Measuring QGP temperature with thermal dielectrons at STAR

Zhen Wang (for the STAR collaboration)

Shandong University

7th International Conference on Chirality, Vorticity and Magnetic Field in Heavy Ion Collisions

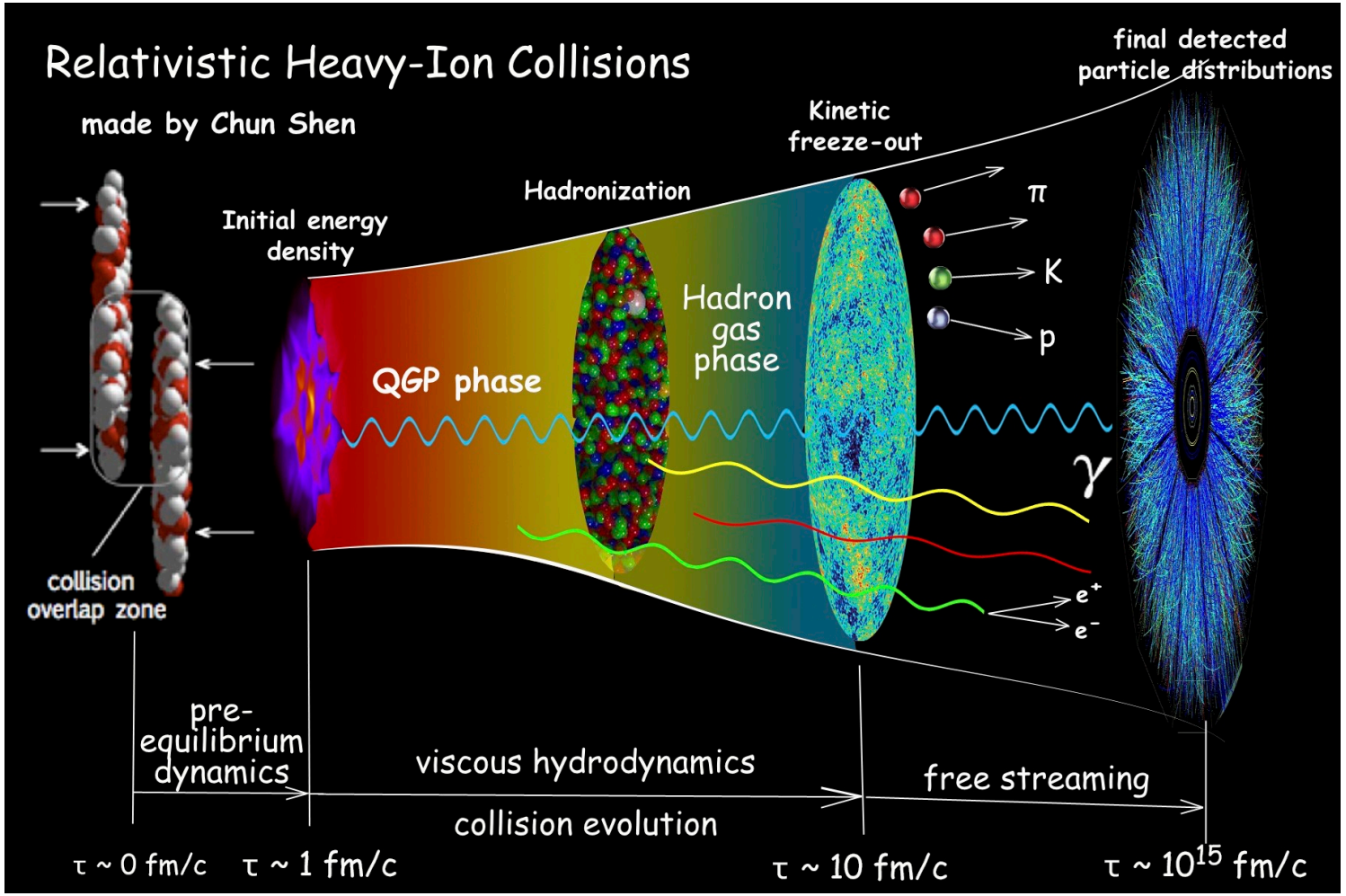
In part supported by U.S. DEPARTMENT OF ENERGY | Office of Science

SHANDONG UNIVERSITY

STAR

NSFC

A “Little Bang” in Heavy Ion collision



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

In laboratory : heavy ion collisions

Temperature, as one of key properties of medium, still poorly known

How to measure the temperature

Hadrons
yield , p_T spectra

Statistical thermal models

Hydrodynamics-inspired models

Chemical freeze-out, T_{ch}

Kinetic freeze-out, T_{kin}

How to measure the temperature

Hadrons
yield , p_T spectra

Statistical thermal models

Hydrodynamics-inspired models

Chemical freeze-out, T_{ch}

Kinetic freeze-out, T_{kin}

Photons
p_T spectra

Dileptons
M_{ll} spectra

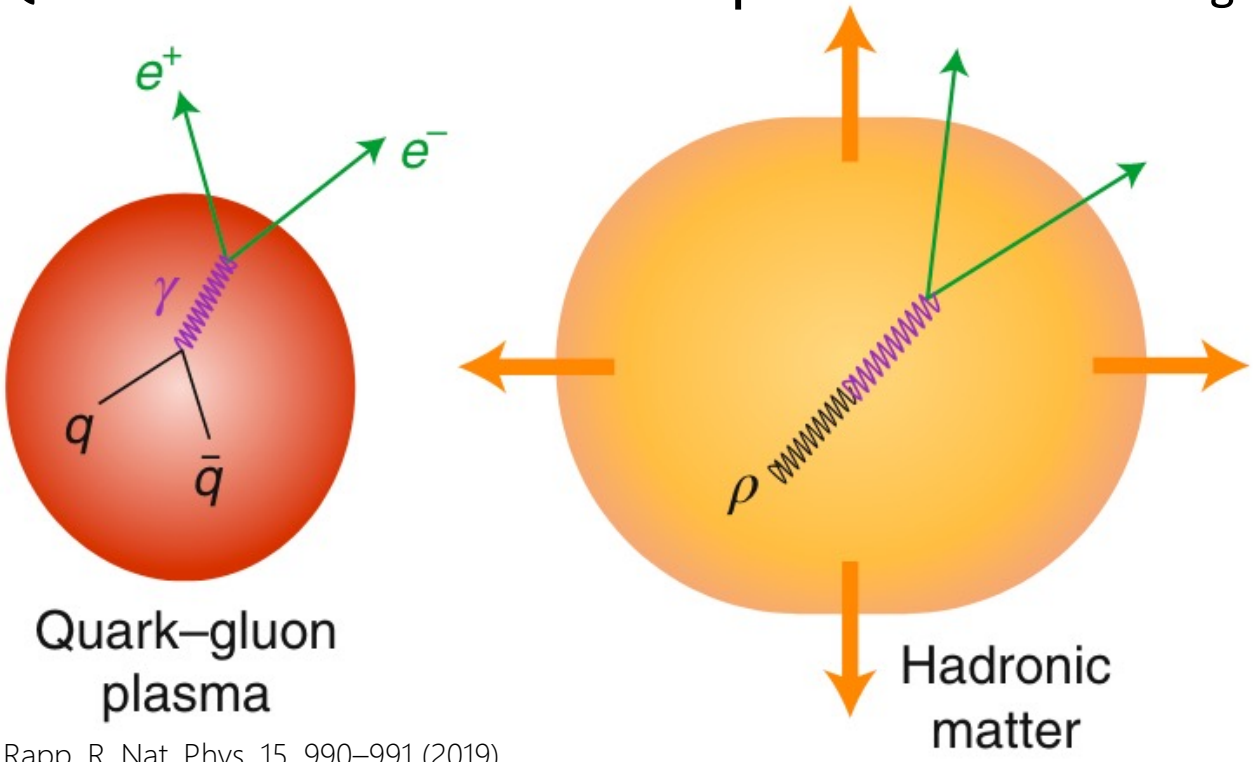
Electromagnetic probes:
- ✓ Minimal interaction with medium
- ✓ Emitting from early stage to final stage

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

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

Thermal dileptons

QGP: $M^{3/2} * e^{-M/T}$ **In-medium ρ:** Relativistic Breit-Wigner $* e^{-M/T}$

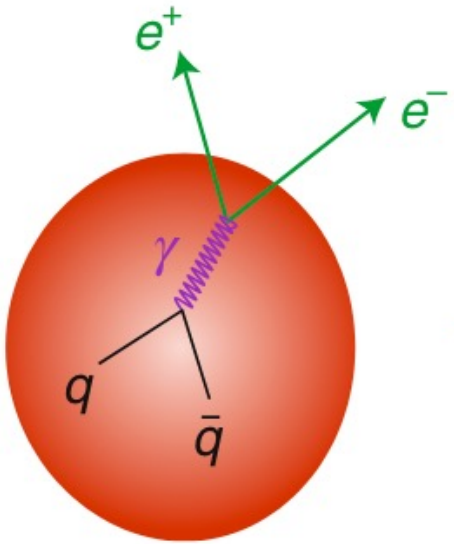


Rapp, R. Nat. Phys. 15, 990–991 (2019).

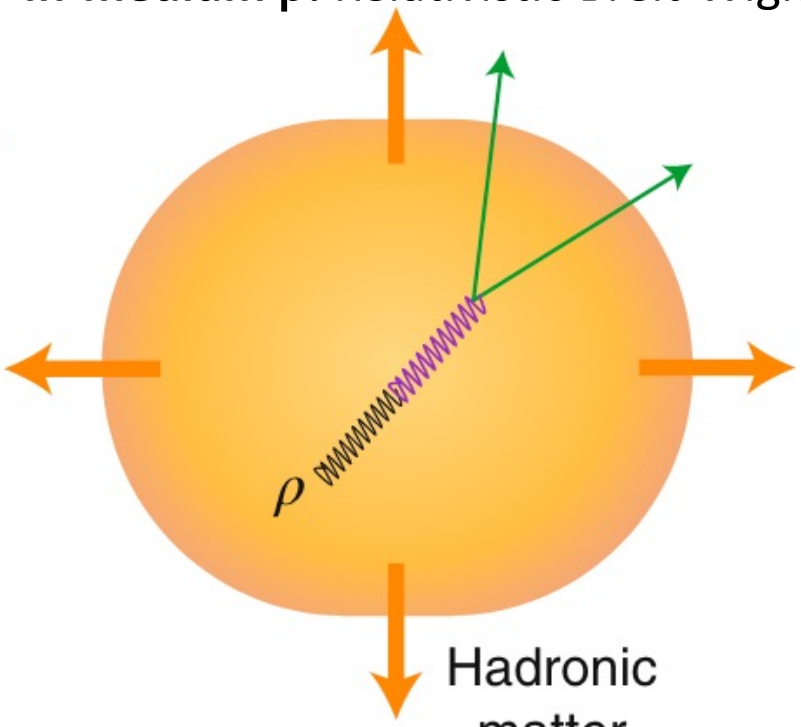
Invariant mass spectra of thermal dileptons can reveal temperature of the hot medium at both **QGP phase** and **hadronic phase**

Thermal dileptons

QGP: $M^{3/2} * e^{-M/T}$ **In-medium ρ:** Relativistic Breit-Wigner $* e^{-M/T}$



Quark–gluon plasma



Hadronic matter

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

inclusive dileptons

Interested signals

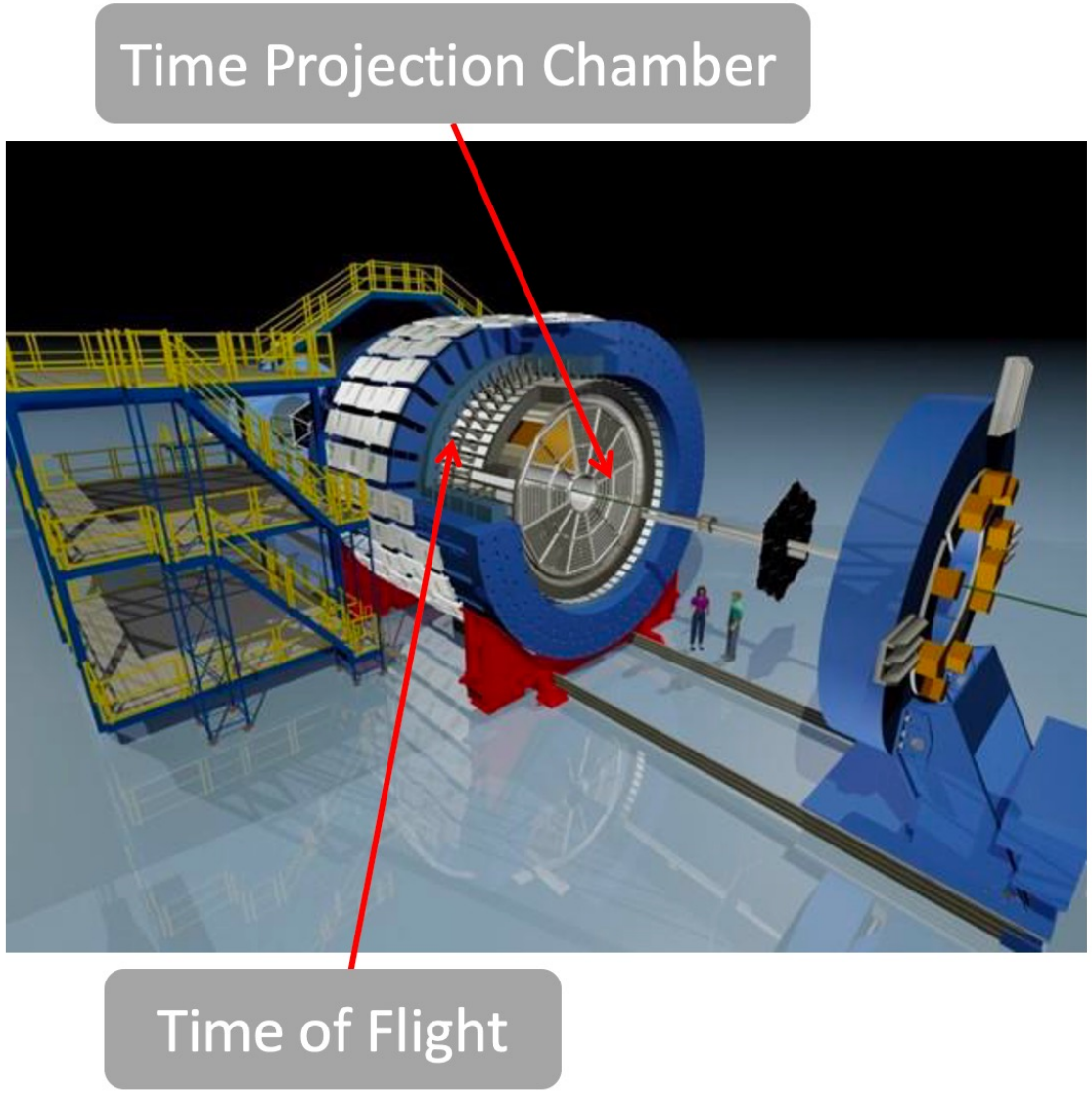
- QGP radiation
- In-medium ρ

Physical backgrounds (hadronic cocktails)

- π^0, η, η' -> γe^+e^-
- ω -> $\pi^0 e^+e^-$
- ϕ -> ηe^+e^-
- ω, ϕ, J/ψ -> e^+e^-
- cc -> 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

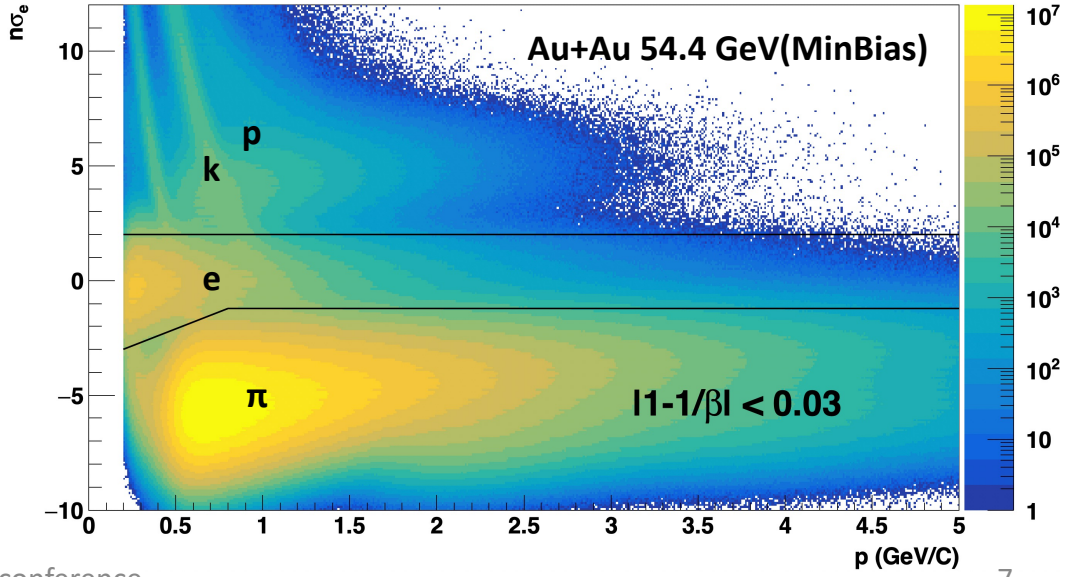


Time Projection Chamber + Time of Flight

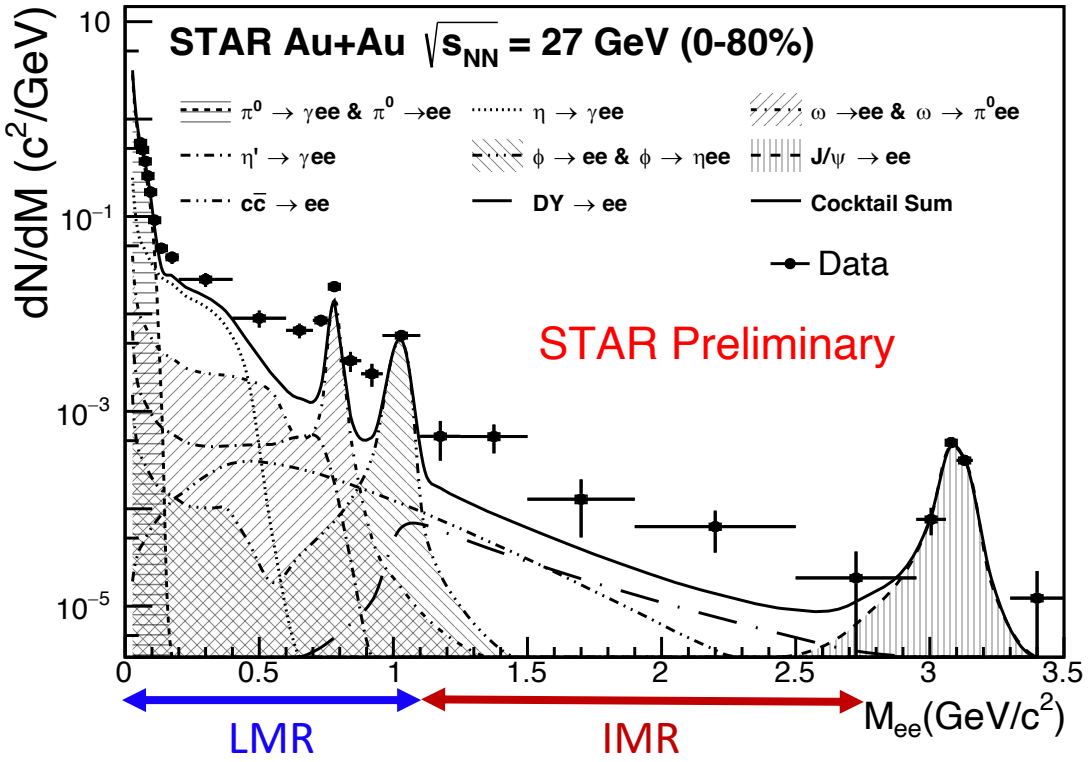
- ✓ Electron identification by dE/dx and velocity
- ✓ High purity electron samples

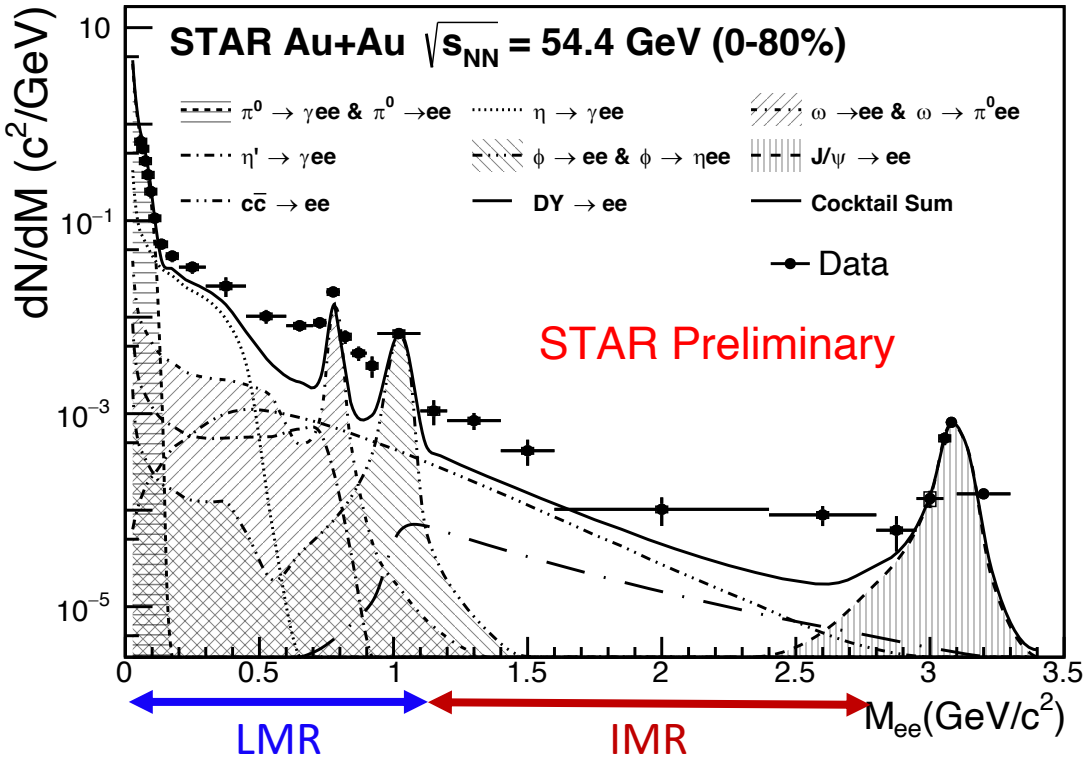
27 and 54.4 GeV dataset

- ✓ Statistics ~ 10 times larger than that in the BES-I 27,39 and 62.4 GeV datasets



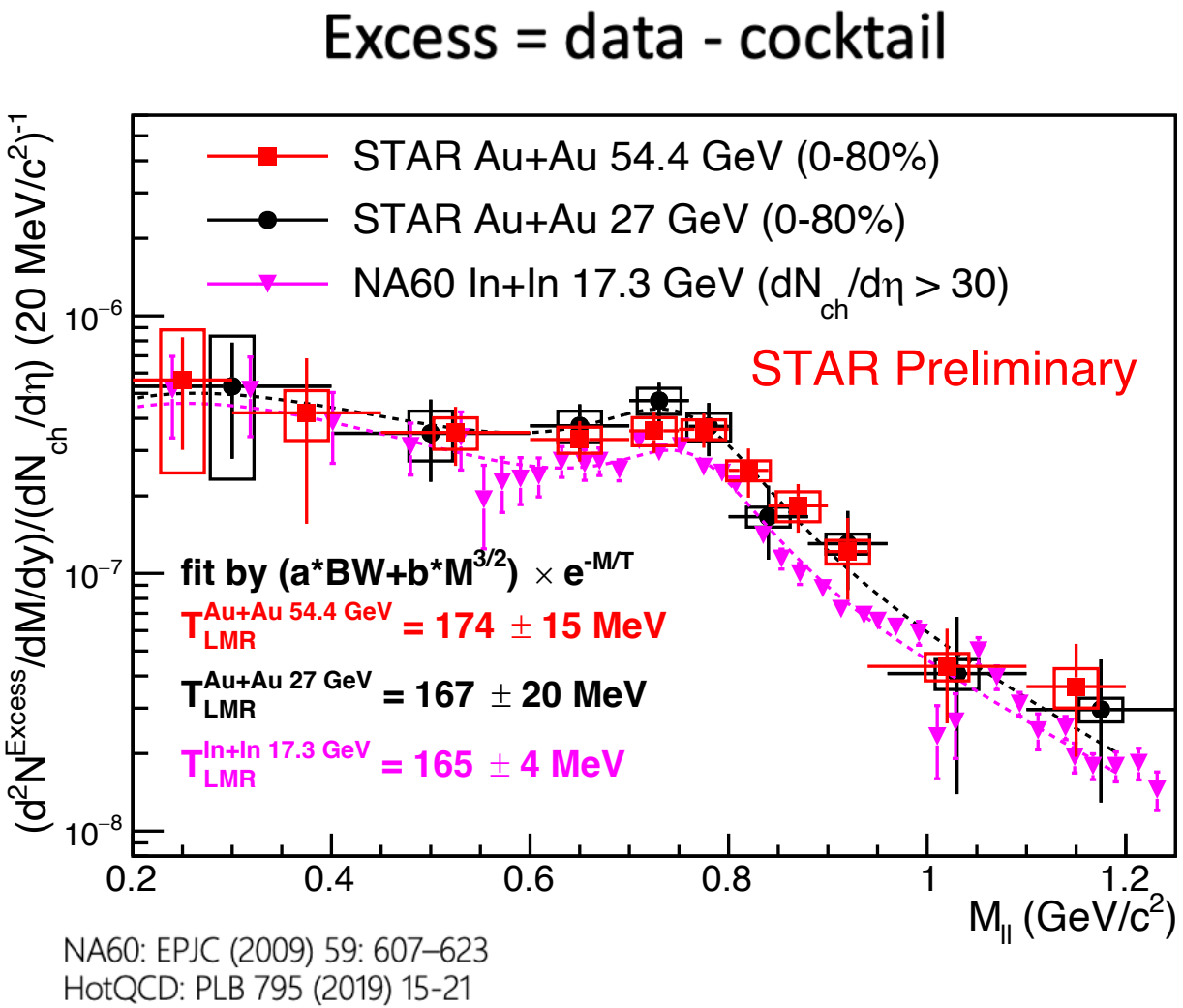
Dielectron spectra





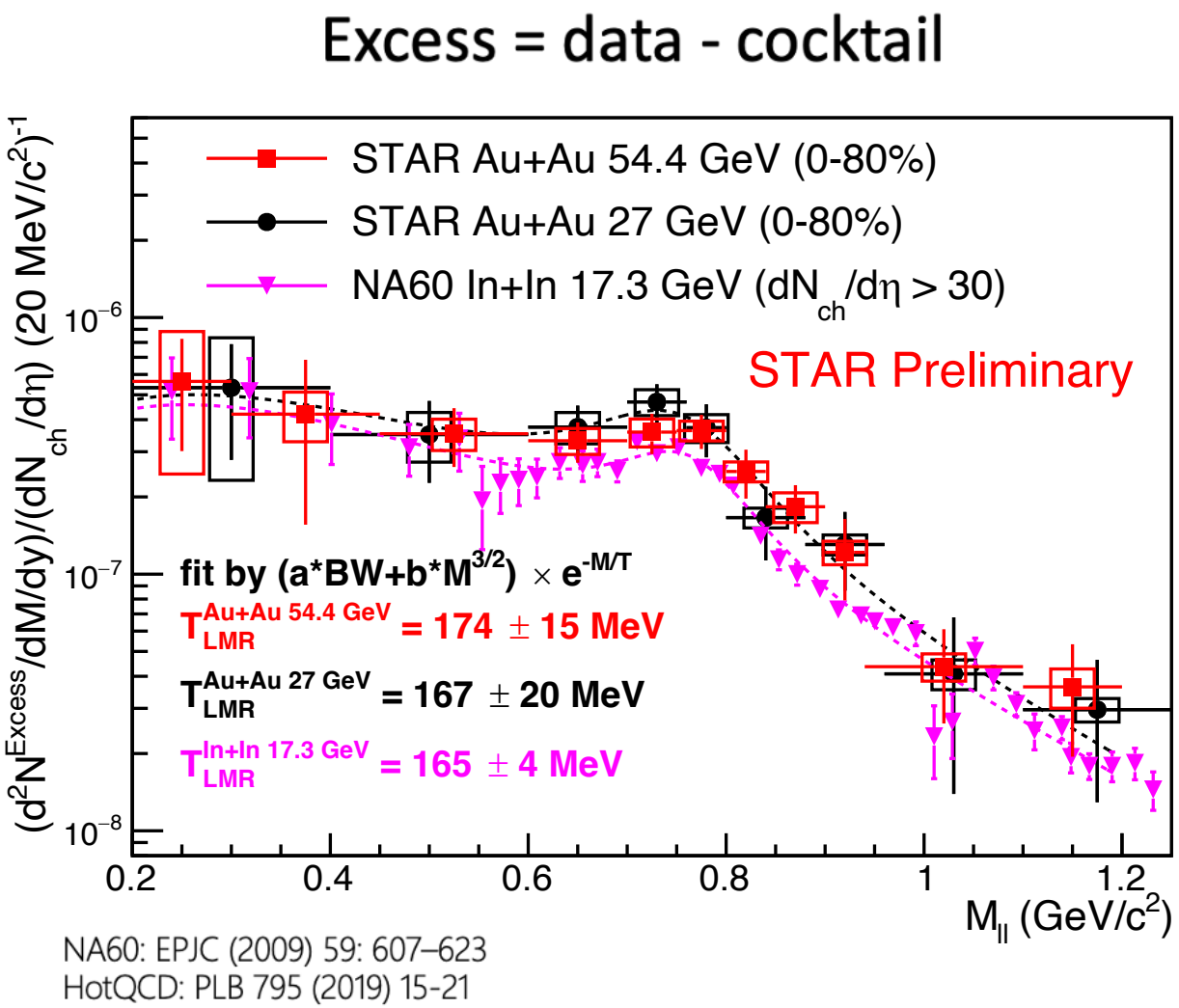
Clear enhancement compared to hadronic cocktail in both low mass region (LMR) and intermediate mass region (IMR)

Temperature extraction from LMR



- ✓ Excess dielectron spectra of 27 and 54.4 GeV Au+Au collisions and 17.3 GeV In+In collisions are similar

Temperature extraction from LMR

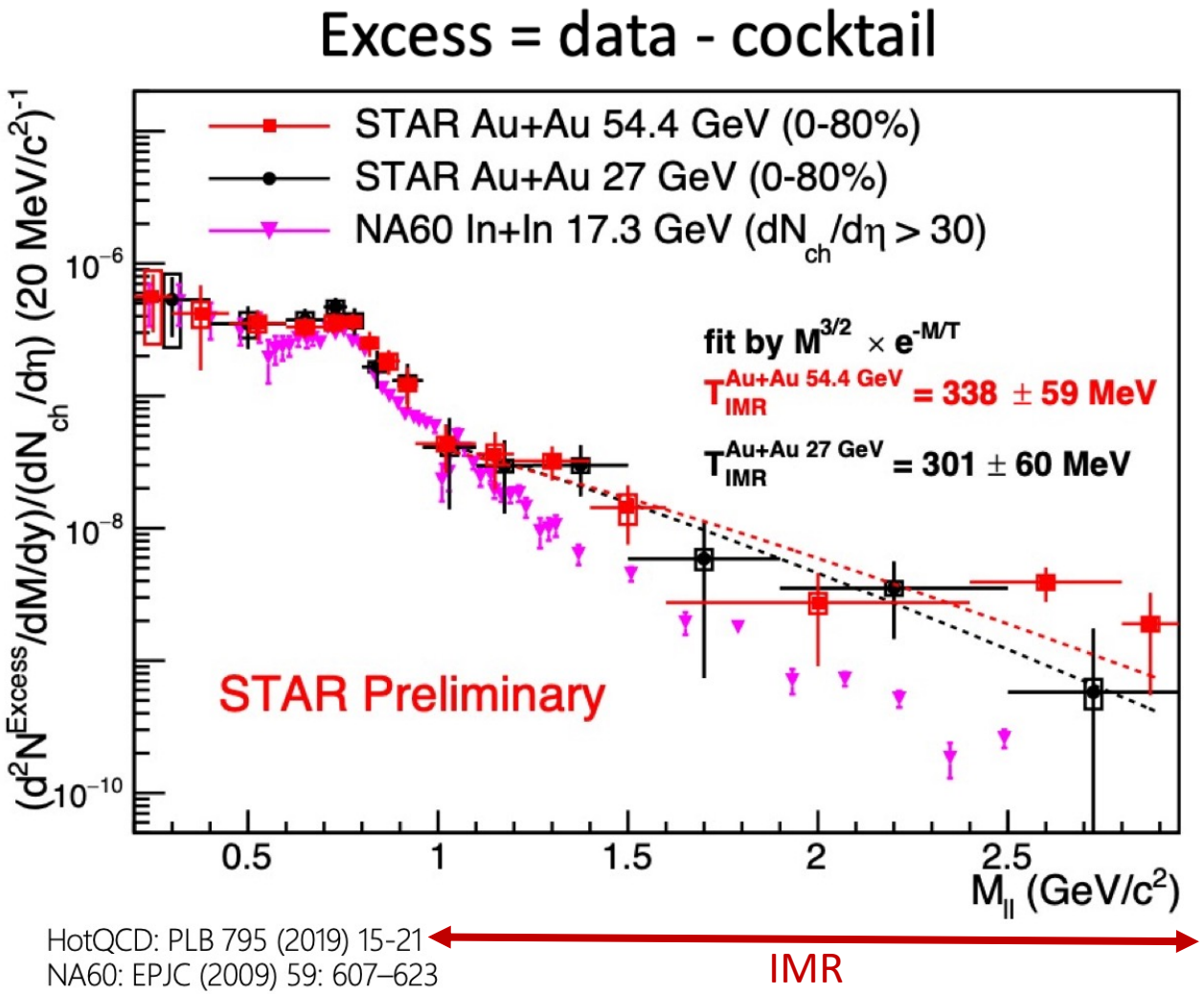


NA60: EPJC (2009) 59: 607–623
HotQCD: PLB 795 (2019) 15-21

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

- ✓ Excess dielectron spectra of 27 and 54.4 GeV Au+Au collisions and 17.3 GeV In+In collisions are similar
- ✓ T is similar despite significant differences in collision energies and system sizes
- ✓ T extracted from low mass region is around the pseudo critical temperature T_{pc} (156 MeV)

Temperature extraction form IMR

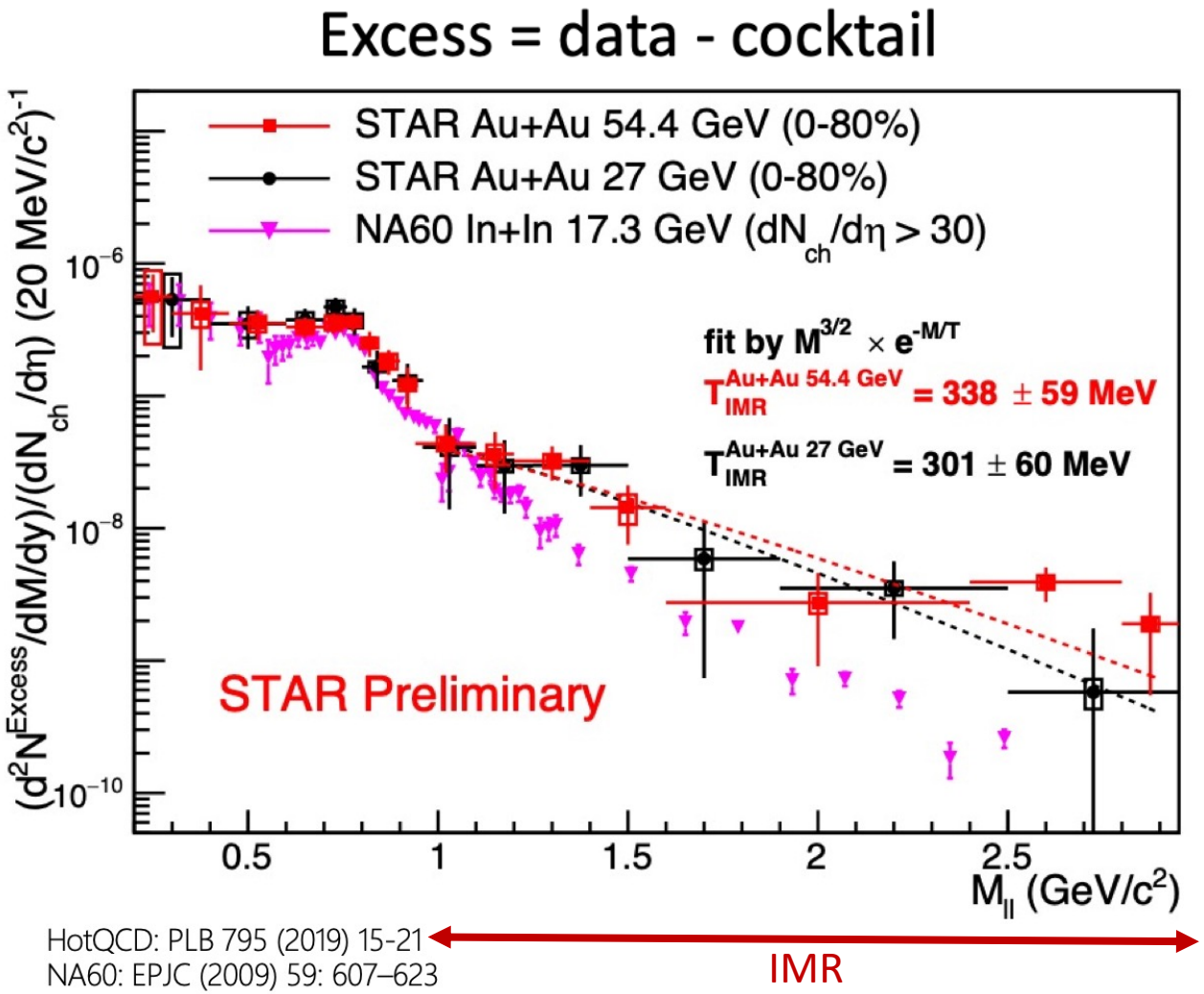


HotQCD: PLB 795 (2019) 15-21
NA60: EPJC (2009) 59: 607–623

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

- ✓ QGP thermal radiation is predicted to be the dominant source in the intermediate mass region
- ✓ T extracted from 27 and 54.4 GeV are consistent with each other

Temperature extraction form IMR

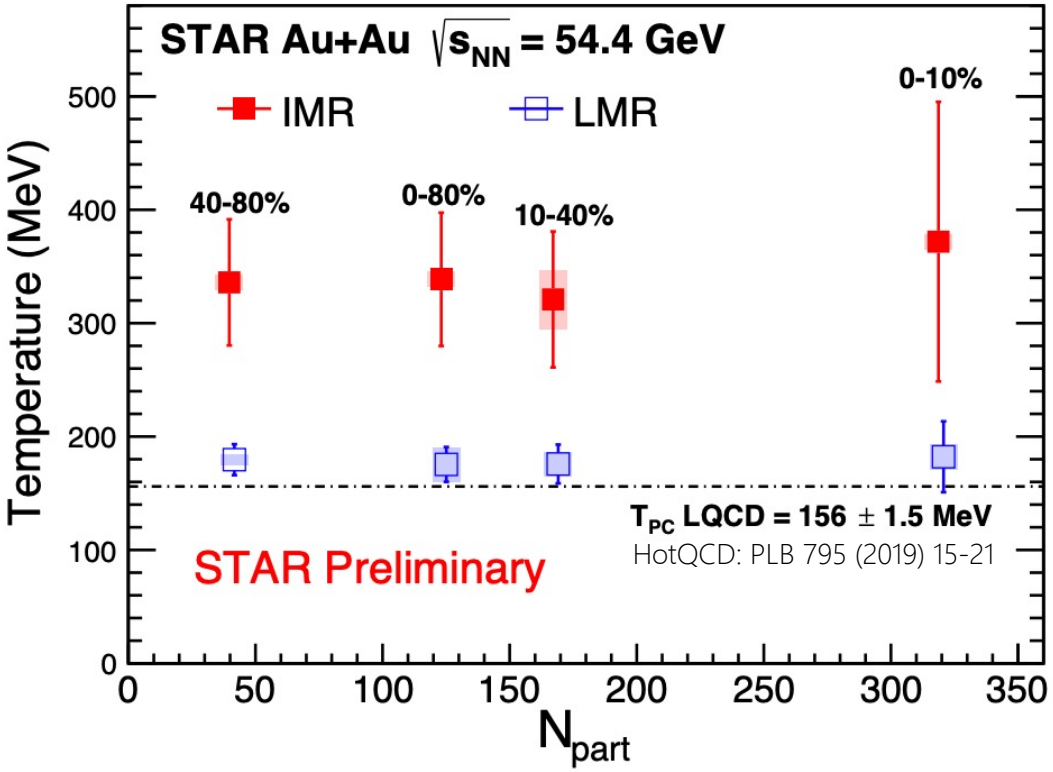


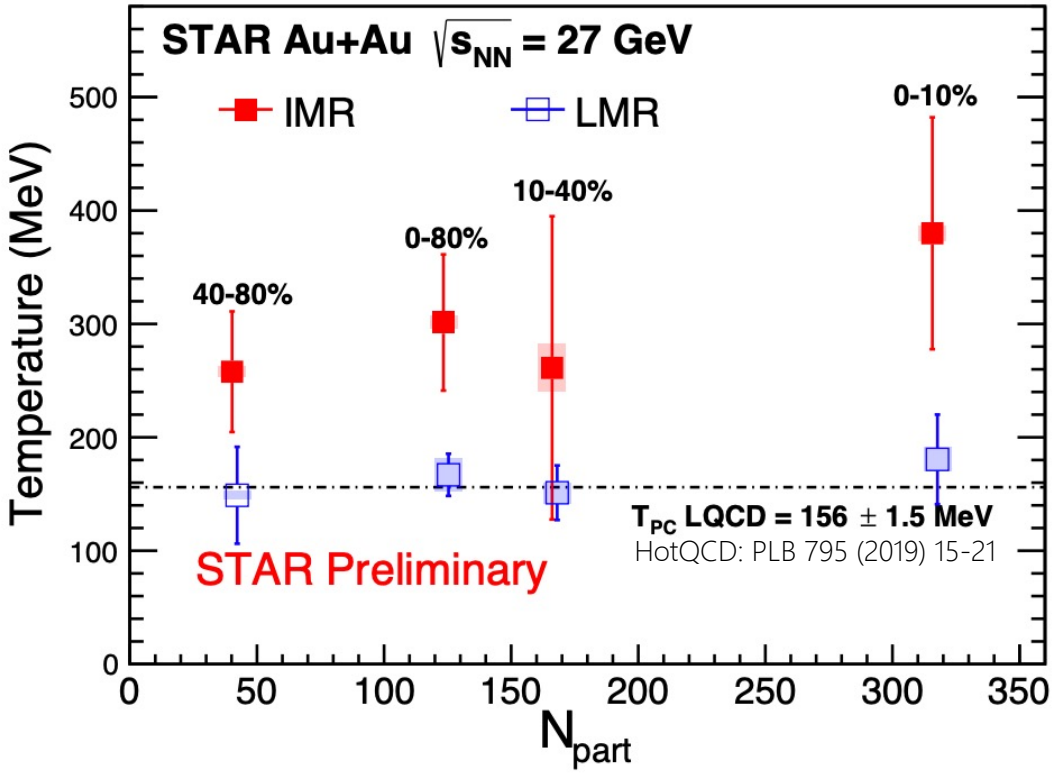
HotQCD: PLB 795 (2019) 15-21
NA60: EPJC (2009) 59: 607–623

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

- ✓ QGP thermal radiation is predicted to be the dominant source in the intermediate mass region
- ✓ T extracted from 27 and 54.4 GeV are consistent with each other
- ✓ T is higher than the pseudo critical temperature T_{pc} (156 MeV), supporting that the emission is predominantly from deconfined partonic phase

Temperature v.s. N_{part}

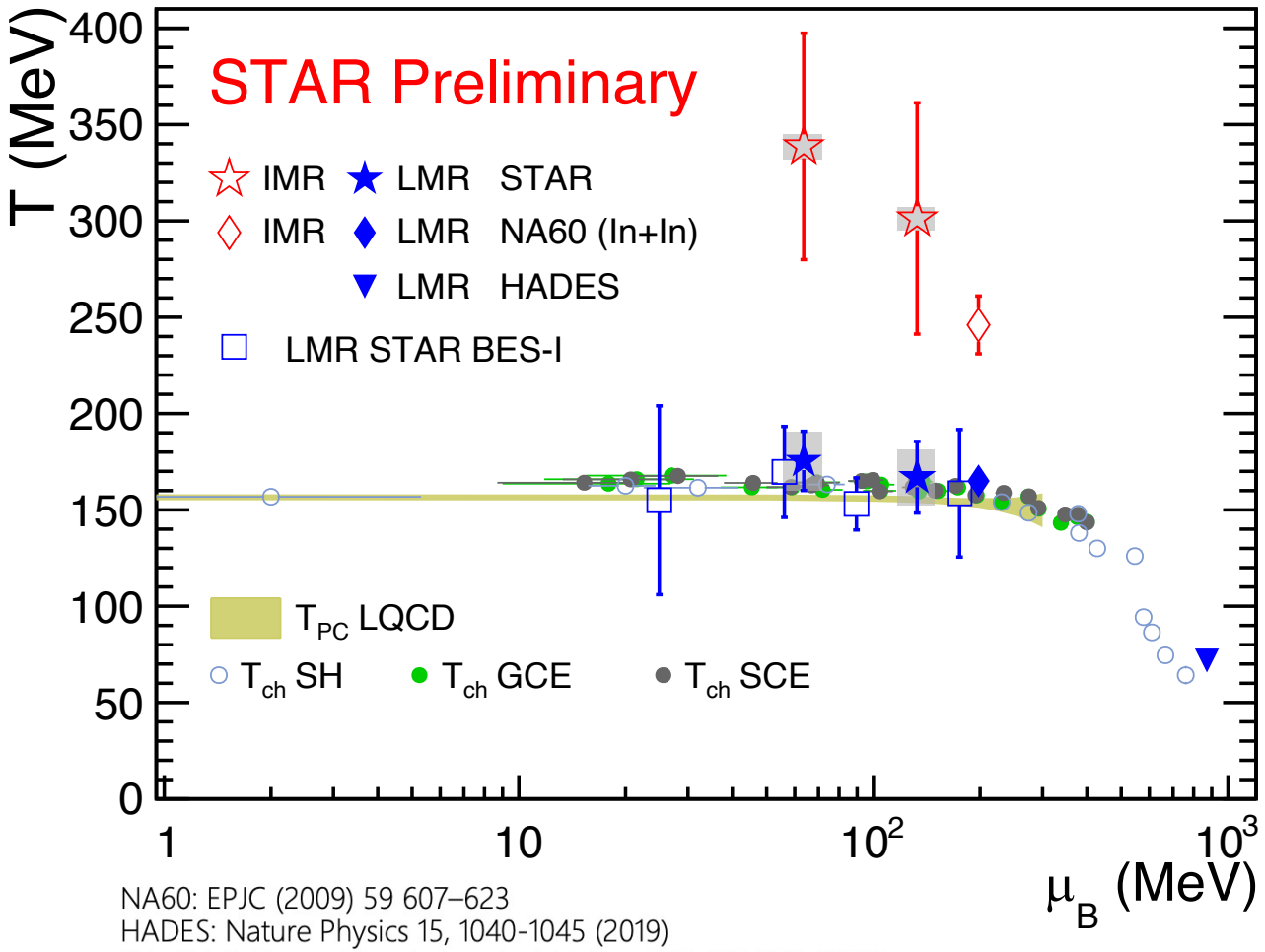




No clear centrality dependence in both mass regions

- ✓ Temperature from low mass region is around the pseudo critical temperature
- ✓ Temperature from intermediate mass region is higher than that in low mass region

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)

Thermal dielectrons in LMR:

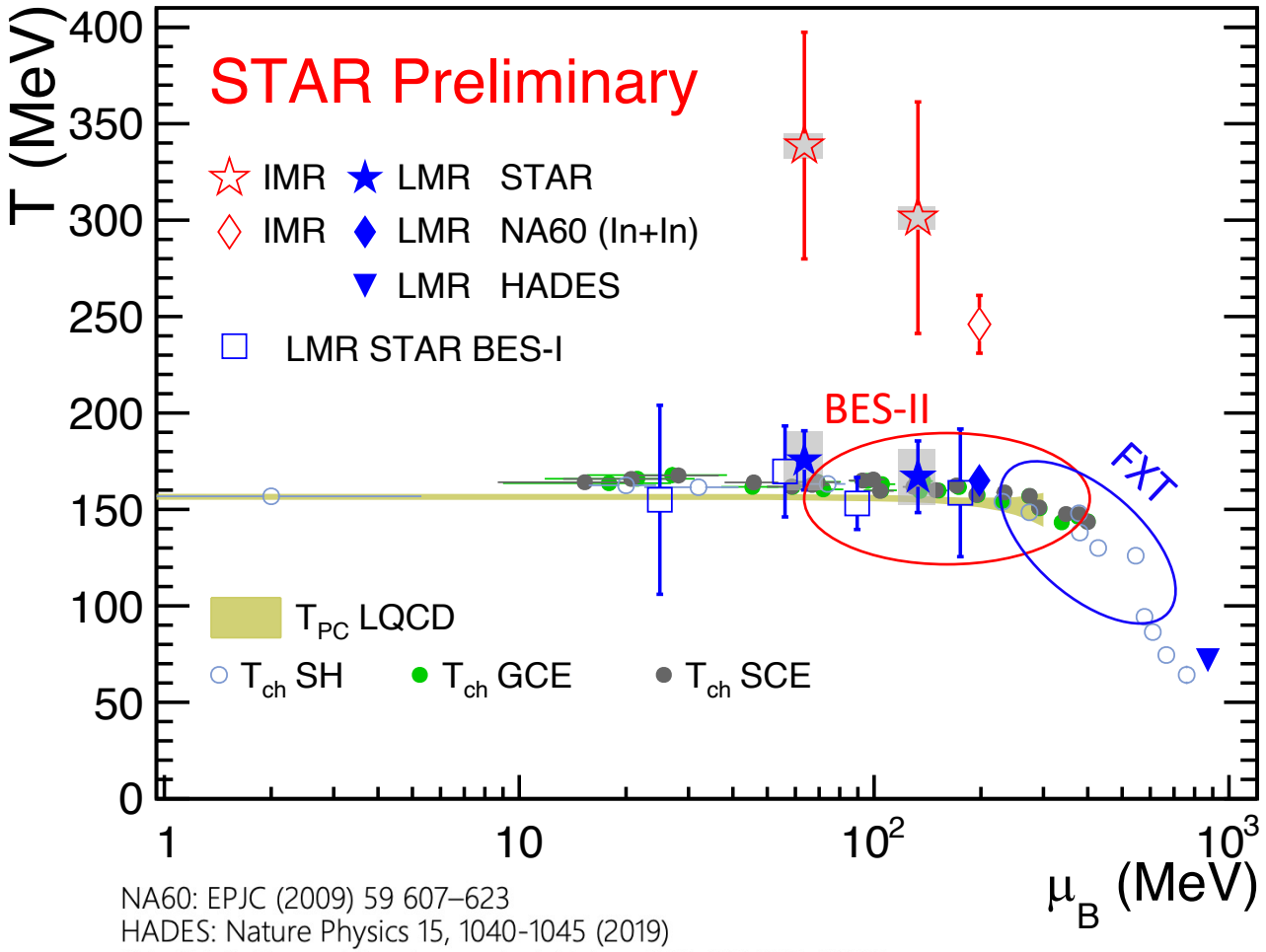
- ✓ T_{LMR} is close to the T_{pc} and T_{ch}
- ✓ Emitted form the hadronic phase, dominantly around the phase transition

Thermal dielectrons in IMR:

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

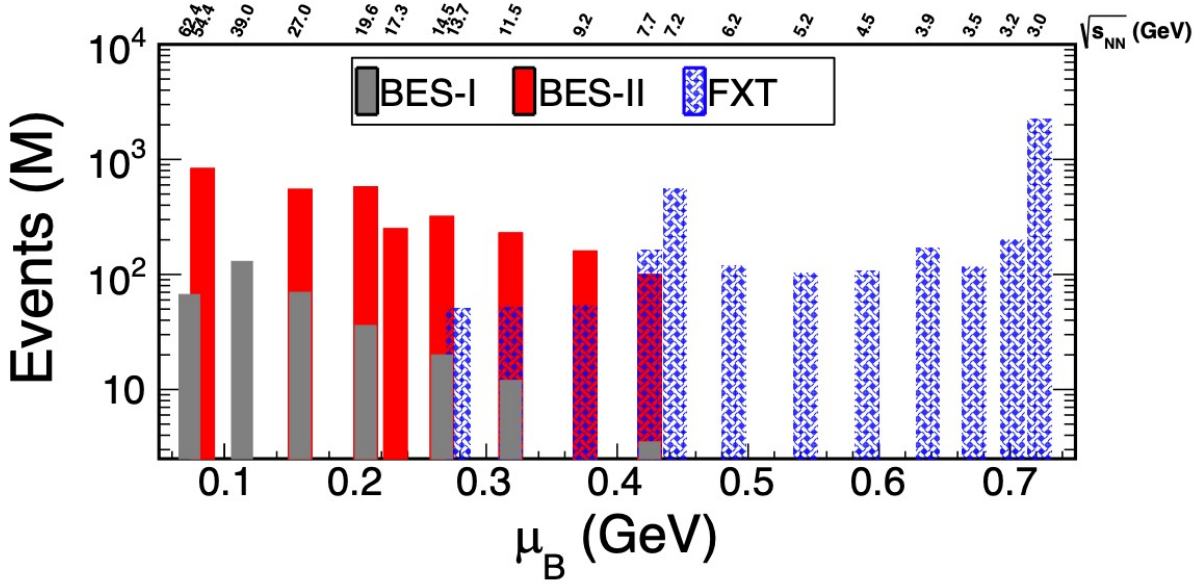
T_{ch} : Chemical freeze-out temperature
T_{pc} : Pseudo critical temperature

Future dielectron measurements with STAR BES-II and FXT program



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)

- ✓ Measurements of dielectron spectra with high statistic data samples will be possible with STAR BES-II and FXT program
- ✓ Enhanced tracking and particle identification capabilities with iTPC and eTOF upgrades



Summary

Low mass region:

- ✓ **T_{LMR} ~ 170 MeV**, first experimental evidence that in-medium ρ is dominantly produced around phase transition

Intermediate mass region:

- ✓ **T_{IMR} ~ 320 MeV**, first QGP temperature measurement at RHIC without distortion by medium flow
- ✓ $T > T_{pc}$, radiation source is QGP thermal radiation