Measuring QGP temperature with thermal dielectrons with STAR BES-II data

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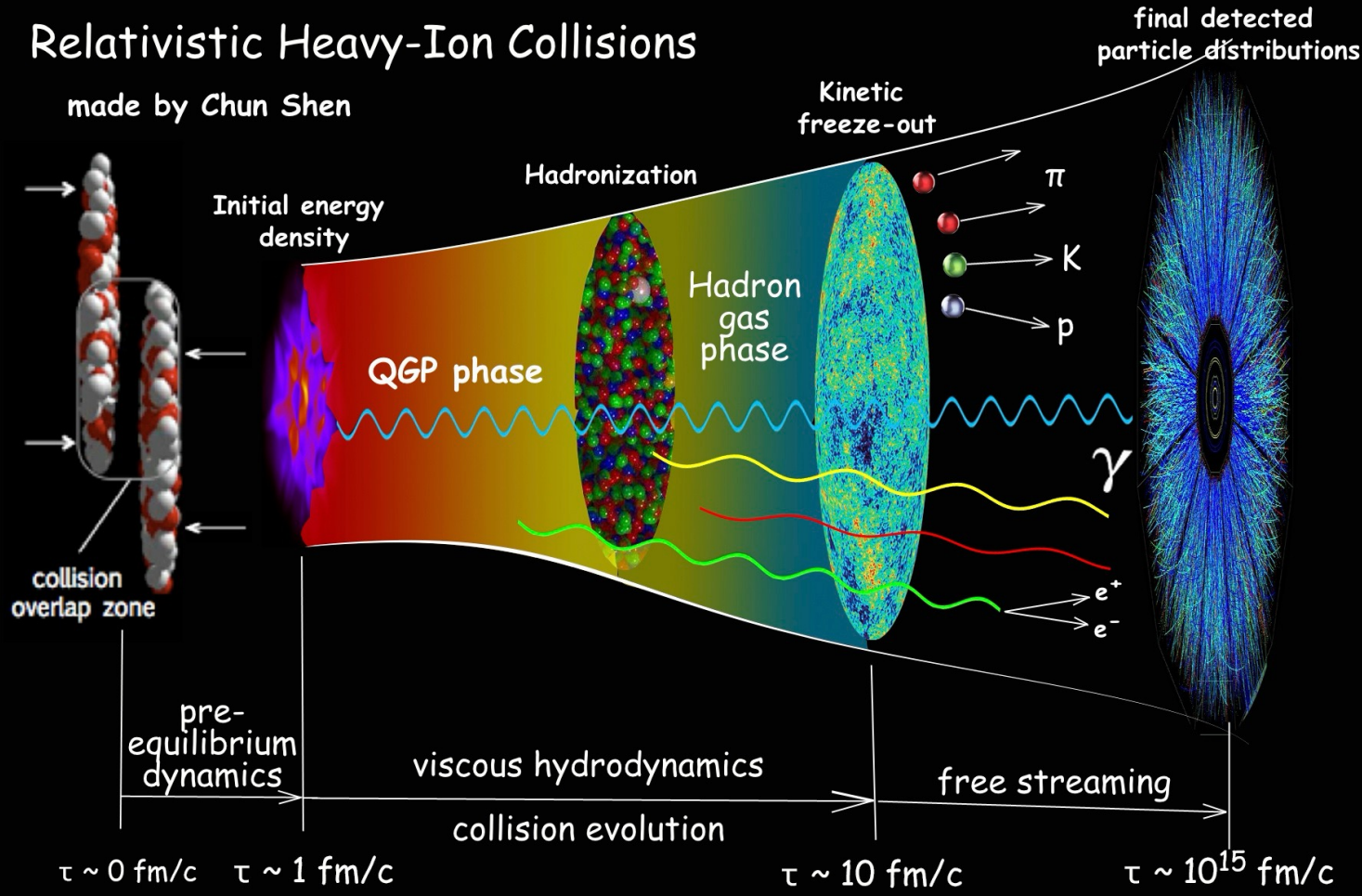
The 15th workshop on QCD Phase Transition and Relativistic Heavy Ion Collisions

A "Little Bang" in Heavy Ion collision

Relativistic Heavy-Ion Collisions
made by Chun Shen

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

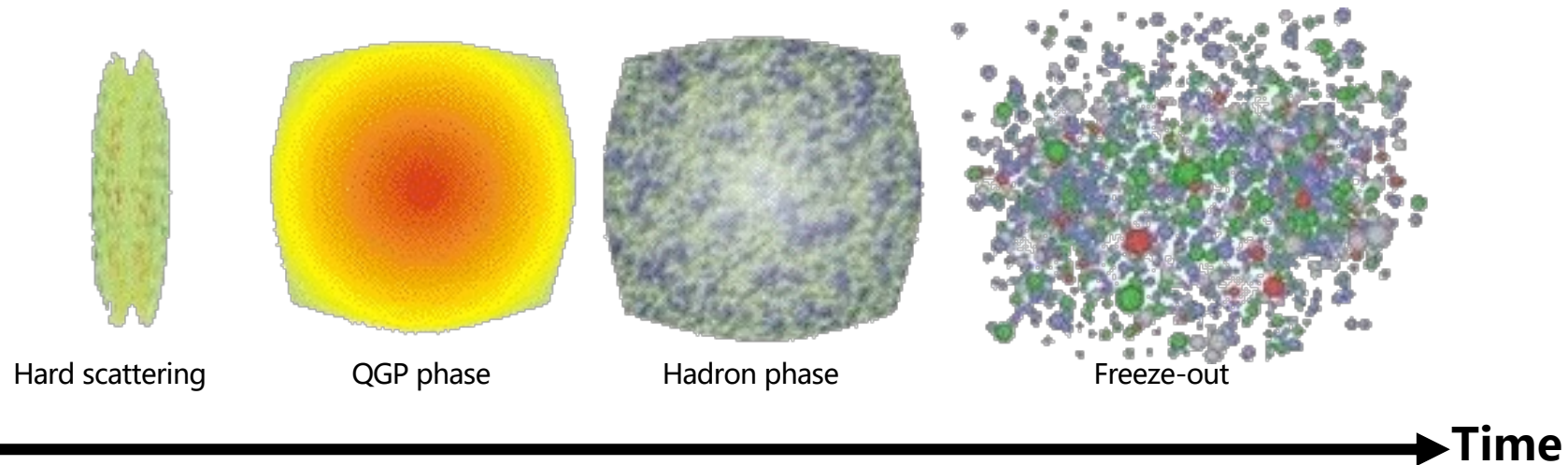**Temperature**, as one of key properties of medium, still poorly known
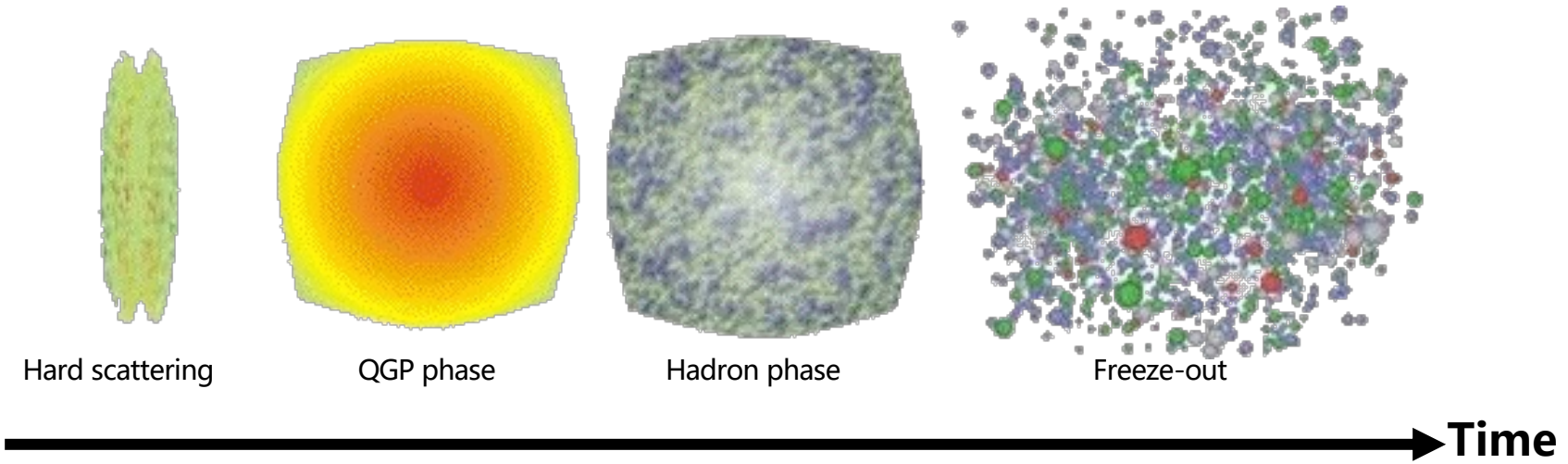
How to measure temperature

Hadrons
yields , p_T spectra

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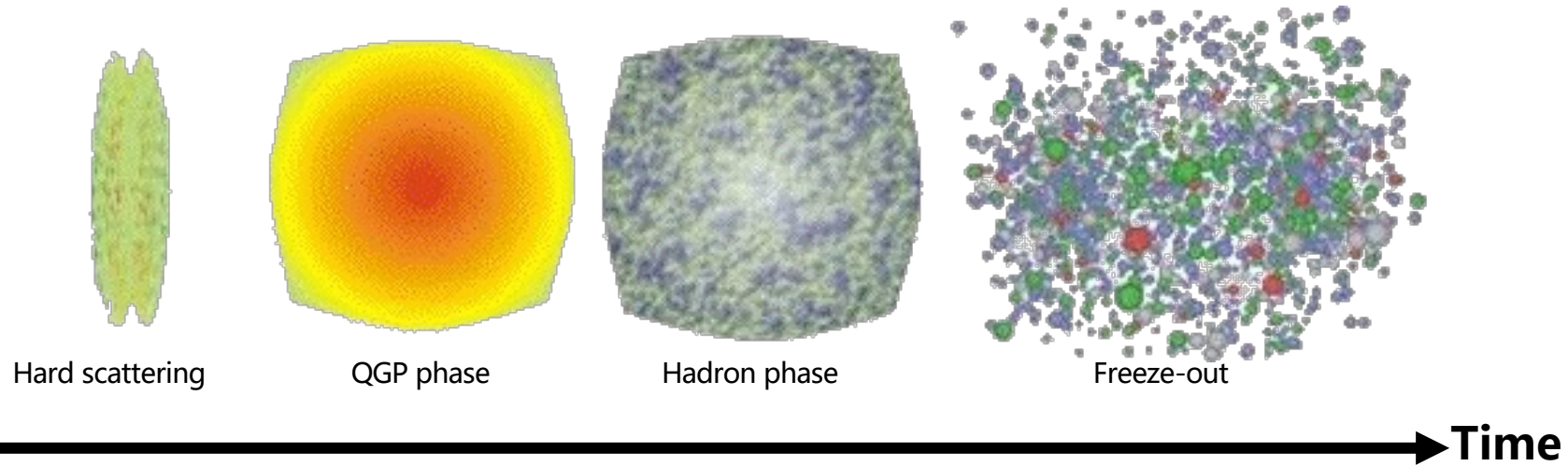- ✓ Extract temperatures of chemical and kinetic freeze-out, T_{ch} and T_{kin}

| Hard scattering | QGP phase | Hadron phase | Freeze-out |

Time

How to measure temperature

Hard scattering   QGP phase   Hadron phase   Freeze-out

Time

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

How to measure temperature

Hard scattering   QGP phase   Hadron phase   Freeze-out

Time

Electromagnetic Probes:
- ✓ Emitting from early stage to final stage
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Photons

p_T spectra

Dileptons

M_{ll} spectra

How to measure temperature

Hard scattering   QGP phase   Hadron phase   Freeze-out
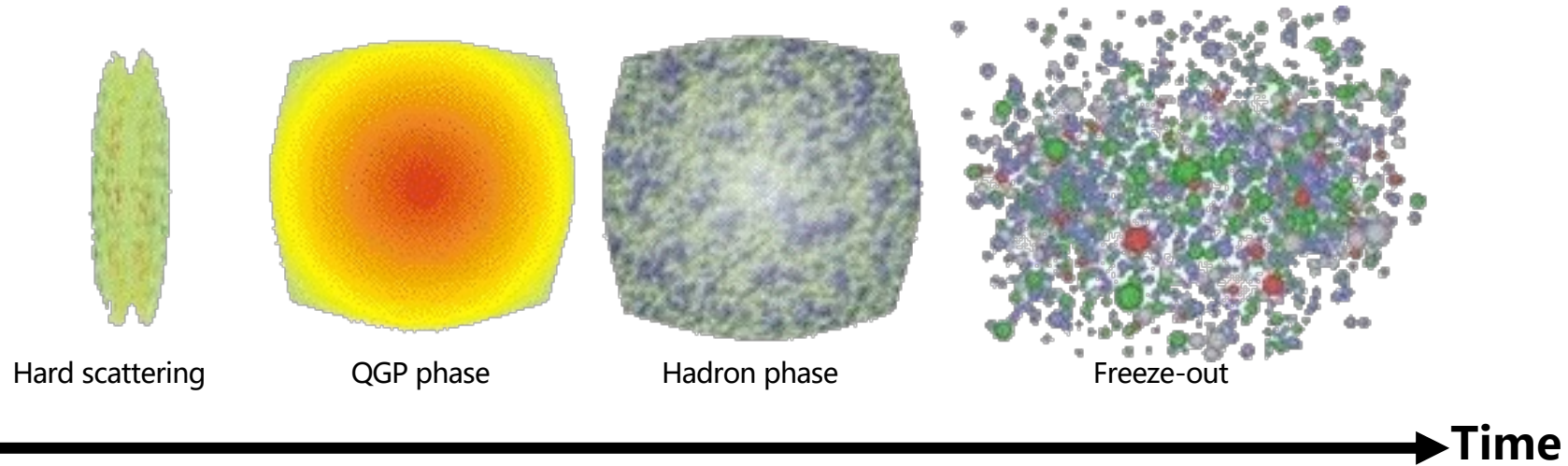
Time

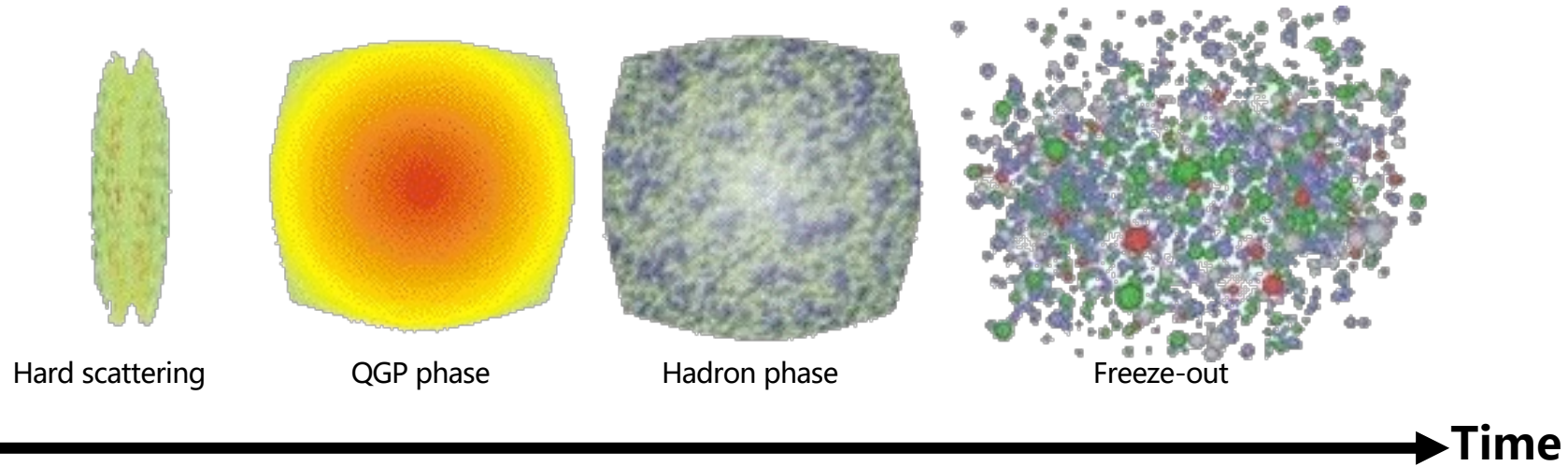## Photons

p_T spectra

Dileptons

M_{ll} spectra

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

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

How to measure temperature

Hard scattering   QGP phase   Hadron phase   Freeze-out

Time →

Photons

p_T spectra

Dileptons

M_{ll} spectra

Electromagnetic Probes:
- ✓ Emitting from early stage to final stage
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Photons:
- ✓ Extract T_{eff} from p_T spectra
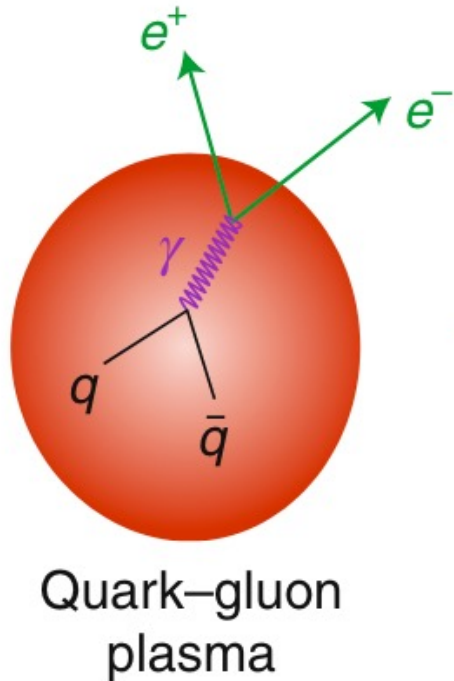- ✓ $T_{eff} \rightarrow T_{QGP}$: medium flow effect

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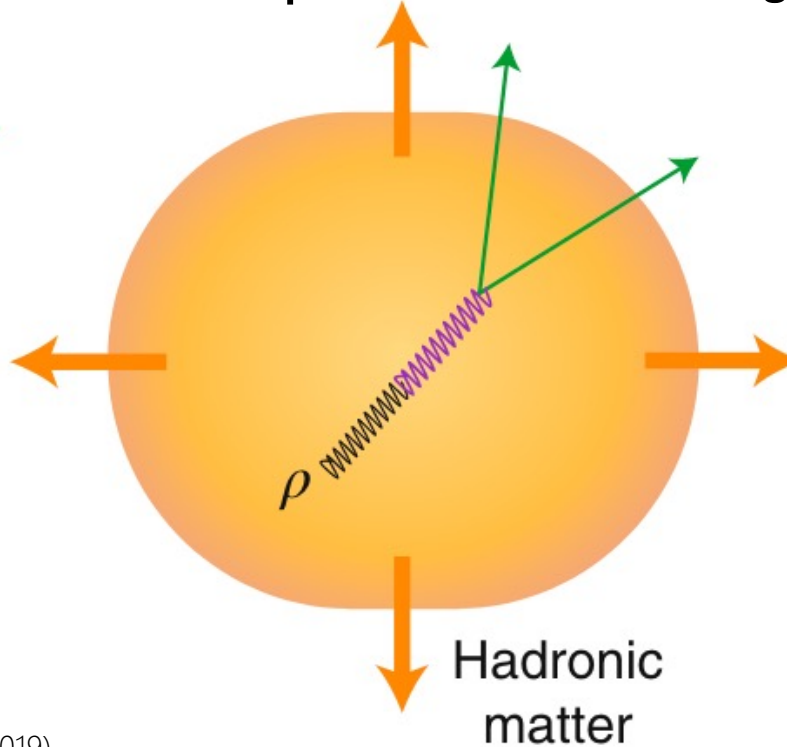- ✓ Only observable to directly access in-medium spectral function

Thermal dileptons

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

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

e^+
e^-
γ
q
$\bar{q}$

Quark–gluon plasma

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

ρ

Hadronic matter

inclusive dileptons

Interested signals

- QGP radiation
- In-medium ρ

Physical backgrounds (hadronic cocktails)

- π^0, η, η' -> $\gamma e^+ e^-$
- ω -> $\pi^0 e^+ e^-$
- ϕ -> $\eta e^+ e^-$
- ω, ϕ, J/ψ -> $e^+ e^-$
- cc -> $e^+ e^- X$
- Drell-Yan

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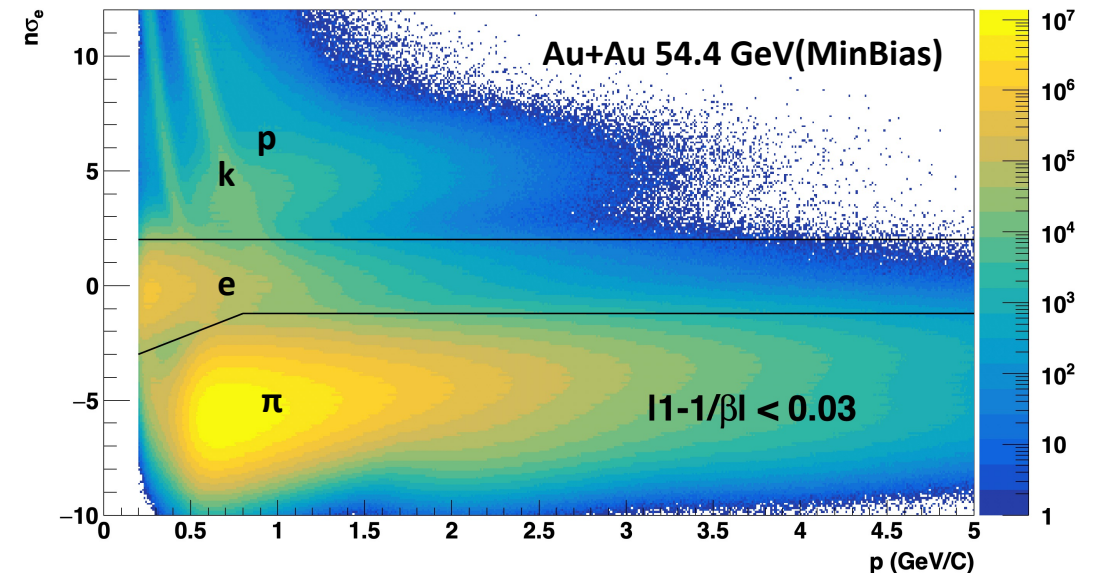
STAR experiment and eID

Time of Flight

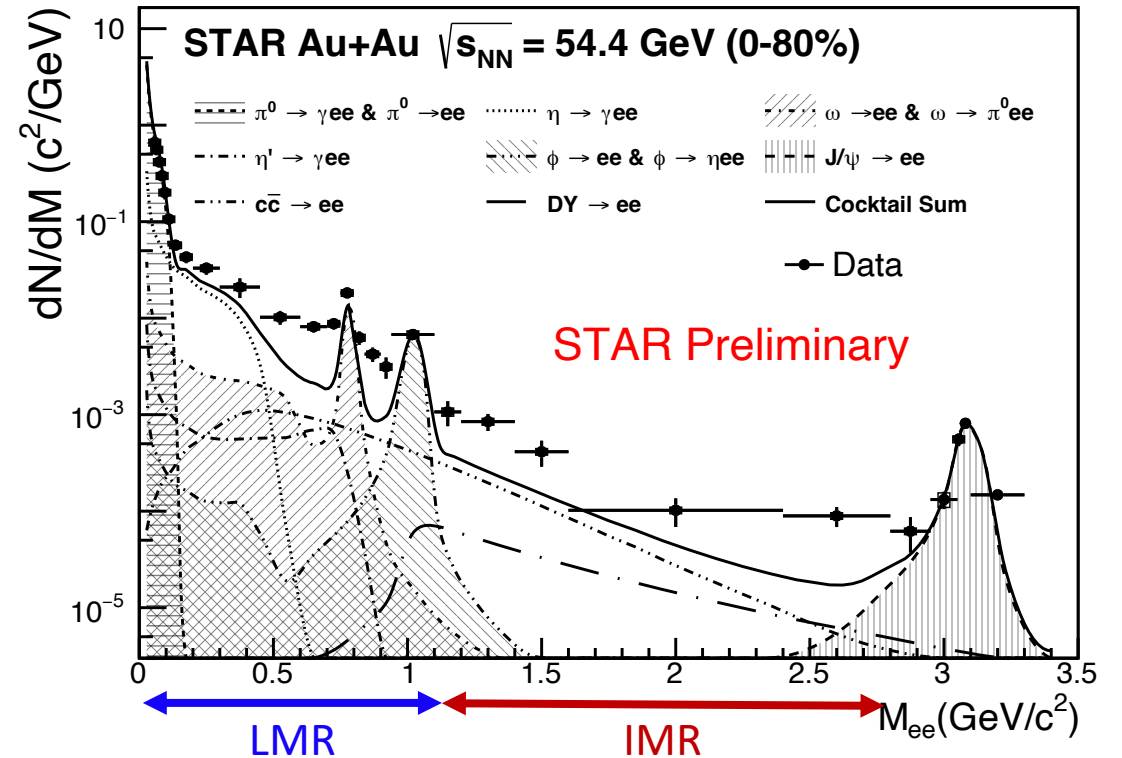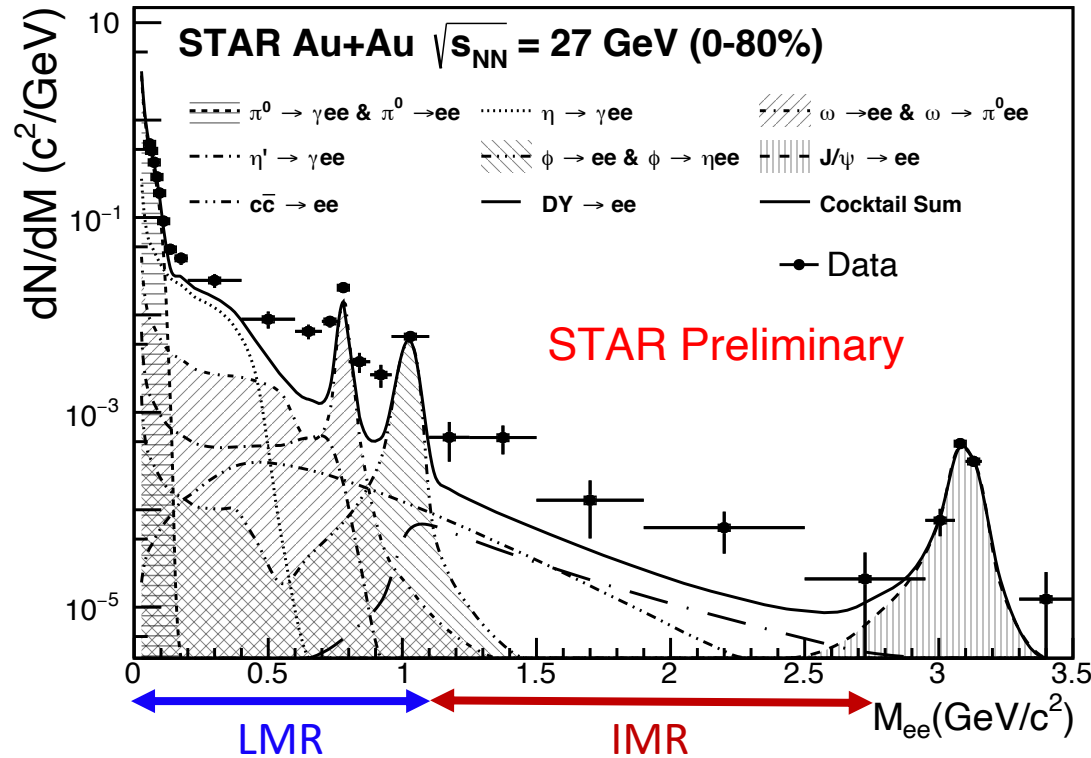Time Projection Chamber + Time of Flight
- ✓ Electron identification by dE/dx and velocity
- ✓ High purity electron samples

$\sqrt{s_{NN}}$ = 27 and 54.4 GeV dataset
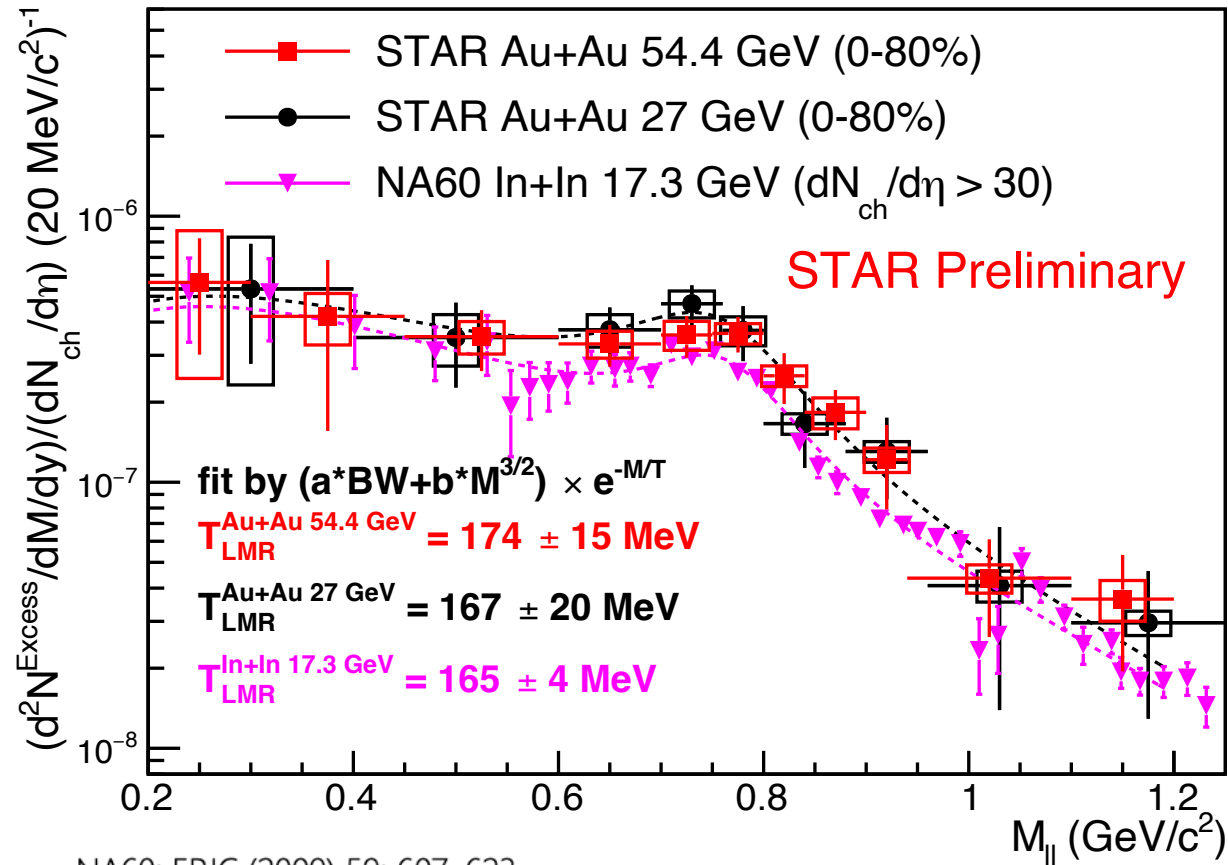- ✓ Statistics ~ 10 times larger than that in the BES-I 27,39 and 62.4 GeV datasets

Dielectron spectra

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

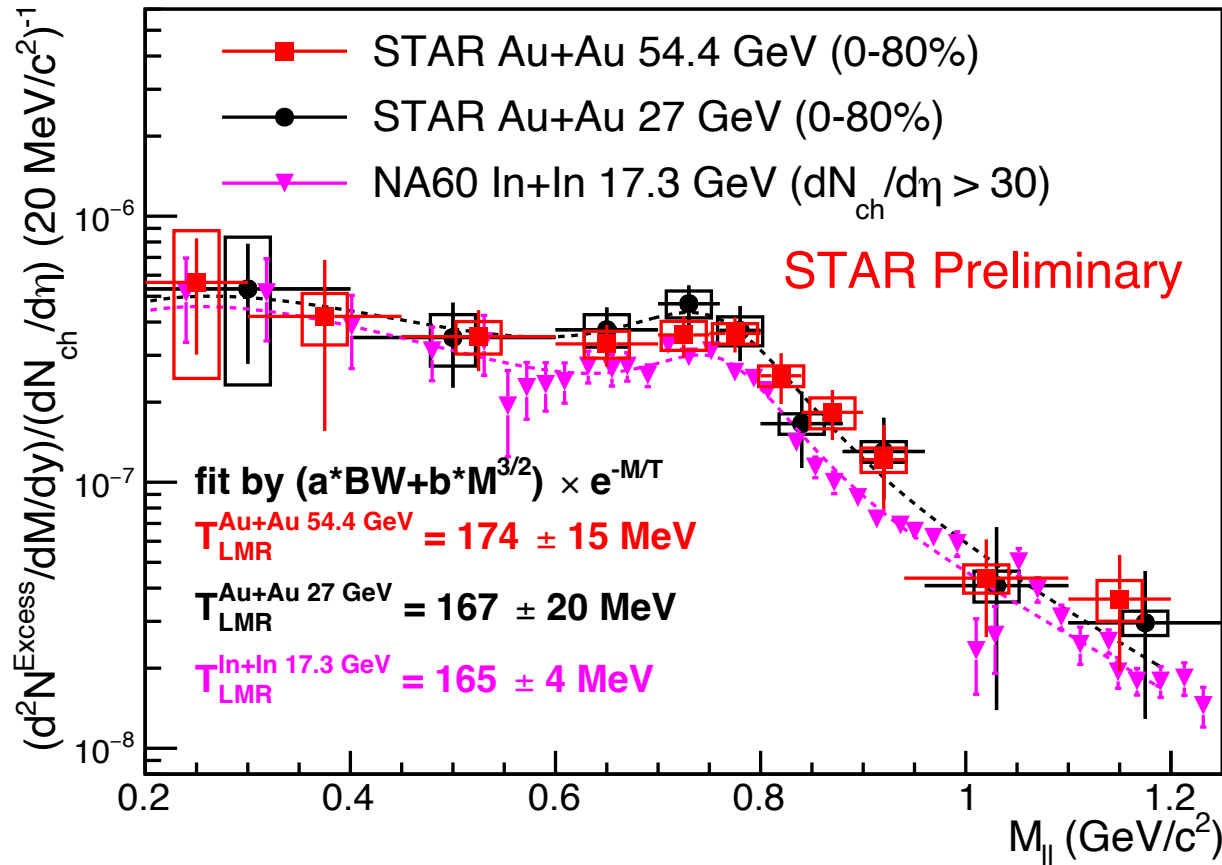# Temperature extraction from LMR

Excess = data - cocktail

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

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

Temperature extraction from LMR

Excess = data - cocktail

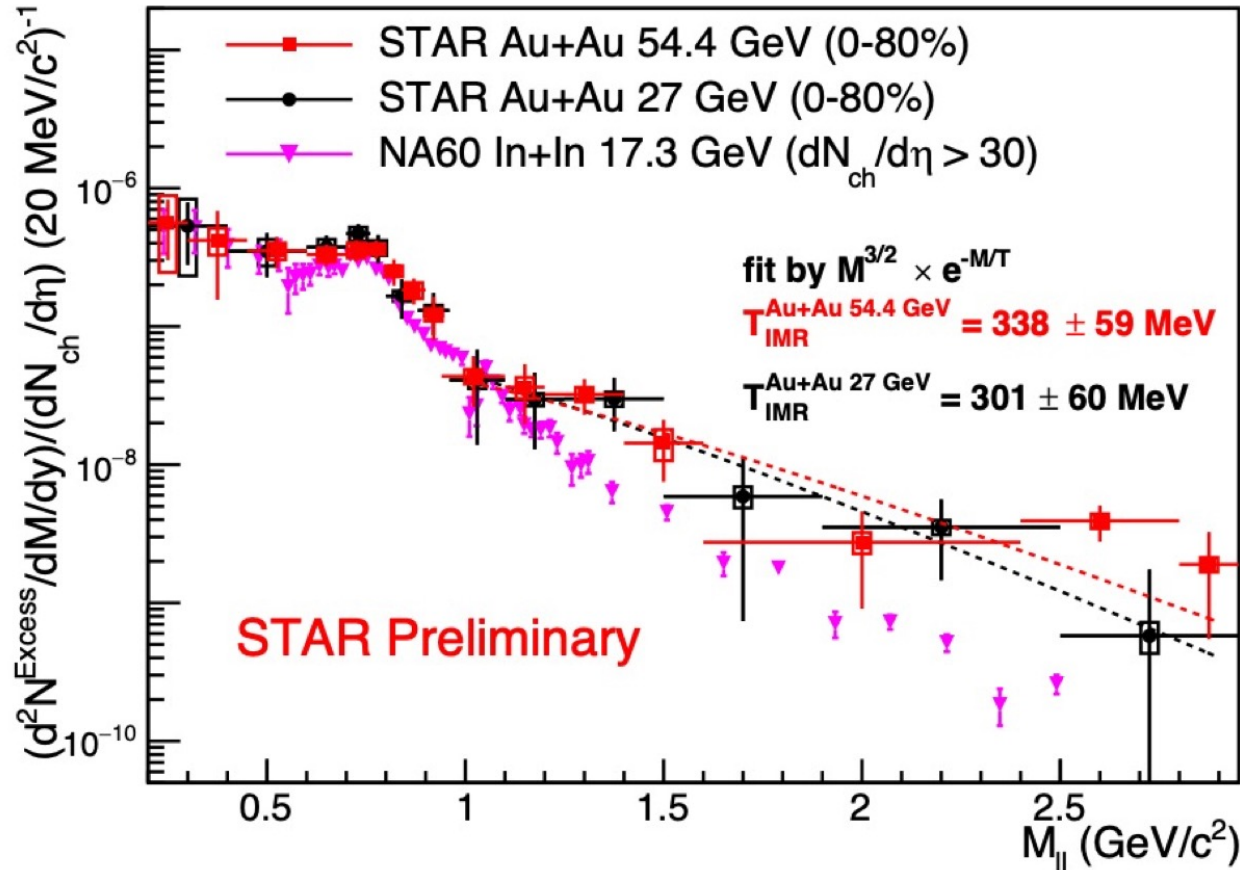**Fitting function:** $(a*BW + b*M^{3/2}) * e^{-M/T}$

- ✓ Excess dielectron spectra in 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)

Excess = data - cocktail

STAR Au+Au 54.4 GeV (0-80%)
STAR Au+Au 27 GeV (0-80%)
NA60 In+In 17.3 GeV ($dN_{ch}/d\eta > 30$)

fit by $M^{3/2} \times e^{-M/T}$

$T_{IMR}^{Au+Au\ 54.4\ GeV} = 338 \pm 59$ MeV

$T_{IMR}^{Au+Au\ 27\ GeV} = 301 \pm 60$ MeV

STAR Preliminary

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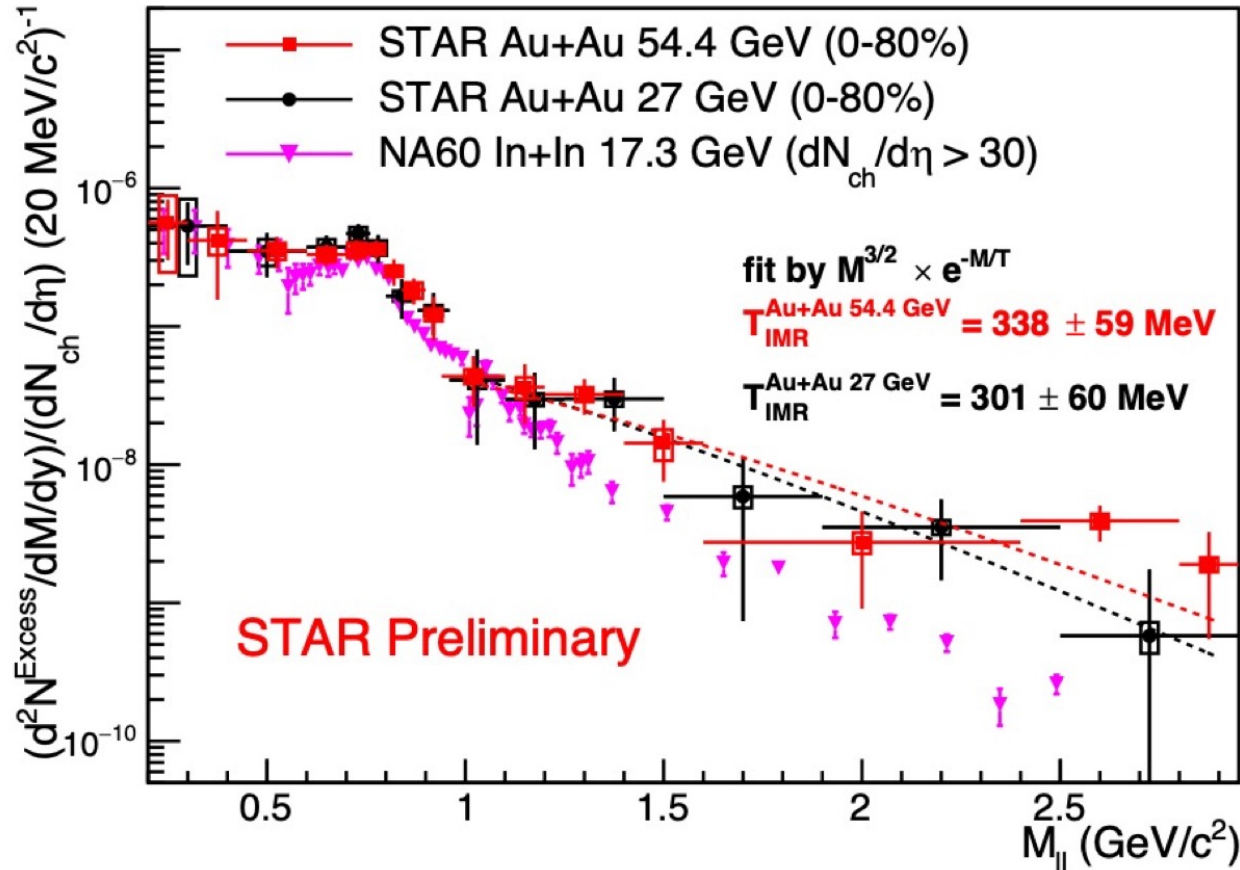NA60: EPJC (2009) 59: 607–623

IMR

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
  - 54.4 GeV : 338 ± 59 MeV
  - 27 GeV : 301 ± 60 MeV

Temperature extraction form IMR

Excess = data - cocktail

- STAR Au+Au 54.4 GeV (0-80%)
- STAR Au+Au 27 GeV (0-80%)
- NA60 In+In 17.3 GeV ($dN_{ch}/d\eta > 30$)

fit by $M^{3/2} \times e^{-M/T}$

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STAR Preliminary

$(d^2N^{Excess}/dM/dy)/(dN_{ch}/d\eta)$ (20 MeV/c²)⁻¹ vs M_{ll} (GeV/c²)

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

IMR

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
  - 54.4 GeV : 338 ± 59 MeV
  - 27 GeV : 301 ± 60 MeV

- ✓ T is higher than the pseudo critical temperature T_{pc} (156 MeV), supporting that the emission is predominantly from deconfined partonic phase
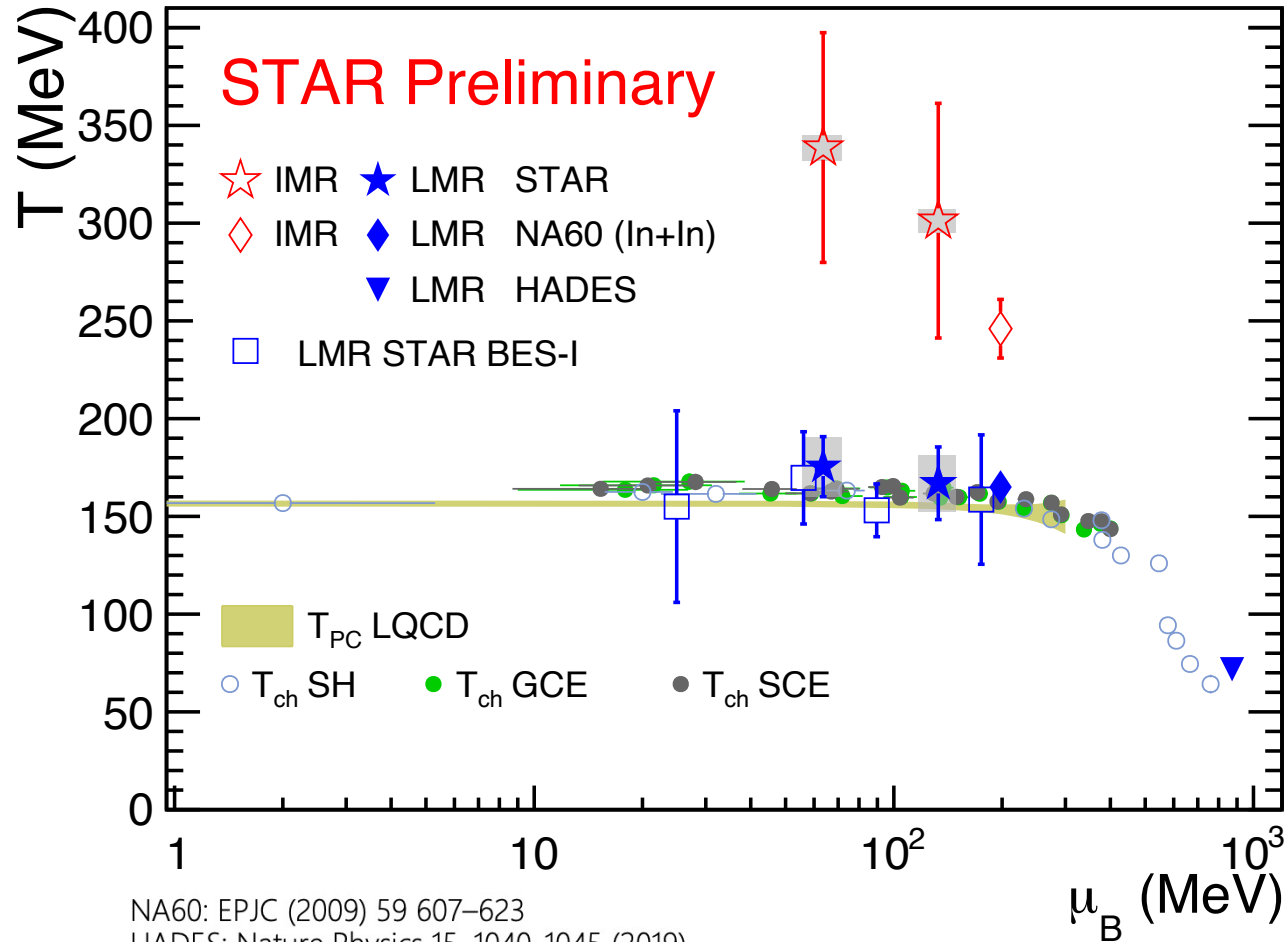
Temperature v.s. N_{part}
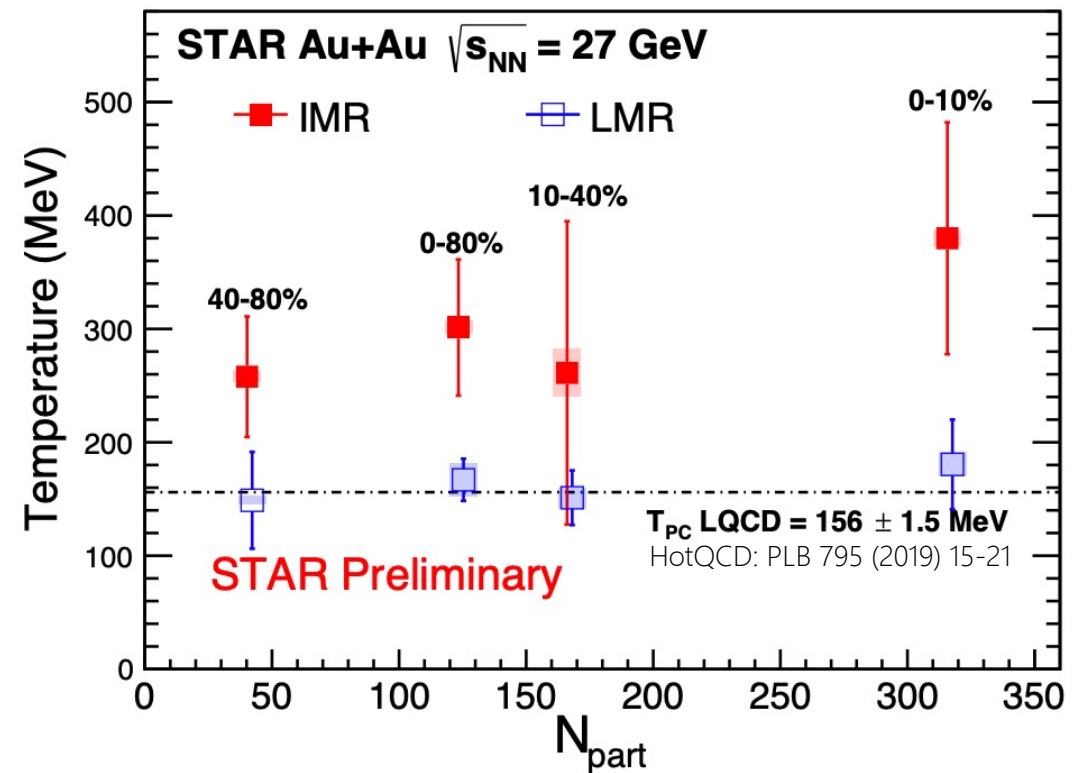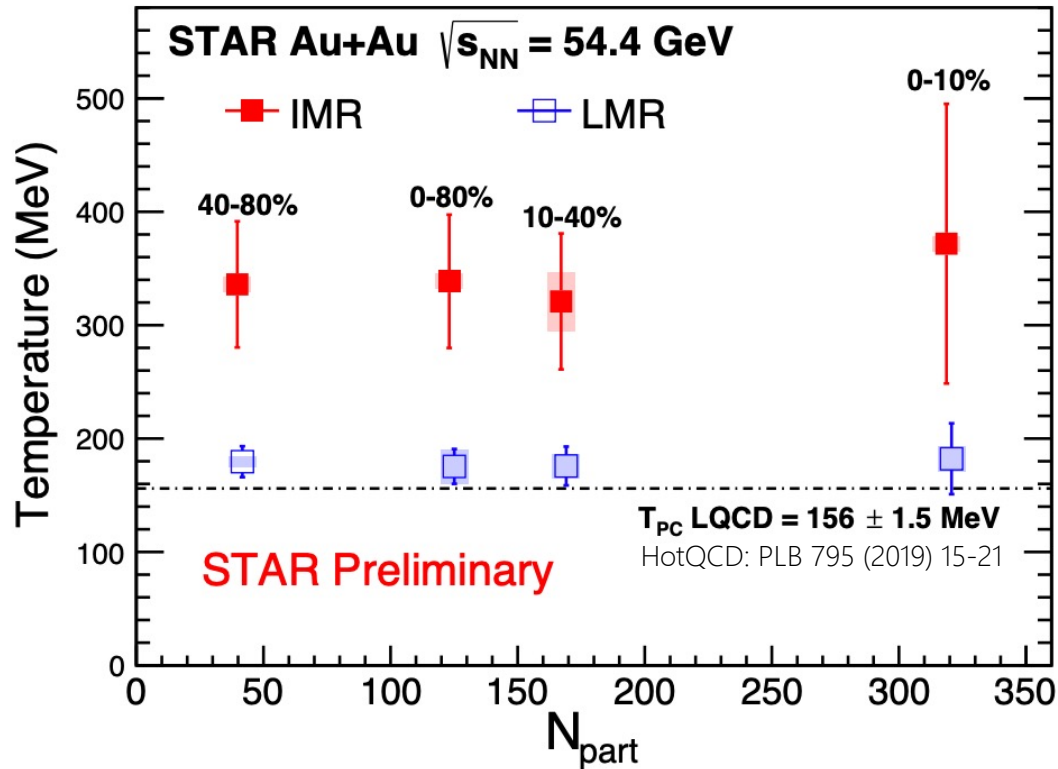
No clear centrality dependence in both mass regions

✓ 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

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
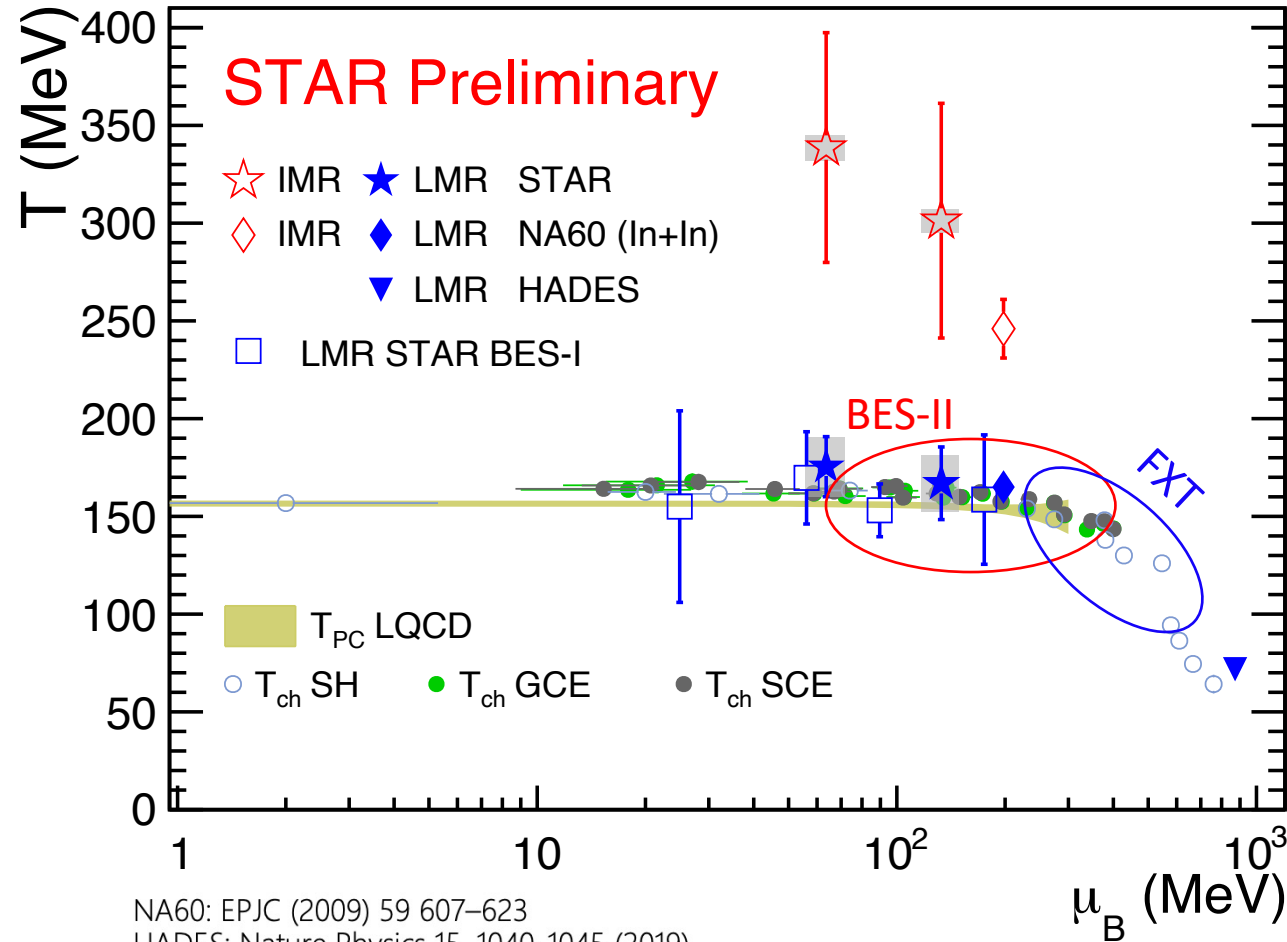
Thermal dielectrons in IMR:

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

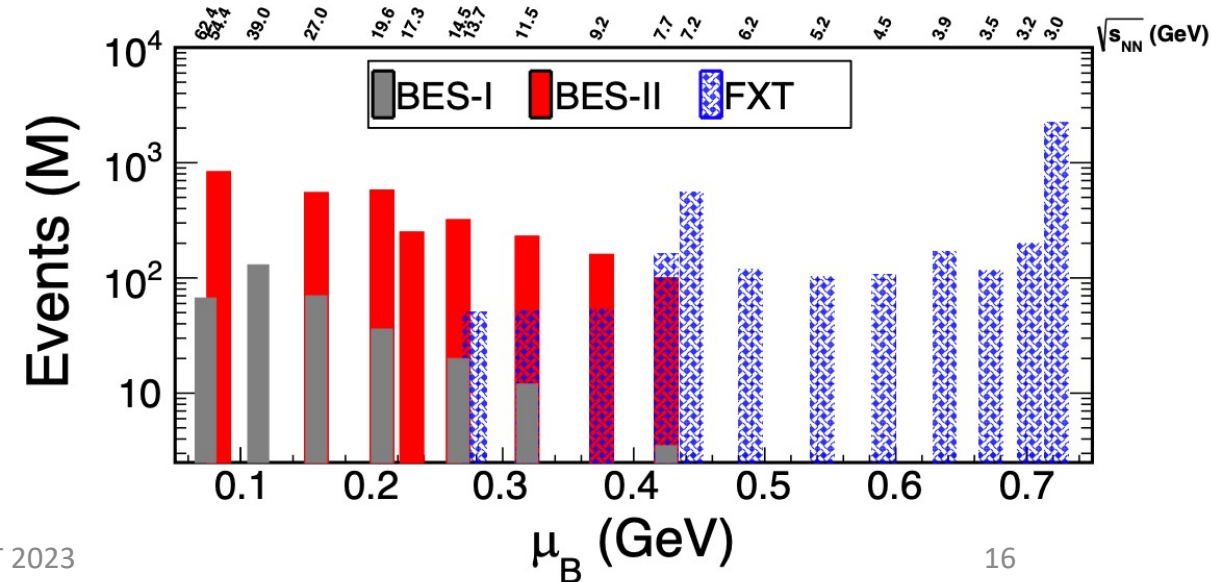T_{ch} : Chemical freeze-out temperature
T_{pc} : Pseudo critical temperature

In-plot text:

STAR Preliminary

☆ IMR ★ LMR STAR
◇ IMR ◆ LMR NA60 (In+In)
         ▼ LMR HADES
☐ LMR STAR BES-I

T_{PC} LQCD
○ T_{ch} SH   ● T_{ch} GCE   ● T_{ch} SCE

T (MeV)
μ_B (MeV)

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)

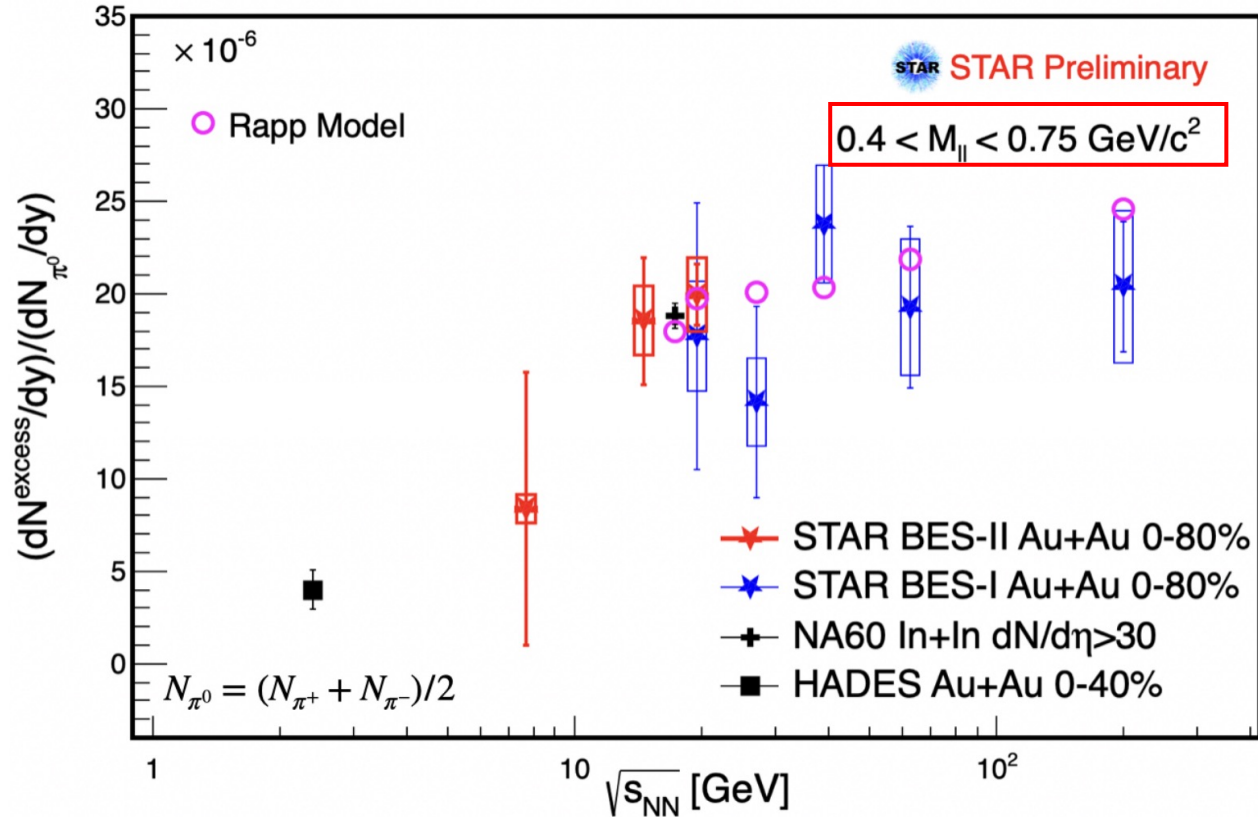# Dielectron measurements with STAR BES-II and FXT program

STAR Preliminary

✓ BES-II and FXT data will cover the large gap between the STAR and HADES data

Tch GCE/SCE: STAR PRC 96, 044904 (2017)

Dielectron measurements with STAR BES-II and FXT program

- ✓ 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
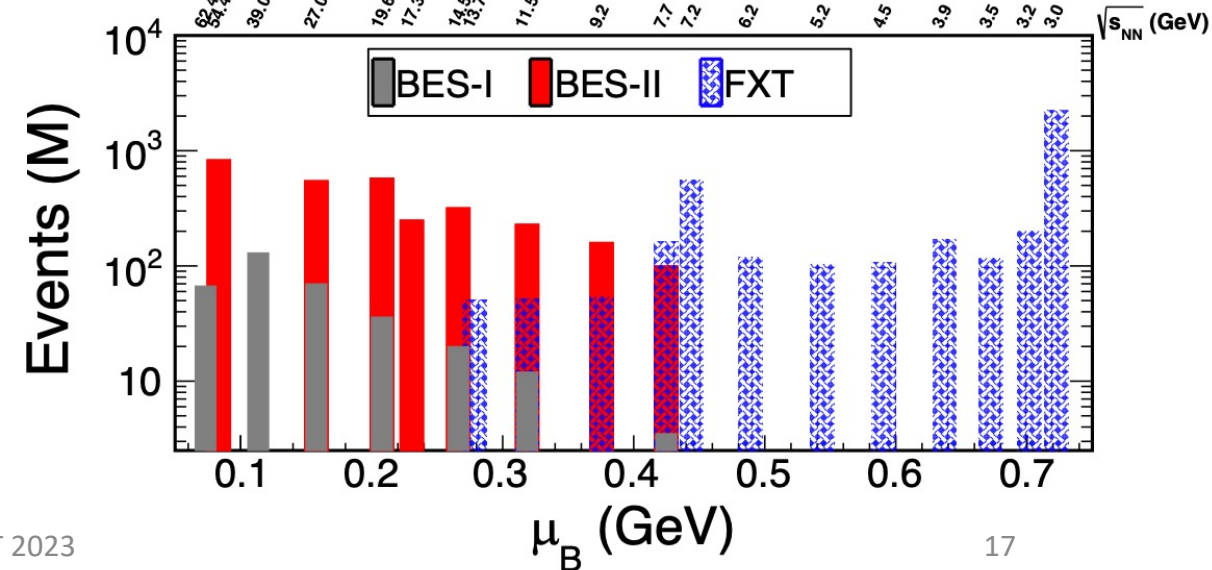
Summary

Low mass region:

✓ **T_{LMR} : 54.4 GeV : 338 ± 59 MeV**

          27 GeV : 301 ± 60 MeV

✓ First experimental evidence that in-medium ρ is predominantly produced around phase transition

Intermediate mass region:

✓ **T_{IMR} :54.4 GeV : 338 ± 59 MeV**

          27 GeV : 301 ± 60 MeV

✓ First QGP temperature measurement at RHIC without distortion by medium flow

✓ $T > T_{pc}$, radiation source is predominantly QGP thermal radiation