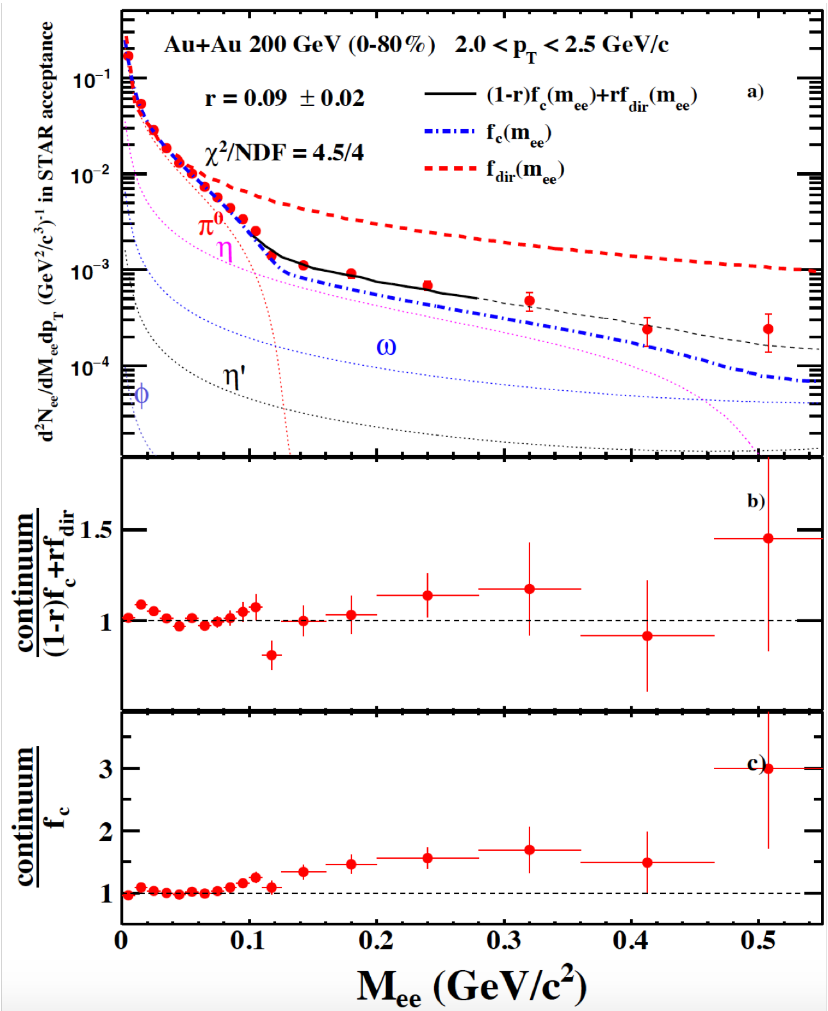
direct virtual photon component

: two-component fit to dielectron continuum.

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

Two-component fitting on dielectron continuum

STAR, PLB, 770 (2017) 451-458



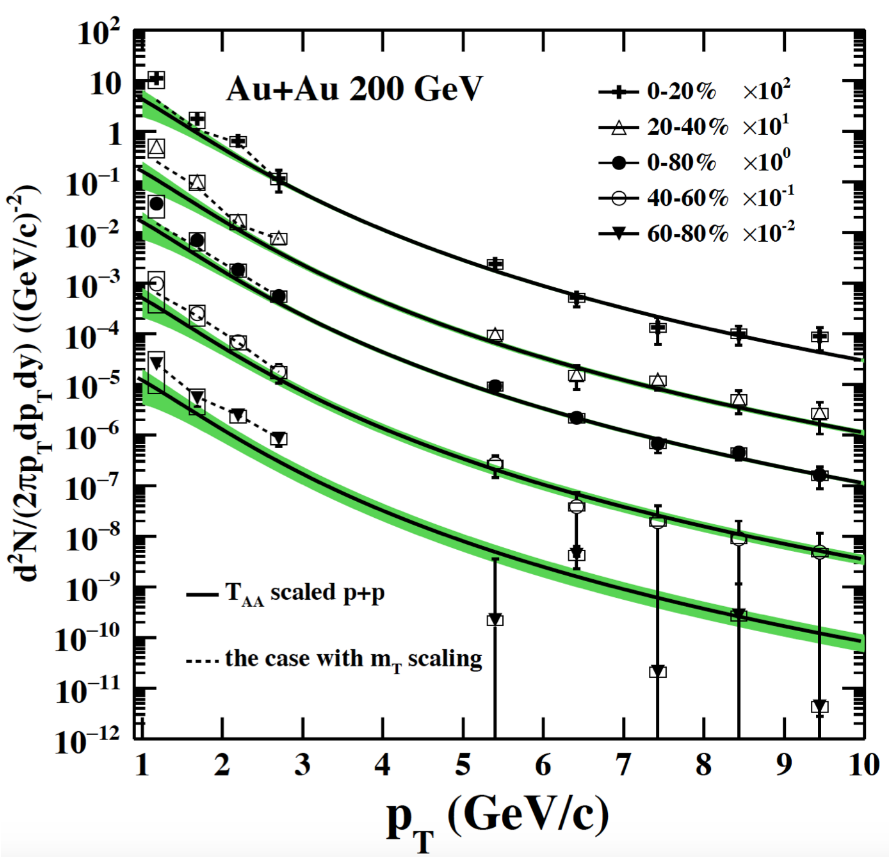
pass STAR acceptance normalize to 0-30 MeV/c^2

cocktail normalized to 0-30 MeV/c^2

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

Direct photon yield

STAR, PLB, 770 (2017) 451-458



$$\frac{2\alpha dN_{\gamma}^{dir}(p_T)}{3\pi M_{ee} dp_T} = rF_{dir}\frac{1}{M_{ee}},$$

$$\frac{d^2N_{\gamma}^{dir}(p_T)}{2\pi p_T dp_T dy} = \frac{3rF_{dir}}{4\alpha p_T dy} = r\frac{d^2N_{\gamma}^{inc}(p_T)}{2\pi p_T dp_T dy}$$

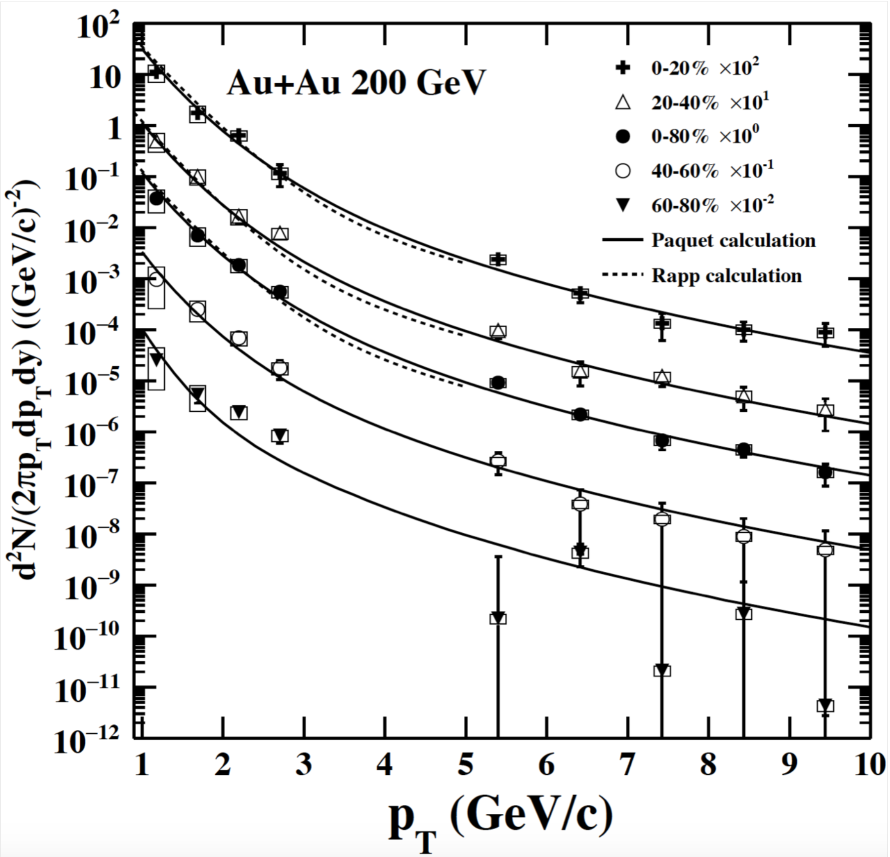
F_{dir}: f_{dir} normalization factor

Thermal photons can be observed

Compared to p+p reference (from PHENIX collaboration)

Comparison to model calculations

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 photon yields**

Summary and outlook

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

Dilepton – rho broadening scenario describes the excesses in LMR

- ✓ **Measurements from RHIC top energy down to 19.6 GeV**
- ✓ **Coherent low p_T dielectron production joins dilepton "club" – may link to EM field**

Direct photons – thermal photons observed in Au+Au collisions

- ✓ **Model calculations simultaneously describe both dielectron and direct photon results**

Current and future opportunities:

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 Run18

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

BES-II in Run 19 and Run 20

- ✓ *Different total baryon densities, scan on "critical" region*

The analyses on EM probes such as dileptons and direct photons will be further studied on these different collision species.