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

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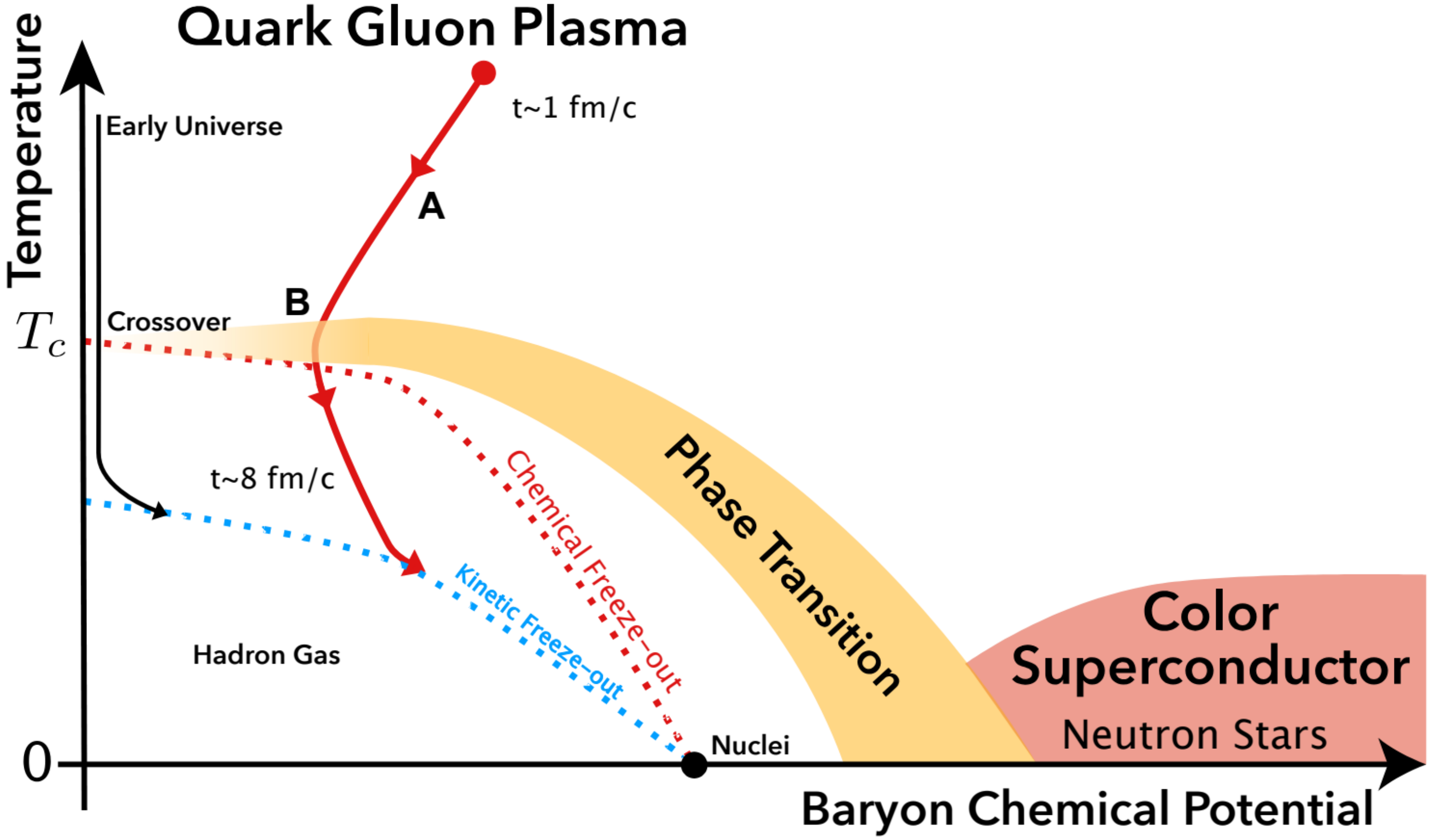
Shandong University

Spicy Gluons (胶麻) 2024

QCD phase diagram

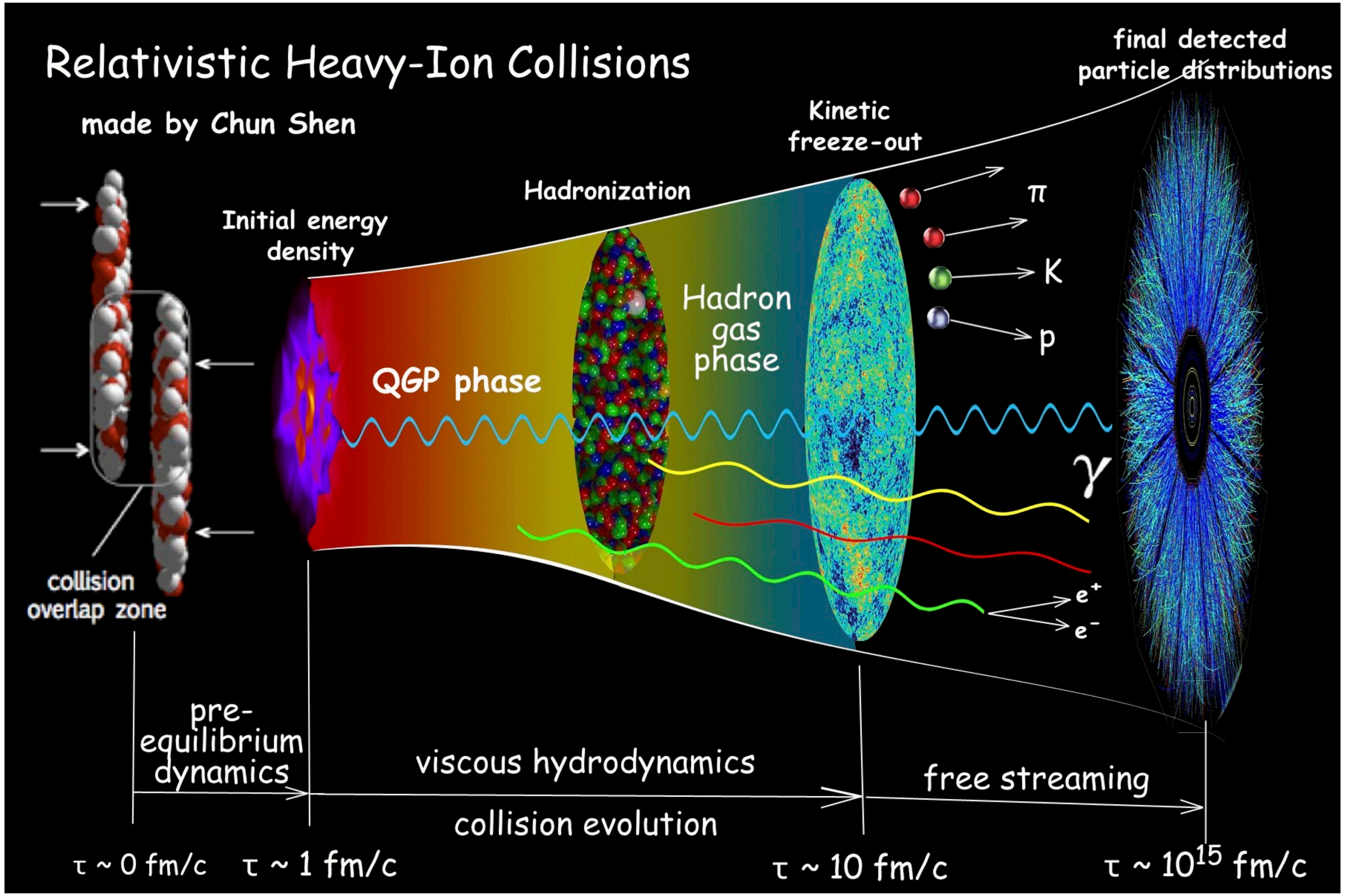


STAR, arXiv: 2402.01998

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

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

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

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

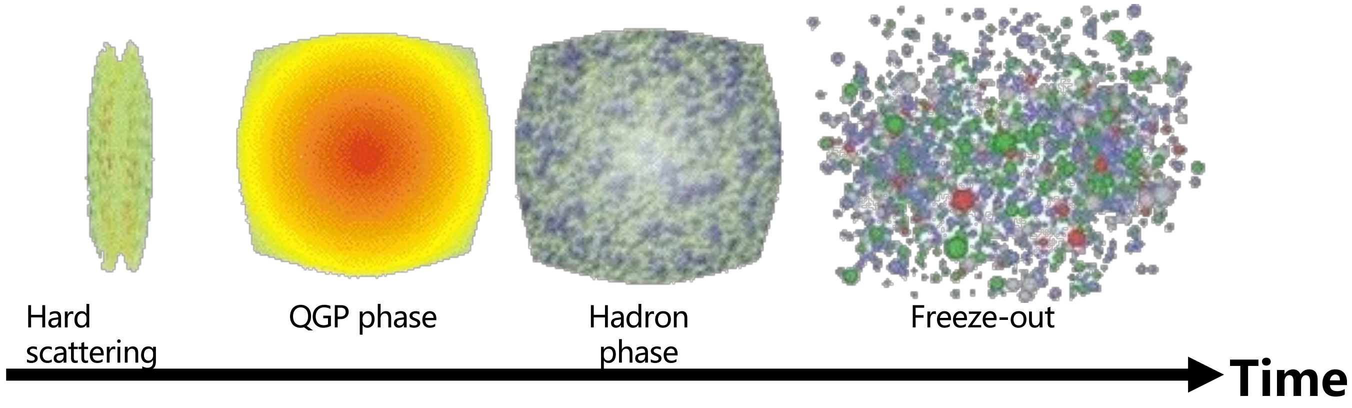
Extract the information from the final detected particles

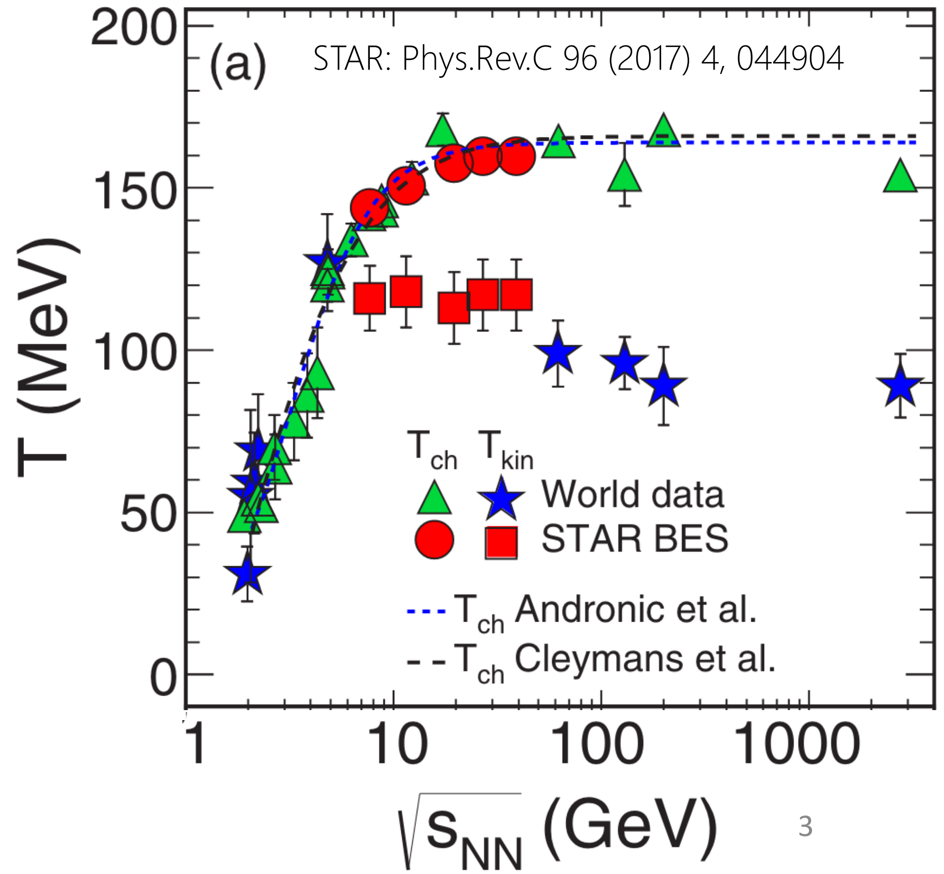
How to measure temperature

Hadrons
yields , p_T spectra

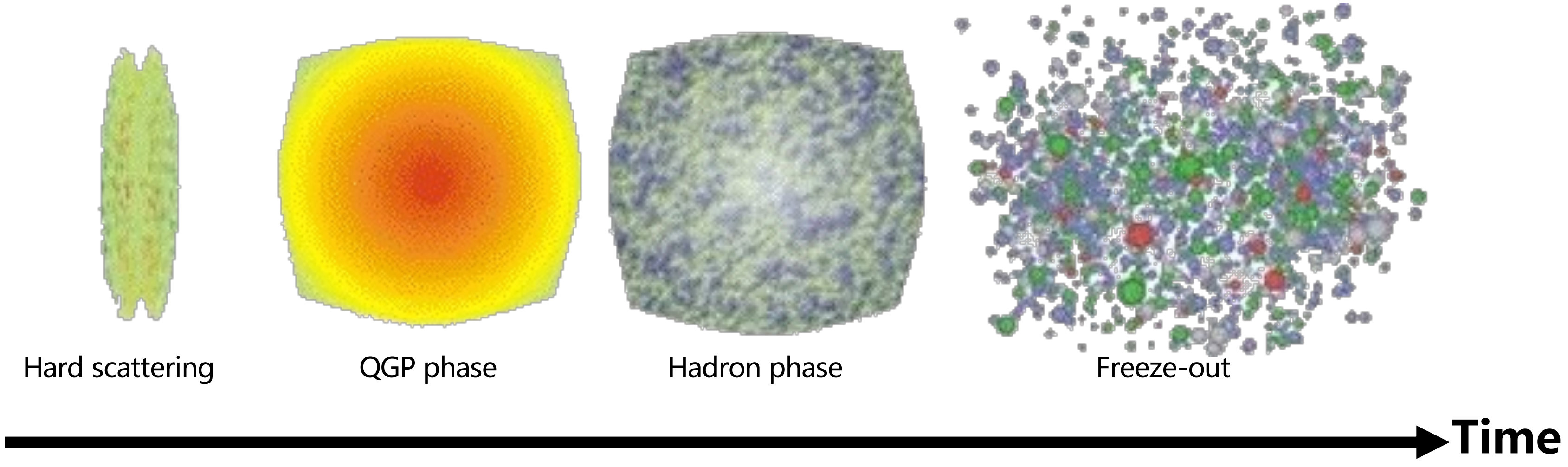
Hadrons:

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





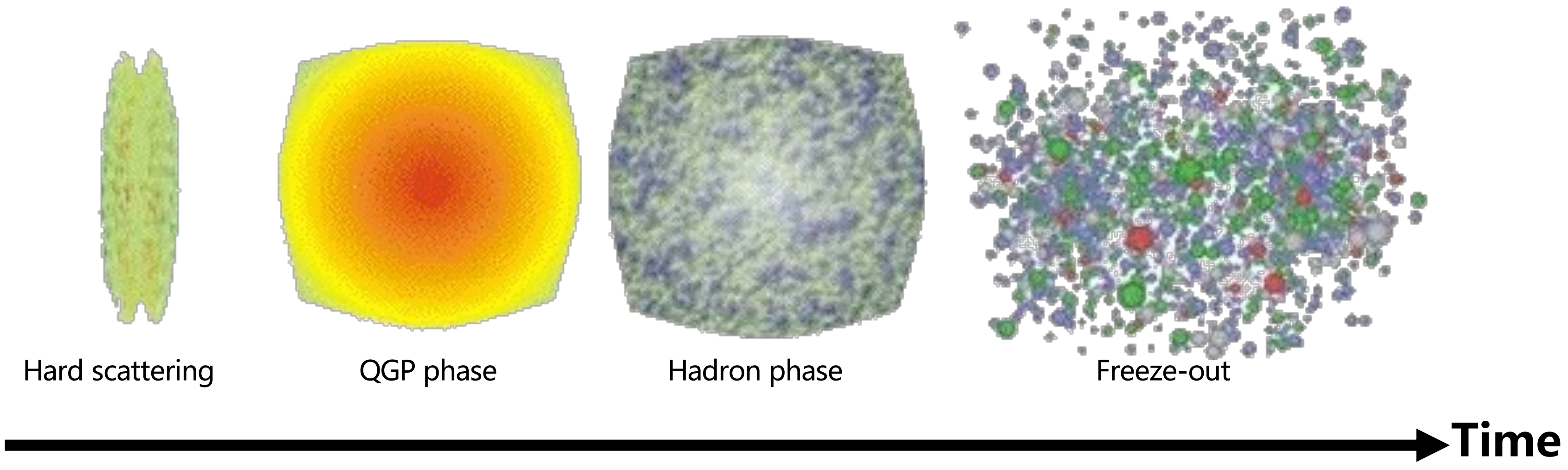
How to measure temperature



Electromagnetic Probes:

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

How to measure temperature



Photons
p_T spectra

Dileptons
M_{ll} spectra

Electromagnetic Probes:
- ✓ Emitted from early stage to final stage
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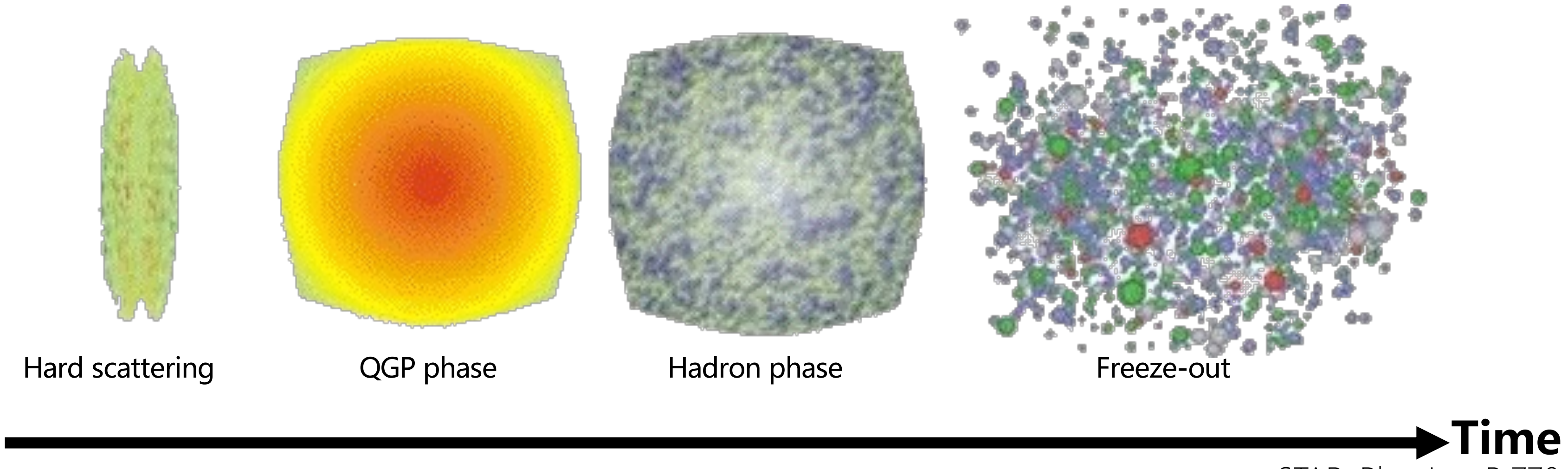
How to measure temperature



Photons

p_T spectra

Dileptons

M_{ll} spectra

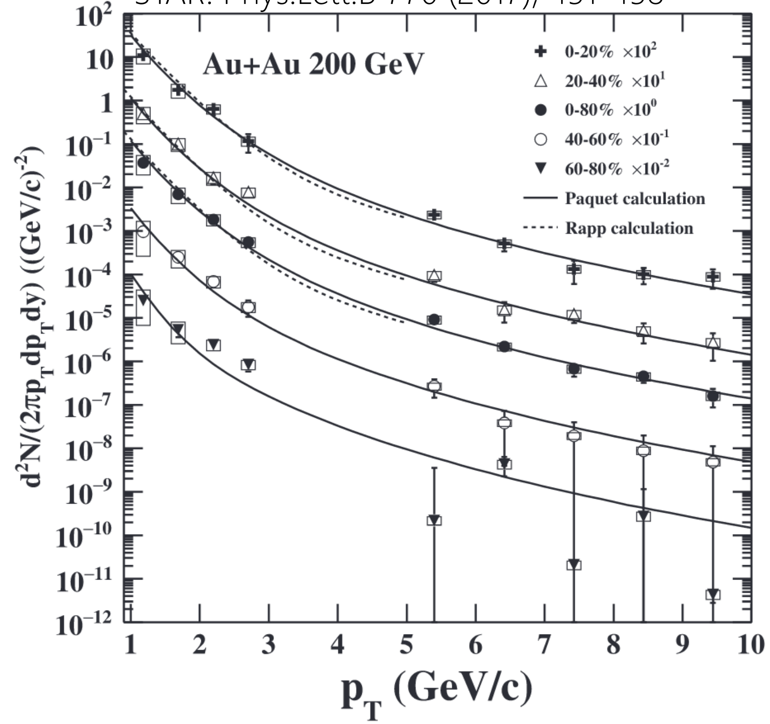
Electromagnetic Probes:

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

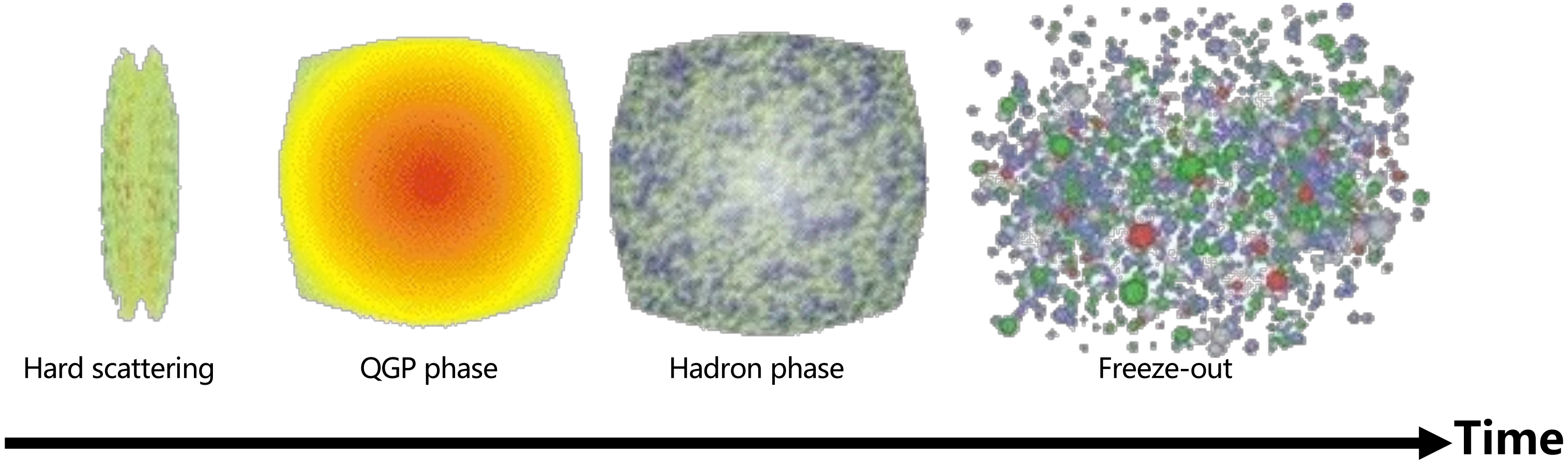
Photons:

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

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



How to measure temperature



Photons

p_T spectra

Dileptons

M_{ll} spectra

Electromagnetic Probes:

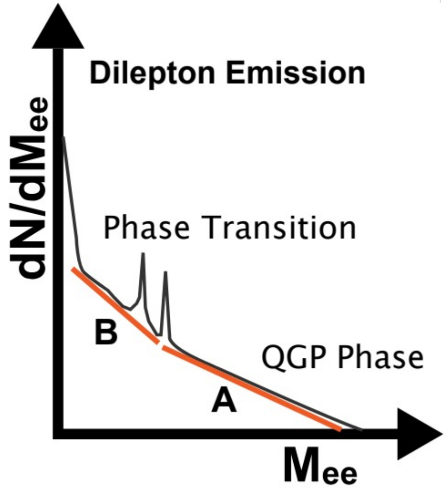
- ✓ Emitted from early stage to final stage
- ✓ Minimal interaction with medium

Photons:

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

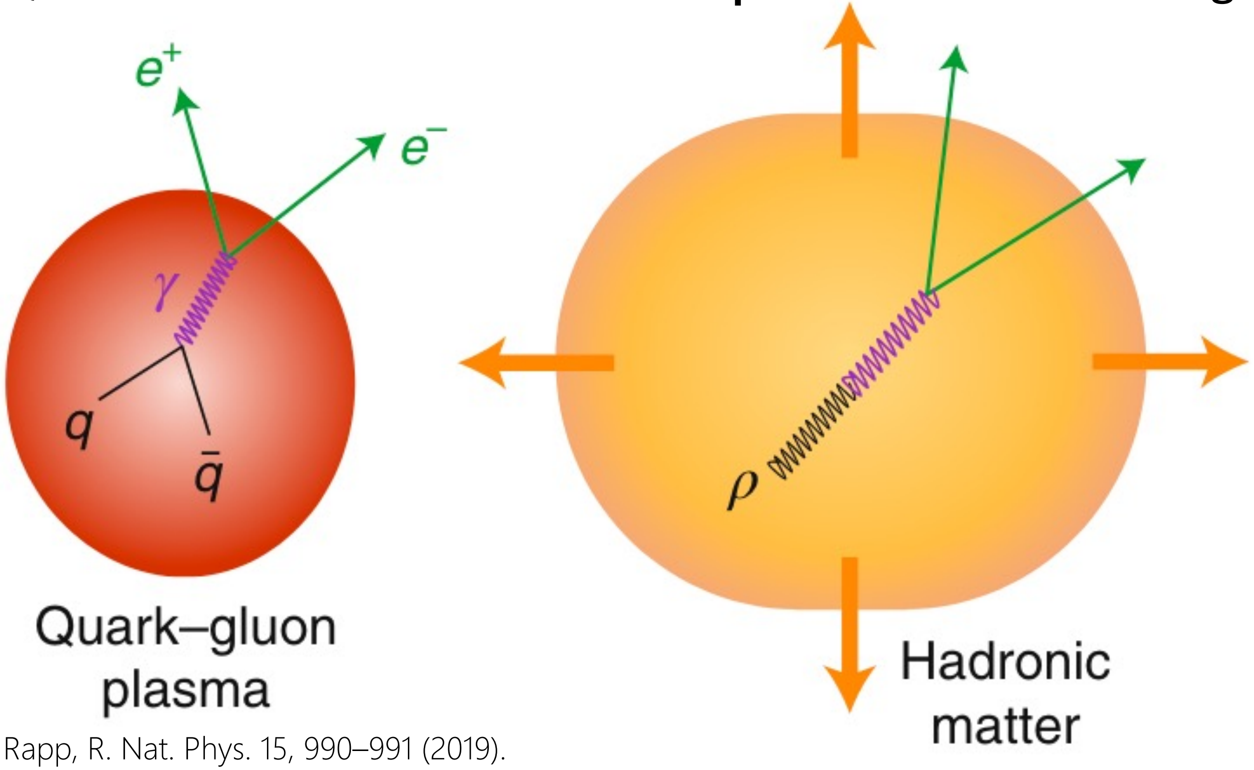
Dileptons:

- ✓ 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 $* e^{-M/T}$



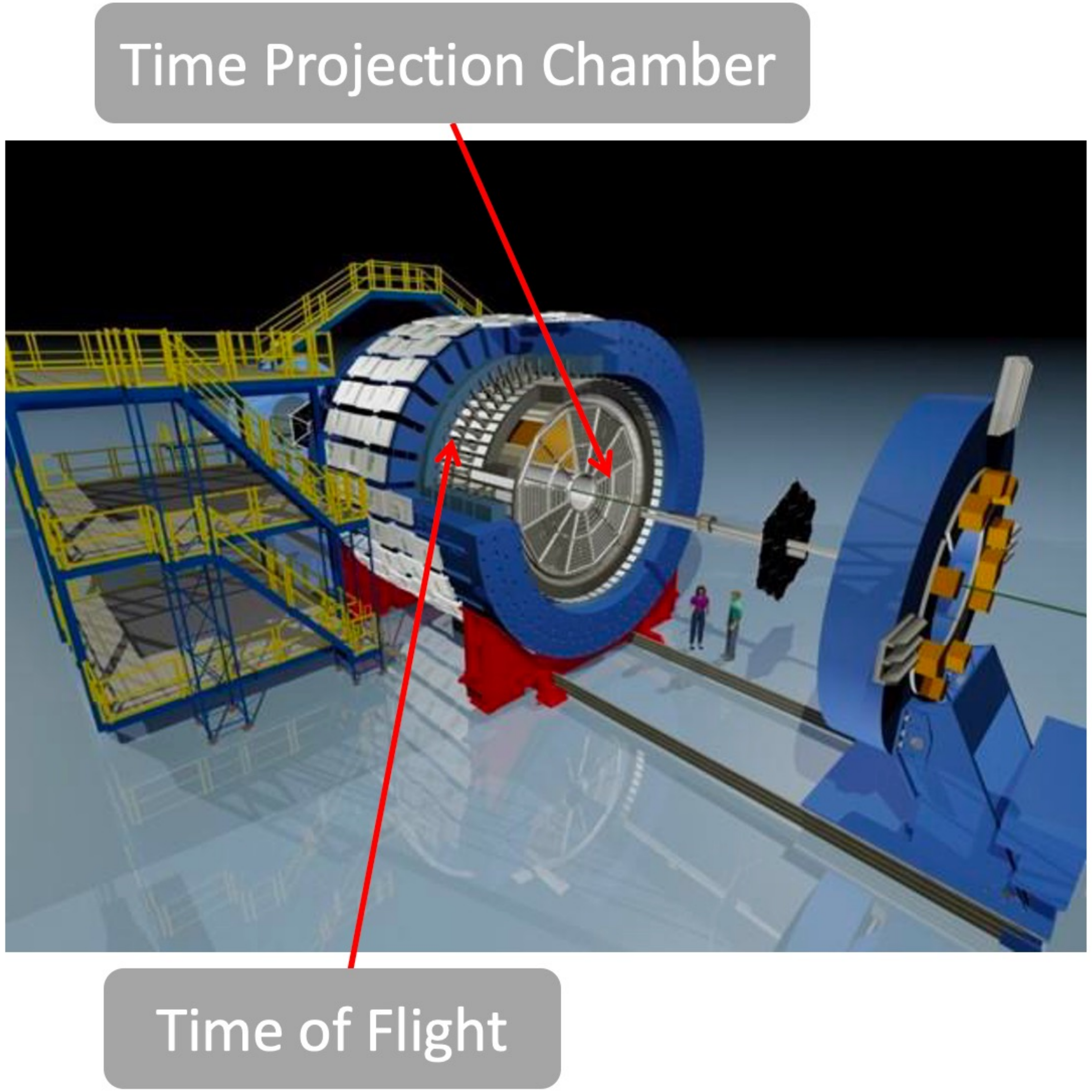
Rapp, R. Nat. Phys. 15, 990–991 (2019).

inclusive dileptons

Interested signals	**Physical backgrounds (hadronic cocktails)**
• QGP radiation • In-medium ρ	• 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

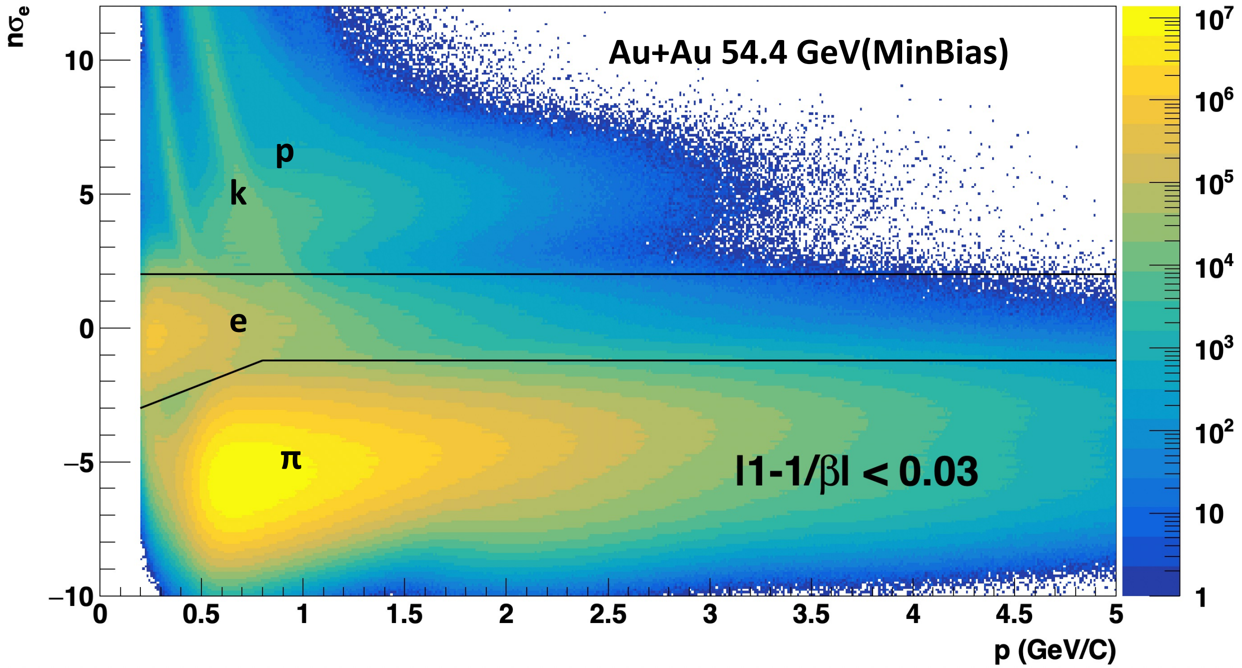
Invariant mass spectra from thermal dileptons can reveal temperature of the hot medium at both **QGP phase** and **hadronic phase**

STAR experiment and eID



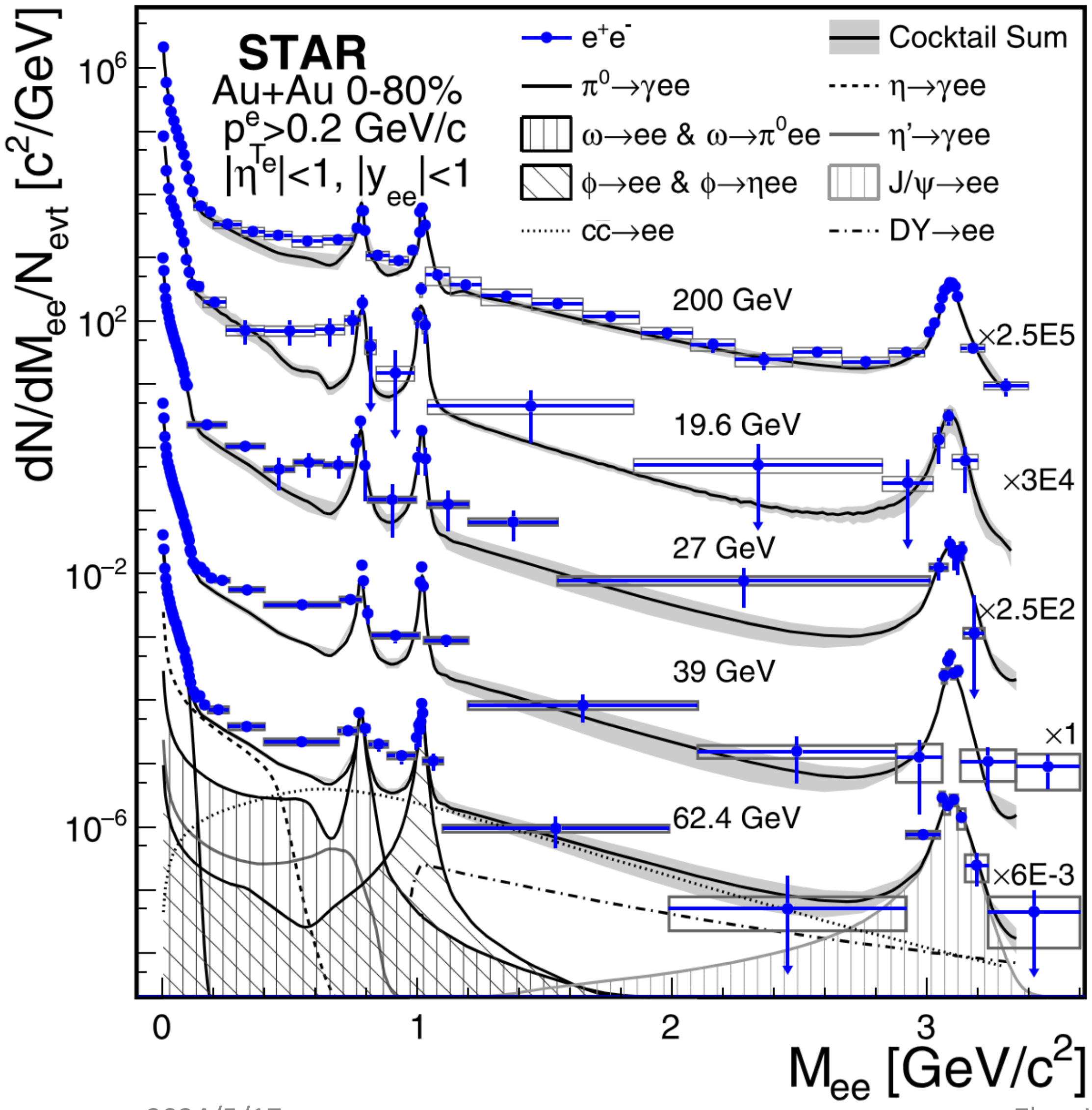
Time Projection Chamber + Time of Flight

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



STAR BES-I Dielectron measurements

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



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

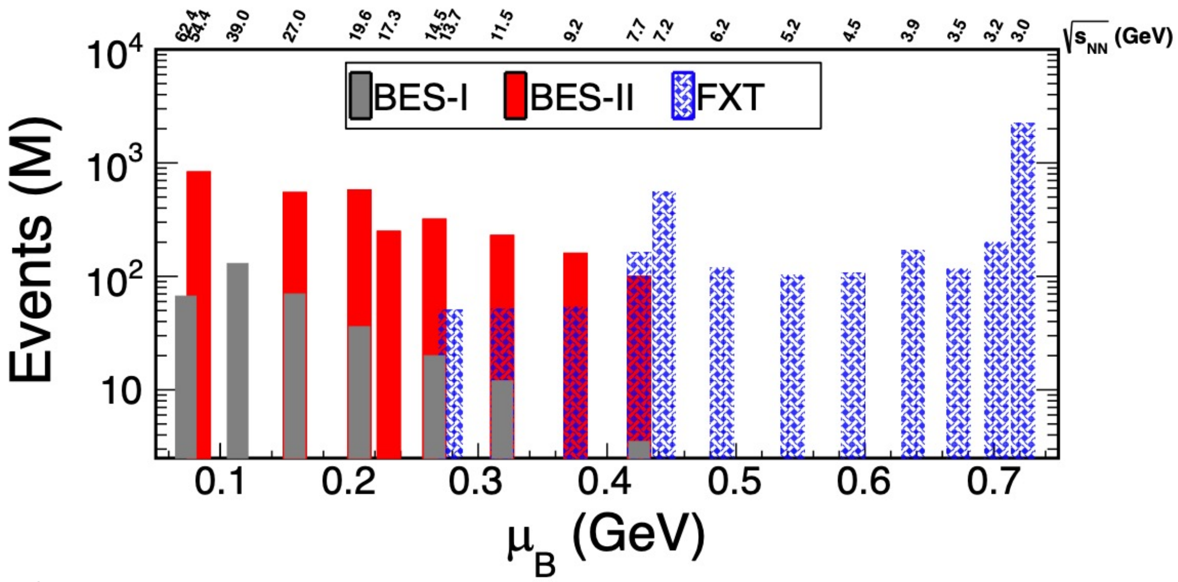
- High statistics
- Hard to extract excess yield in intermediate mass region

$\sqrt{s_{NN}}$ = 19.6 – 62.4 GeV :

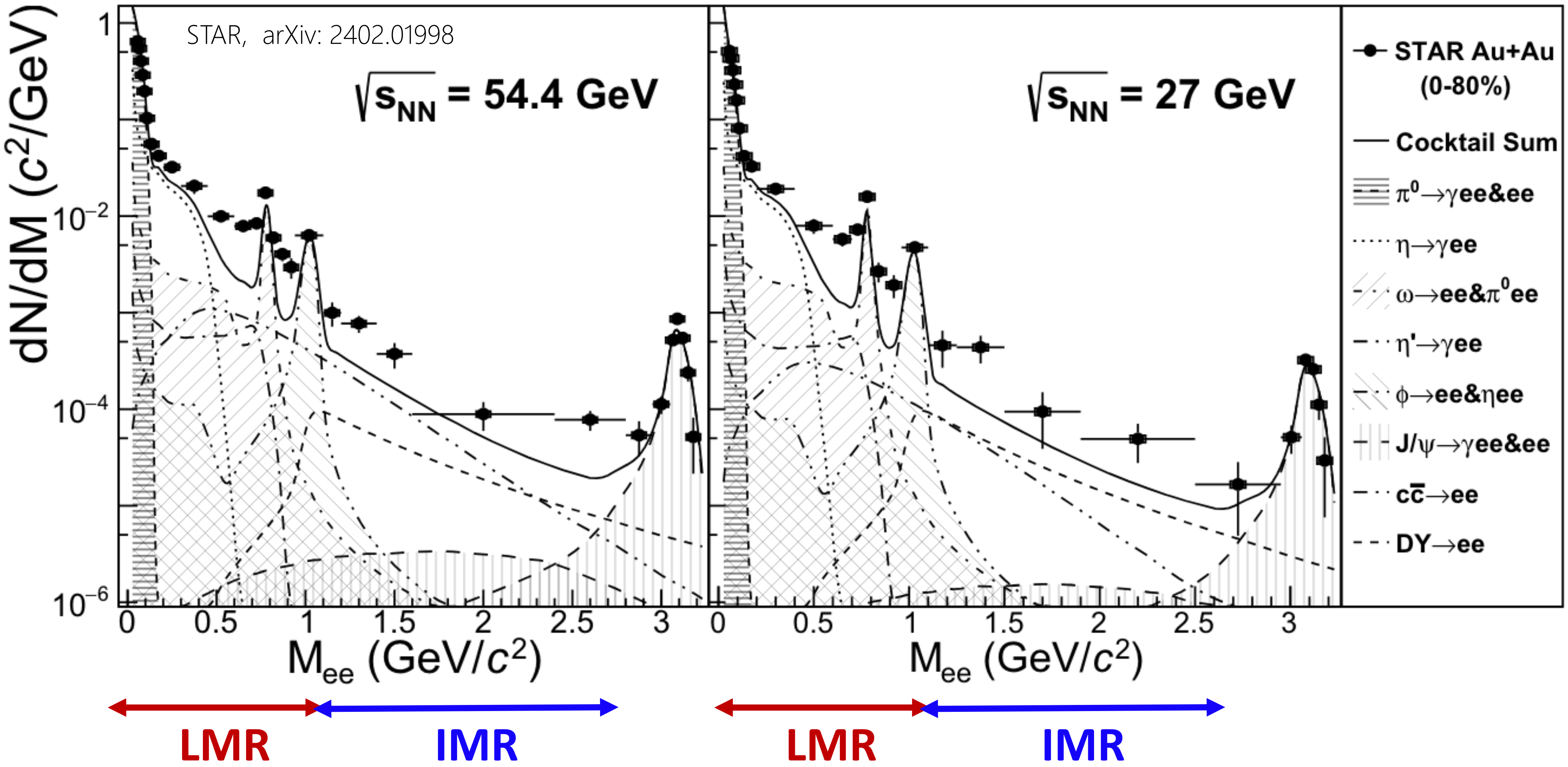
- Lack of statistics

BES–II :

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



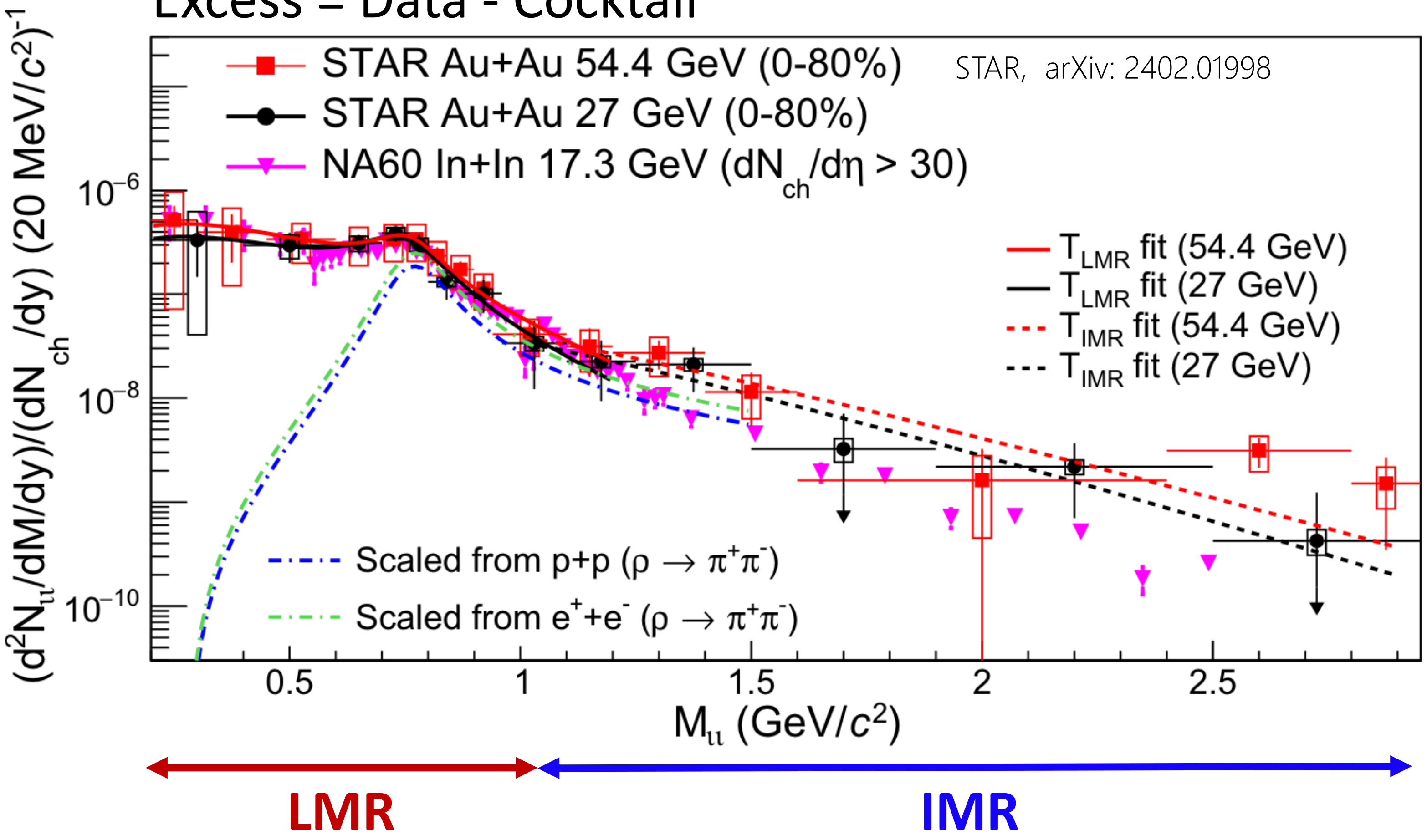
Dielectron spectra



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

Excess yield

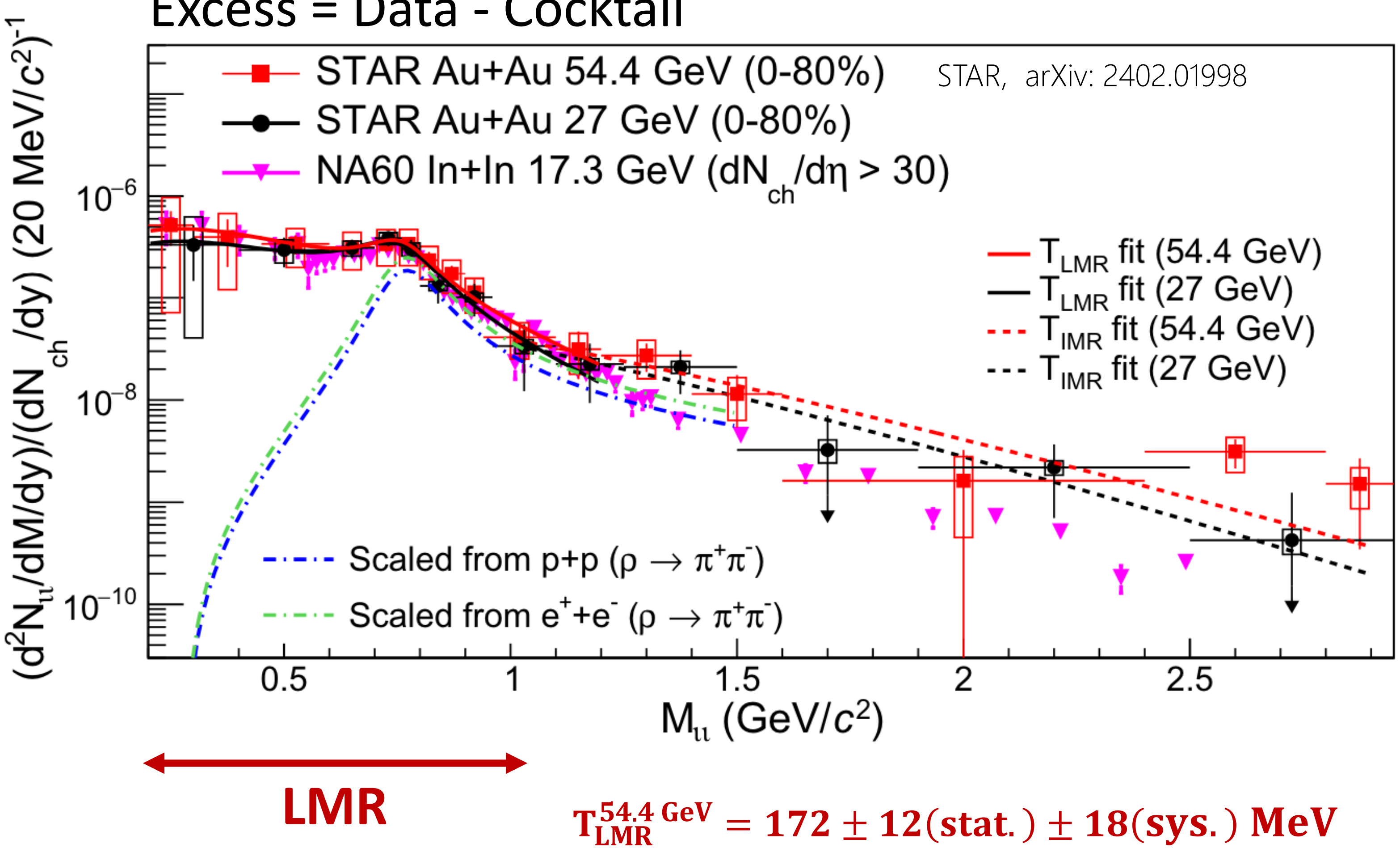
Excess = Data - Cocktail



Excess dilepton spectra at LMR in 27 and 54.4 GeV Au+Au collisions and 17.3 GeV In+In collisions are similar

Temperature extraction from LMR

Excess = Data - Cocktail



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

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

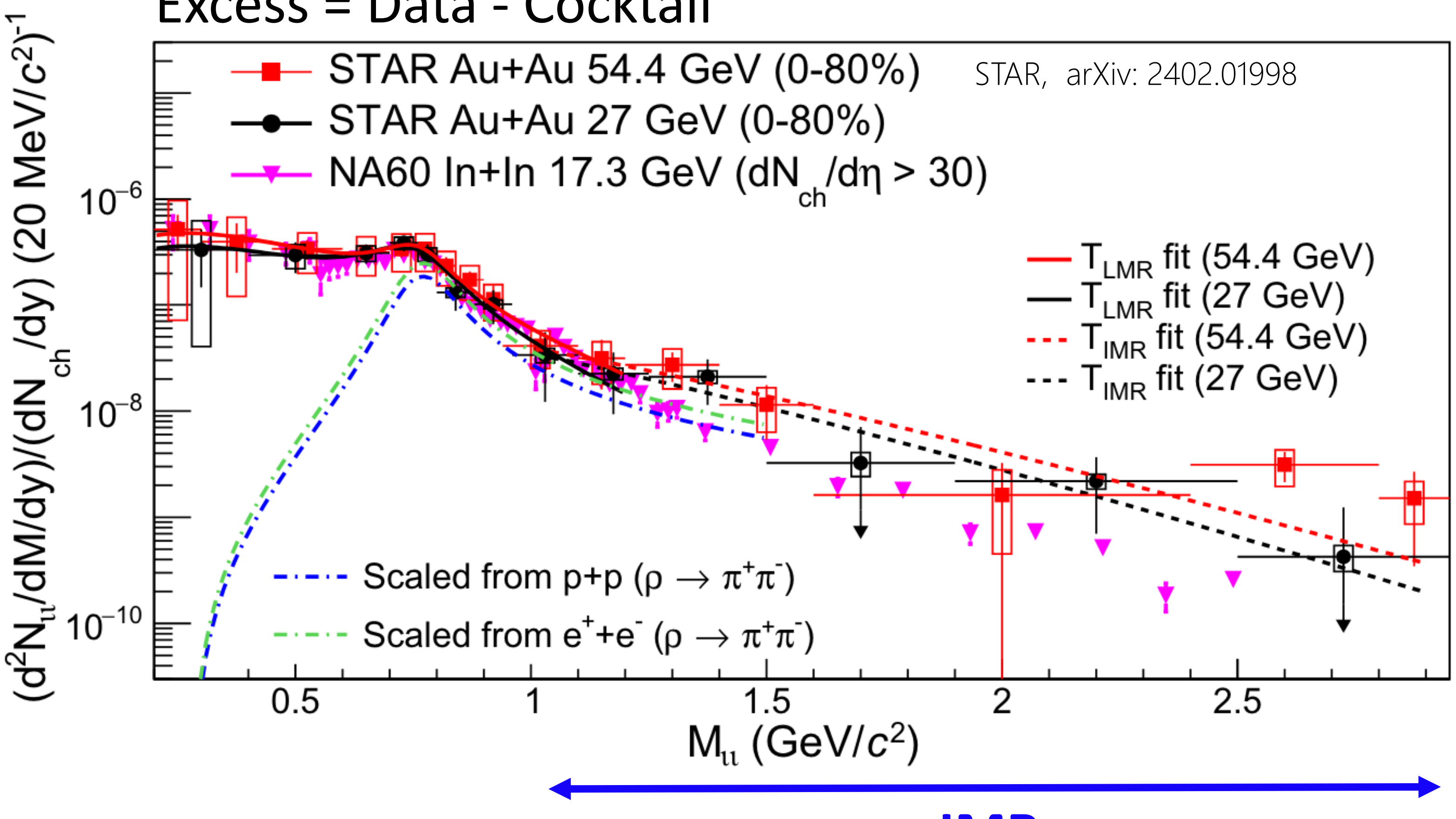
Low mass region:

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

- ✓ 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 from IMR

Excess = Data - Cocktail



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

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

Low mass region:

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

- ✓ 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)

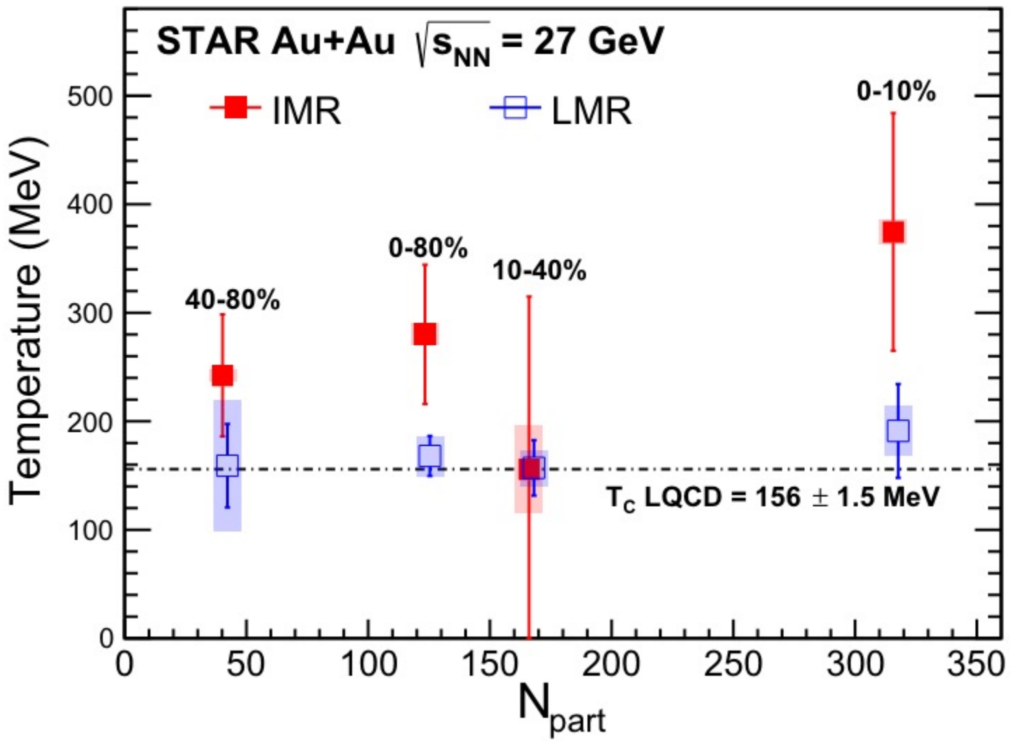
Intermediate mass region:

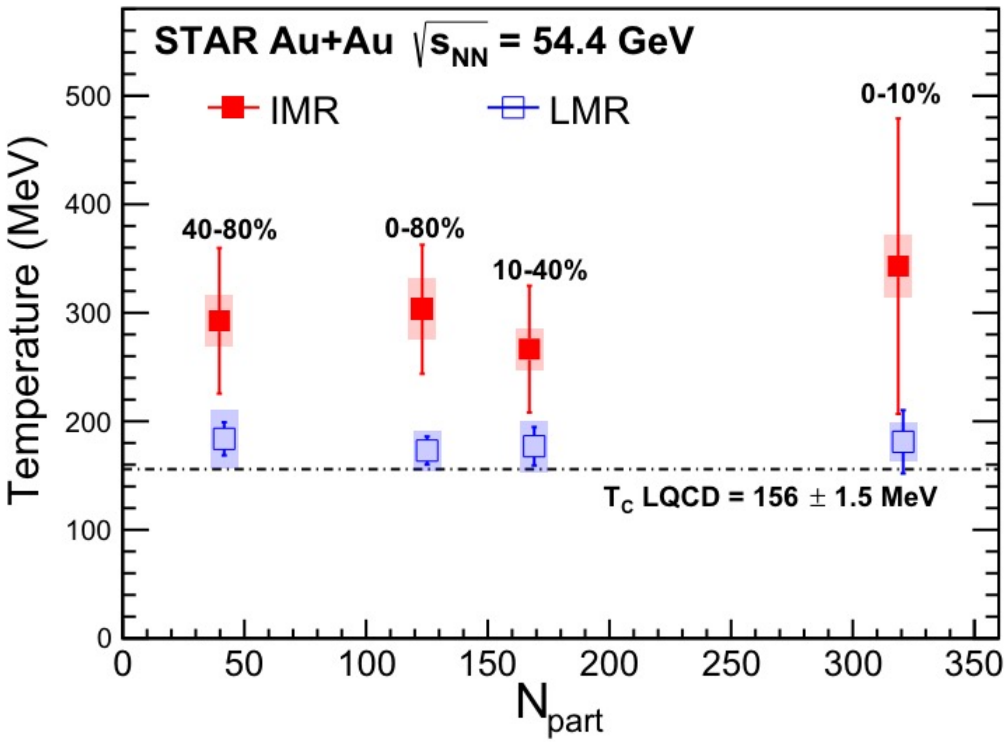
$M^{3/2} * e^{-M/T}$

- ✓ QGP thermal radiation is predicted to be the dominant source in the intermediate mass region
- ✓ 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}

STAR, arXiv: 2402.01998

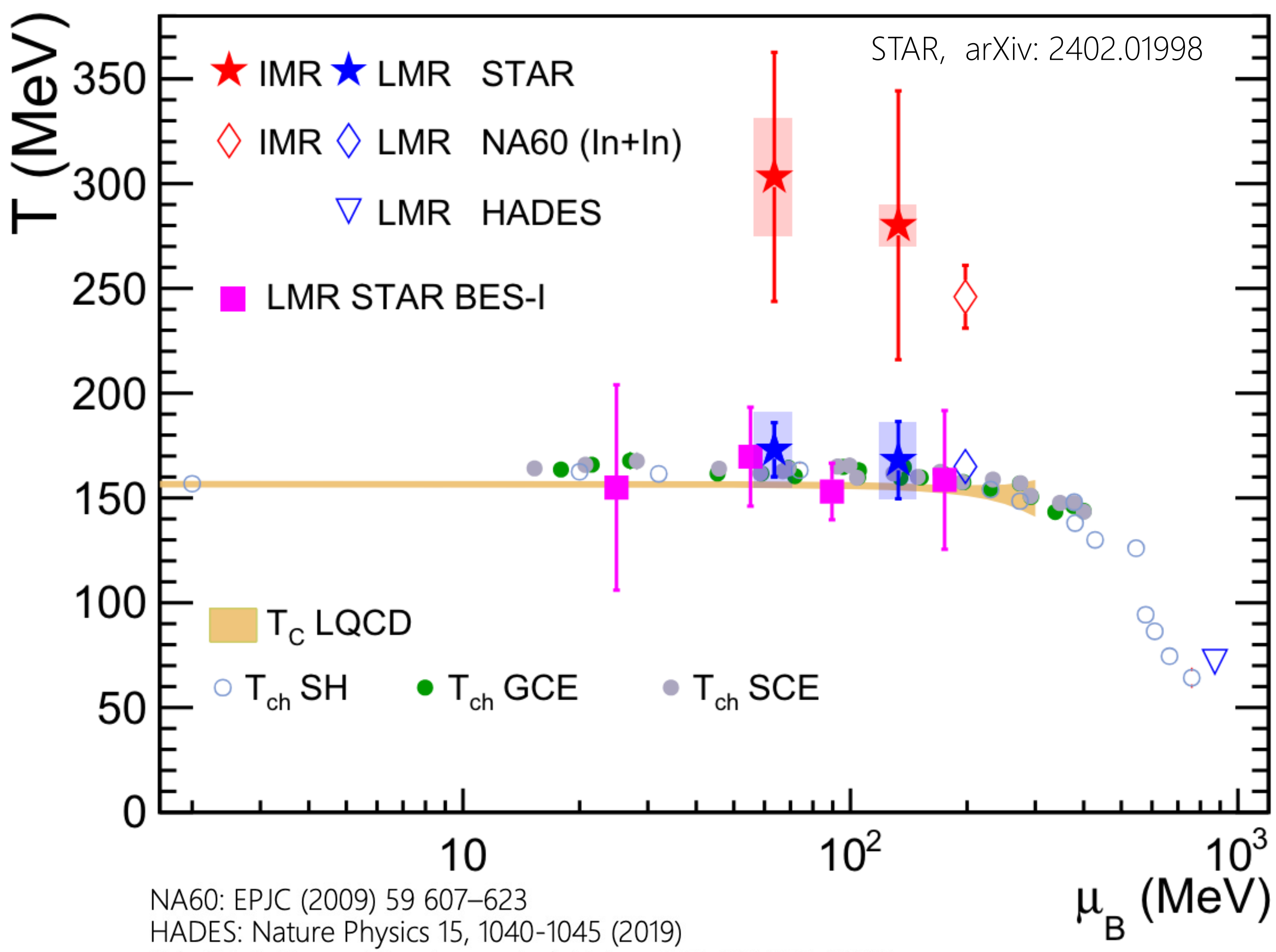




No clear centrality dependence in both mass regions

- ✓ 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:

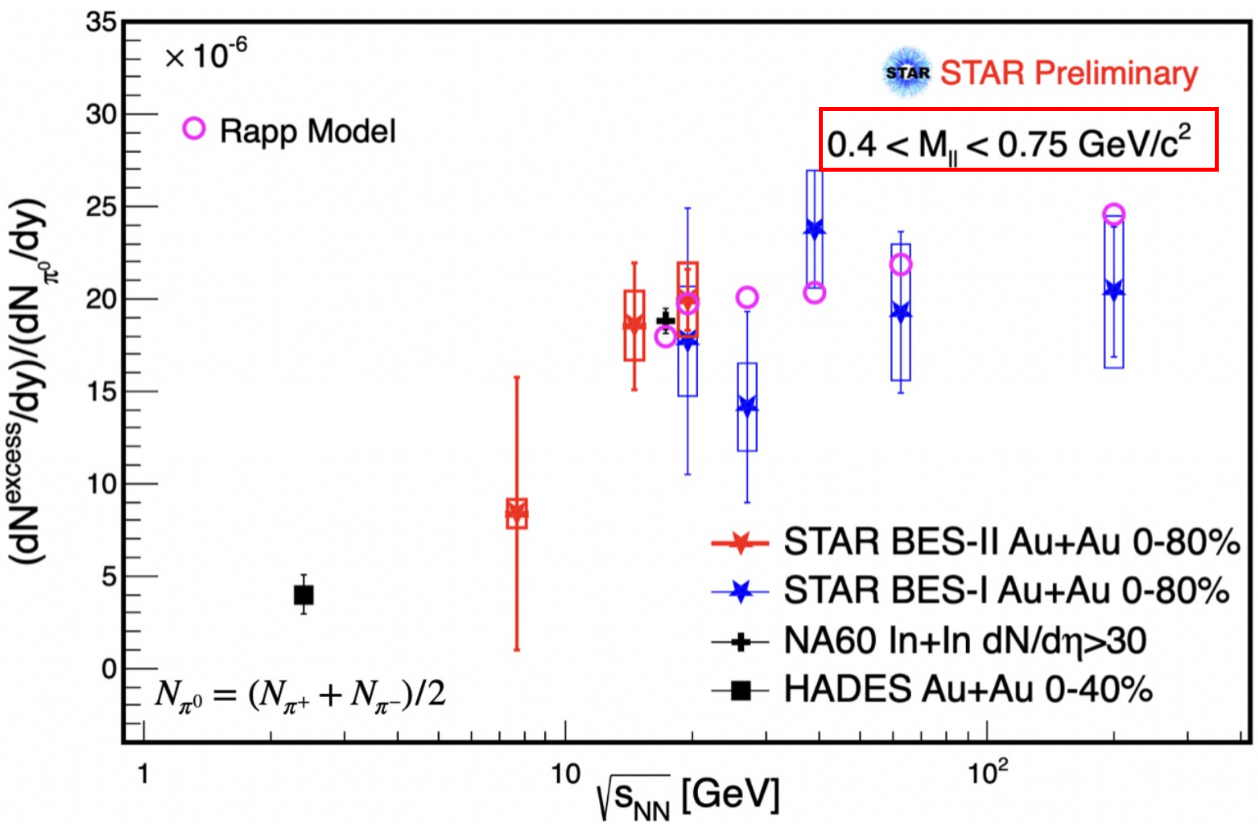
- ✓ T_{LMR} is close to the T_{pc} and T_{ch}
- ✓ Emitted form the hadronic phase, dominantly around the phase transition

Thermal dielectrons in IMR:

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

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

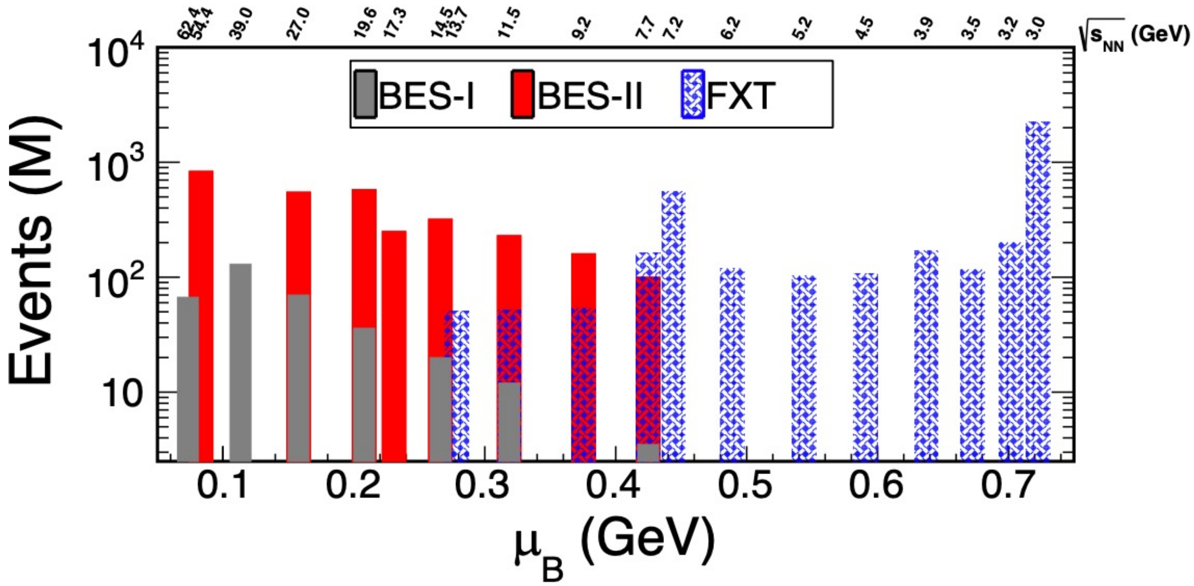
Dielectron measurements with STAR BES-II and FXT program



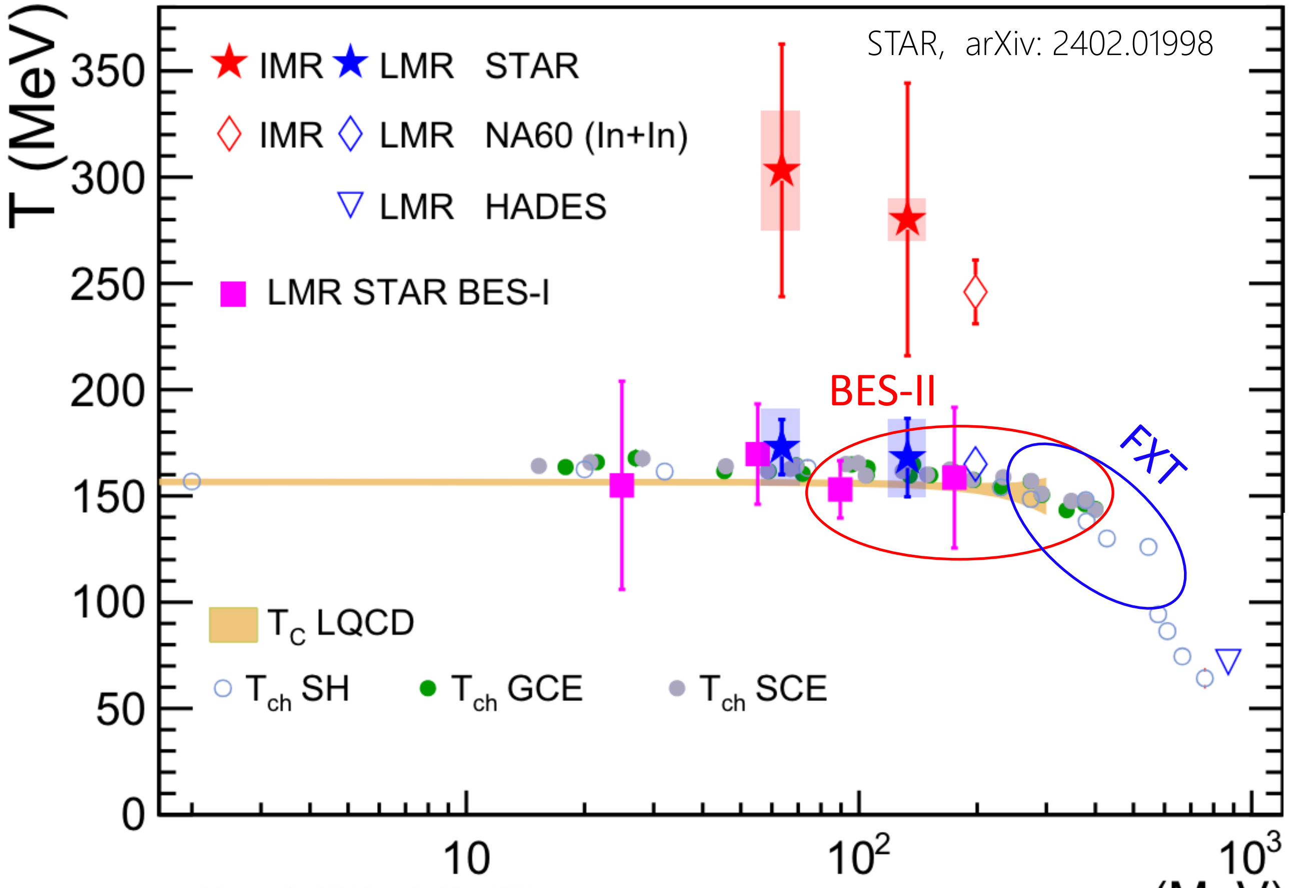
STAR: Phys. Rev. C 107, L061901 (2023)
STAR: PLB750 (2015) 64
NA60: EPJ C 59 (2009) 607
HADES: Nat. Phys. 15, 1040–1045 (2019)

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

- ✓ 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



Dielectron measurements with STAR BES-II and FXT program



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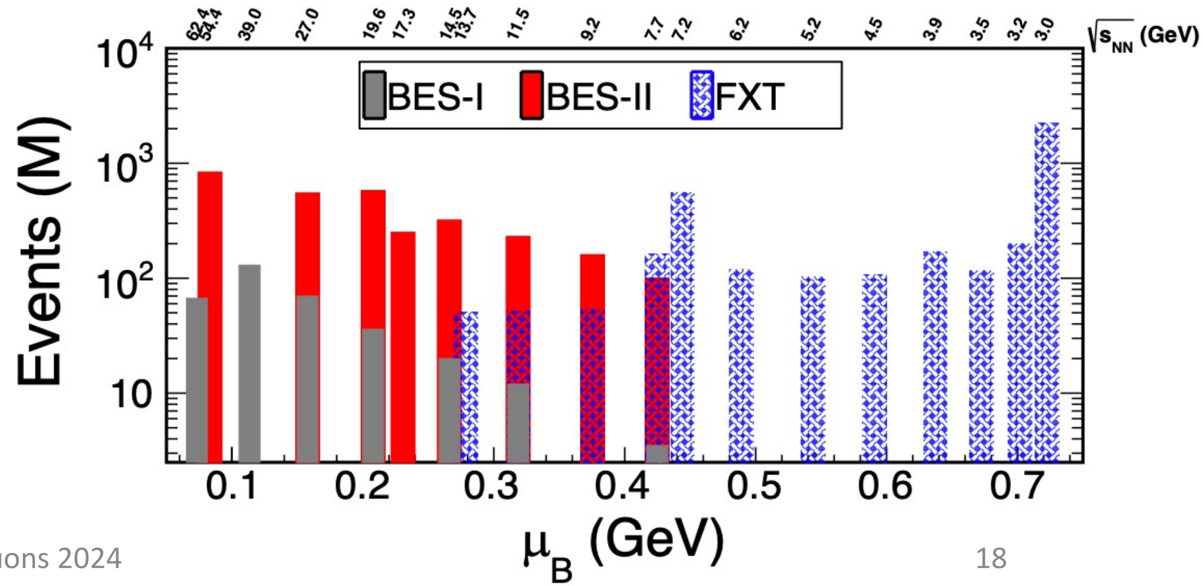
- ✓ BES-II and FXT data will cover the large gap between the STAR and HADES data
- ✓ The normalized integrated excess yields in mass window $0.4<M_{ee}<0.75$ GeV/c^2 were obtained
- ✓ Working on T extraction with BES-II data



Summary

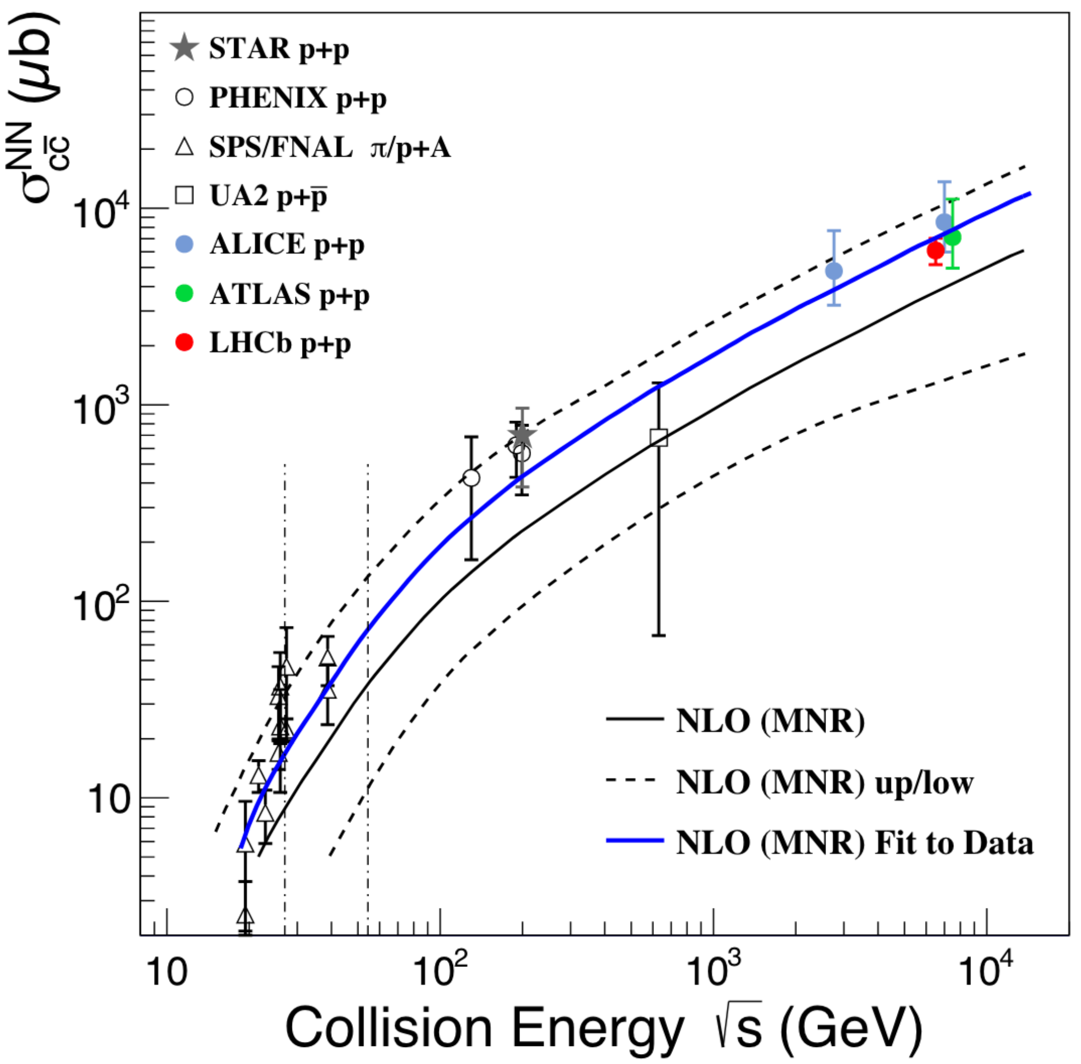
Low mass region:

- ✓ T_{LMR} : 54.4 GeV : 172 ± 12 ±18 MeV
  27 GeV : 167 ± 21 ± 28 MeV
- ✓ First experimental evidence that in-medium ρ is predominantly produced around phase transition

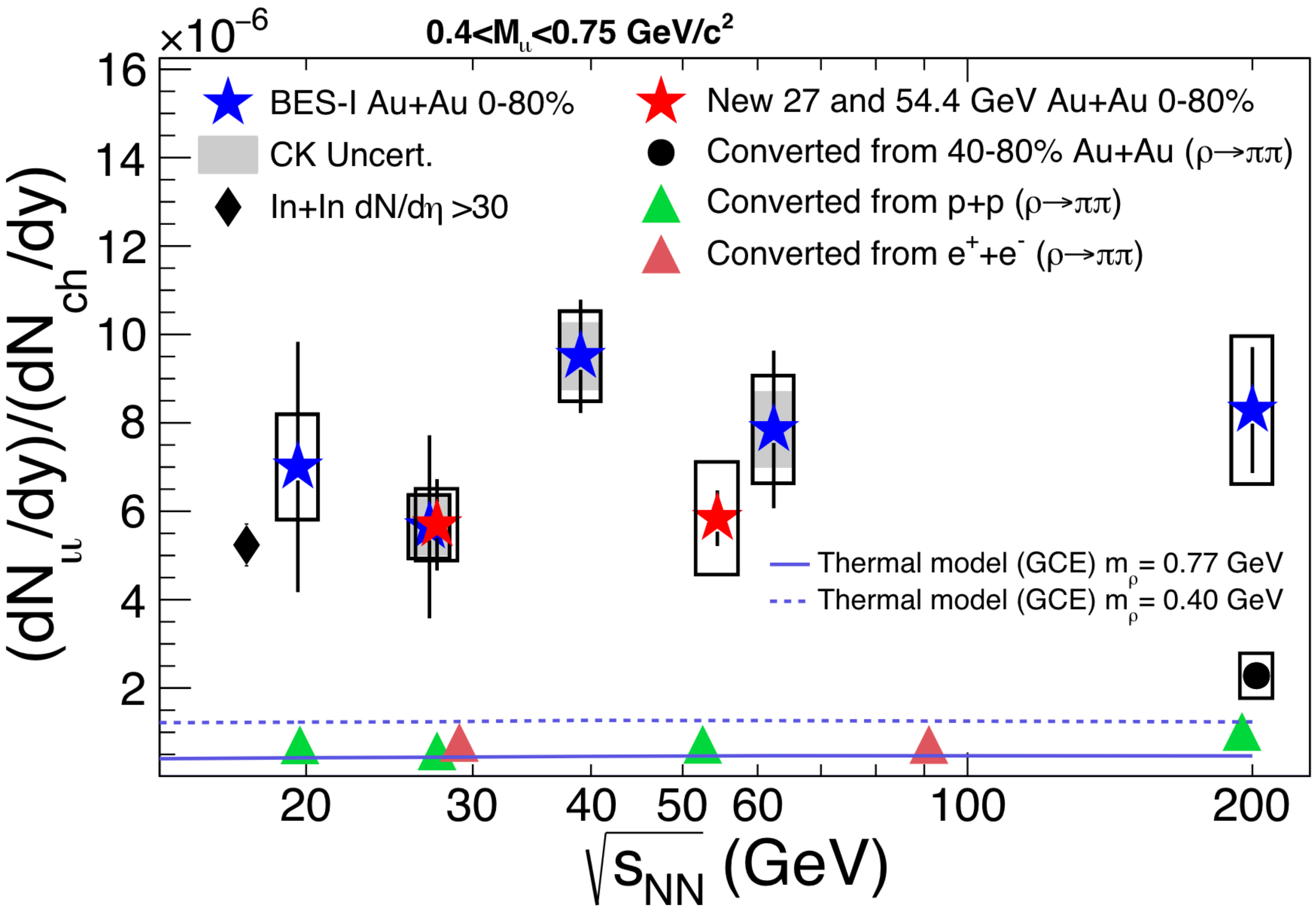
Intermediate mass region:

- ✓ T_{IMR} :54.4 GeV : 303 ± 59 ± 28 MeV
  27 GeV : 280 ± 64 ± 10 MeV
- ✓ First QGP temperature measurement at RHIC without distortion by medium flow
- ✓ $T > T_{pc}$, radiation source is predominantly QGP thermal radiation

Backup


STAR p+p
PHENIX p+p
SPS/FNAL π/p+A
UA2 p+p̄
ALICE p+p
ATLAS p+p
LHCb p+p
NLO (MNR)
NLO (MNR) up/low
NLO (MNR) Fit to Data
$\sigma_{c\bar{c}}^{NN}$ (μb)
Collision Energy $\sqrt{s}$ (GeV)
10
10^2
10^3
10^4

Backup



×10⁻⁶
0.4<Mμμ<0.75 GeV/c²
BES-I Au+Au 0-80%
CK Uncert.
In+In dN/dη >30
New 27 and 54.4 GeV Au+Au 0-80%
Converted from 40-80% Au+Au (ρ→ππ)
Converted from p+p (ρ→ππ)
Converted from e⁺+e⁻ (ρ→ππ)
Thermal model (GCE) mρ = 0.77 GeV
Thermal model (GCE) mρ = 0.40 GeV
(dNμμ/dy)/(dNch/dy)
√sNN (GeV)
16
14
12
10
8
6
4
2
20
30
40
50
60
100
200