Thermal dielectron measurement in Au+Au collisions with STAR BES-II data

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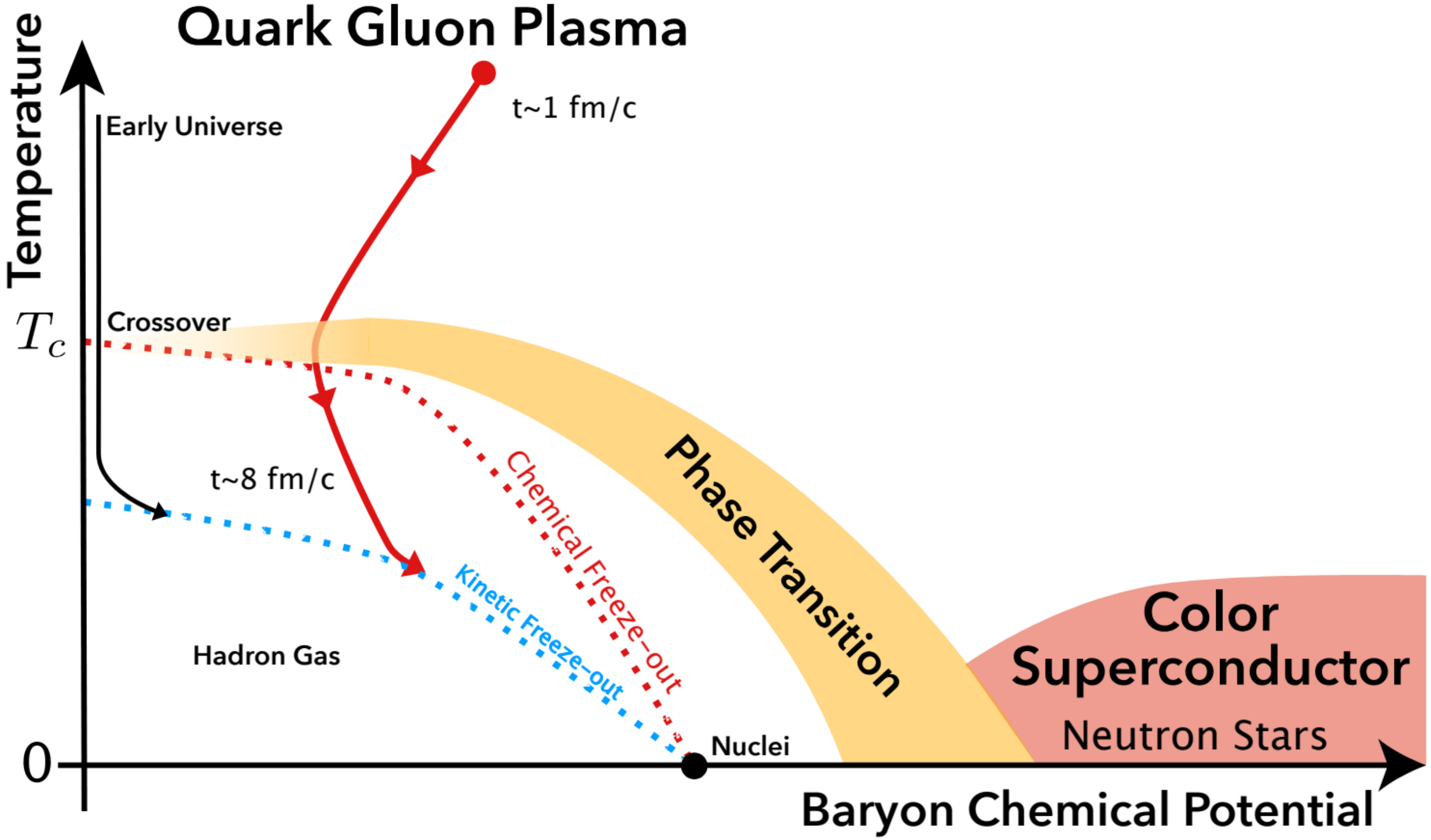
NSFC

QCD phase diagram

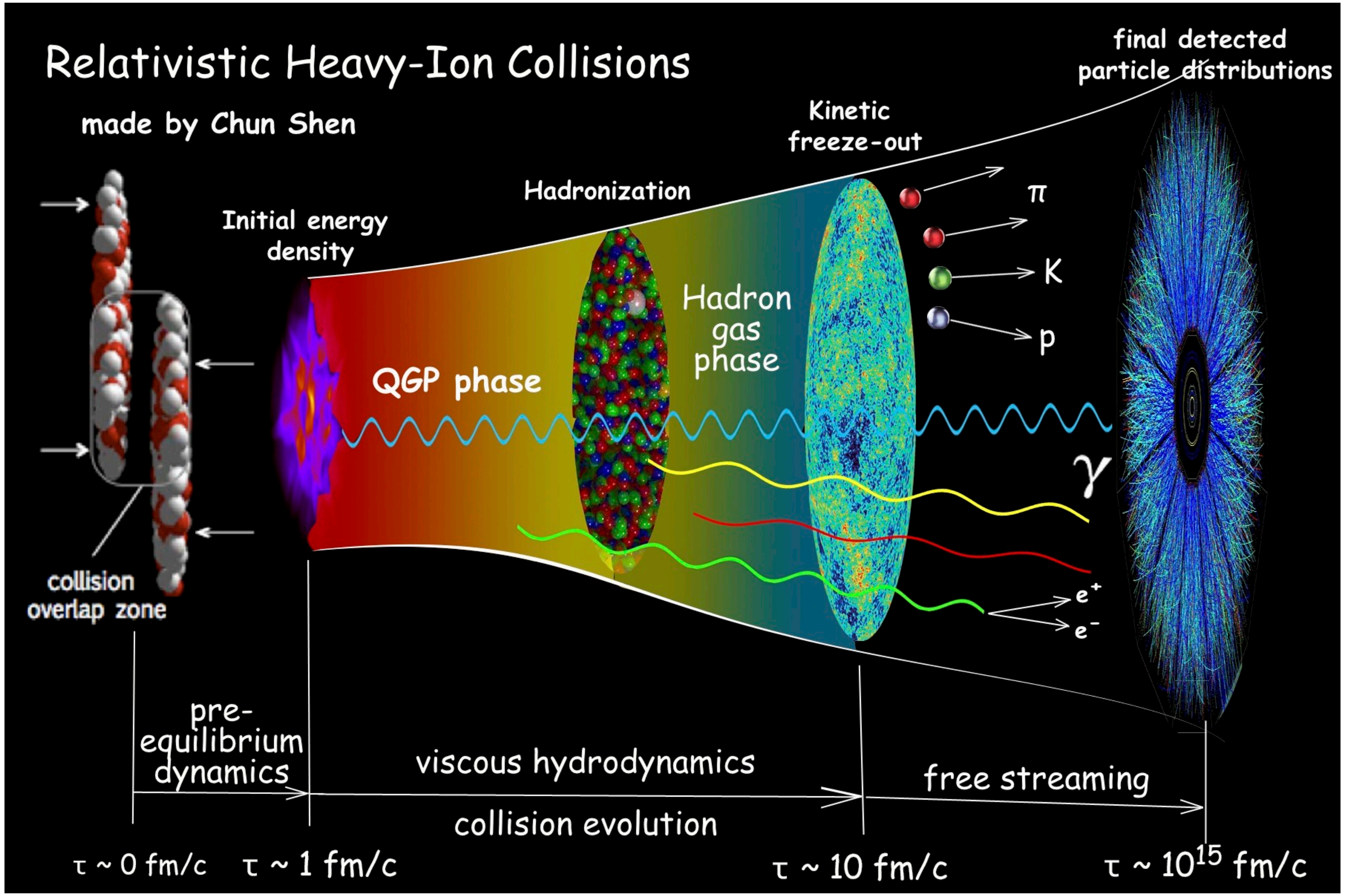


STAR, arXiv: 2402.01998

Deconfined QCD matter produced at extreme high temperatures and/or baryon densities

Study phase structure in the $T - \mu_B$ plane

A "Little Bang" in heavy ion collisions



C.Shen https:// u.osu.edu/vishnu/2014/08/06/sketch-of-relativistic-heavy-ion- collisions

Deconfined QCD matter produced at extreme high temperatures and/or baryon densities

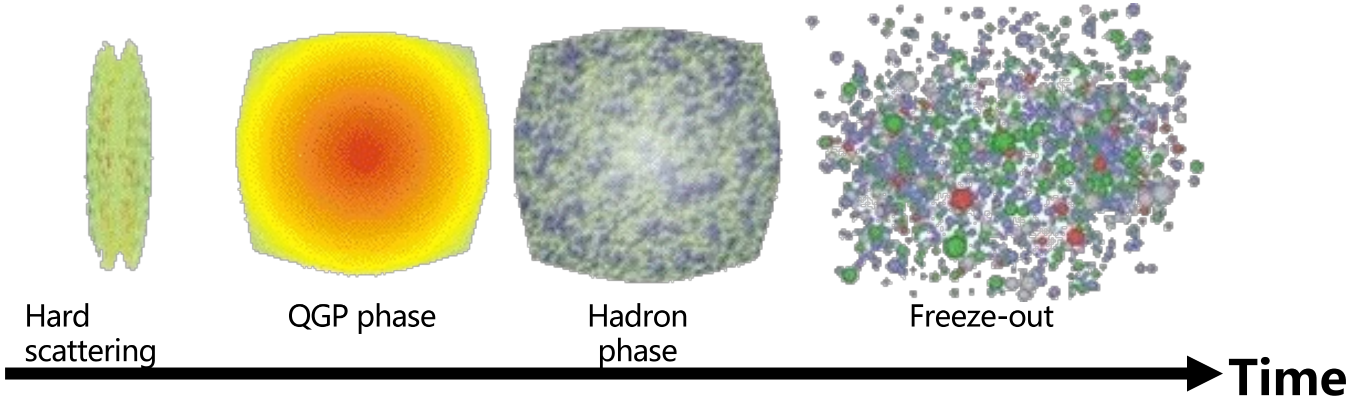
Study phase structure in the $T - \mu_B$ plane

Extract the information from the final detected particles

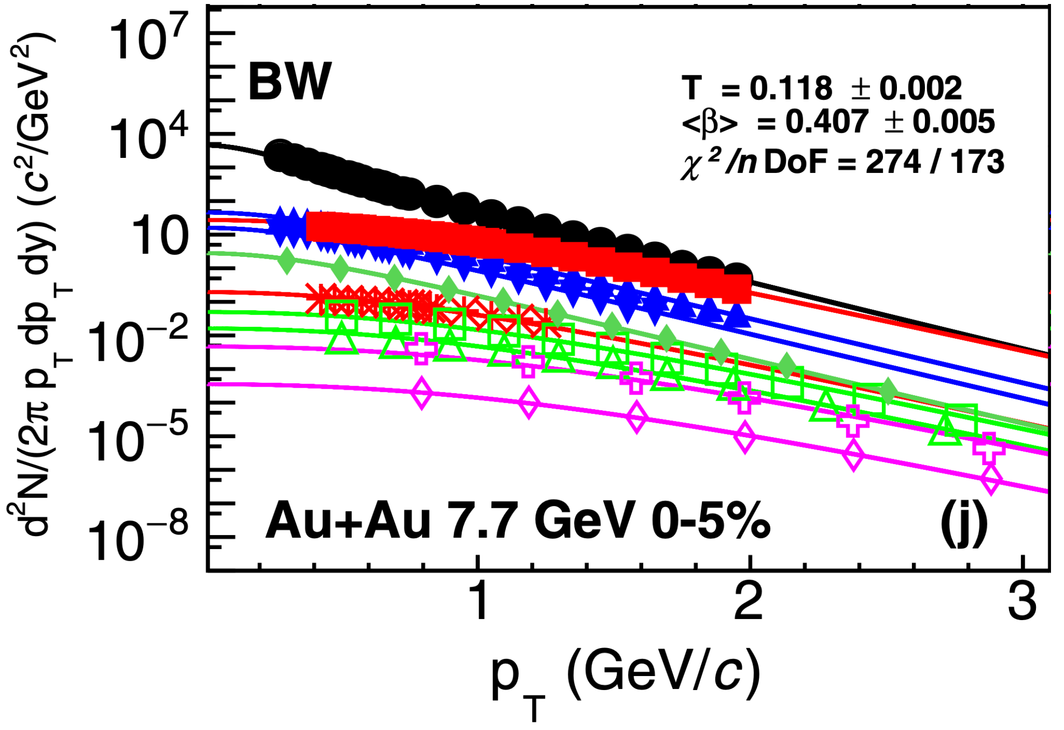
How to measure temperature

Hadrons
yields , p_T spectra

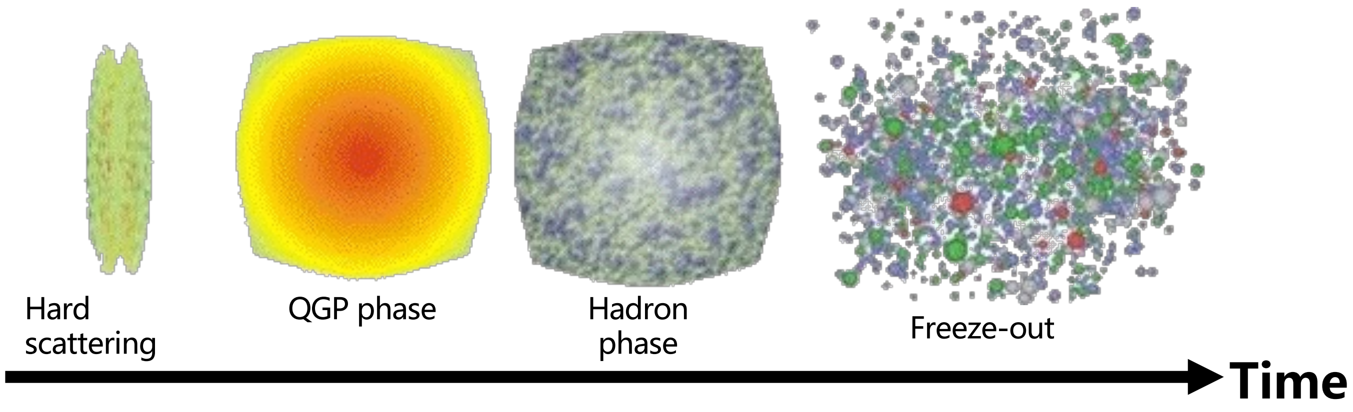
Hadrons:
- ✓ Large yields
- ✓ Infer QGP properties when the hadrons decouple
- ✓ Extract temperatures of chemical and kinetic freeze-out, T_{ch} and T_{kin}



STAR: Phys.Rev.C 96 (2017) 4, 044904



How to measure temperature



Photons

p_T spectra

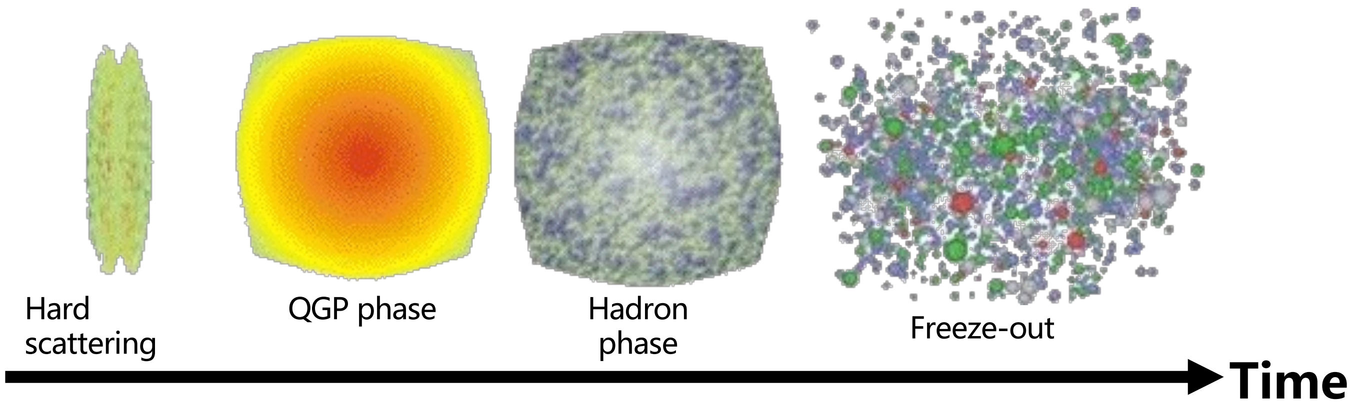
Dileptons

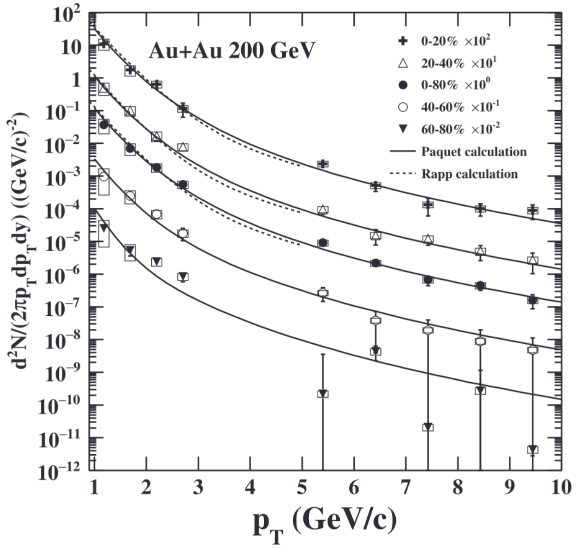
M_{ll} spectra

Electromagnetic Probes:

- ✓ Emitted from early stage to final stage
- ✓ Minimal interaction with medium

How to measure temperature





STAR: Phys.Lett.B 770 (2017), 451-458

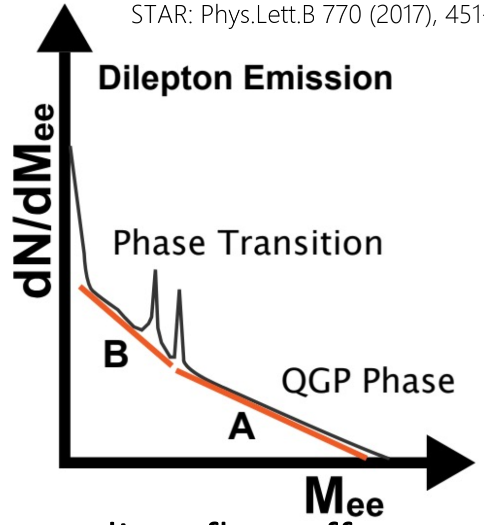
Photons
p_T spectra

Dileptons
M_{ll} spectra

Electromagnetic Probes:
- ✓ Emitted from early stage to final stage
- ✓ Minimal interaction with medium

Photons:
- ✓ Extract T_{eff} from p_T spectra
- ✓ $T_{eff} \rightarrow T_{QGP}$: medium effect

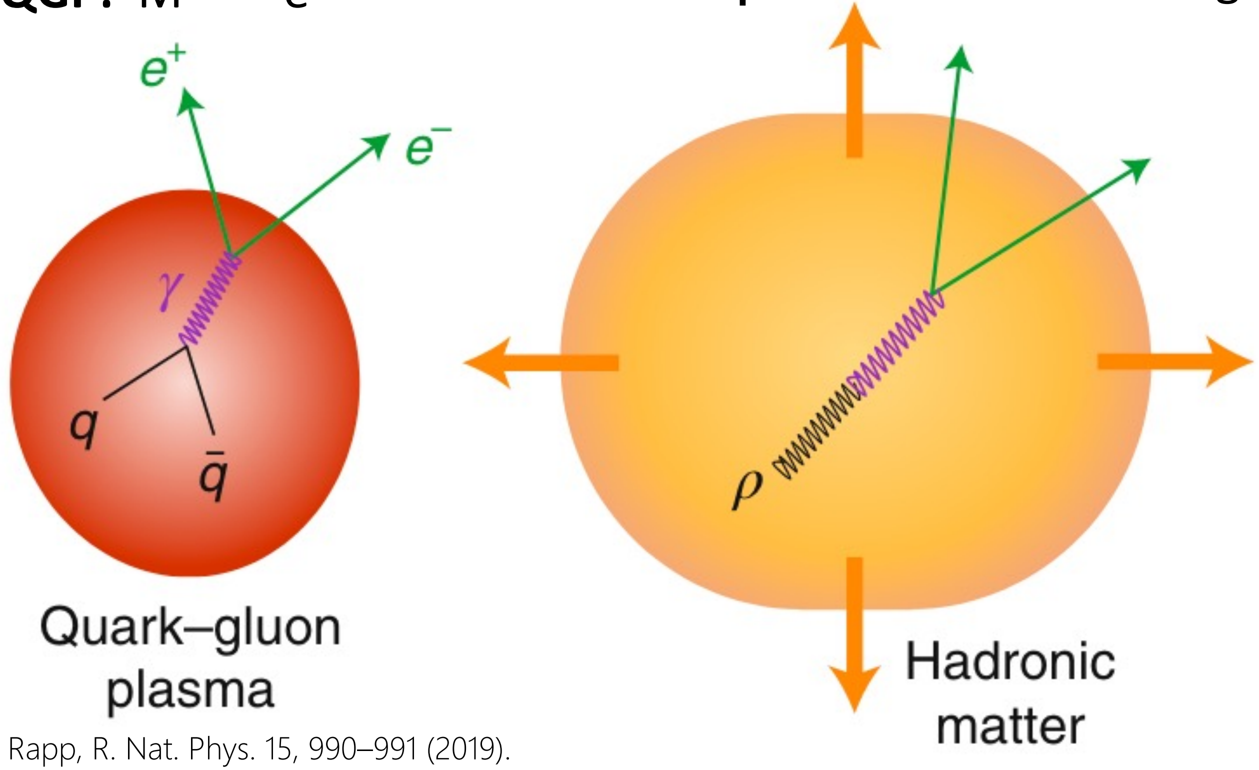
Dileptons:
- ✓ Temperature measurement without distortion by medium flow effects
- ✓ Only observable to directly access in-medium spectral function



Thermal dileptons

QGP: $M^{3/2} * e^{-M/T}$

In-medium ρ: Relativistic Breit-Wigner * $e^{-M/T}$



Rapp, R. Nat. Phys. 15, 990–991 (2019).

inclusive dileptons

Interested signals

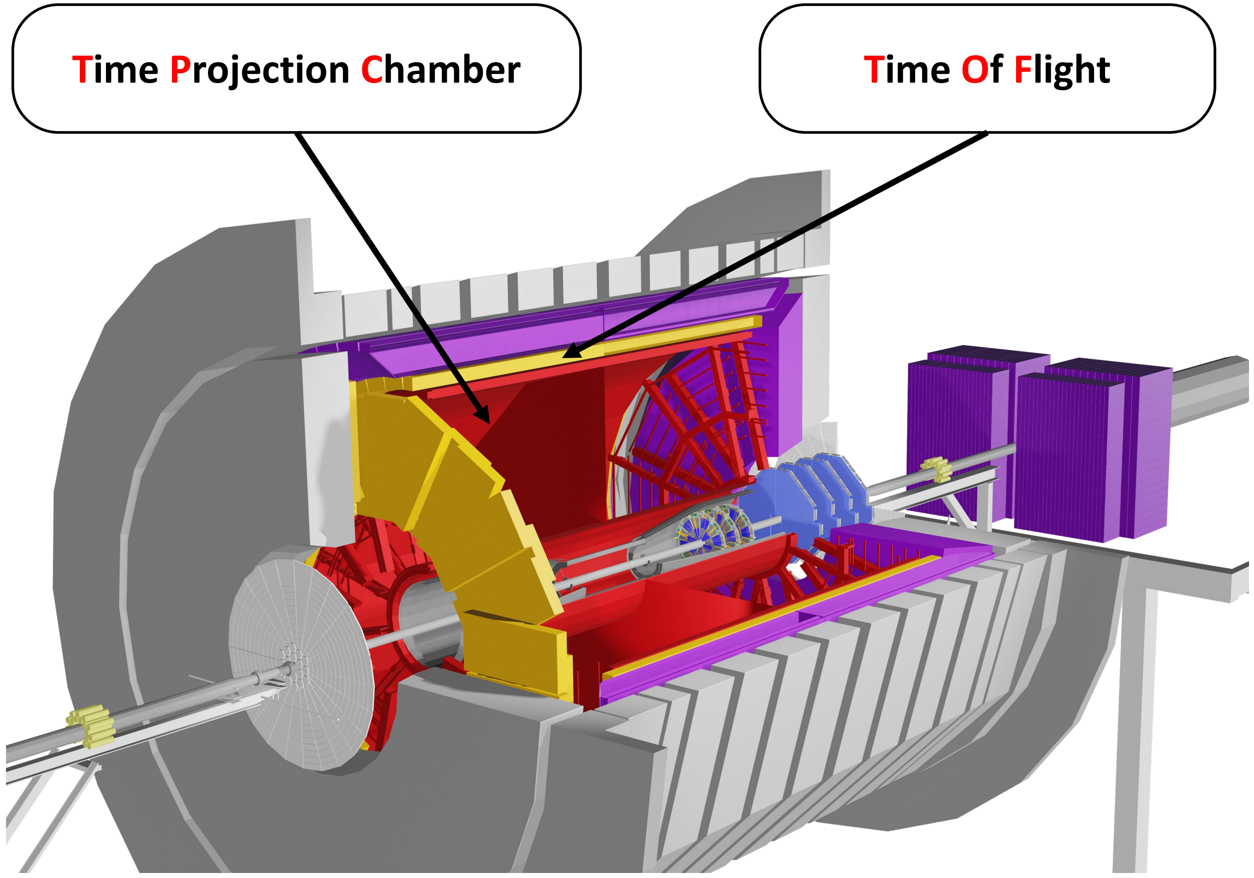
- QGP radiation
- In-medium ρ

Physical backgrounds (hadronic cocktails)

- π^0, η, η' -> γe^+e^-
- ω -> $\pi^0 e^+e^-$
- ϕ -> ηe^+e^-
- ω, ϕ, J/ψ -> e^+e^-
- $c\bar{c}$ -> e^+e^-X
- Drell-Yan

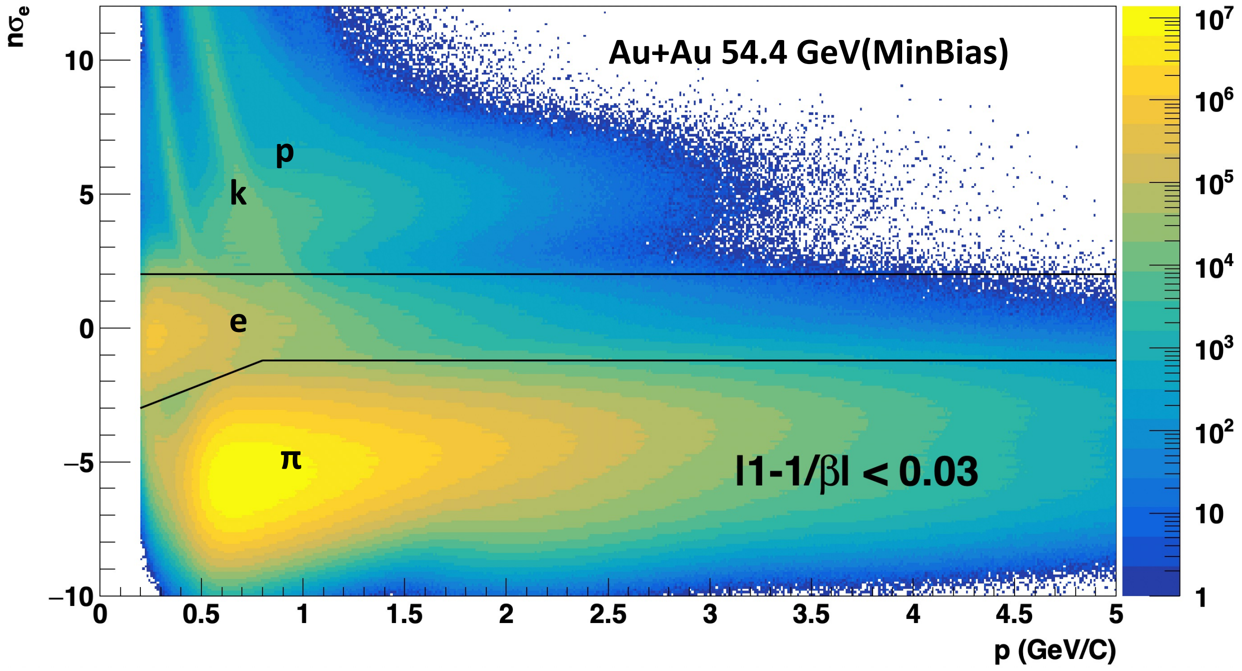
Invariant mass spectra of thermal dileptons can reveal temperature of the hot medium at both **QGP phase** and **hadronic phase**

STAR experiment and eID



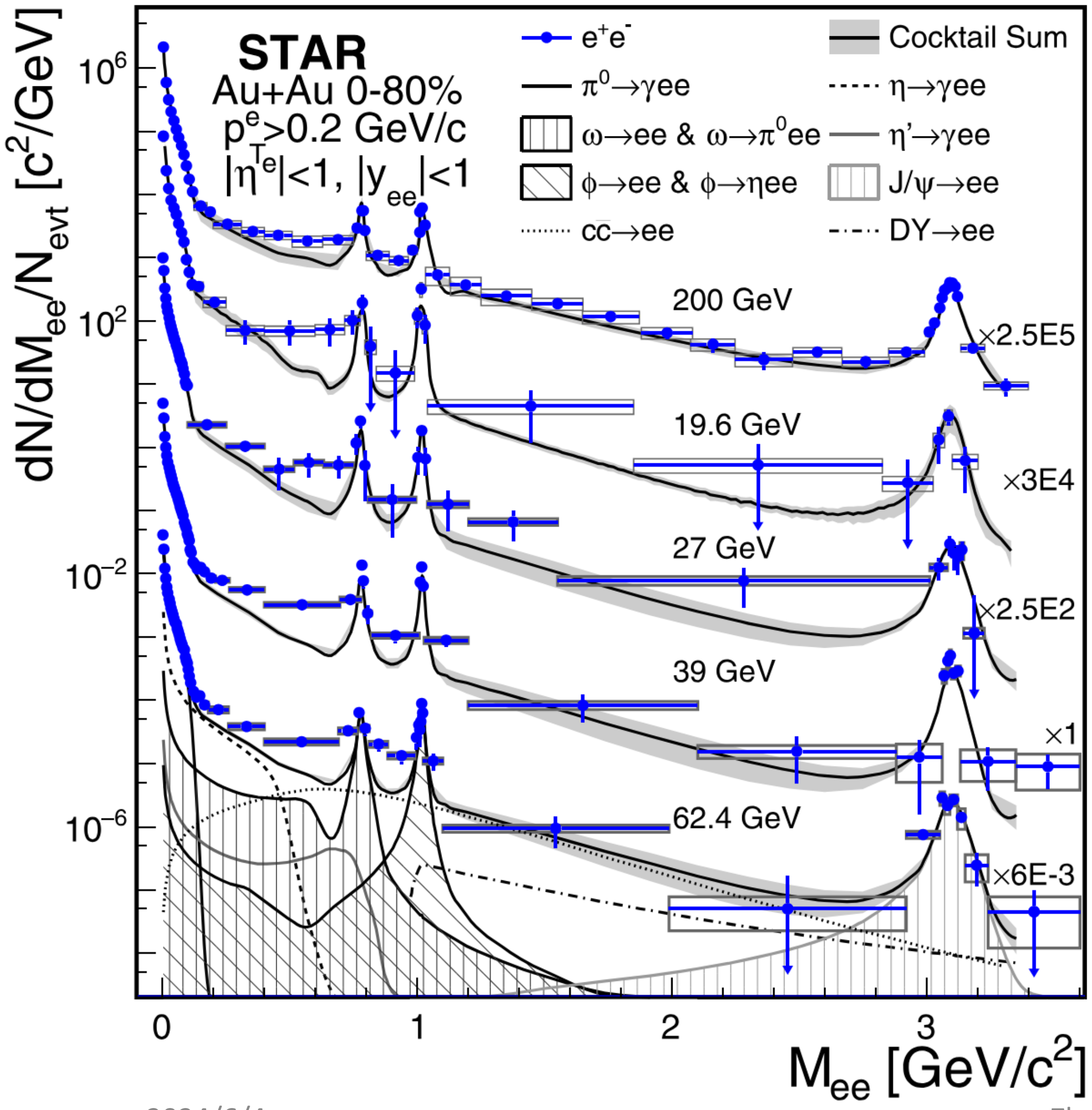
Time Projection Chamber + Time of Flight detectors

- ✓ Charge particle tracking and momentum measurement
- ✓ Electron identification by dE/dx and velocity
- ✓ High purity electron samples



STAR BES-I Dielectron measurements

STAR: Phys.Rev.C 107 (2023) 6, L061901



$\sqrt{s_{\mathrm{NN}}} = 200$ GeV:

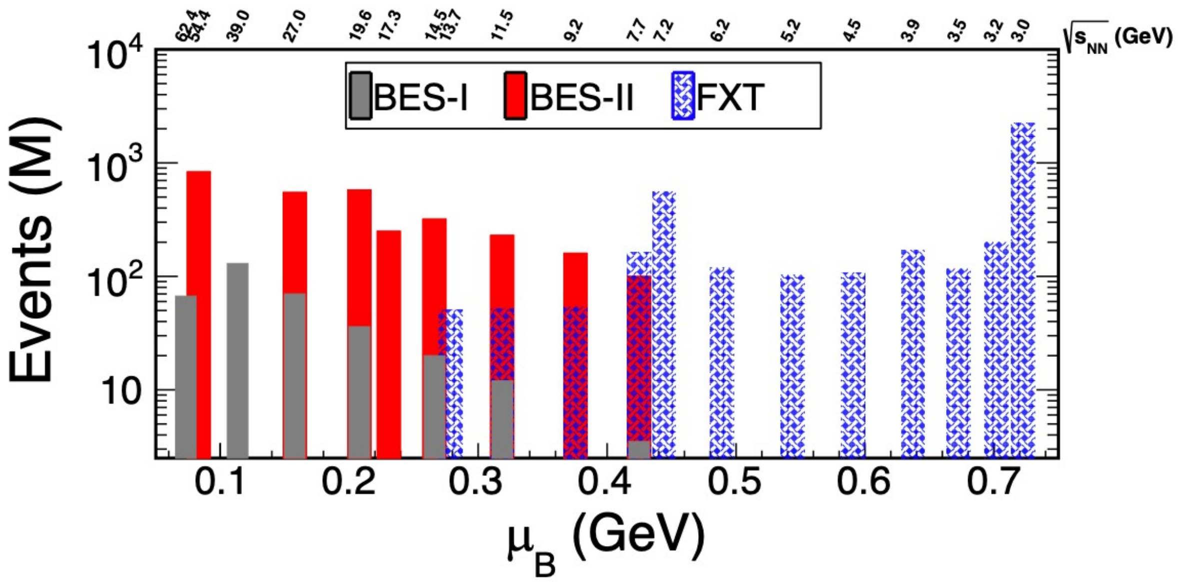
- High statistics
- Open charm dominate the intermediate mass region

$\sqrt{s_{\mathrm{NN}}} = 19.6 - 62.4$ GeV :

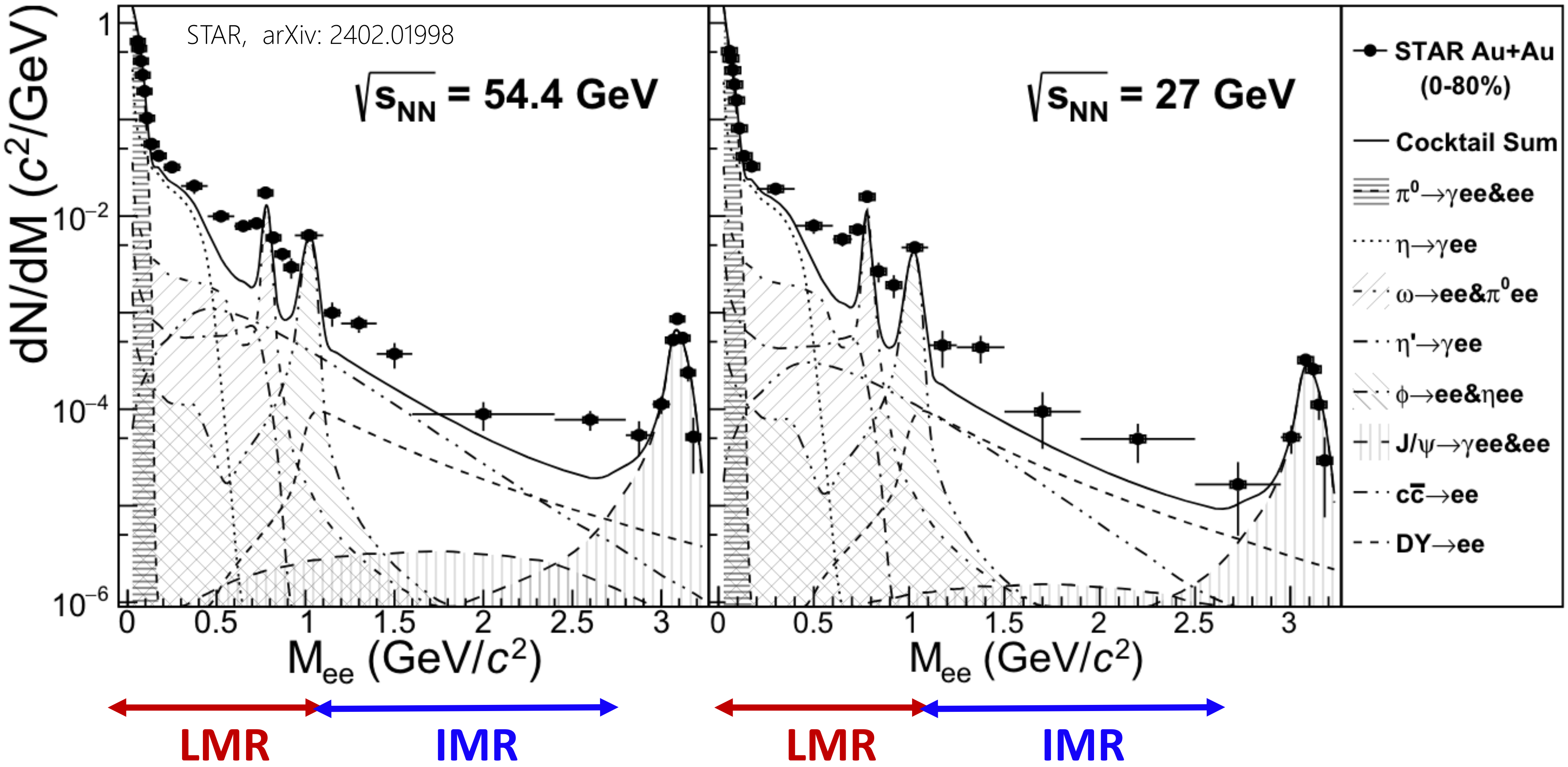
- Statistically limited

BES–II :

✓ Statistics ~ 10 times larger than that in the BES-I datasets



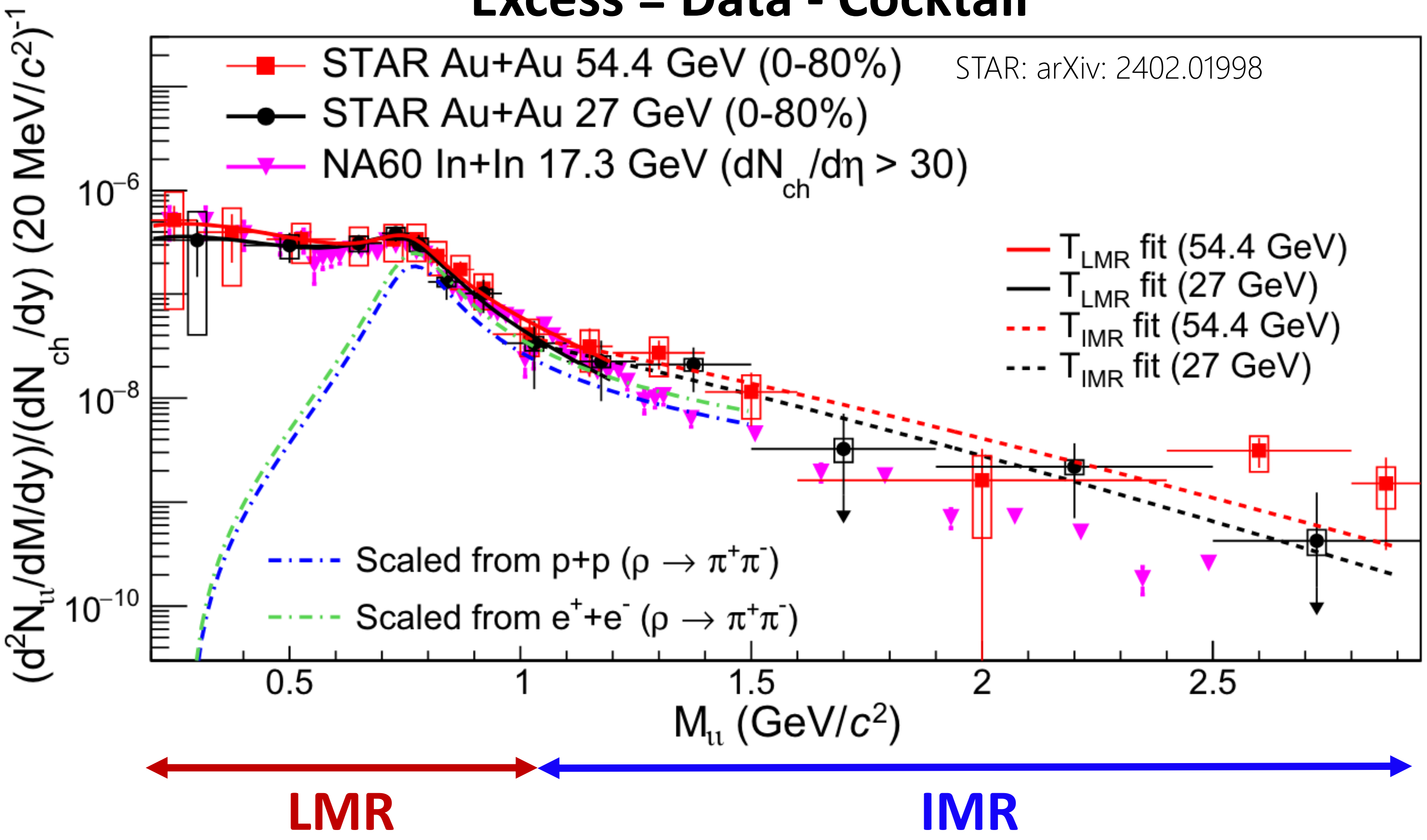
Dielectron spectra



Clear enhancement compared to hadronic cocktail in both low mass region (LMR) and intermediate mass region (IMR)

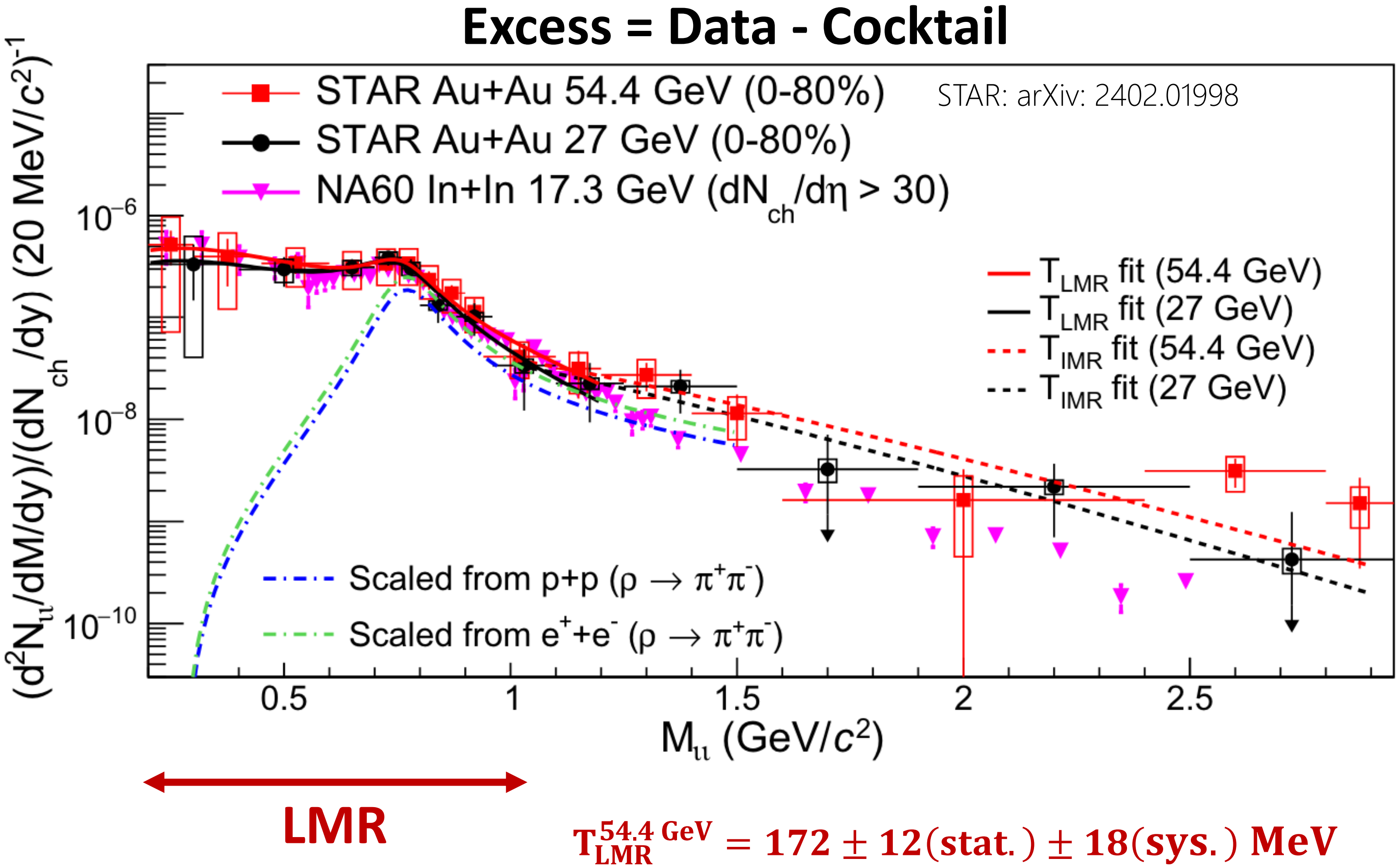
Excess yield

Excess = Data - Cocktail



Excess dilepton spectra in LMR at $\sqrt{s_{NN}}$ = 27 and 54.4 GeV Au+Au collisions and at $\sqrt{s_{NN}}$ = 17.3 GeV In+In collisions are similar

Temperature extraction from LMR



Low mass region:

$(a * BW + b * M^{3/2}) * e^{-M/T}$

- ✓ Similar T_{LMR} for STAR and NA60 measurements
- ✓ T_{LMR} around the pseudo critical temperature T_{pc} (156 MeV)

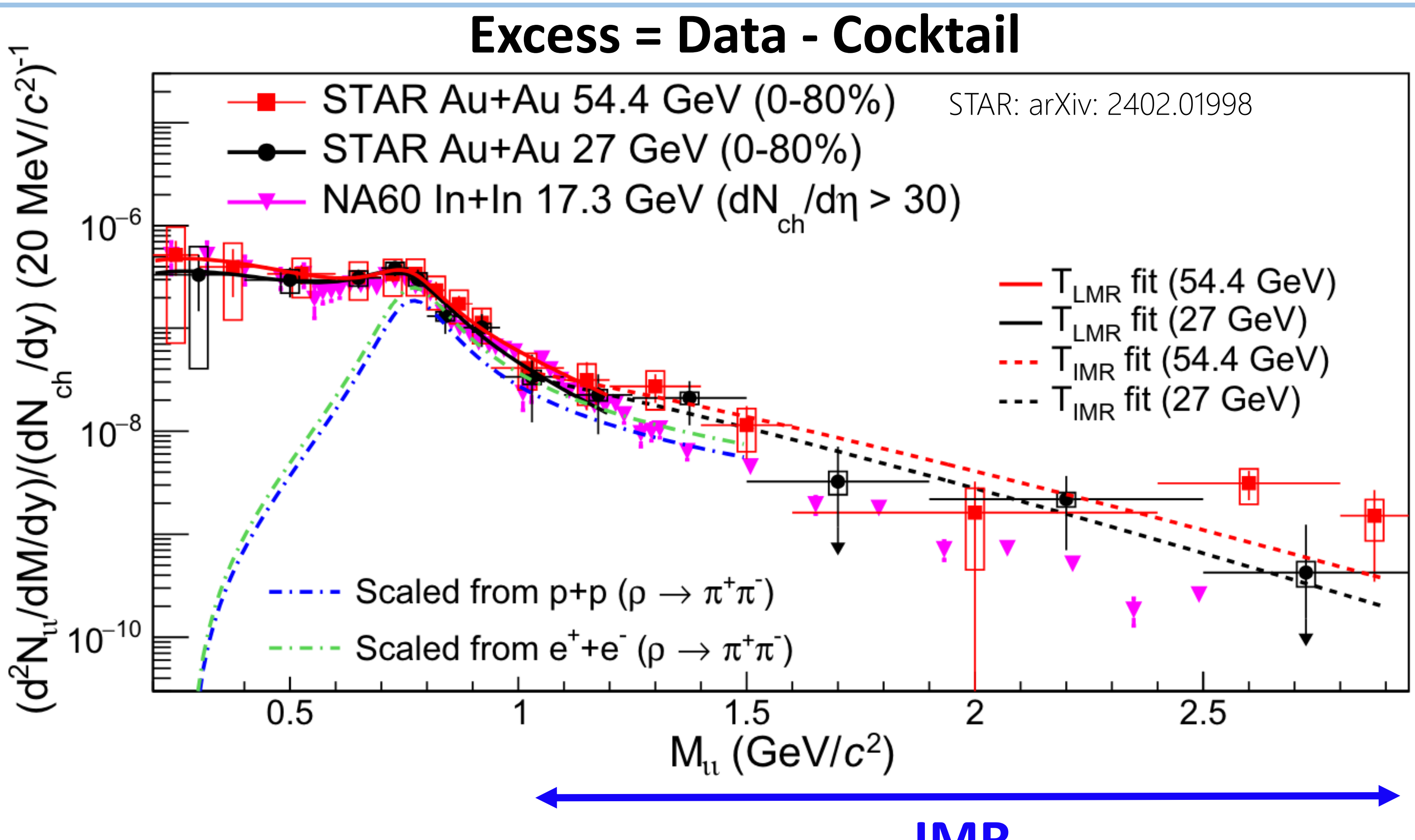
$$T_{LMR}^{54.4\ GeV} = 172 \pm 12(stat.) \pm 18(sys.)\ MeV$$

$$T_{LMR}^{27\ GeV} = 167 \pm 21(stat.) \pm 18(sys.)\ MeV$$

$$T_{LMR}^{17.3\ GeV} = 165 \pm 4\ MeV$$

T_{PC}: HotQCD, Phys.Lett.B 795 (2019) 15-21
NA60: EPJC (2009)59 607-623

Temperature extraction from IMR



$$T_{IMR}^{54.4\ GeV} = 303 \pm 59(stat.) \pm 28(sys.)\ MeV$$

$$T_{IMR}^{27\ GeV} = 280 \pm 64(stat.) \pm 10(sys.)\ MeV$$

T_{PC}: HotQCD, Phys.Lett.B 795 (2019) 15-21; NA60: EPJC (2009)59 607-623

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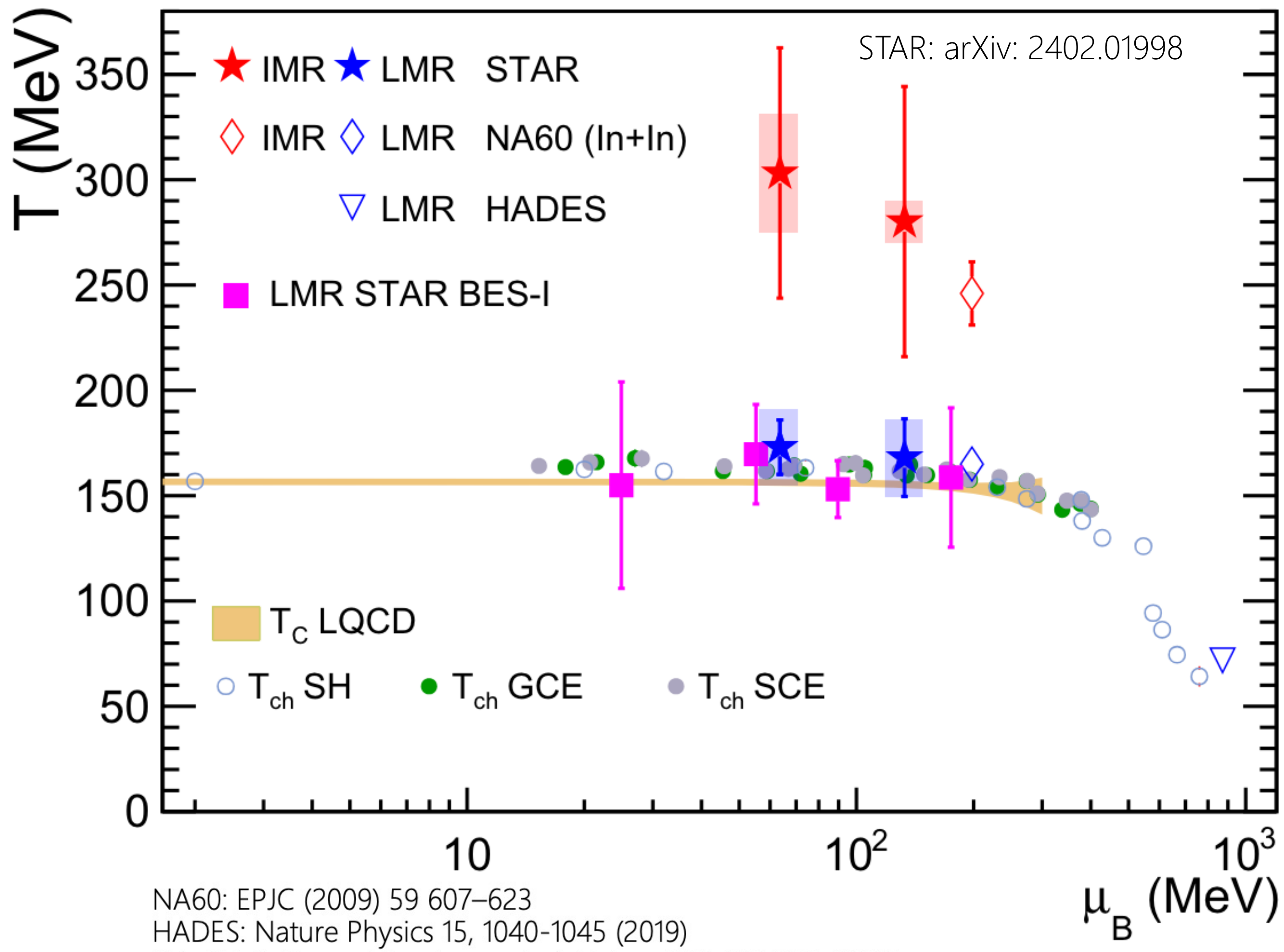
Intermediate mass region：

$M^{3/2} * e^{-M/T}$

- ✓ QGP thermal radiation is predicted to be the dominant source in the IMR
- ✓ T_{IMR} is higher than the pseudo critical temperature T_{pc} (156 MeV) supporting that the emission is predominantly from deconfined partonic phase

Temperature v.s. μ_B



NA60: EPJC (2009) 59 607–623
HADES: Nature Physics 15, 1040-1045 (2019)
Tch SH: P. Braun-Munzinger et al. Nature 561, 321-330 (2018)
Tch GCE/SCE: STAR PRC 96, 044904 (2017)
T_{pc}: HotQCD, Phys.Lett.B 795 (2019) 15-21

Thermal dielectrons in LMR:

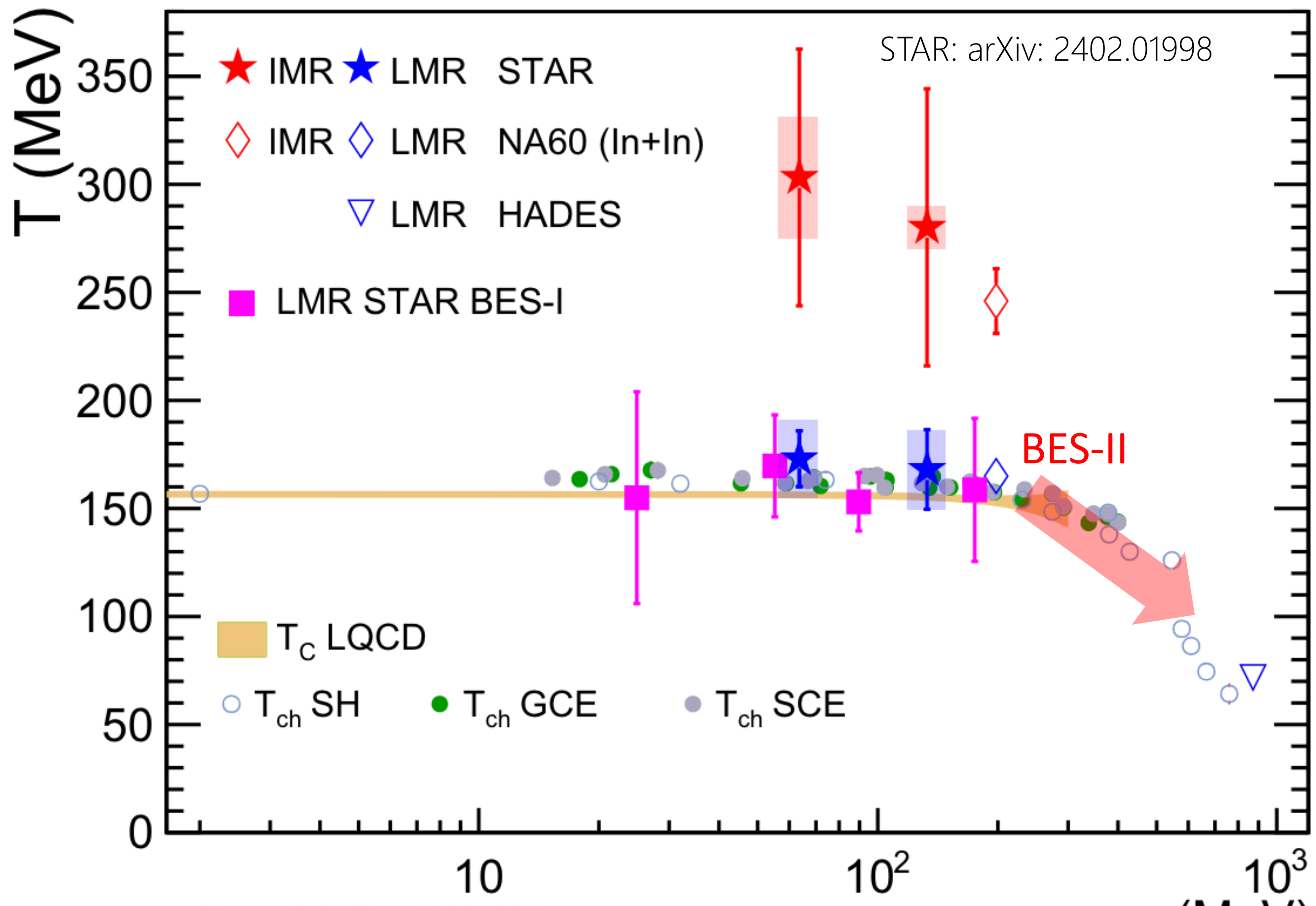
- ✓ T_{LMR} is close to the T_{pc} and T_{ch}
- ✓ Emitted form the hadronic phase, dominantly around the phase transition

Thermal dielectrons in IMR:

- ✓ T_{IMR} is higher than T_{LMR} ,T_{pc} and T_{ch}
- ✓ Emitted from the partonic phase

T_{ch} : Chemical freeze-out temperature
T_{pc} : Pseudo critical temperature

Temperature v.s. μ_B



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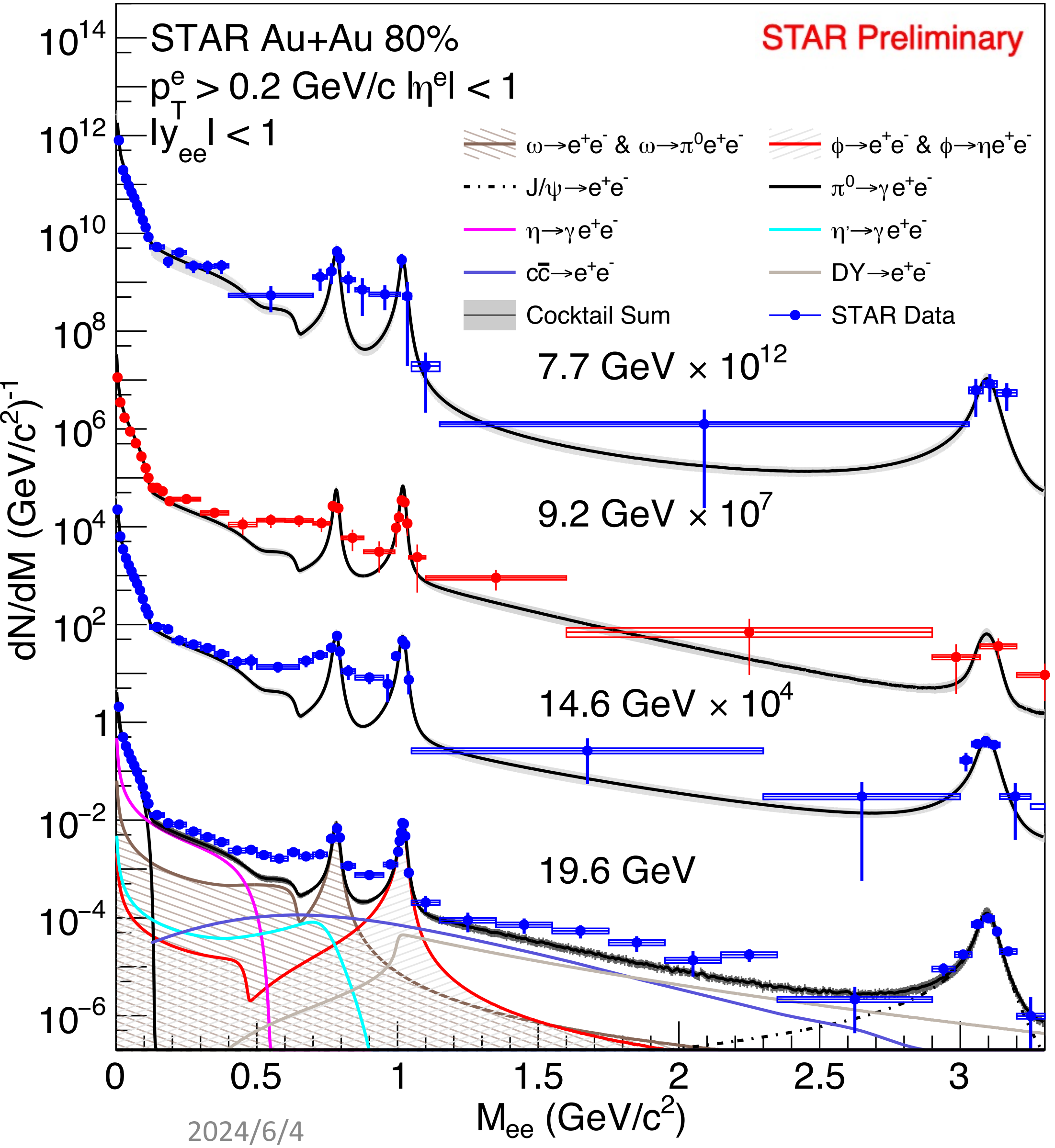
- ✓ Emitted from the partonic phase

T_{ch} : Chemical freeze-out temperature
T_{pc} : Pseudo critical temperature

BES-II:

- ✓ Probing the thermal dilepton in the high baryon density region

Dielectron spectra for $\sqrt{s_{NN}} \leq 19.6$ GeV

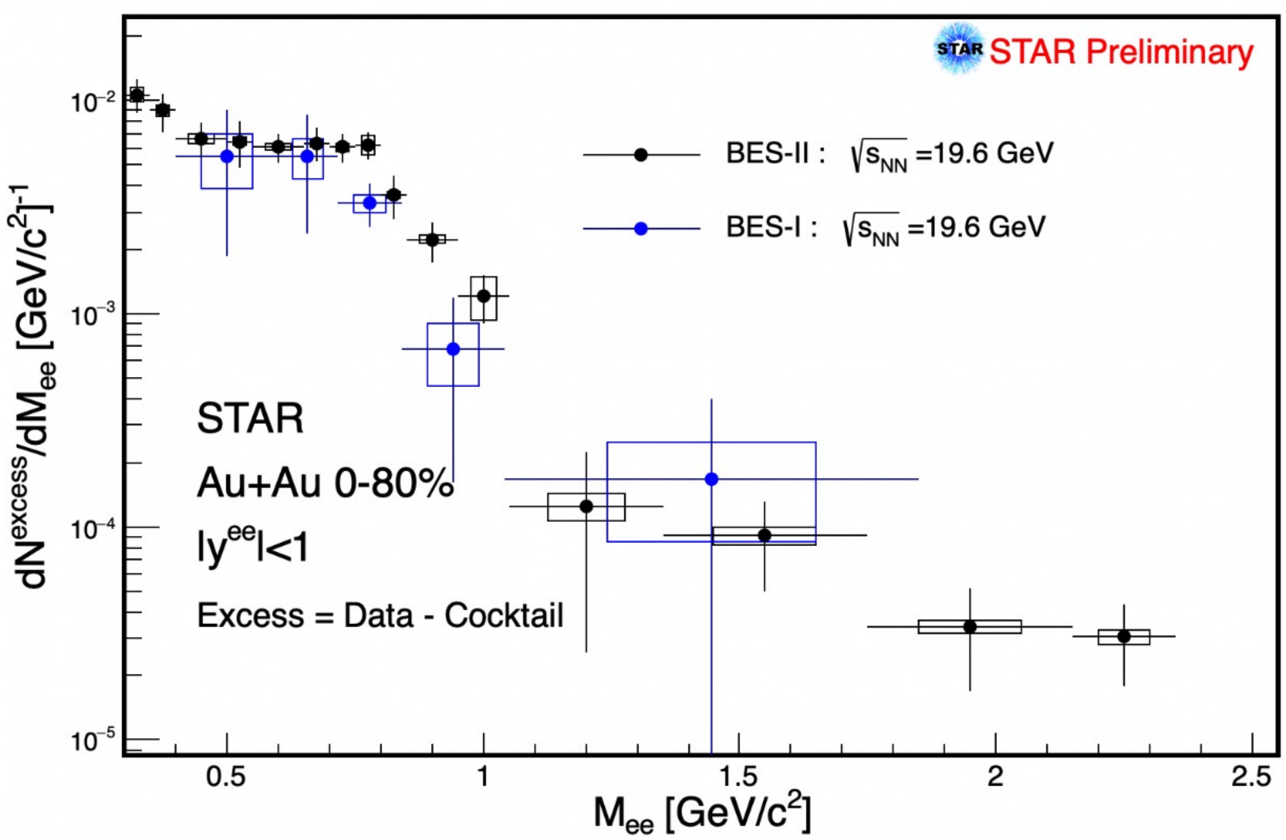


BES-II collision mode at $\sqrt{s_{NN}} = 7.7 - 19.6$ GeV

- ✓ First dielectron measurements under $\sqrt{s_{NN}} =$ 19.6 GeV at RHIC
- ✓ New 9.2 GeV dielectron spectra were obtained
- ✓ Excess observed in low mass region

BES-I V.S. BES-II

Excess = Data - Cocktail

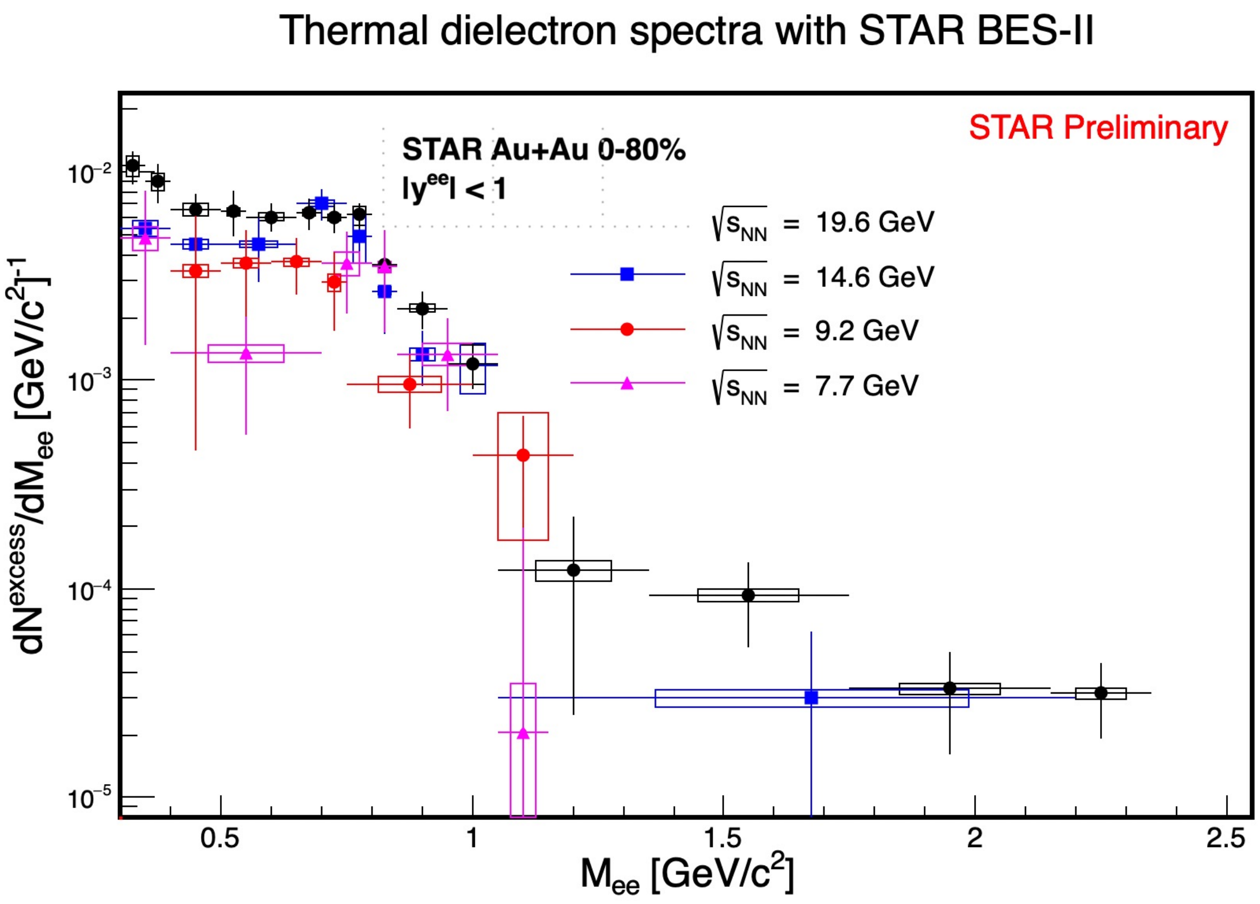


Excess yield invariant mass spectra at $\sqrt{s_{NN}}$ = 19.6 GeV

- ✓ BESI and BES-II results are consistent
- ✓ Much better statistical and systematic uncertainties at BES-II than BES-I
  - ✓ Total error reduced by a factor of ~4
  - ✓ Better precision for extended analysis

BES-II @ 7.7 – 19.6 GeV

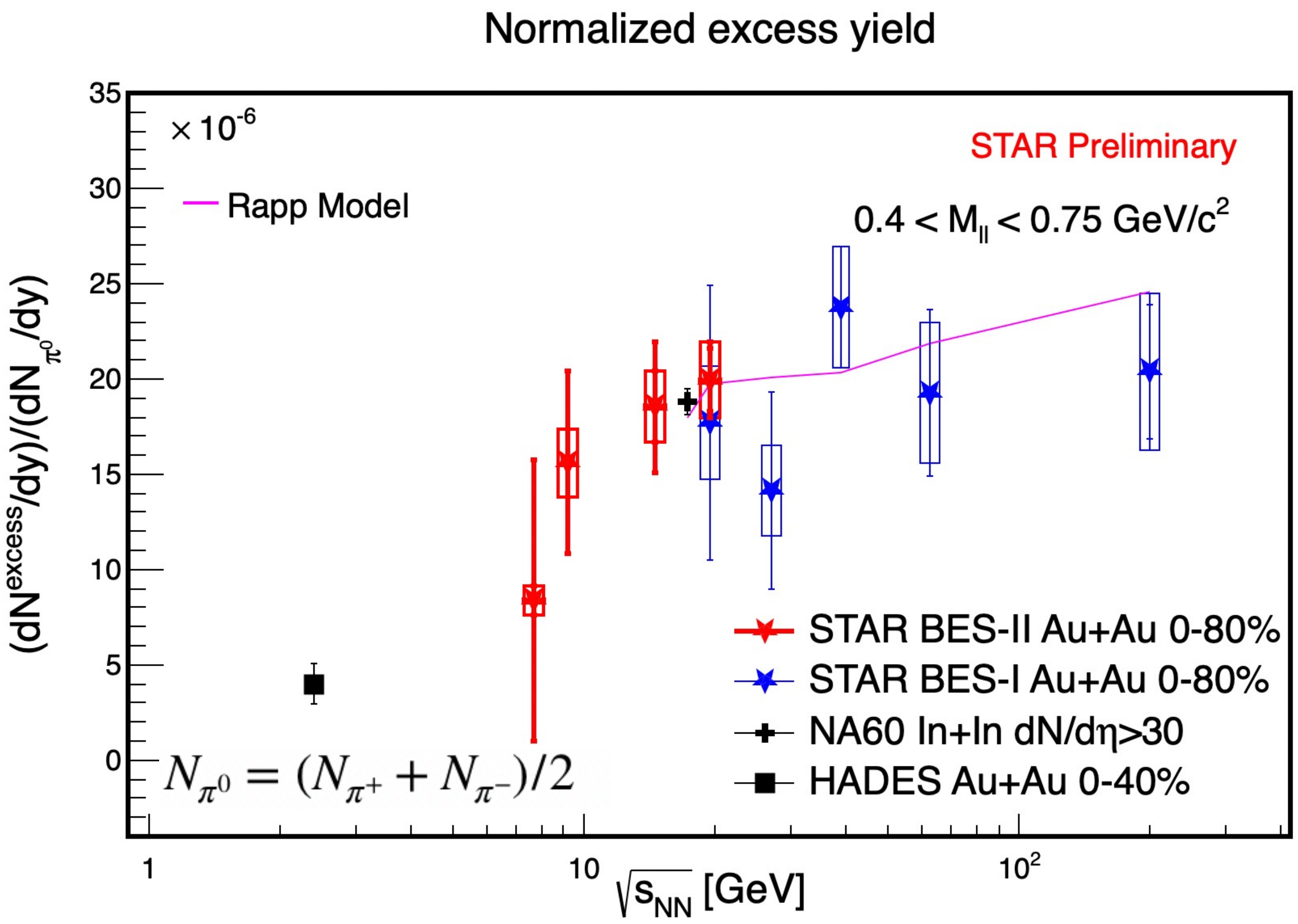
Excess = Data - Cocktail



Mass spectra of excess dielectron yields at different $\sqrt{s_{NN}}$ = 7.7 - 19.6

- ✓ Different environment for medium interactions
  - ✓ Baryon chemical potential
  - ✓ Temperature

BES-II @ 7.7 – 19.6 GeV



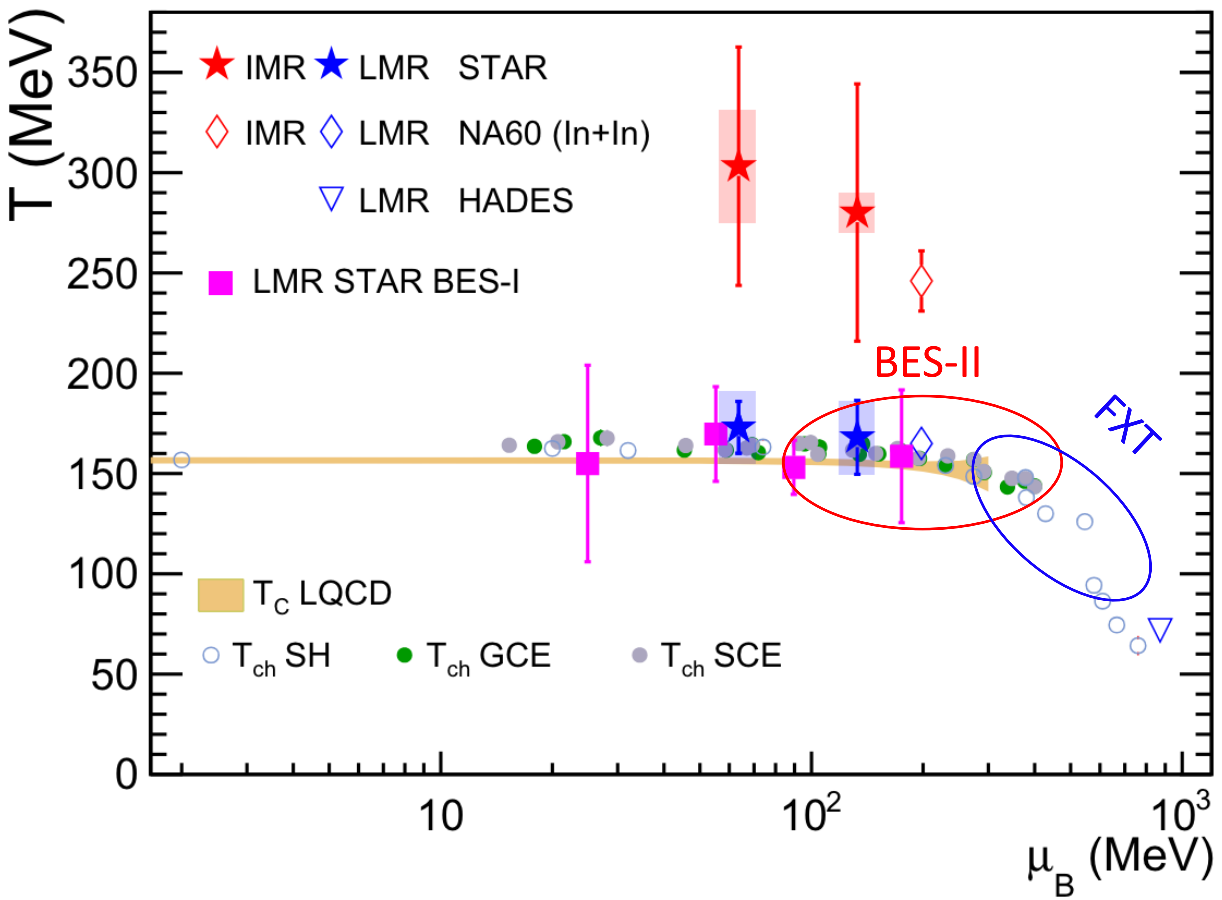
Mass spectrum of excess dielectron at different $\sqrt{s_{NN}}$

- ✓ Different environment for medium interactions
  - ✓ Baryon chemical potential
  - ✓ Temperature
- ✓ Integrated excess yield
  - ✓ Normalized by π^0 yield
  - ✓ New result @ 9.2 GeV
  - ✓ Hint of decreasing trend below 19.6 GeV

R. Rapp, Phys. Rev. C 63, 054907 (2001)
H. van Hees and R. Rapp, Phys. Rev. Lett. 97, 102301 (2006)

Dielectron measurements with STAR BES-II and FXT program

STAR, arXiv: 2402.01998



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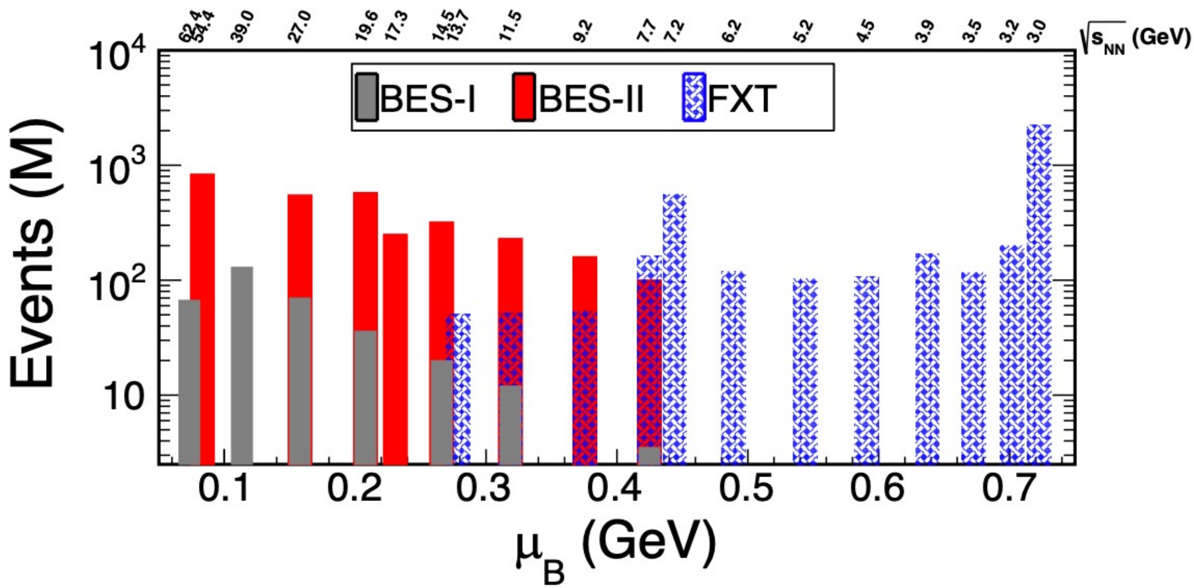
- ✓ BES-II and FXT data will cover the large gap between the STAR and HADES data
- ✓ The normalized integrated excess yields in mass window $0.4<M_{ee}<0.75$ GeV/c^2 were obtained
- ✓ Working on T extraction with BES-II data



Summary

Temperature @ 27 & 54.4 GeV:

- ✓ T_{LMR}: Close to T_{pc} and T_{ch}, provide a new insight to study the phase transition temperature
- ✓ T_{IMR}: Higher than T_{pc} and T_{ch}, first QGP temperature at RHIC

Thermal dielectron yields with BES-II:

- ✓ High precision measurement compared to BES-I measurements
- ✓ New thermal dielectron measurements at $\sqrt{s_{NN}}$ = 9.2 GeV presented
- ✓ Excess yield spectra for different T and μ_B

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Thanks for your attention!