Temperature Measurements via Thermal Dileptons in Au+Au Collisions at 27 and 54.4 GeV with the STAR experiment

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Supported in part by the
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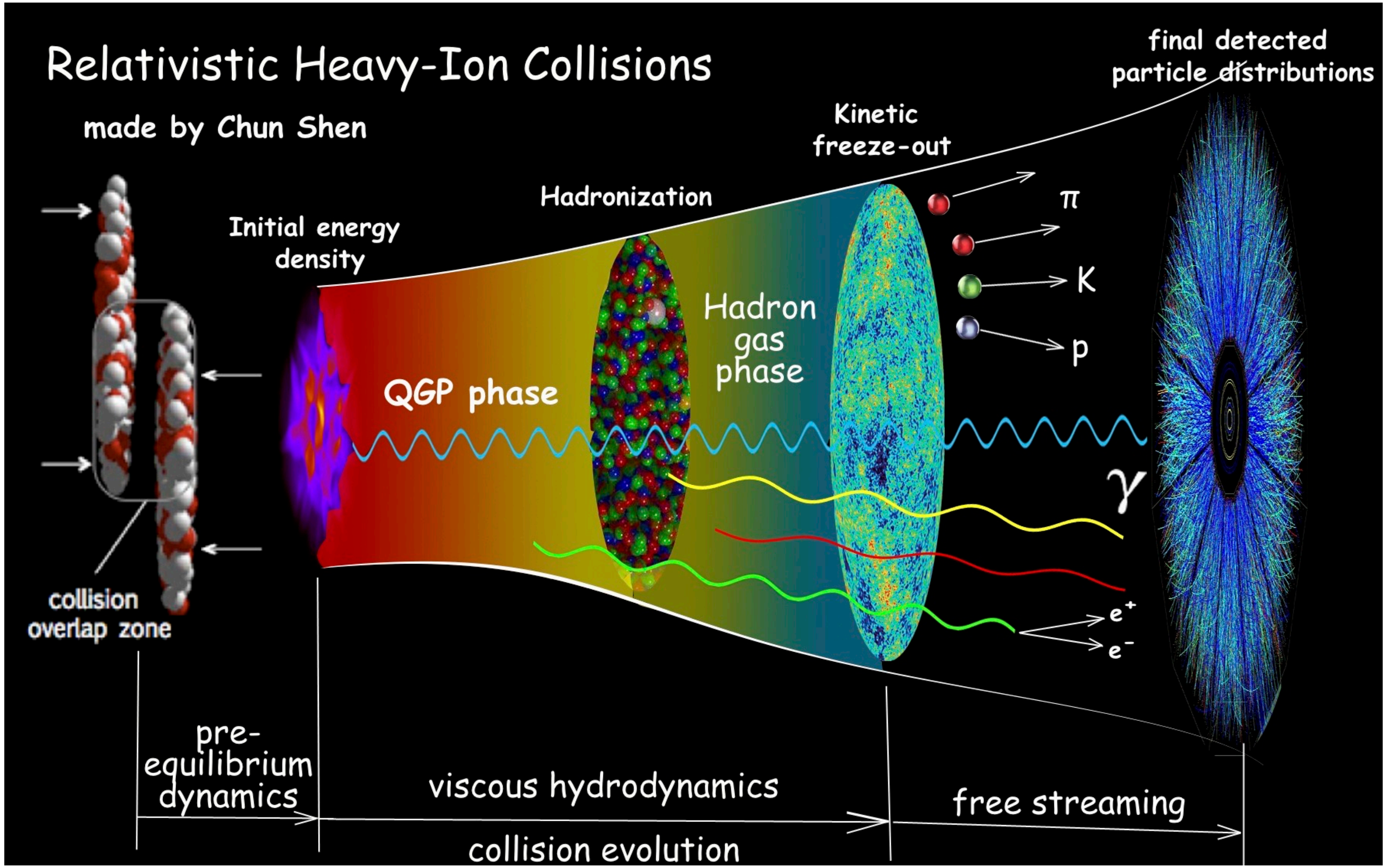
QM QUARK MATTER KRAKÓW 2022

STAR

A "Little Bang" in Heavy-Ion Collision

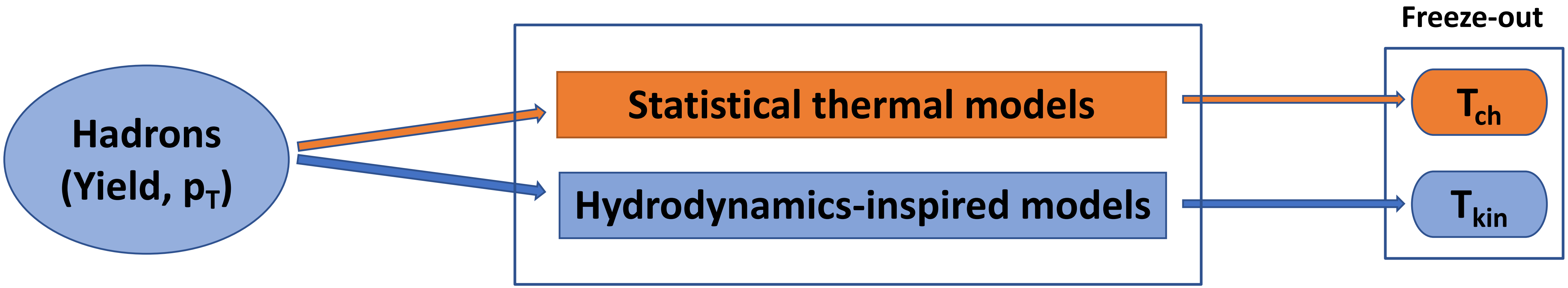


Expanding and cooling down

Study extreme QCD matter at **early** stages from **final** detected particles

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

Why Dileptons?



Why Dileptons?

Hadrons
(Yield, p_T)

Statistical thermal models

Hydrodynamics-inspired models

Freeze-out

T_{ch}

T_{kin}

EM probes

Photons
(p_T)

Leptons
(m_{ll})

- Emitted from early to final stages
- Carry original information of emission sources
- Probe earlier and hotter phases of medium

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- Hydrodynamics-inspired models → Freeze-out: T_{kin}

EM probes

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- Carry original information of emission sources
- **Probe earlier and hotter phases of medium**

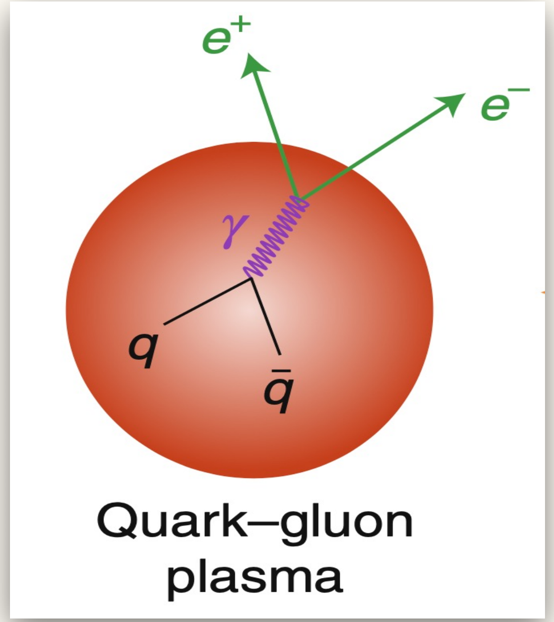
Photons (p_T)

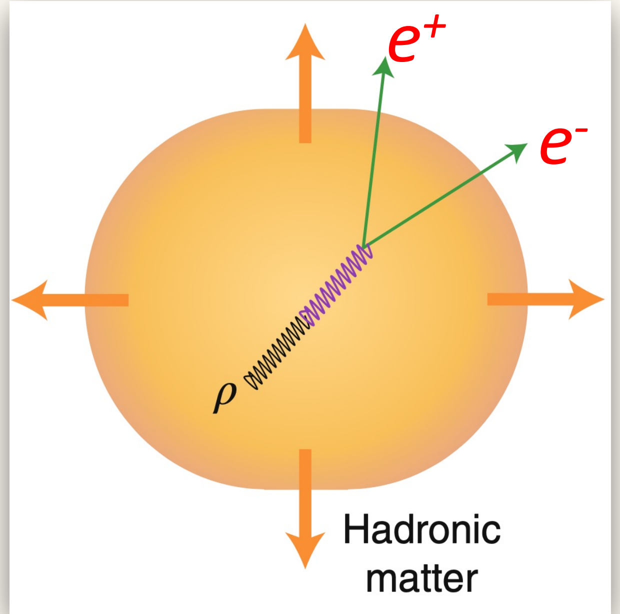
- T_{eff} **WARNING:** blue-shift effects

Leptons (m_{ll})

- **T measurement** without distortion by blue-shift effects
- **Only observable to directly access in-medium spectral function**

Why Dileptons?





Courtesy of Ralf Rapp

STAR: PRL 92, 092301 (2004), Rapp: PLB 753 (2016) 586

Medium talks to us:

$$q + \bar{q} \longrightarrow \gamma^* \longrightarrow e^+ + e^-$$

$$\pi^+ + \pi^- \longrightarrow \rho \longrightarrow e^+ + e^-$$

Modified

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

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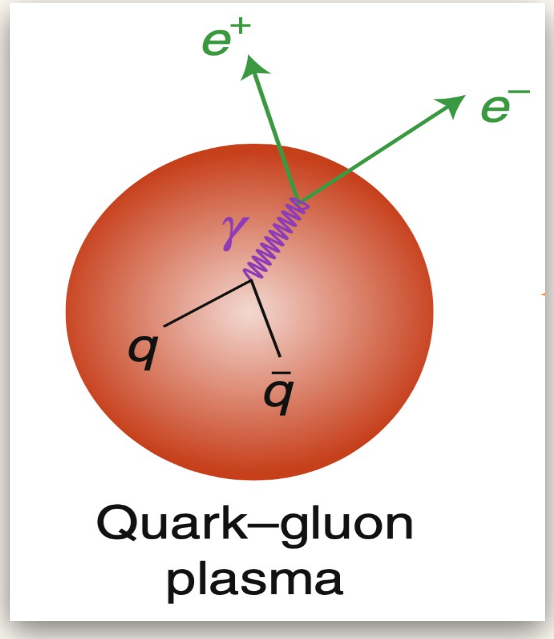

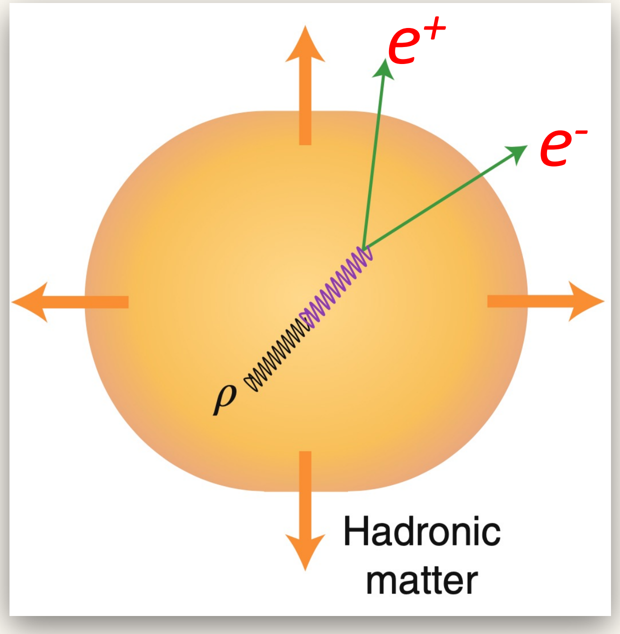

Courtesy of Ralf Rapp

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

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

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Modified

Dilepton language decoder

Temperature

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

How to Measure Thermal Dileptons?

Inclusive signals
(space-time integral)

Interested signals:
- QGP radiation
- In-medium ρ decays

+

Physical background (Cocktails):
- Drell-Yan
- $\pi^0, \eta, \eta' \rightarrow \gamma e^+e^-$
- $\omega, \varphi \rightarrow e^+e^-, \omega \rightarrow \pi^0 e^+e^-, \varphi \rightarrow \eta e^+e^-$
- $J/\psi \rightarrow e^+e^-, c\bar{c} \rightarrow e^+eX$

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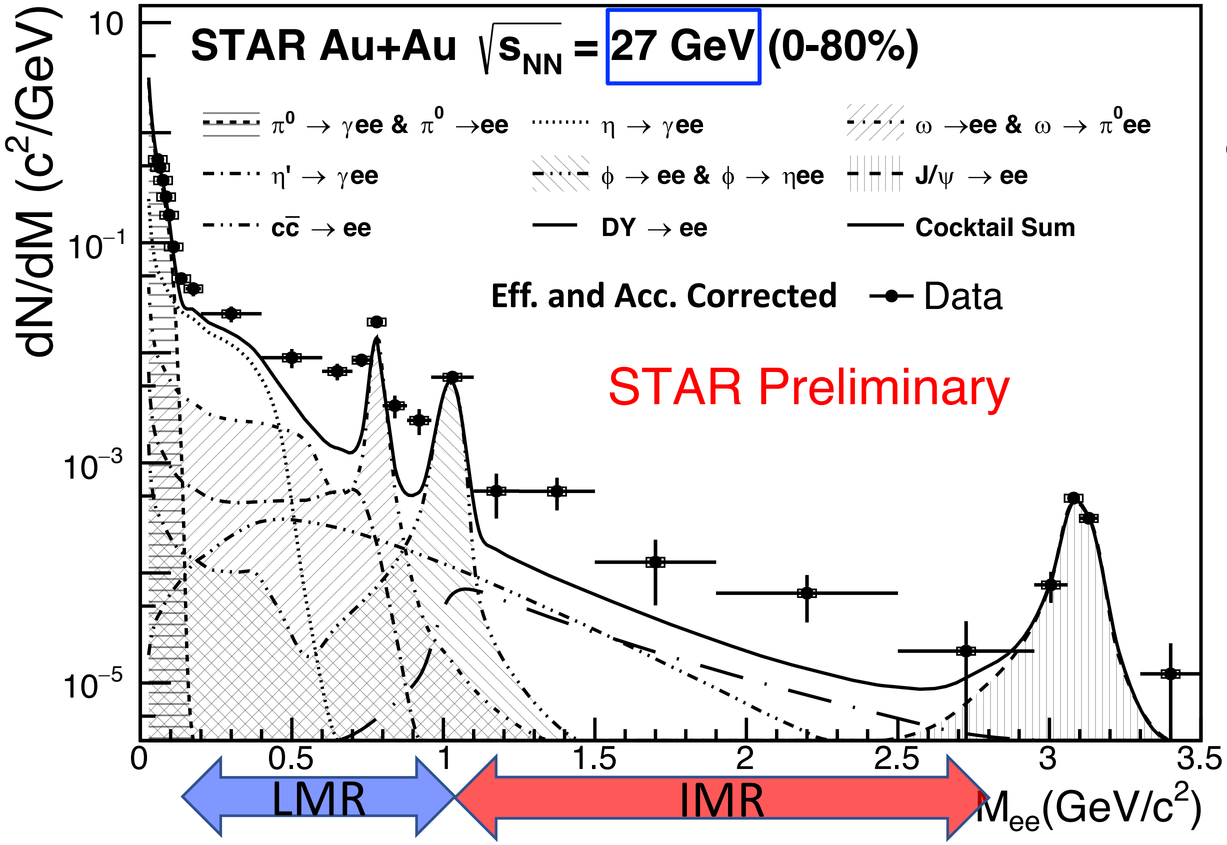
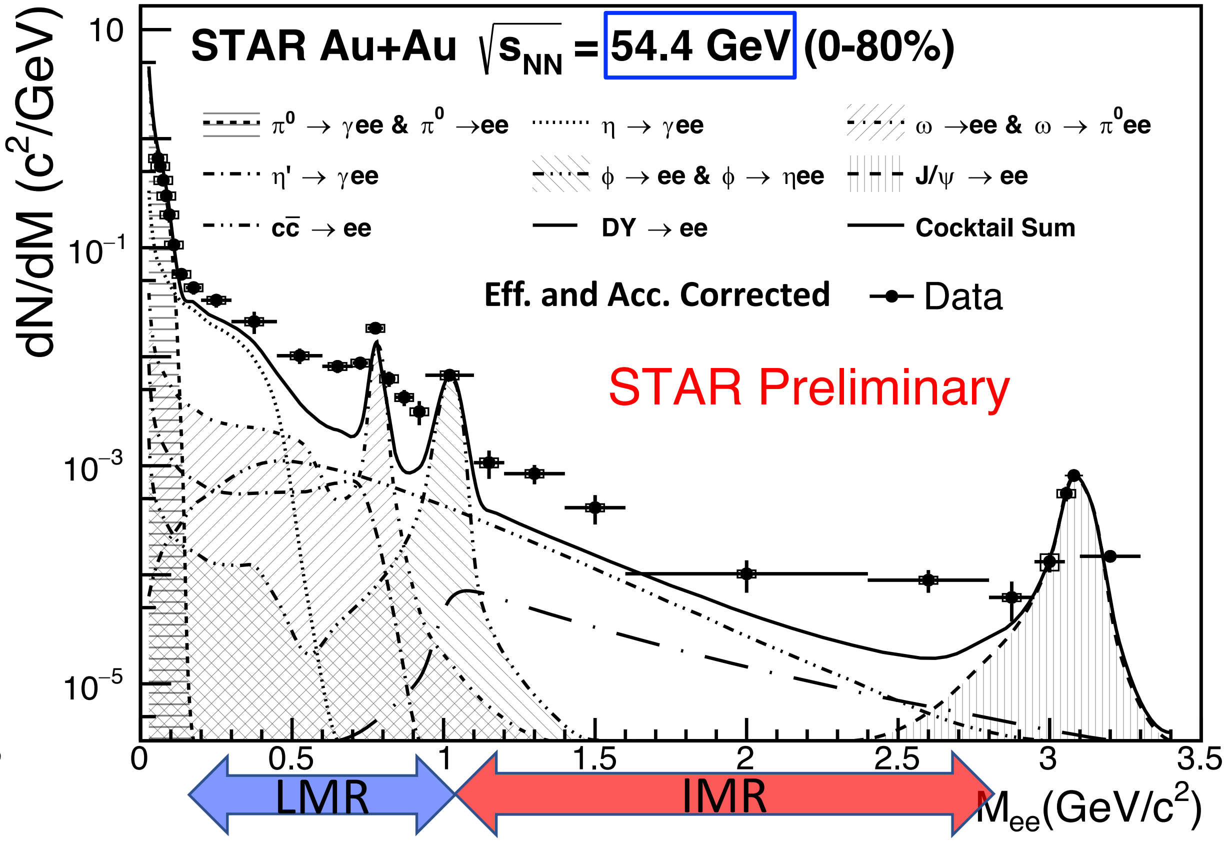
Physical background can be determined using the well-established cocktail simulation techniques

Interested signals = **Inclusive signals** − **Physical background**

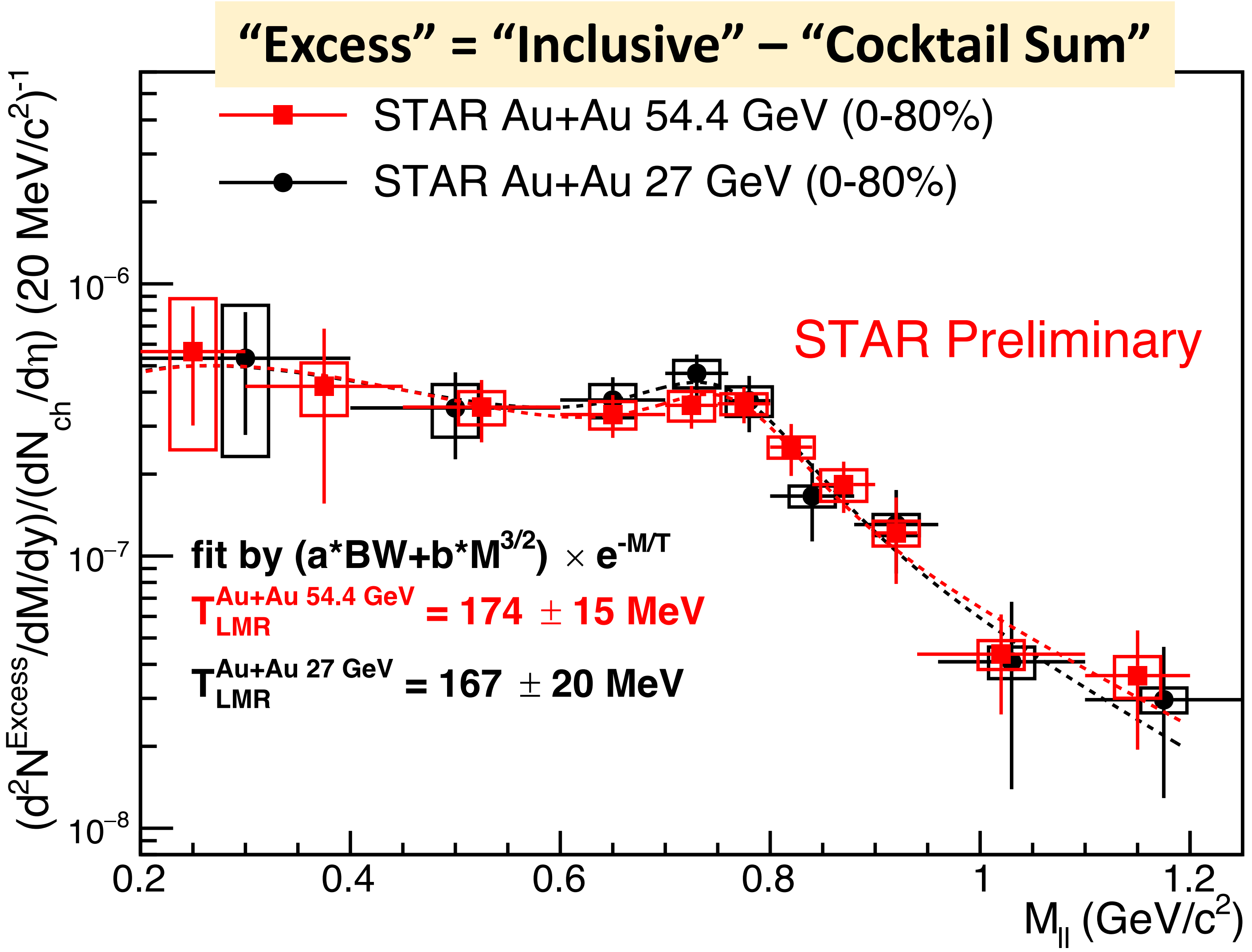
Fully Corrected Data vs. Cocktail





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

Low Mass Thermal Dielectron



In-medium ρ dominant

Charge density normalized mass spectral in 54.4 and 27 GeV Au+Au collisions are similar

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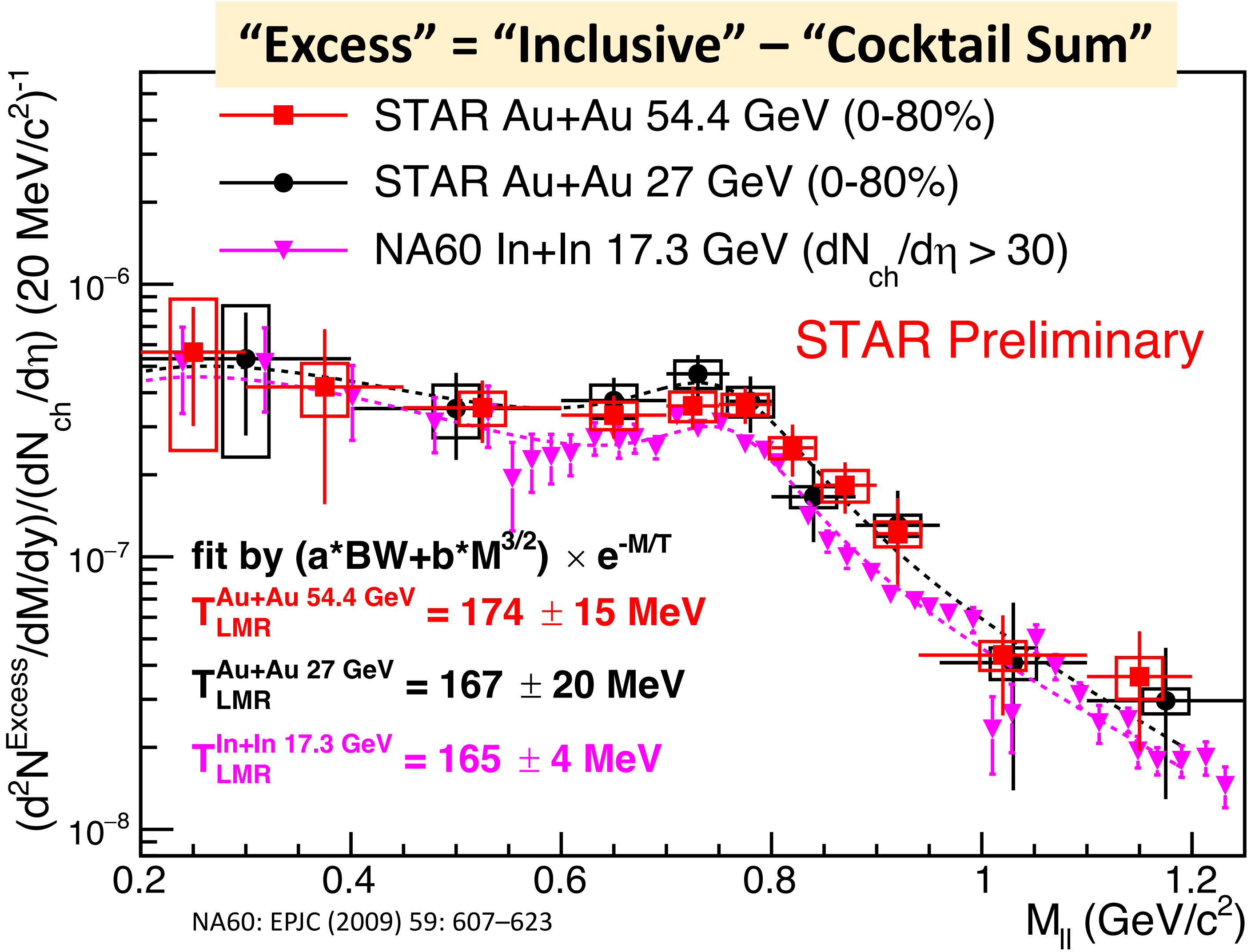

NA60: EPJC (2009) 59: 607–623

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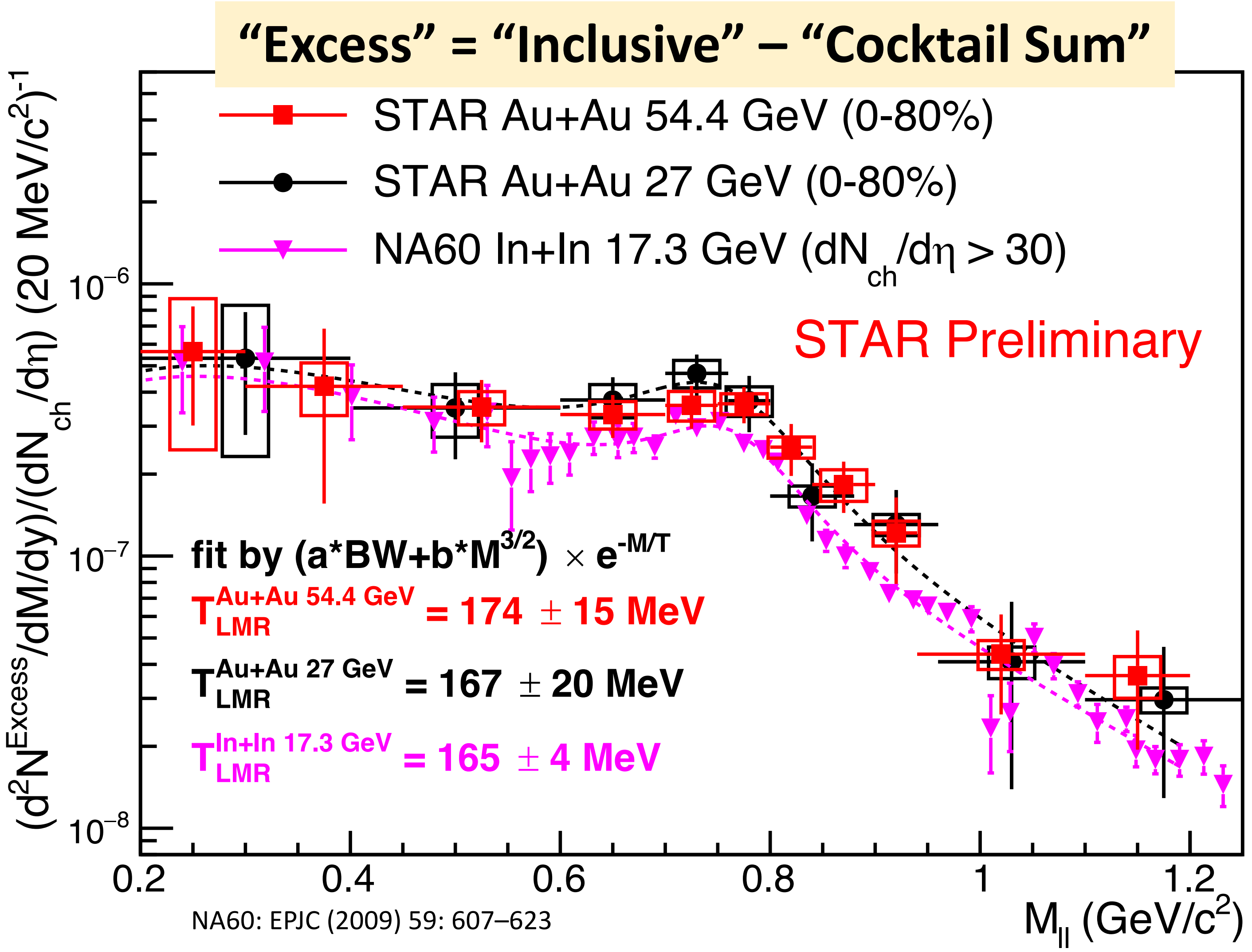

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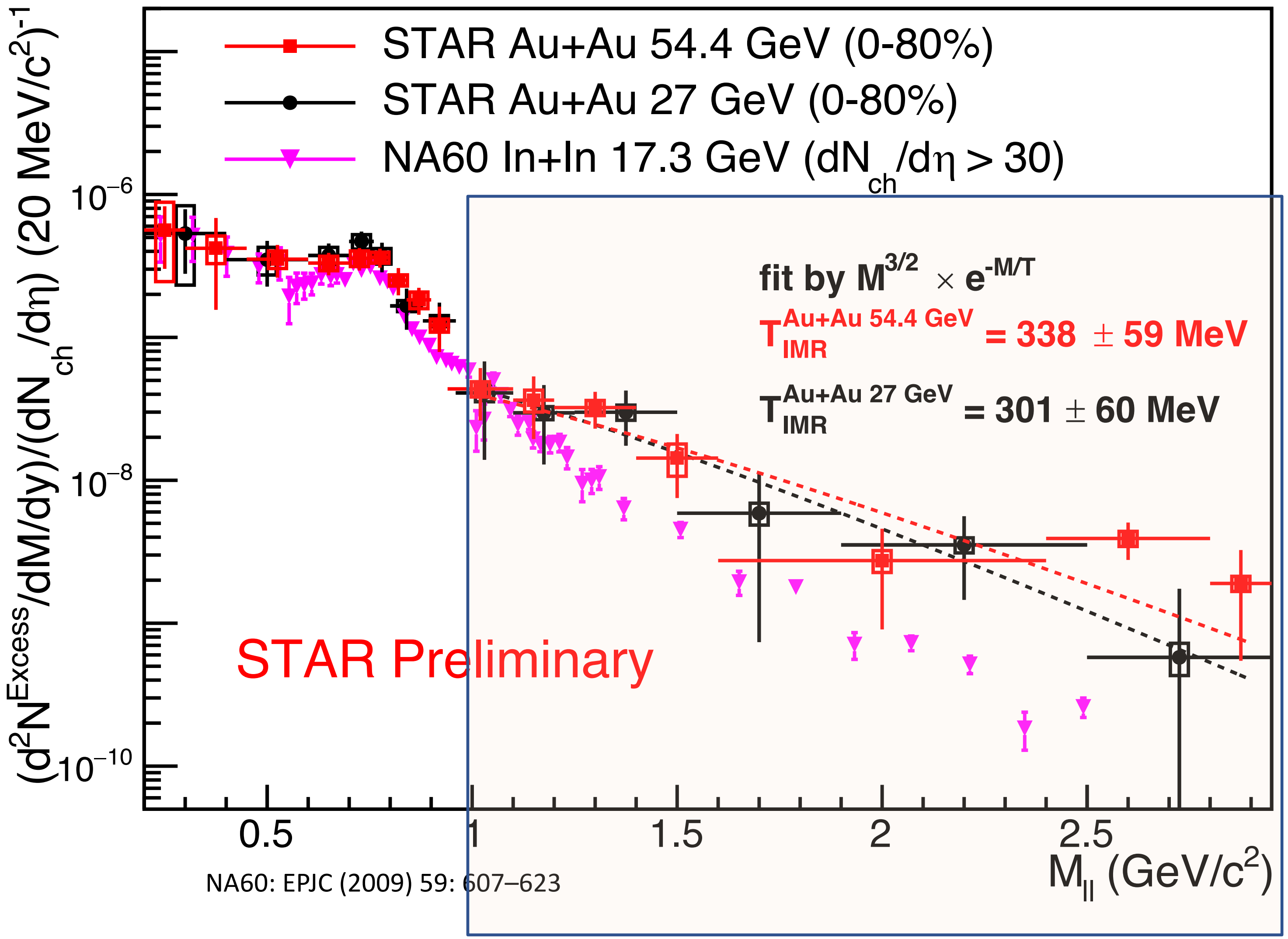
Charge density normalized yields are higher than NA60 results: **hint of a longer medium lifetime**

Low + Intermediate Mass Thermal Dielectron



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IMR: QGP thermometer

27 GeV and 54.4 GeV data are consistent, and higher than NA60

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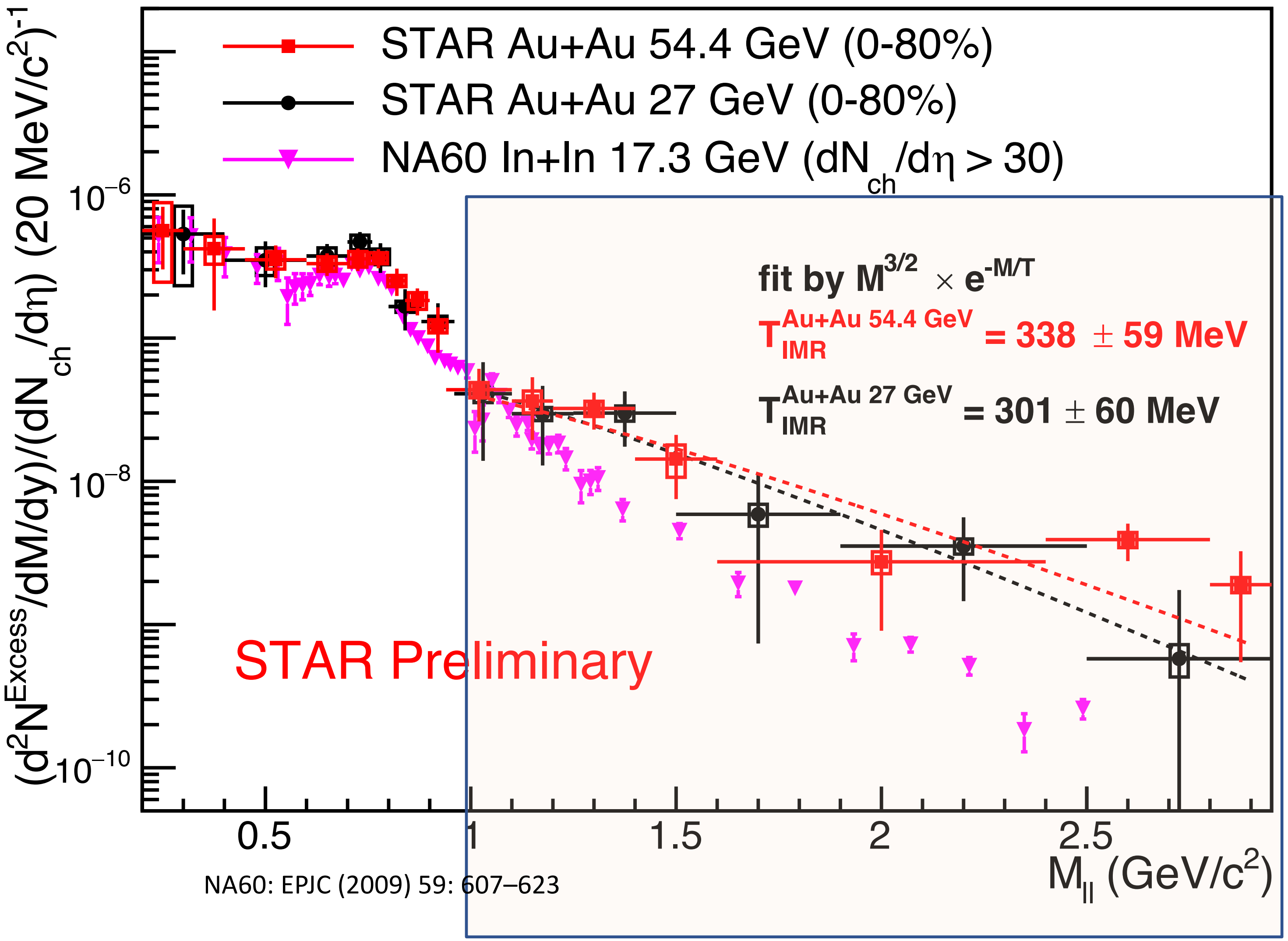

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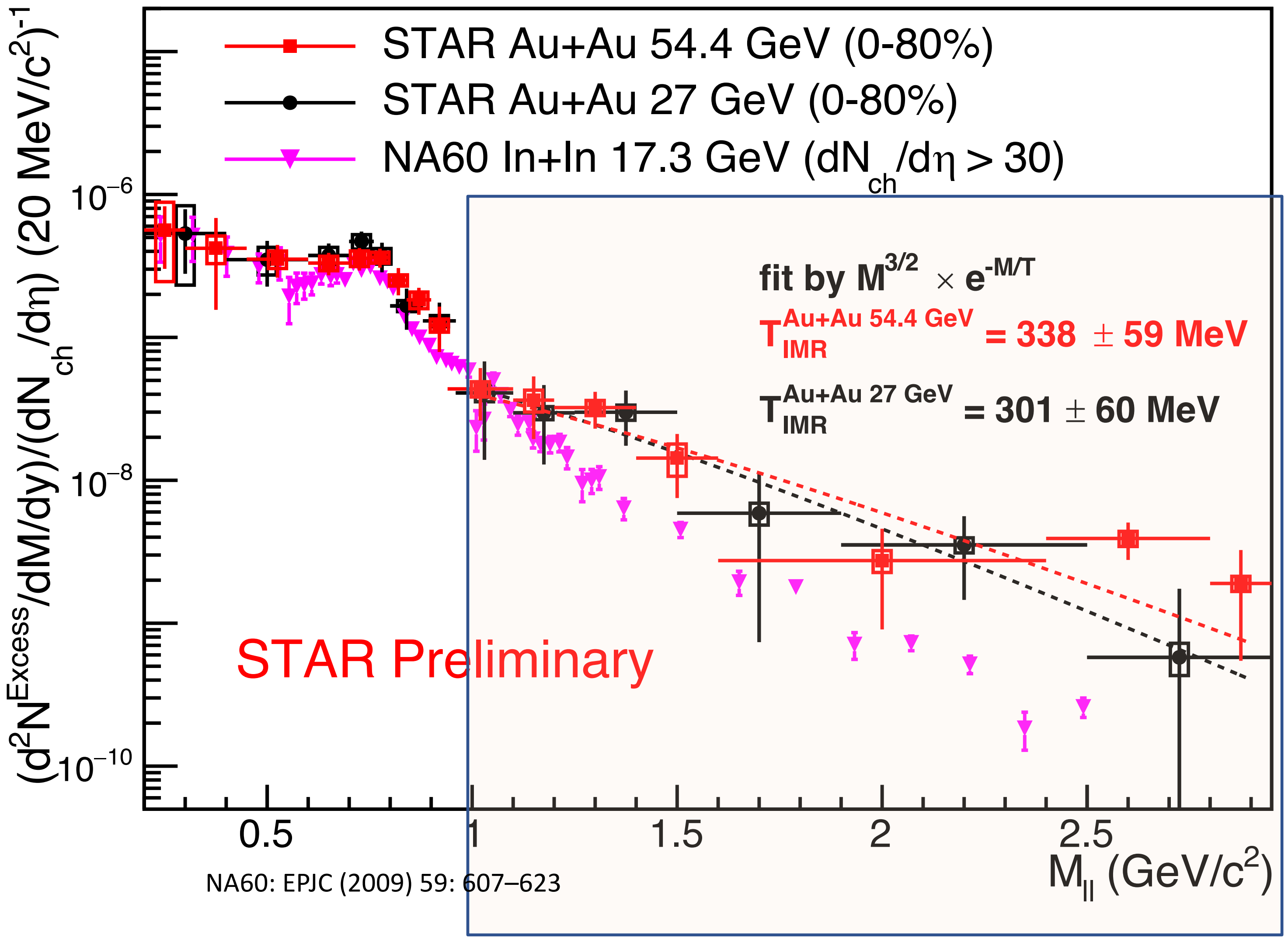

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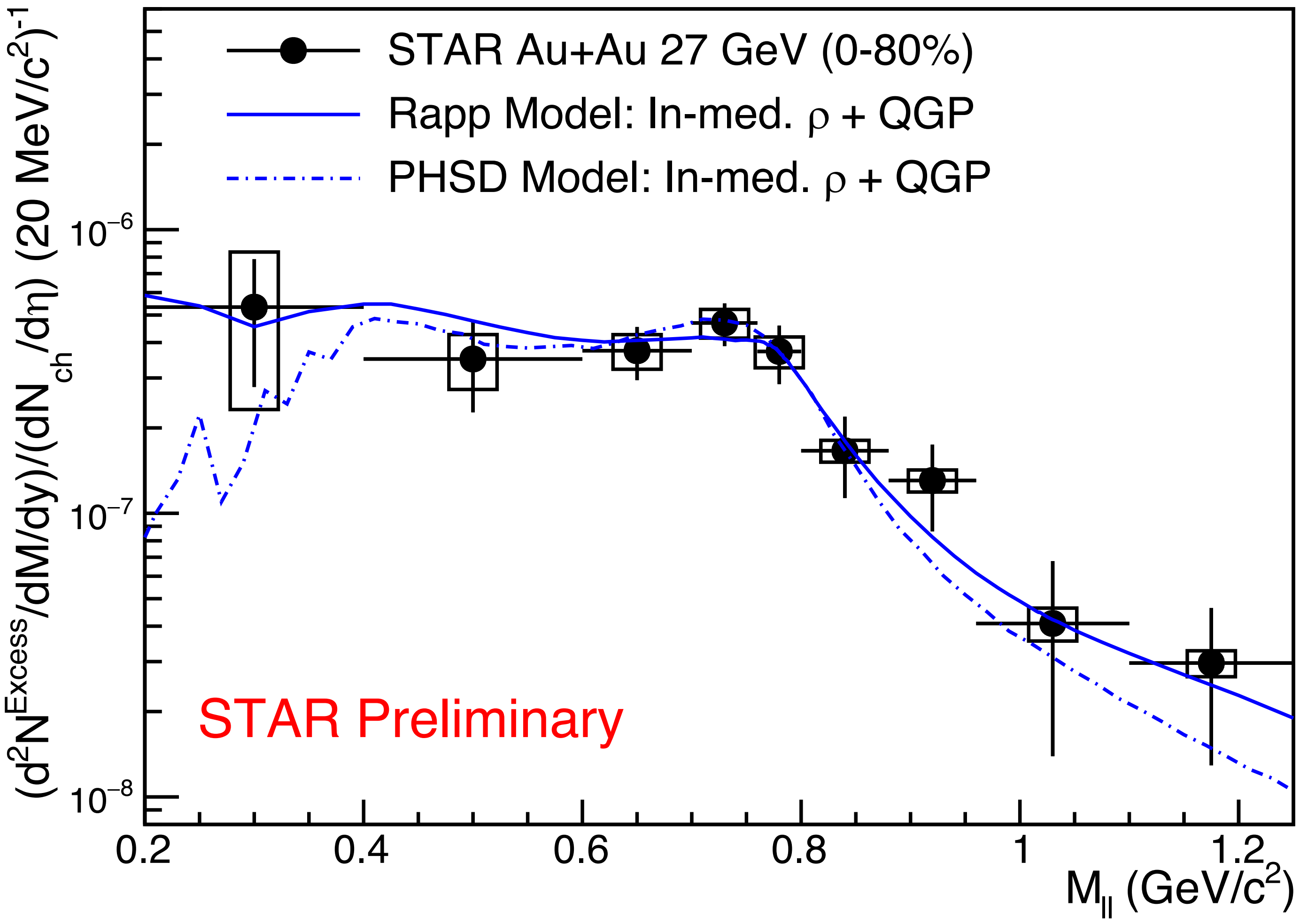
QGP at RHIC is hotter than SPS (205+/-12 MeV)

NA60: AIP Conf. Prcd 1322, 1 (2010)

Compare to Models



Rapp model: PRC 63 (2001) 054907, Adv HEP 2013 (2013) 148253, PLB 753 (2016) 586
PHSD model: NPA 807, 214 (2008); NPA 619, 413 (1997) PRC 97, 064907 (2018)

Both models can **well describe the ρ broadening at LMR**

Rapp model: macroscopic many-body approach
medium described by cylindrical expanding fireball with lQCD EoS; in-medium ρ-propagator; resonance + π cloud + baryons

PHSD model: microscopic transport approach
medium described by Dynamical Quasi-Particle Model (DQPM); microscopic partonic or hadronic scattering; collisional broadening

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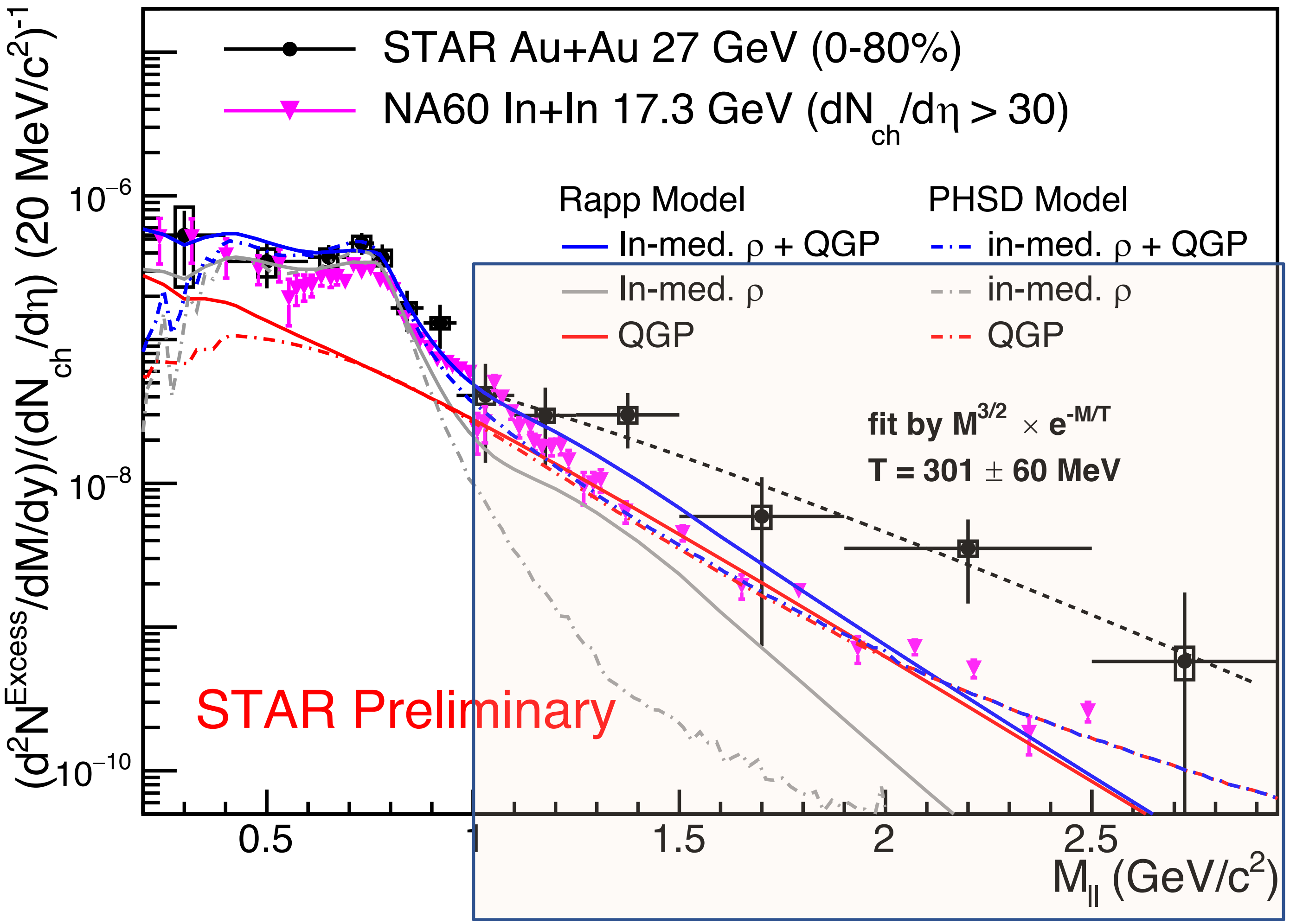

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Both models can **well describe the ρ broadening at LMR but underestimate the IMR → QGP is hotter** than model expectation

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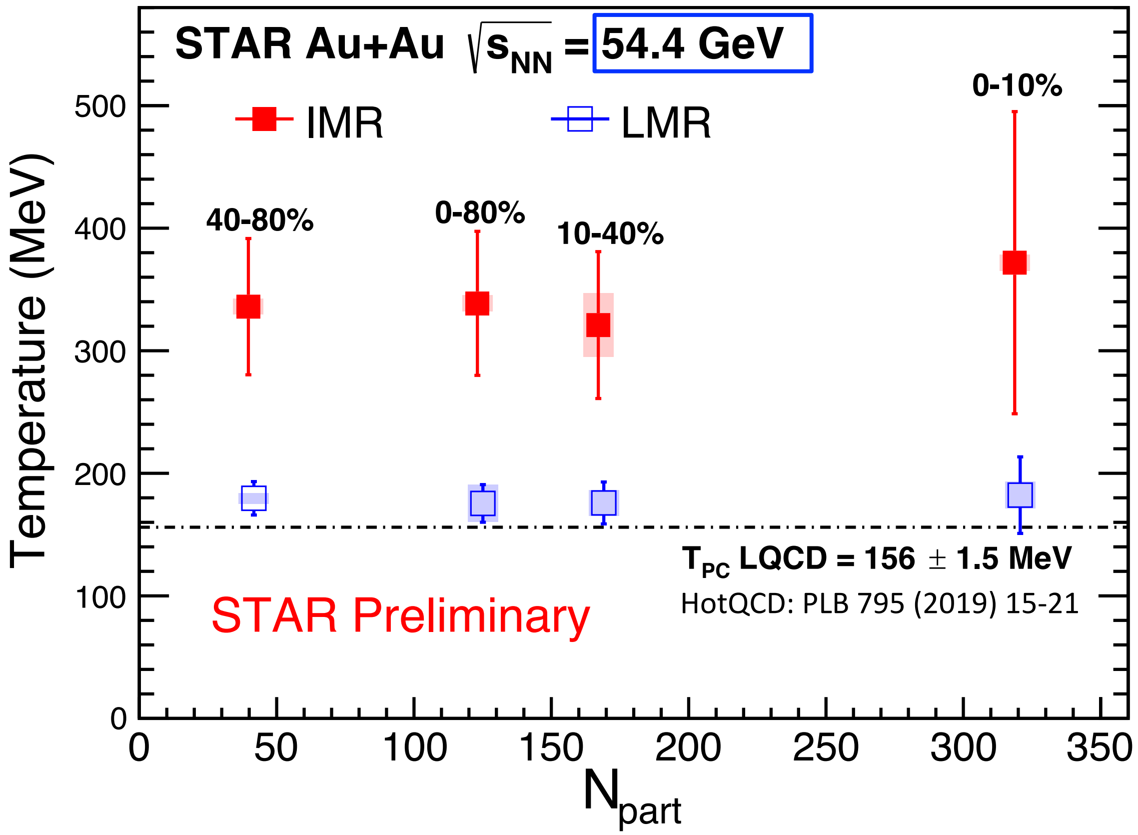
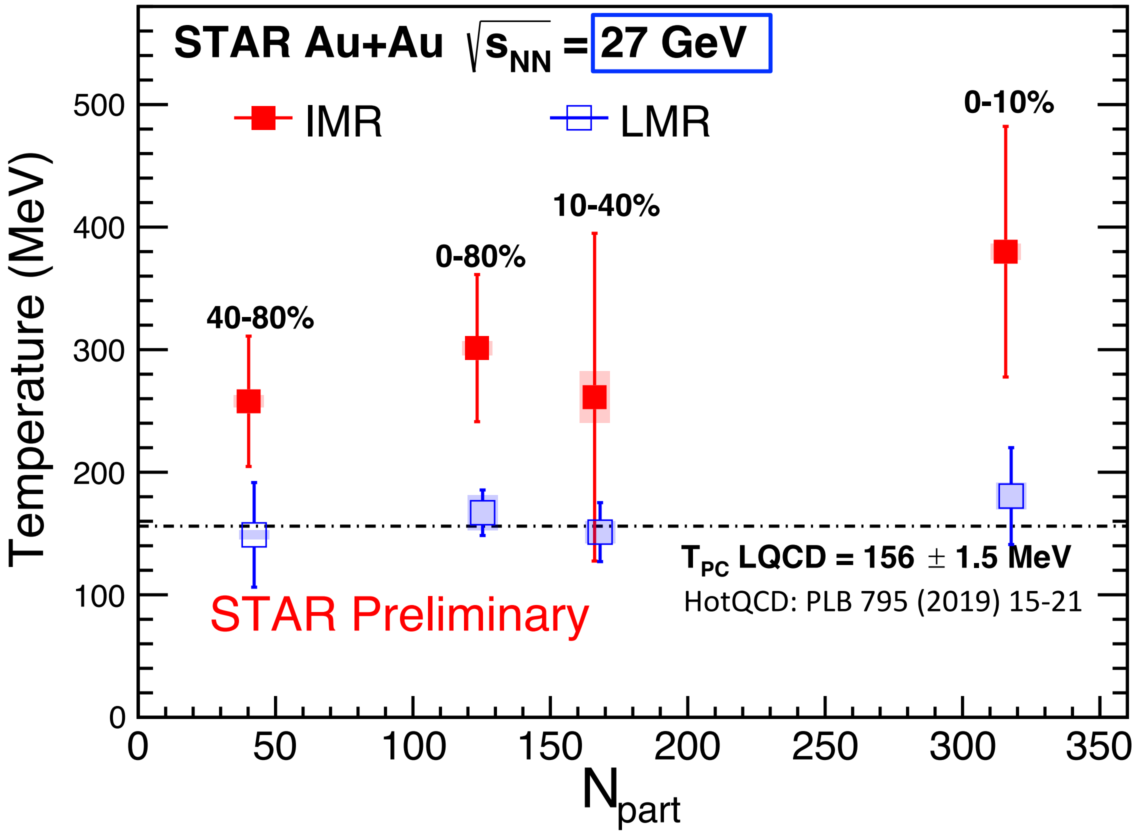
Temperature vs. N_{part}

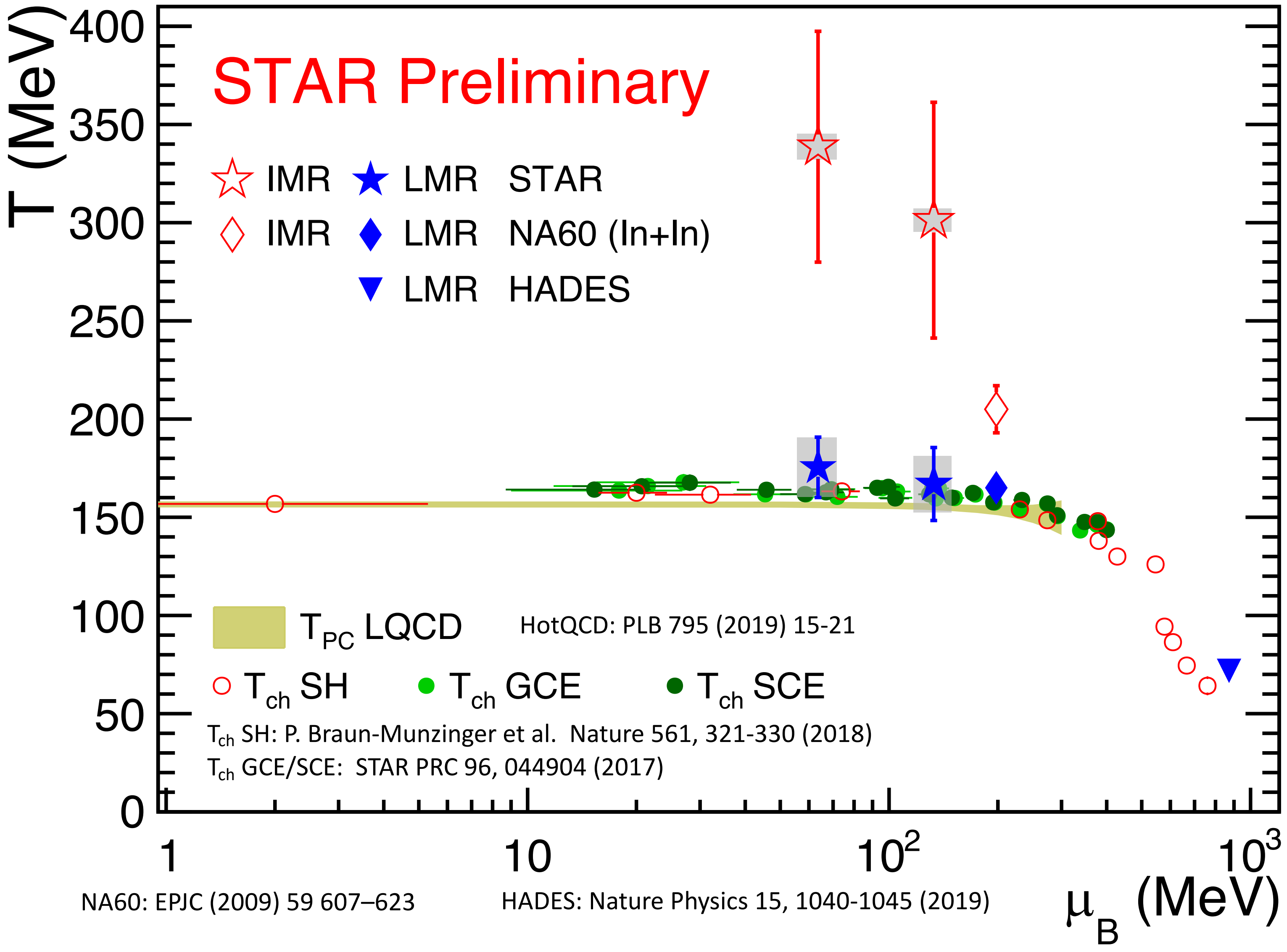




No clear centrality dependence

- Temperature in **LMR** is close to phase transition temperature (T_{pc})
- Temperature in **IMR** is higher than that in **LMR**

Temperature vs. μ_B



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HADES: Nature Physics 15, 1040-1045 (2019)

Thermal dileptons in IMR

- **T always higher than T_{pc} at RHIC and NA60**
- **Emitted from QGP phase**

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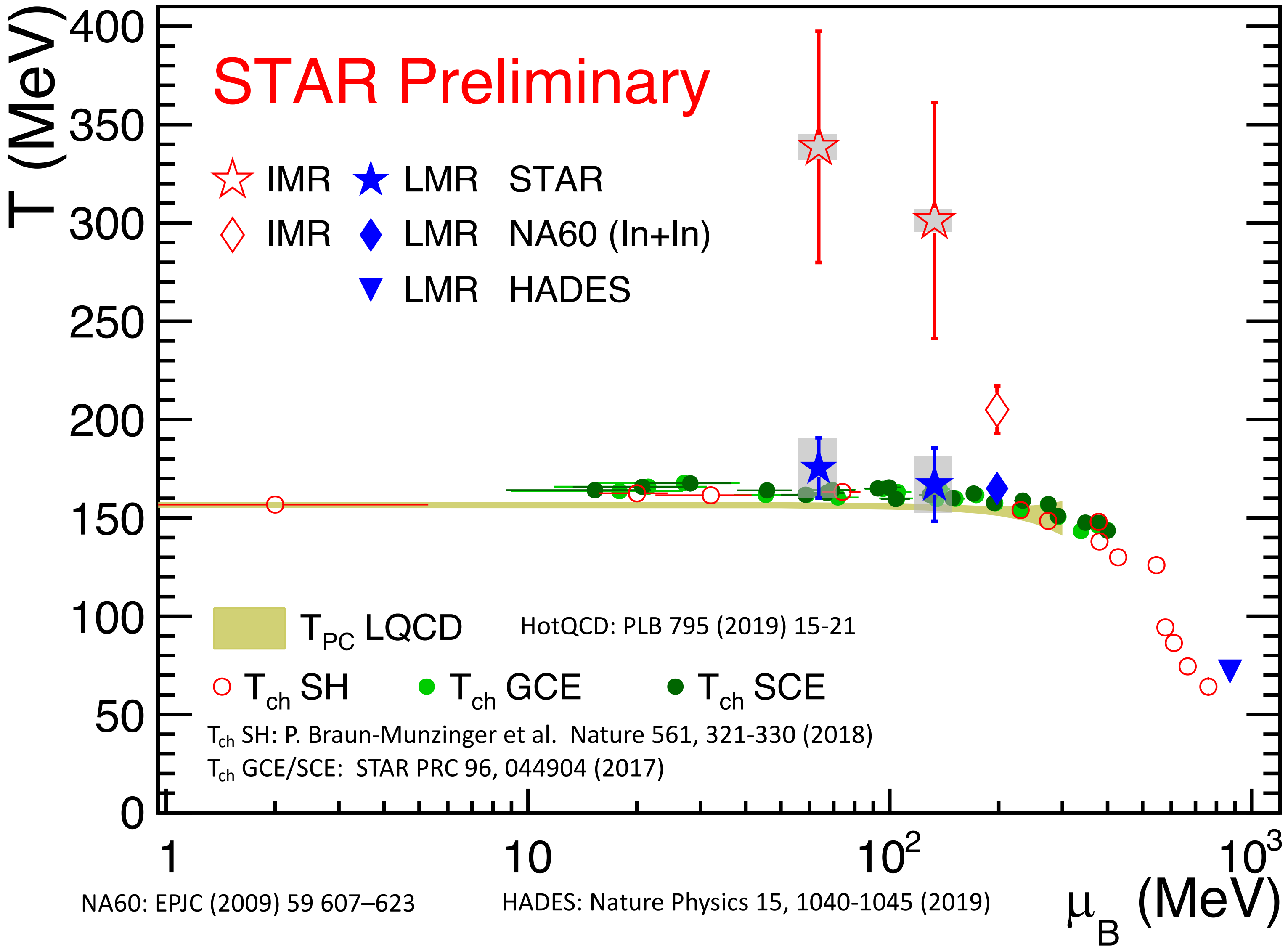

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Thermal dileptons in LMR

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- **Emitted from hadronic phase, dominantly around phase transition**

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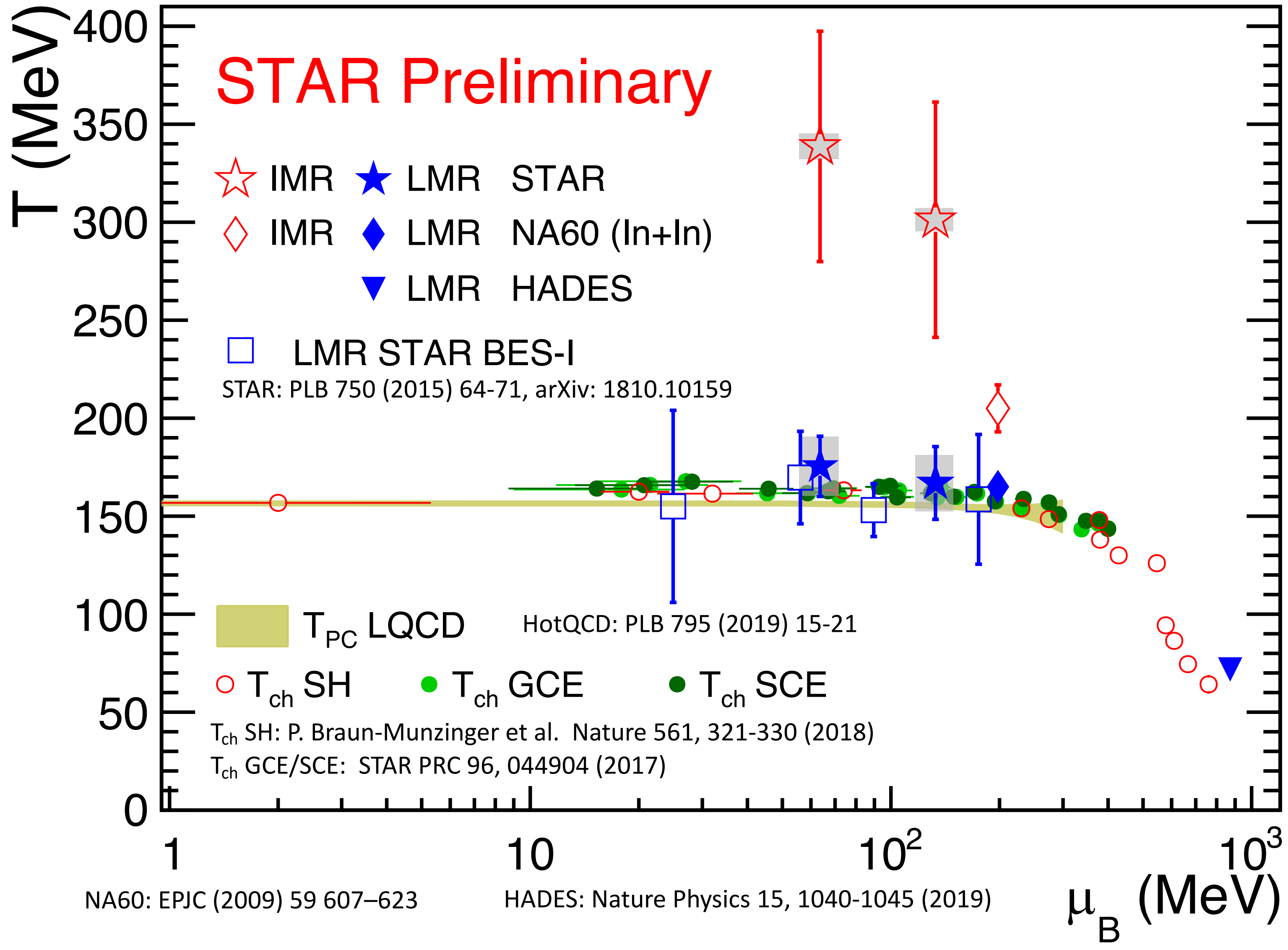

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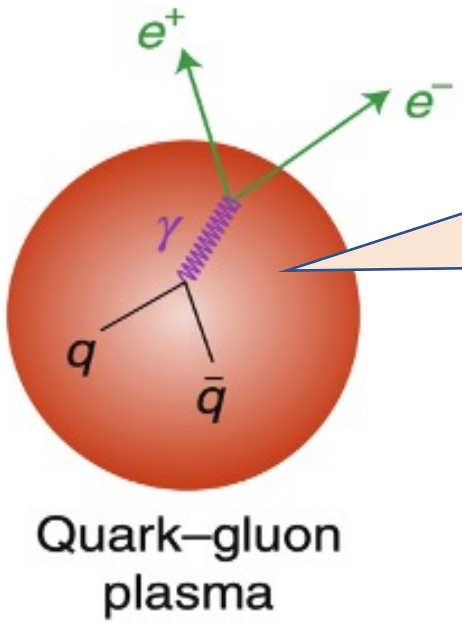
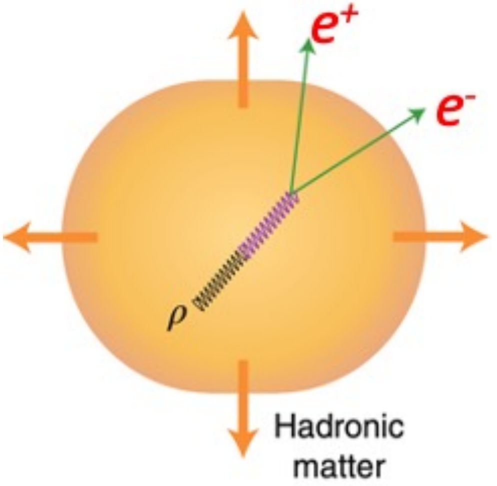
Summary





- T^{IMR} ~ 300 MeV: **First QGP temperature measurement at RHIC without distortion by medium flow** (no blue shift)
- QGP produced at RHIC is **hotter** than that at SPS

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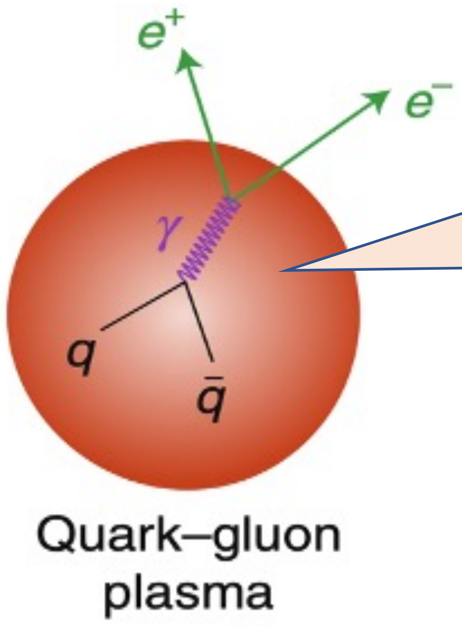

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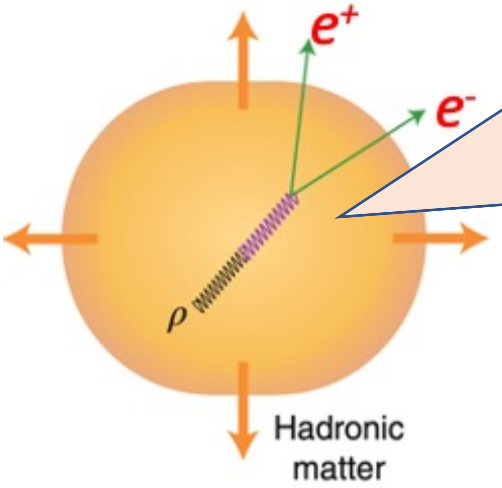
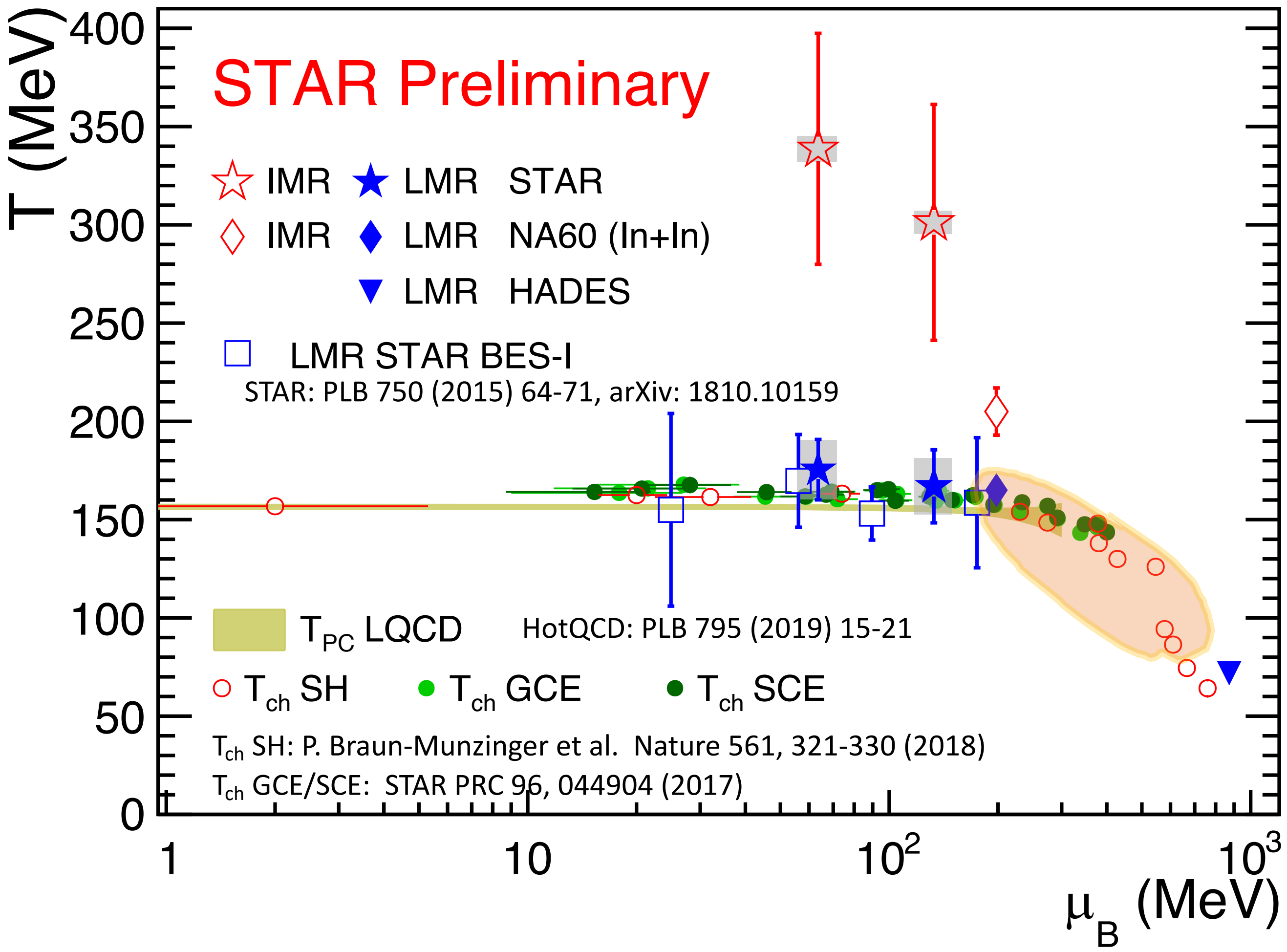


- T^{LMR} ~ 170 MeV: **First experimental evidence that in-medium ρ are dominantly produced at temperature $\sim T_{pc}$**
- In-medium ρ broadening can be described by models
- Normalized dilepton yield ($dN/(dN_{ch}/d\eta)$) is higher in RHIC Au+Au than that in SPS In+In: indicate a longer medium lifetime for larger collision system?

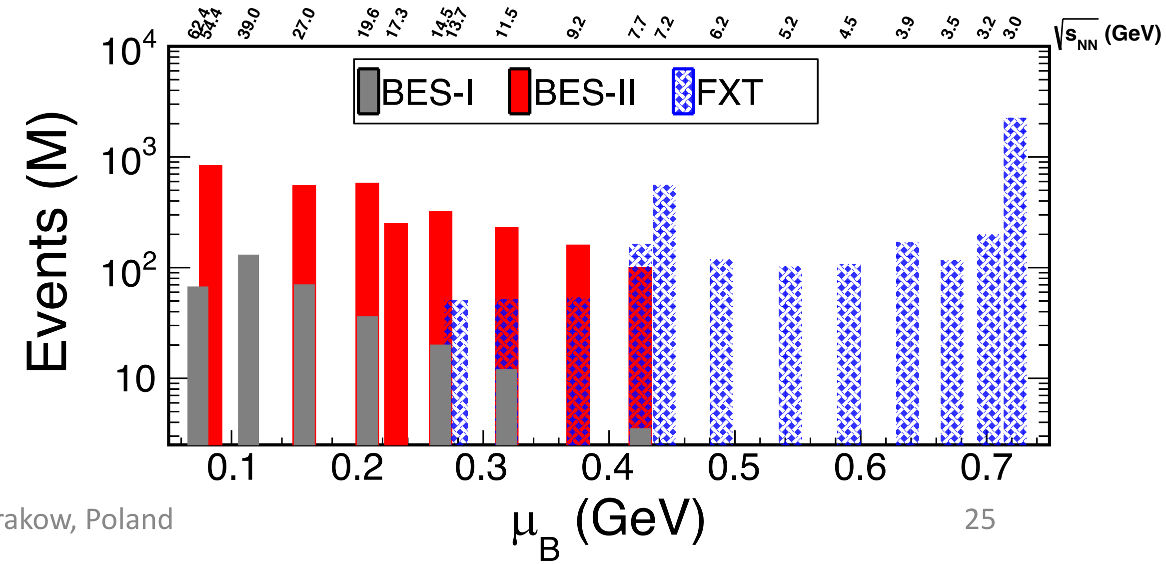
Outlook



NA60: EPJC (2009) 59 607–623 HADES: Nature Physics 15, 1040-1045 (2019)

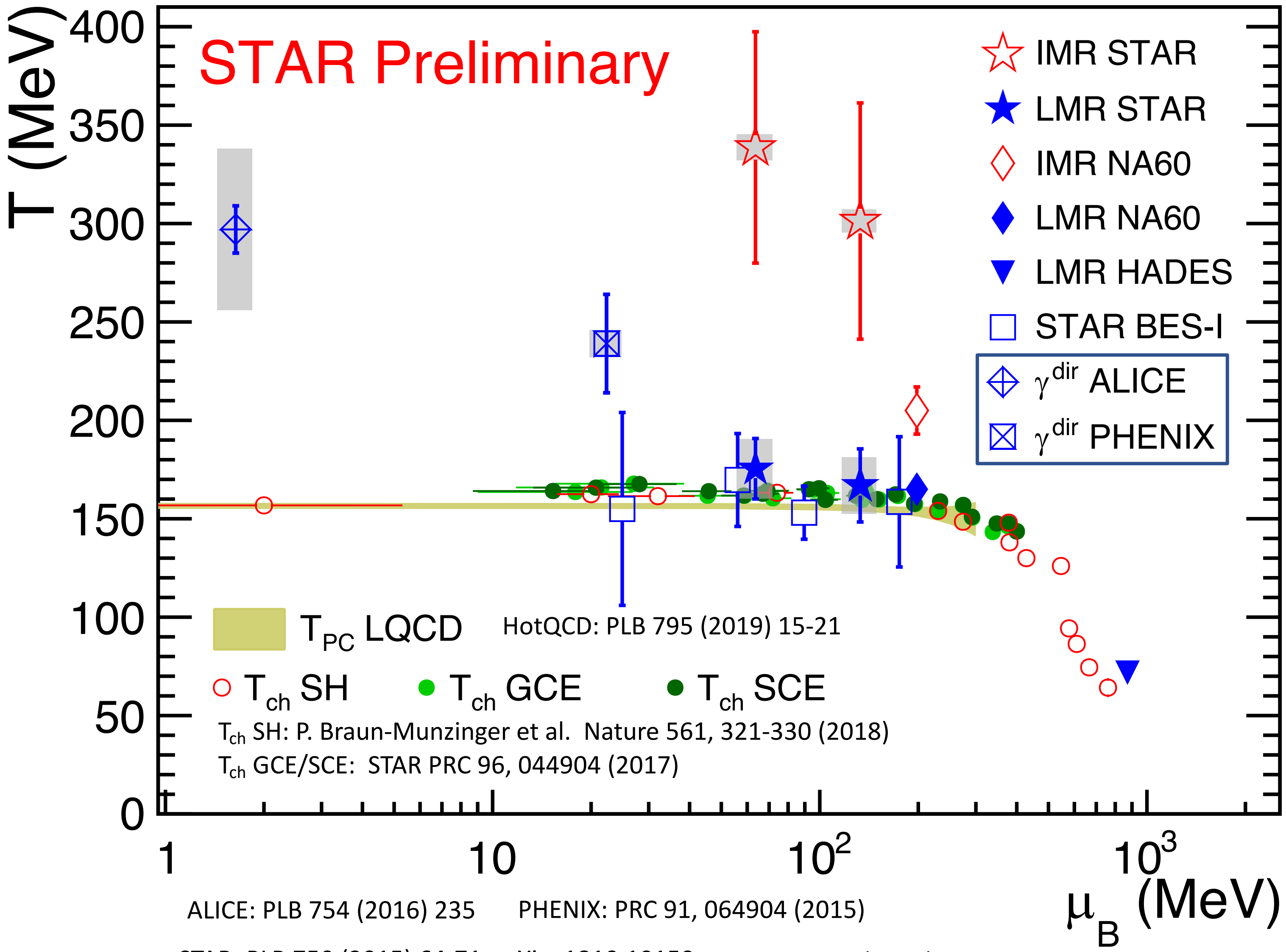
Dielectron with STAR BES-II and FXT program

- **T towards lower collision energy**
- **Search for significant enhancement in thermal dilepton yield → a potential critical point**
- **Data analyses are on-going**



Backup slides

Summary of Temperatures from EM probes



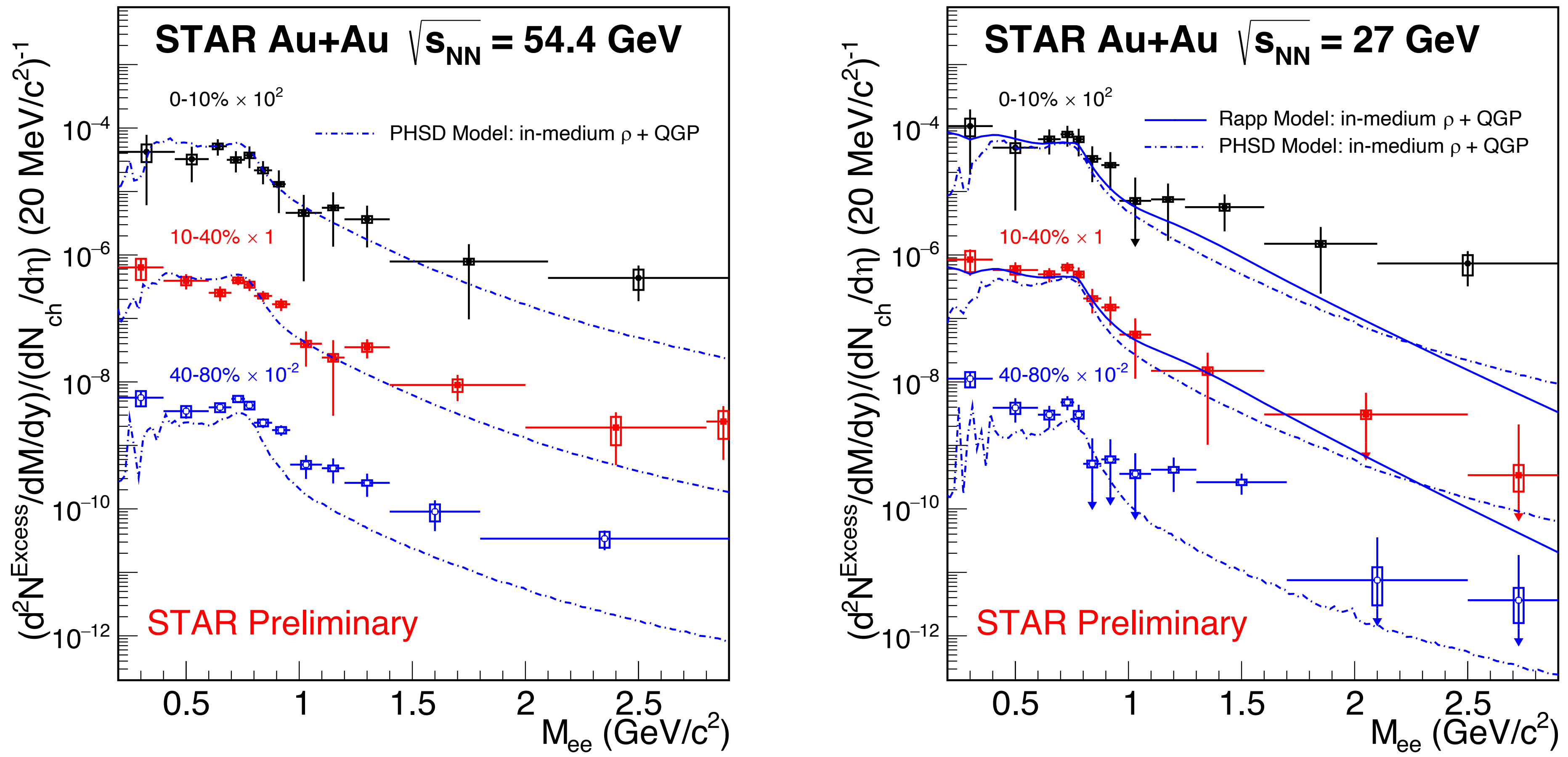
ALICE: PLB 754 (2016) 235 PHENIX: PRC 91, 064904 (2015)

STAR: PLB 750 (2015) 64-71, arXiv: 1810.10159 NA60: EPJC (2009) 59 607–623 HADES: Nature Physics 15, 1040-1045 (2019)

"**Most photons are emitted from fireball regions with T~T_c** near the quark-hadron phase transition, but that **their effective temperature is significantly enhanced by strong radial flow**"

--- C. Shen, U. Heinz, J-F Paquet, C. Gale: PRC 89, 044910 (2014)

Compare to Models in Different Centralities



- In general, models can describe central and semi-central LMR data
- Data in peripheral collisions are higher than PHSD model predictions