Thermal dielectron measurements at RHIC-STAR

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STAR 区域研讨会
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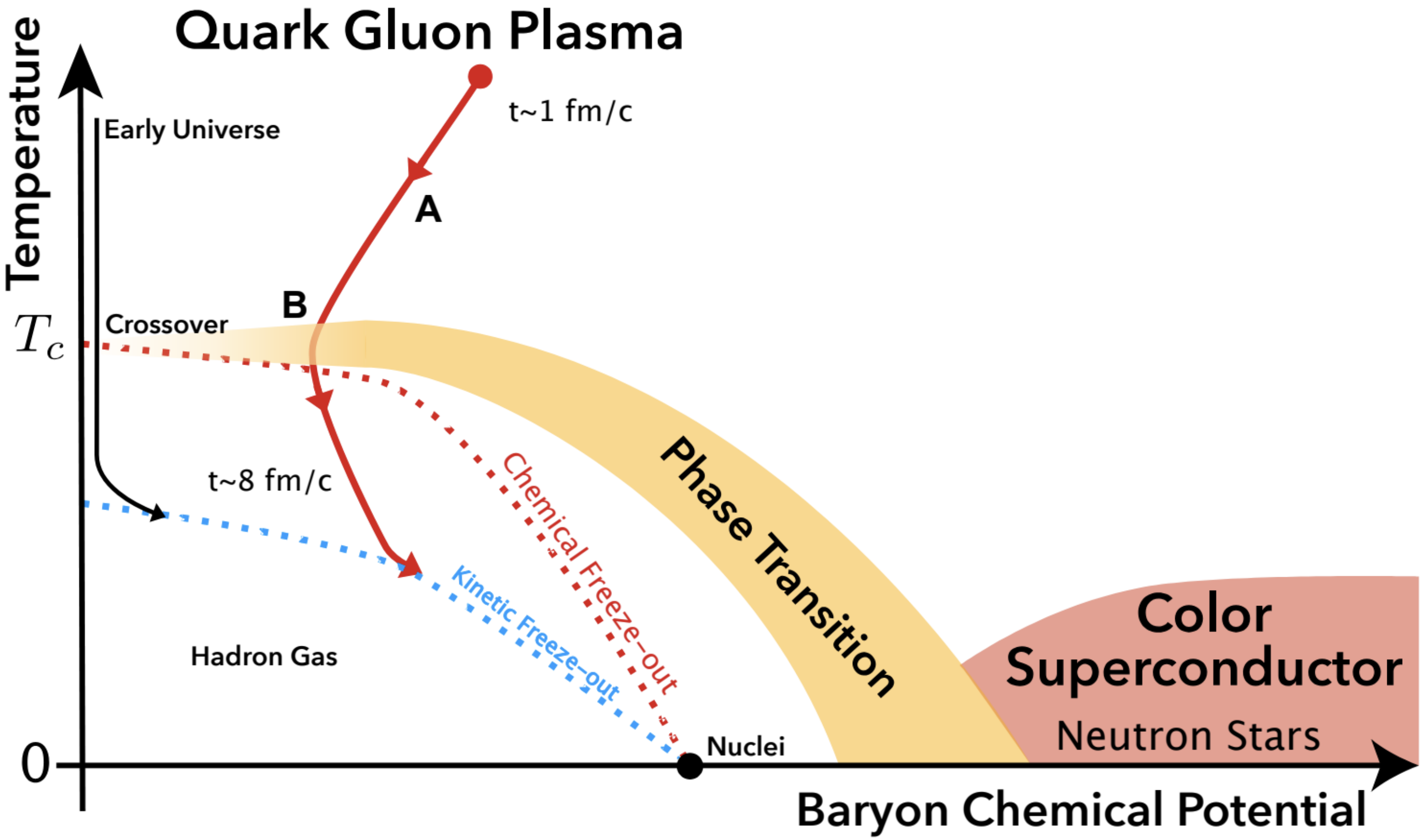
QCD phase diagram



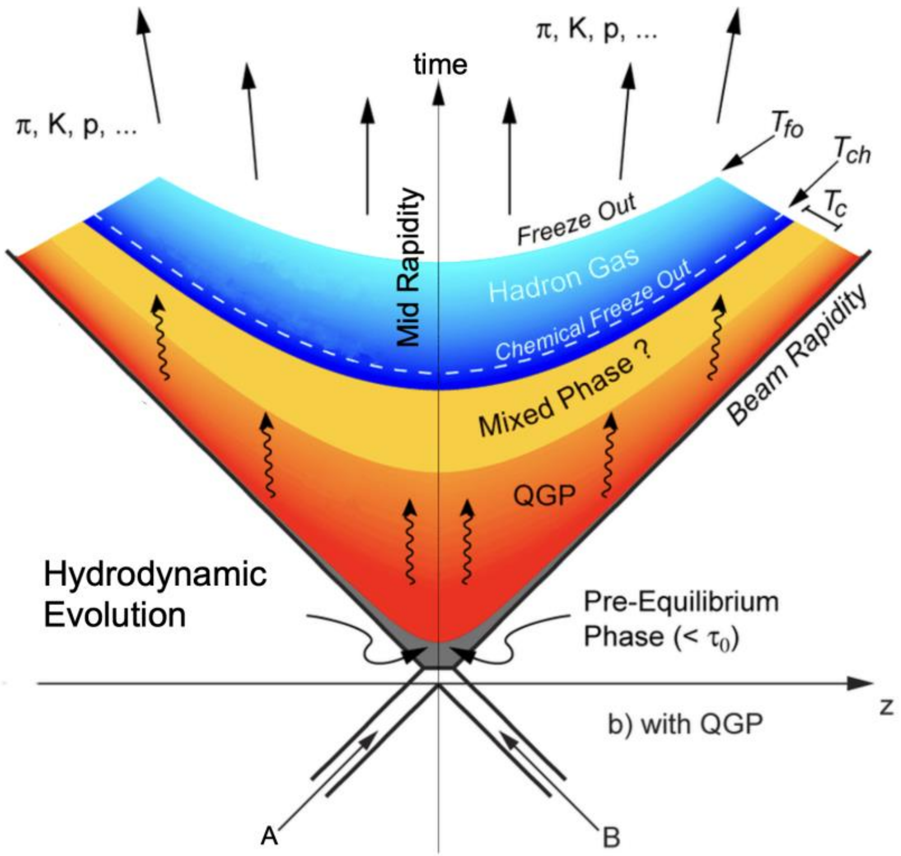
STAR, arXiv: 2402.01998

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

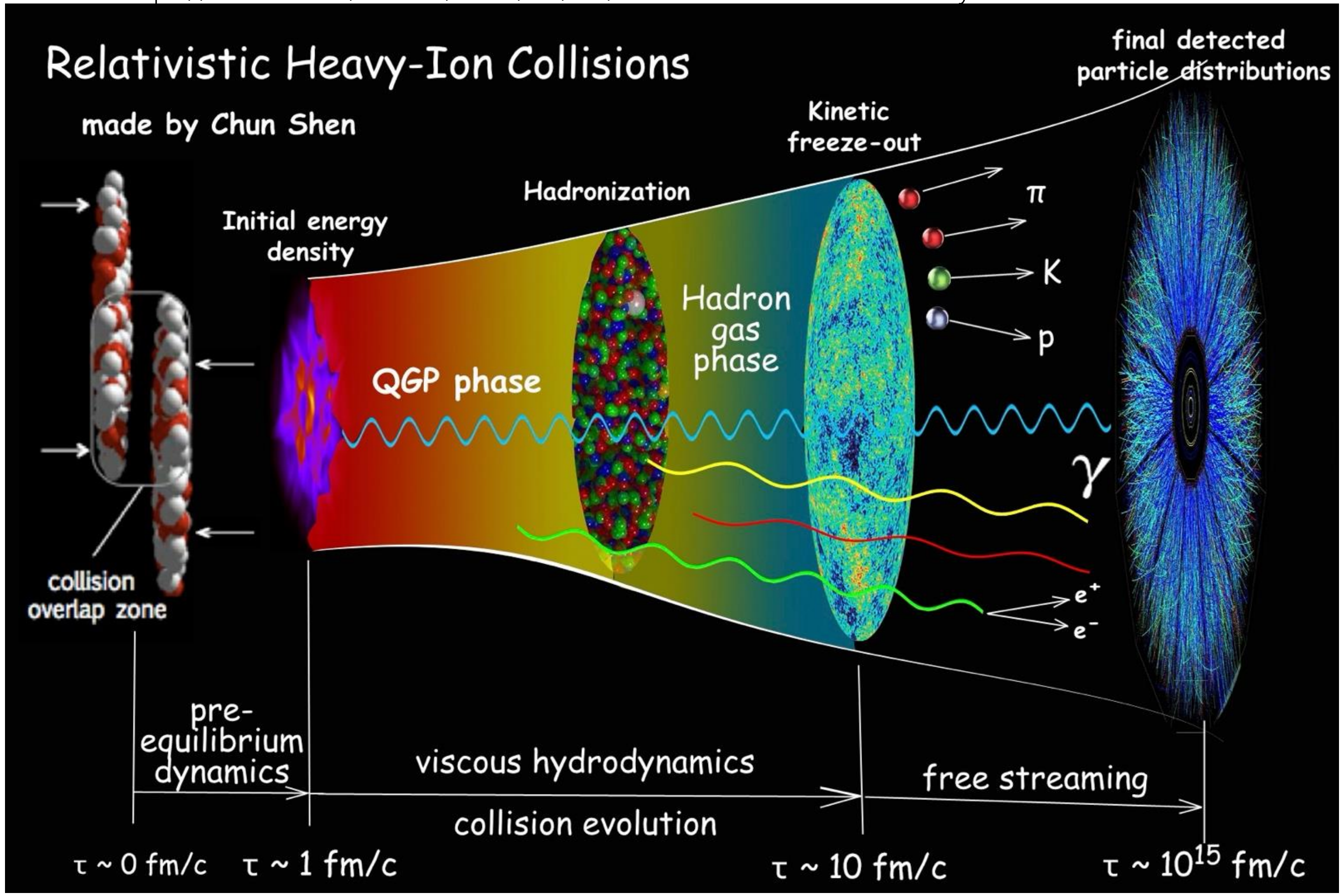
Explore the the phase diagram in the temperature and baryon chemical potential plane

Experimentally, one can generate high energy density by heavy ion collisions

Heavy ion collisions and QGP evolution



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



Extract the information at different stages from different probes

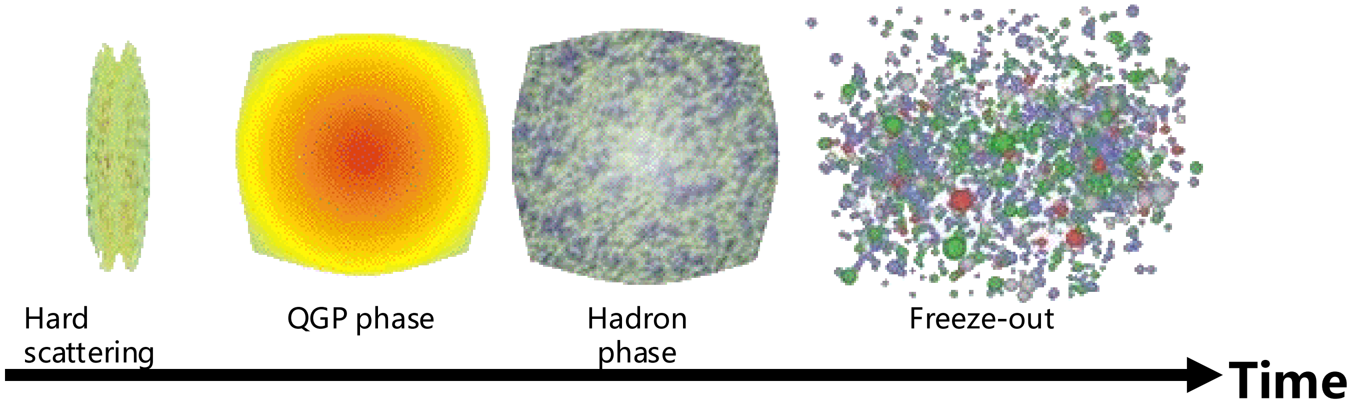
How to measure temperature

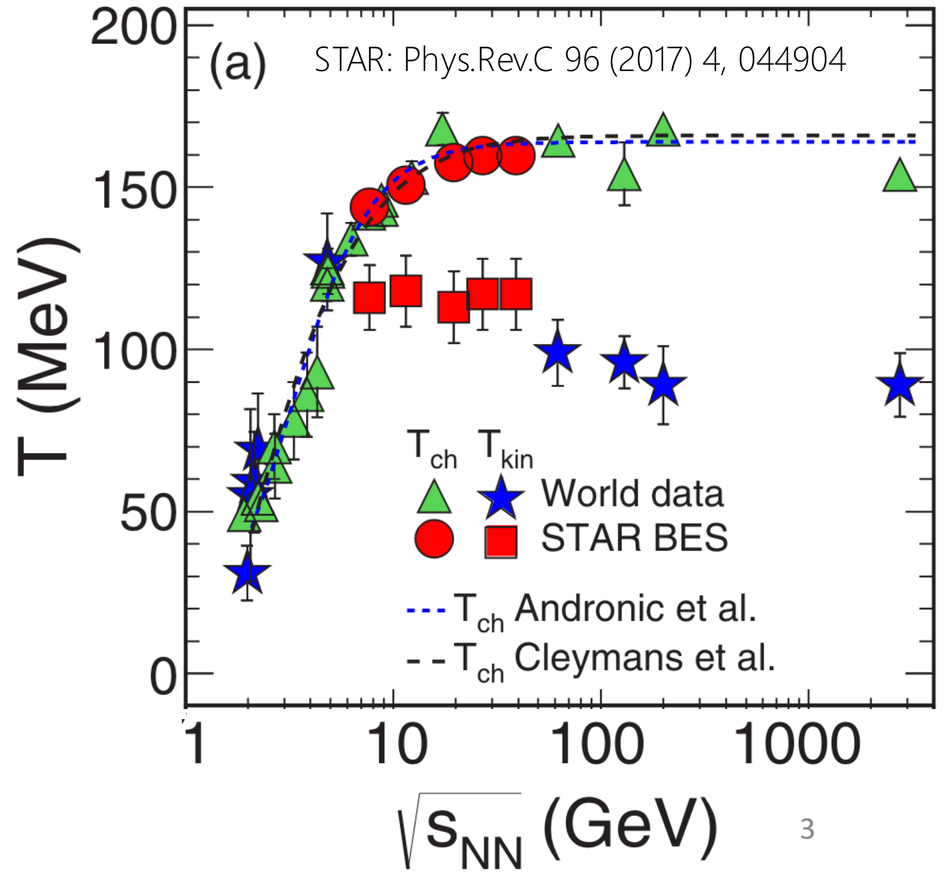
Hadrons

yields , p_T spectra

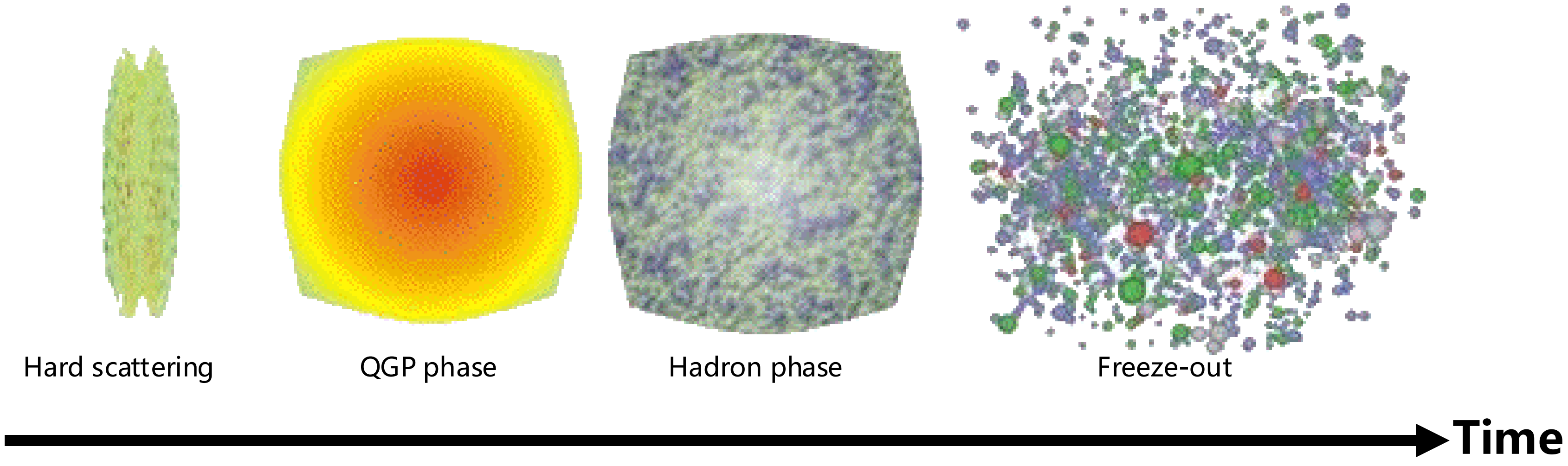
Hadrons:

- ✓ 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



Photons

p_T spectra

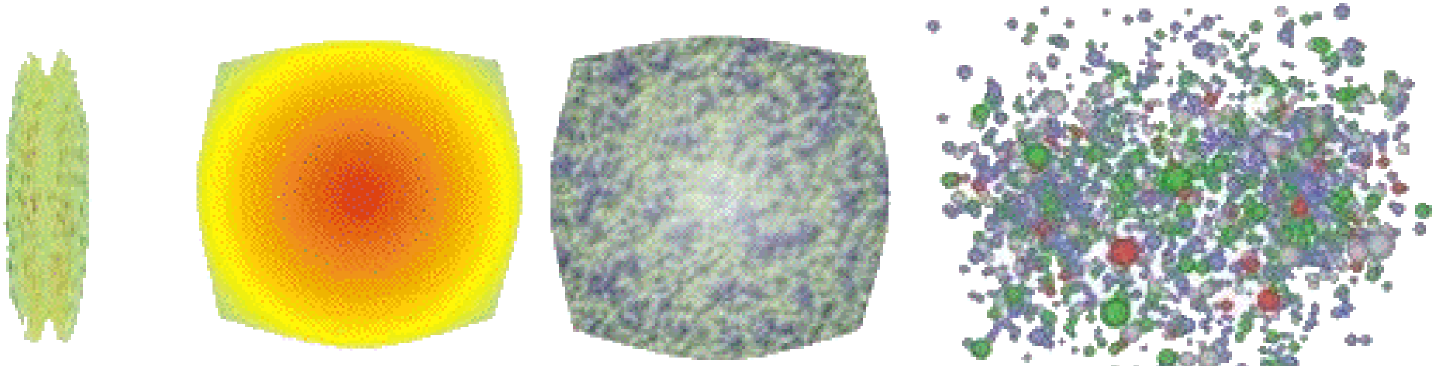
Dileptons

M_{ll} spectra

Electromagnetic Probes:

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

How to measure temperature



Hard scattering QGP phase Hadron phase Freeze-out

Time

Photons

p_T spectra

Dileptons

M_{ll} spectra

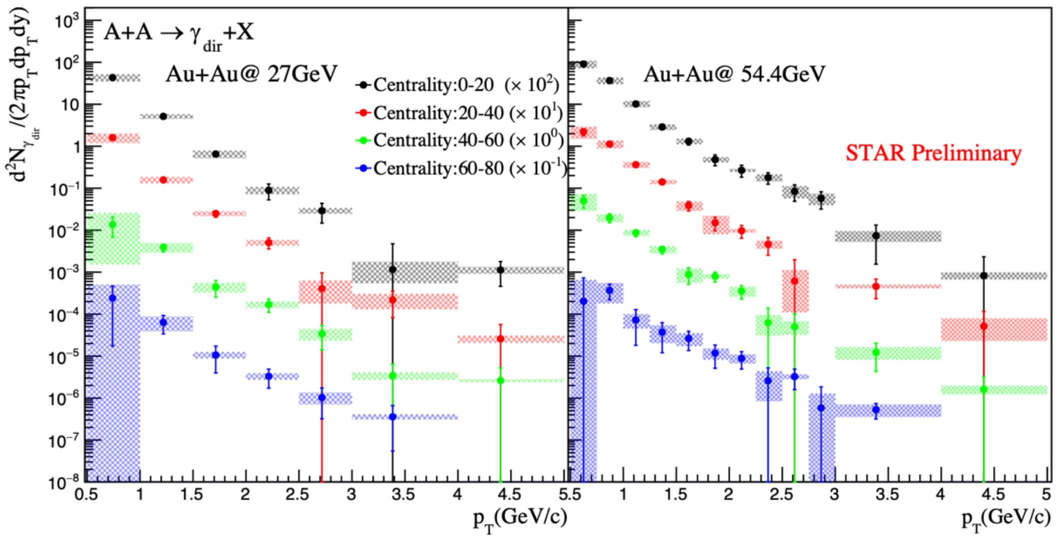
Electromagnetic Probes:

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

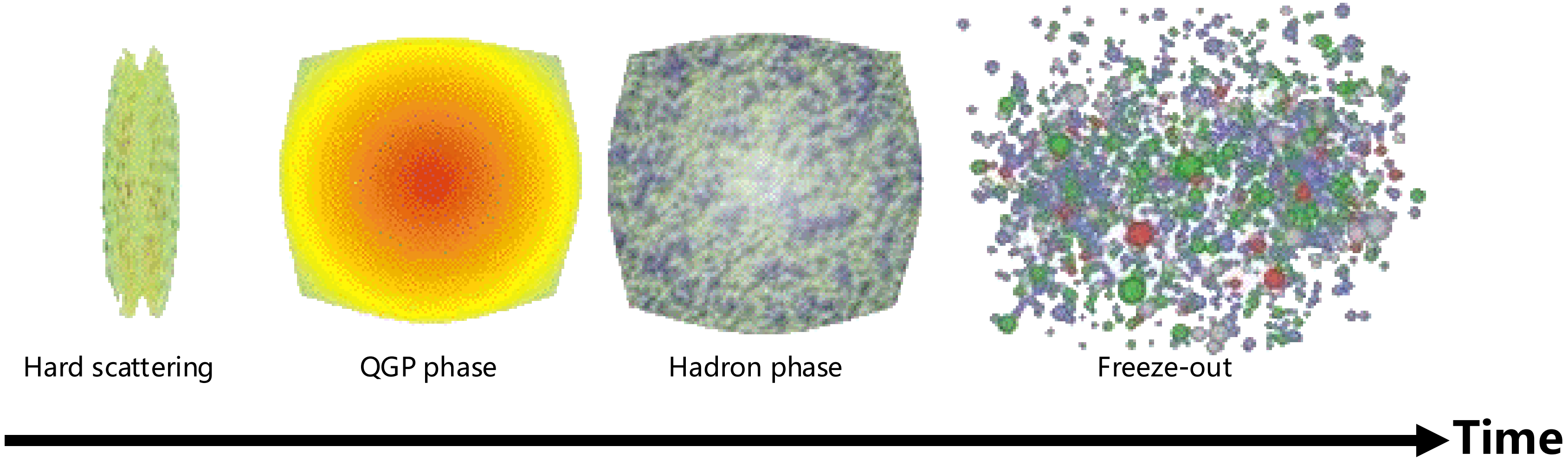
Photons:

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

Xianwen Bao, Hard Probes 2024



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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Photons:

- ✓ Extract T_{eff} from p_T spectra
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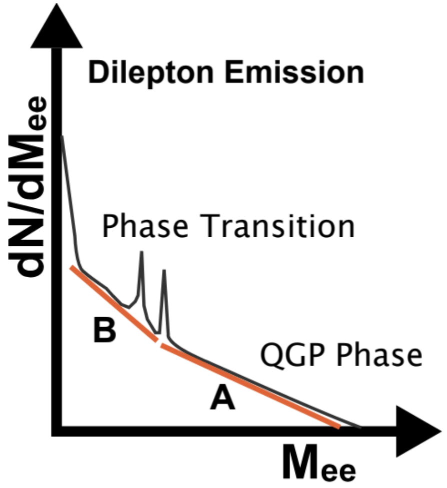
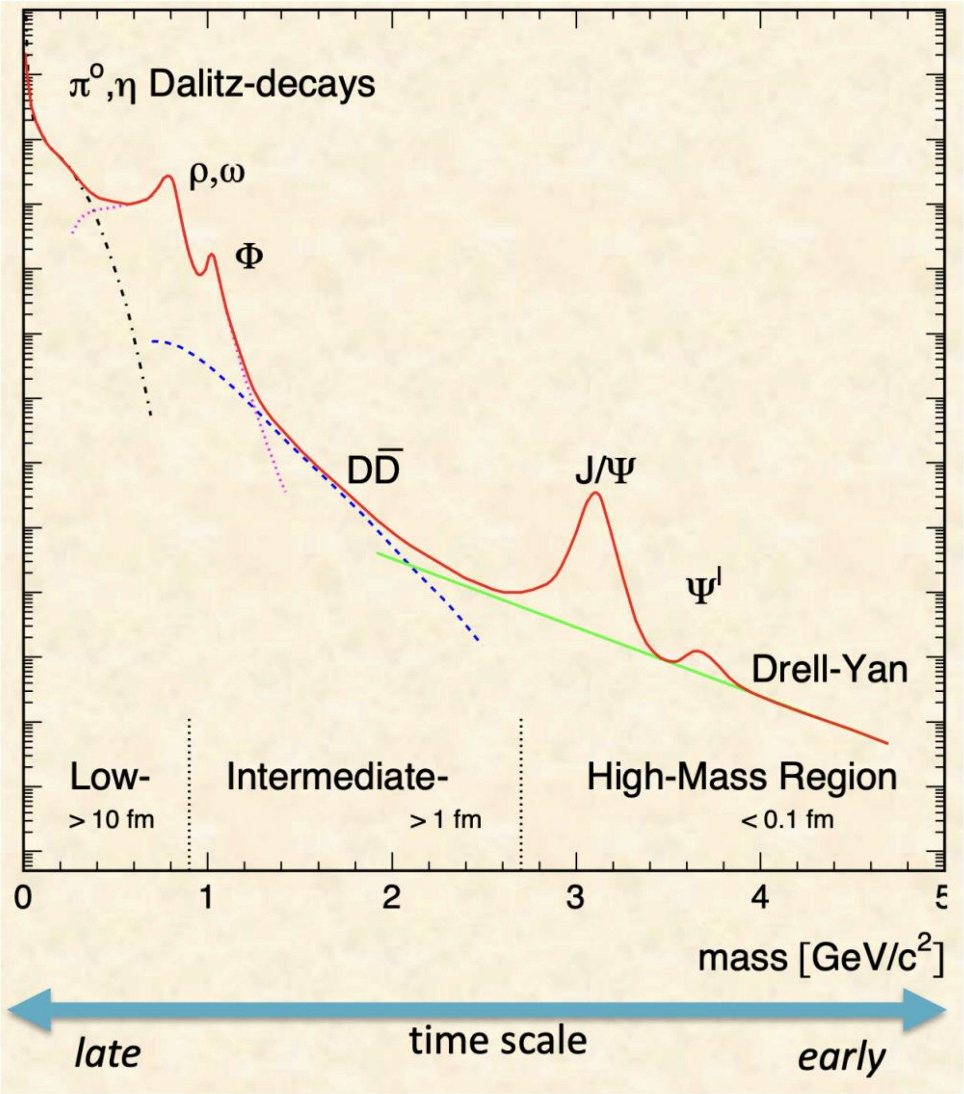
Dileptons:

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



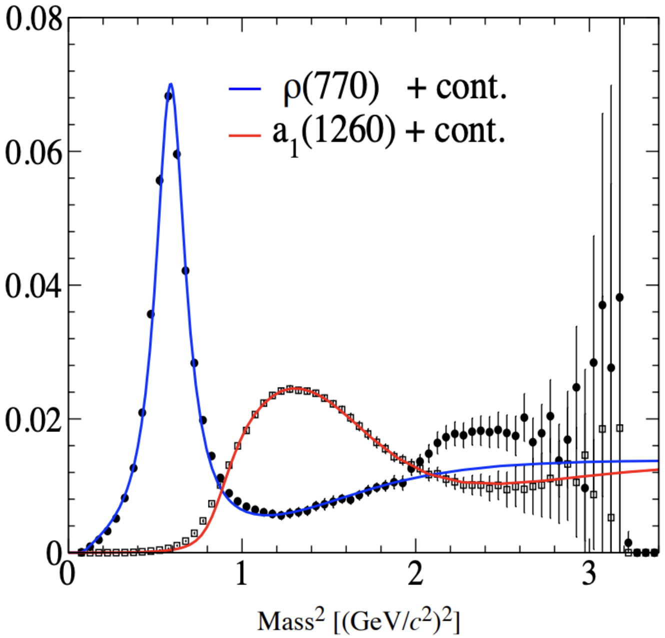
Dielectron measurements



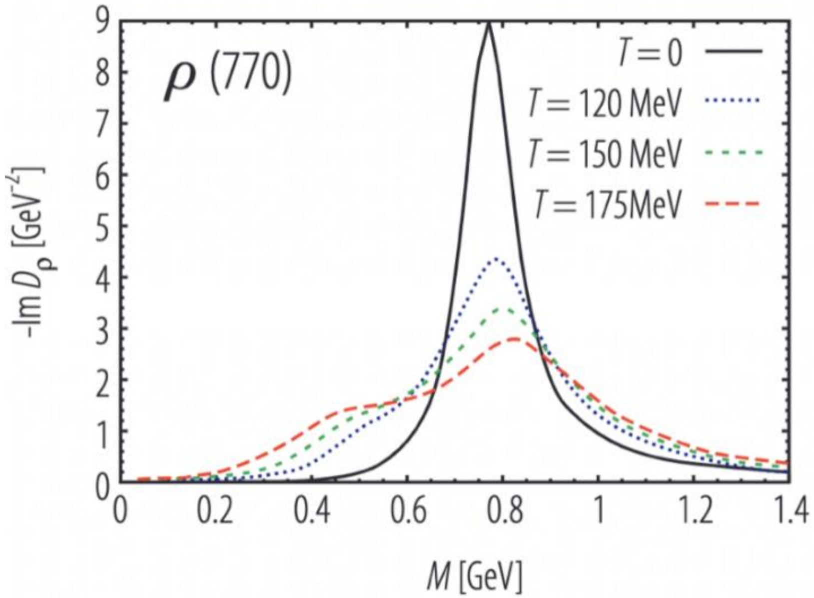
courtesy of Axel Drees

Invariant mass spectra:

- Meson modification in hot and dense medium
  - ρ meson mass spectra boarding
  - Chiral symmetry restoration

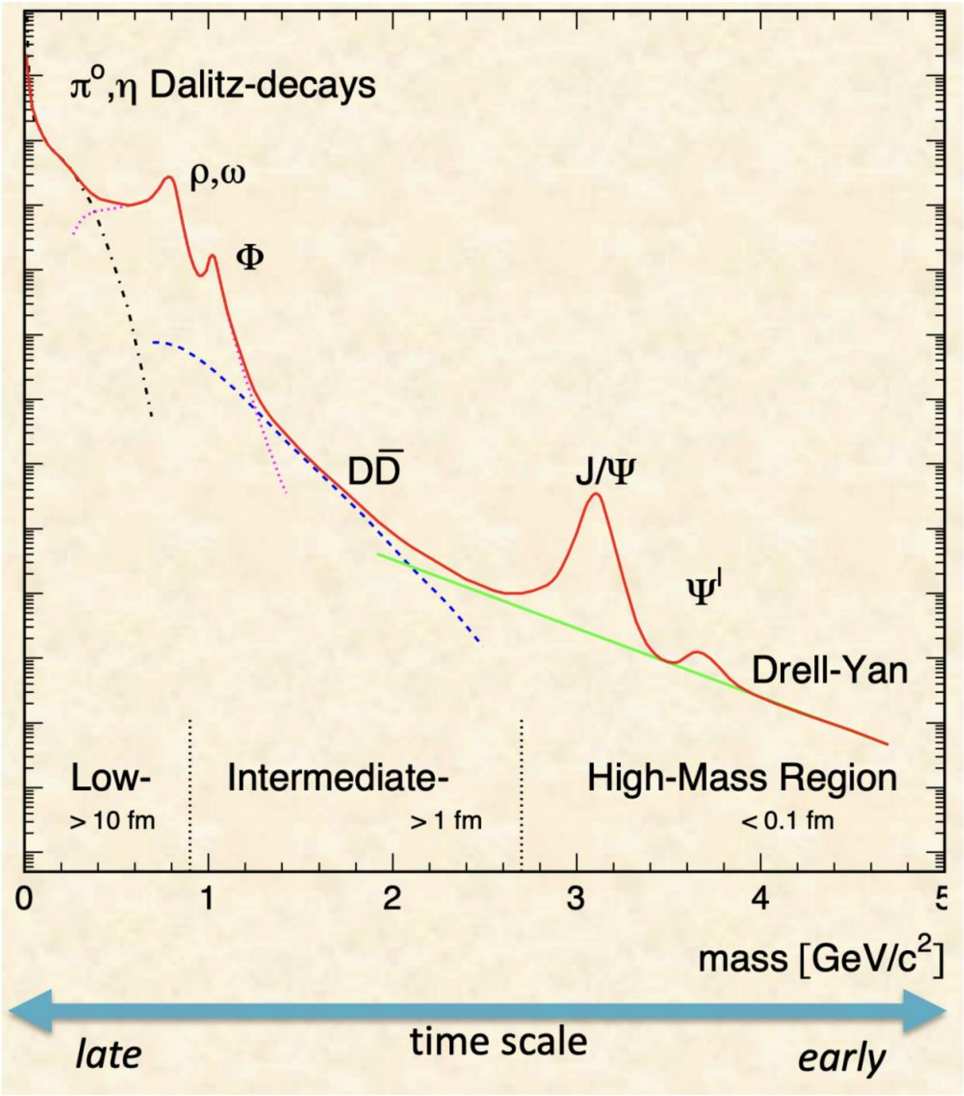


ALEPH: EPJC4 (1998) 409;
R. Rapp Pramana 60 (2003) 675.



Urban, Buballa, Rapp, and Wambach, Nucl. Phys. A 673, 357 (2000).
J. Atchison and R. Rapp, Nucl. Phys. A 1037, 122704 (2023).
Rapp, Acta Phys. Polon. B42 (2011) 2823..

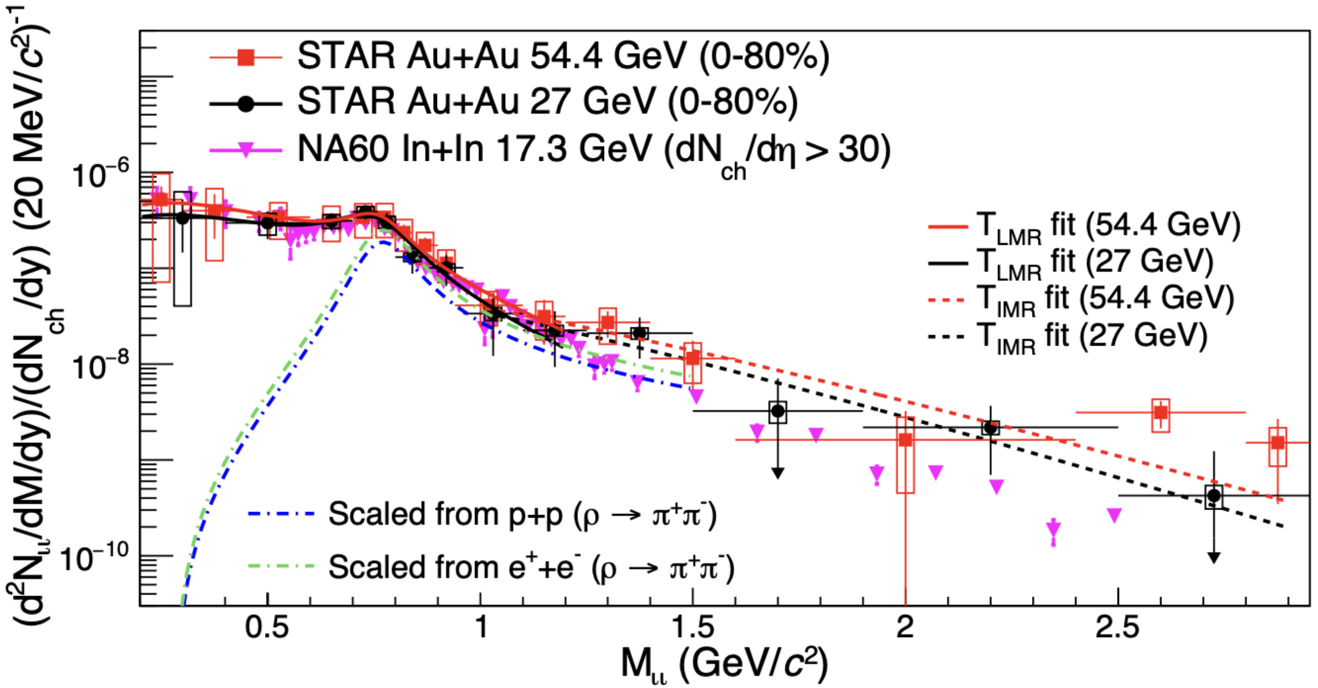
Dielectron measurements



courtesy of Axel Drees

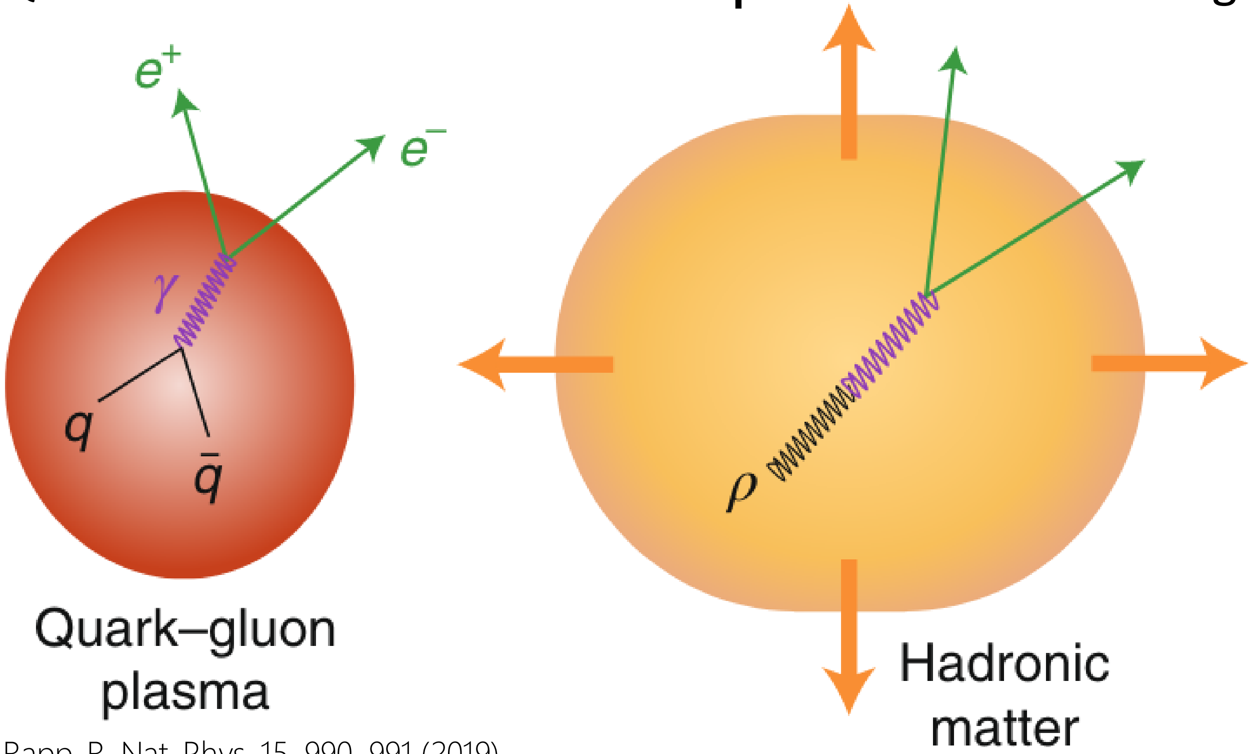
Invariant mass spectra:

- QGP thermal radiation
  - Temperature extraction
  - Large heavy flavor and Drell-Yan contribution in the intermediate mass region



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

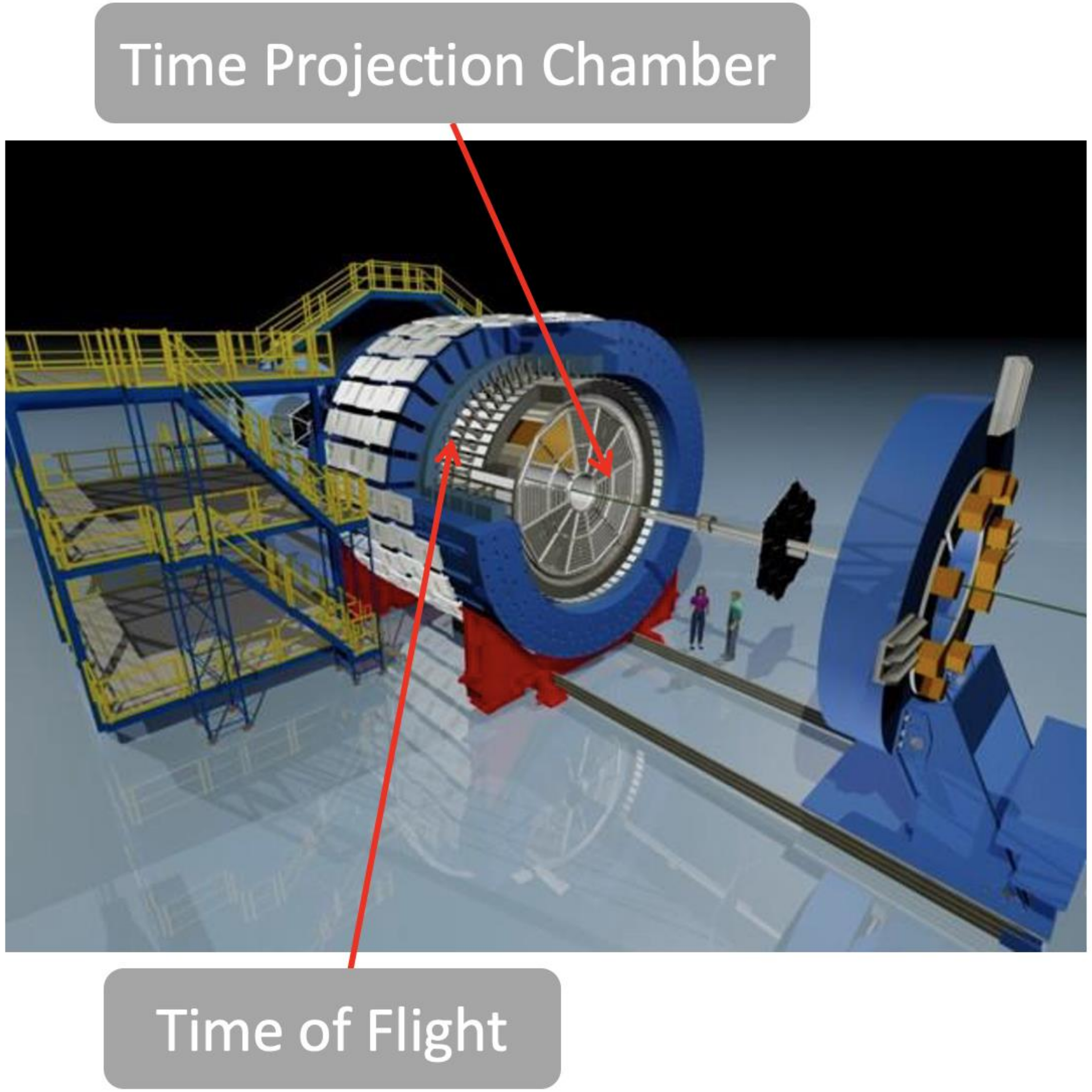
- QGP radiation
- In-medium ρ

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

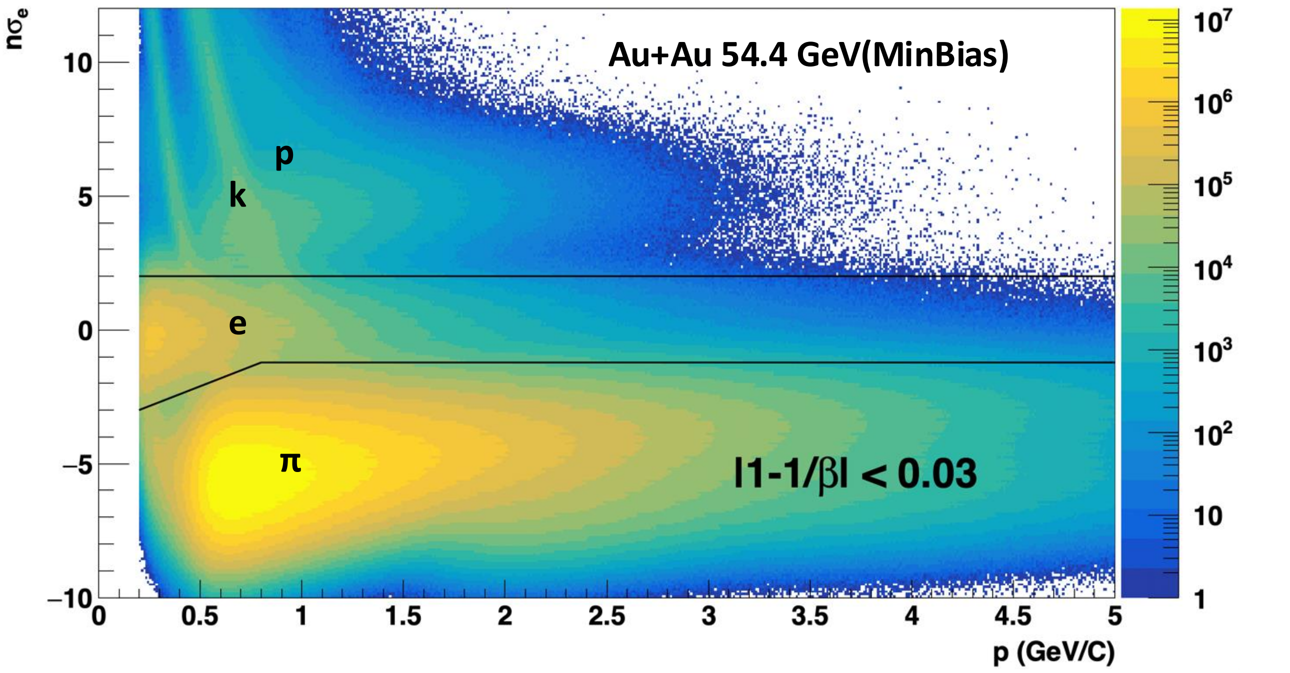
Invariant mass spectra from thermal dileptons can reveal temperature of the hot medium at both **QGP phase** and **hadronic phase**

STAR experiment and eID



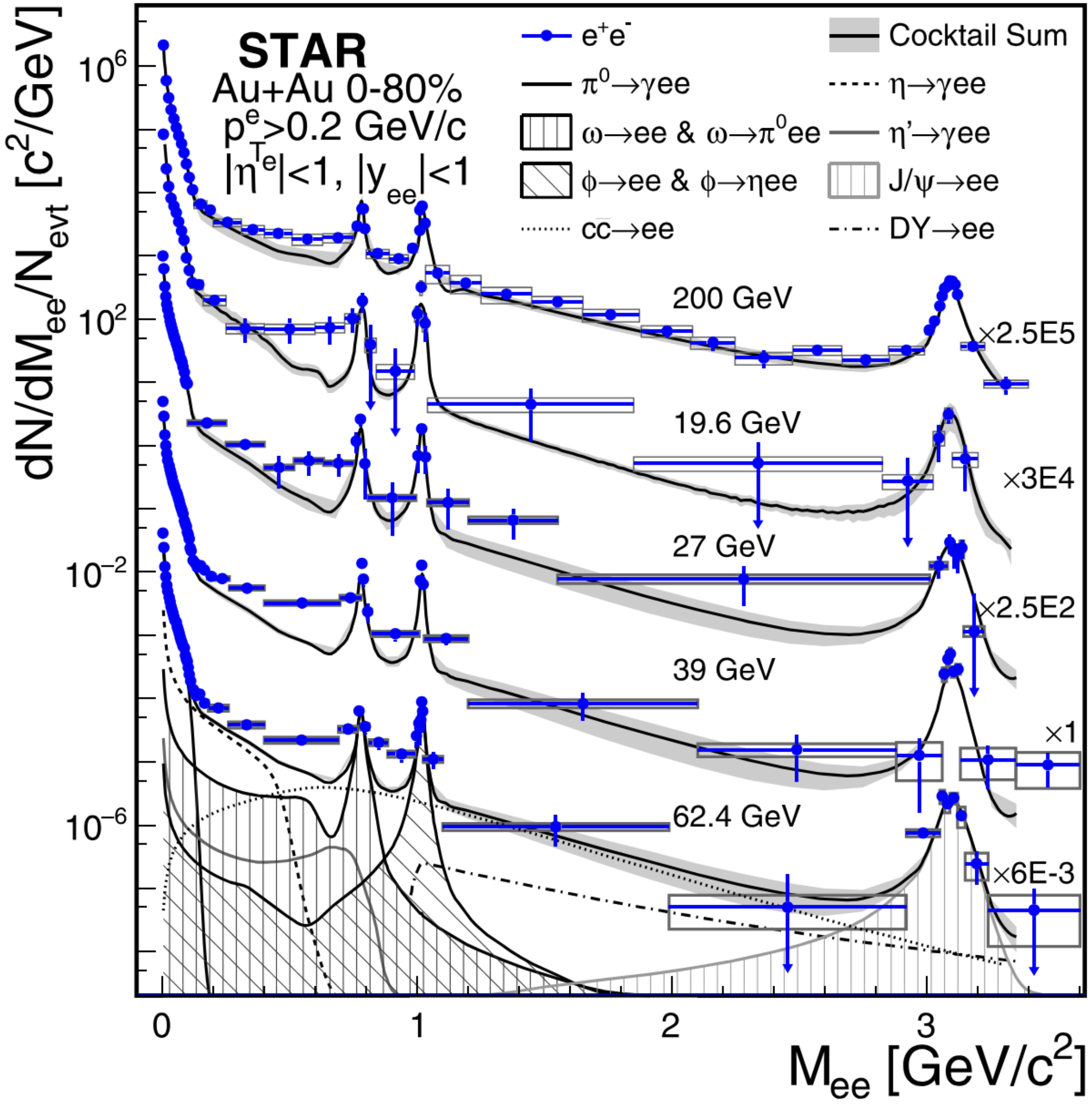
Time Projection Chamber + Time of Flight

- ✓ 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:

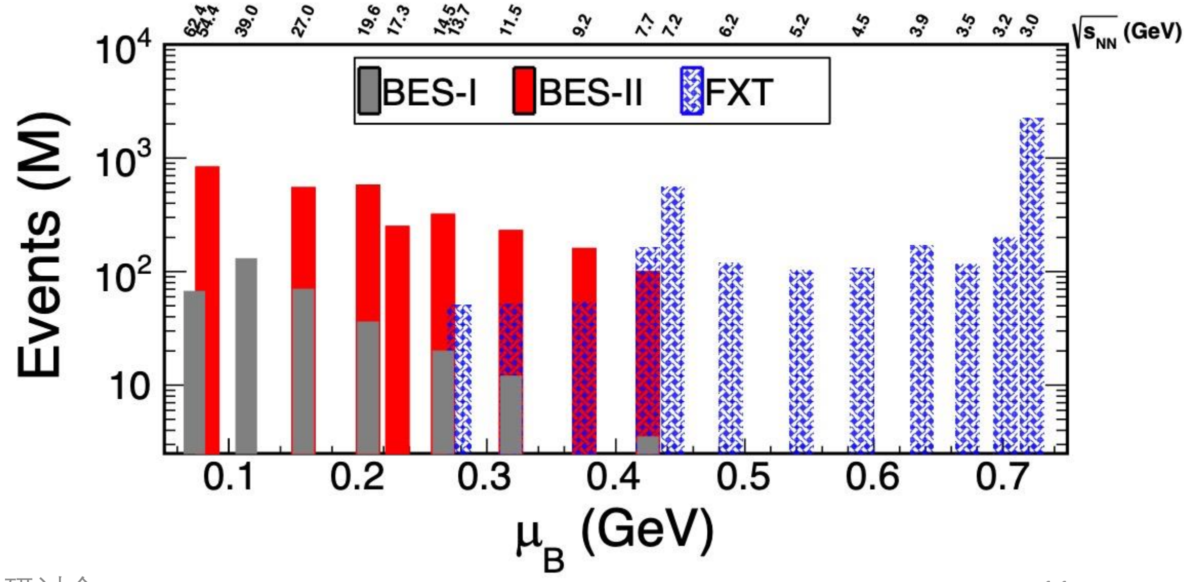
- High statistics
- Hard to extract excess yield in intermediate mass region

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

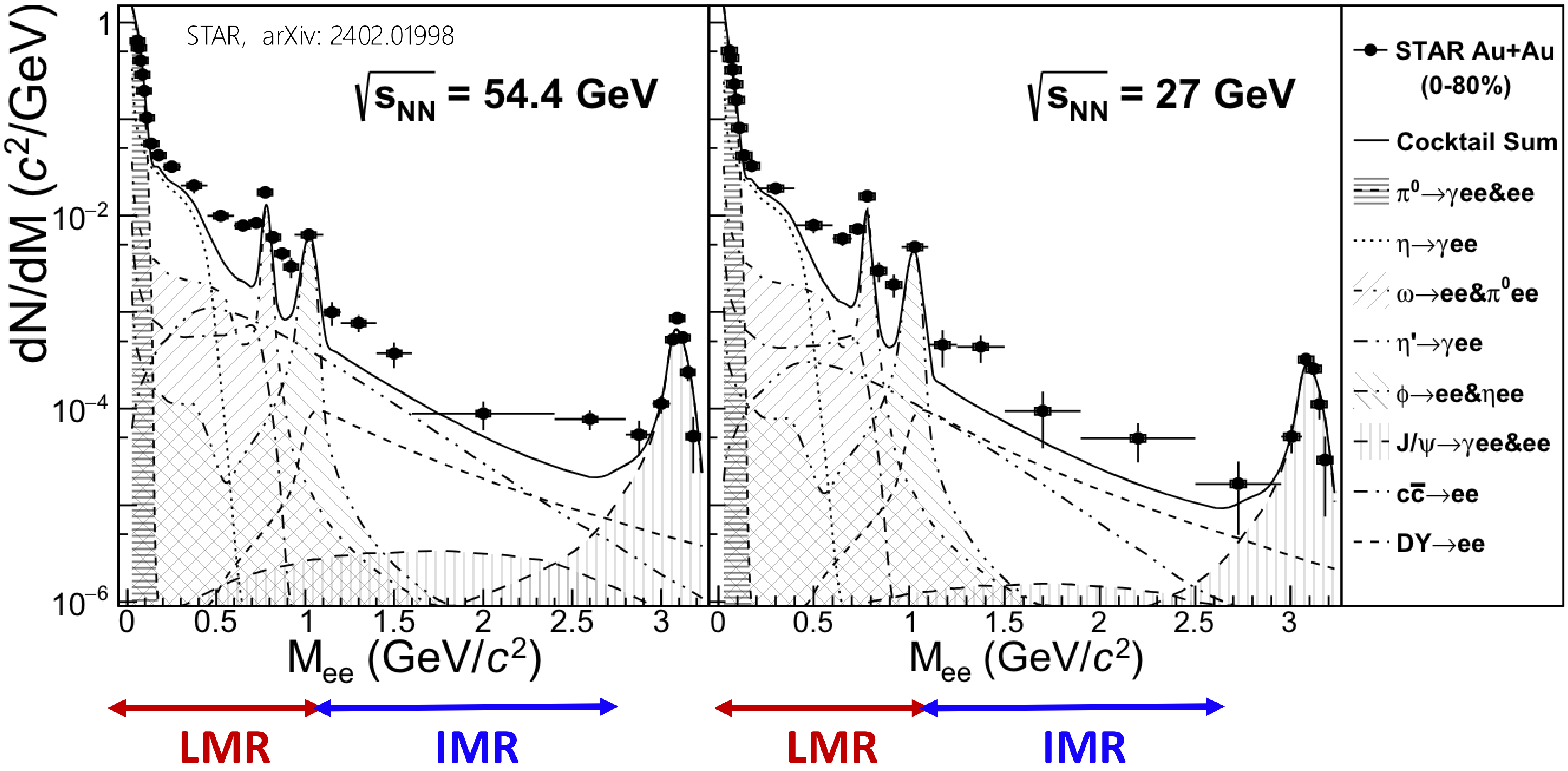
- Lack of statistics

BES–II :

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



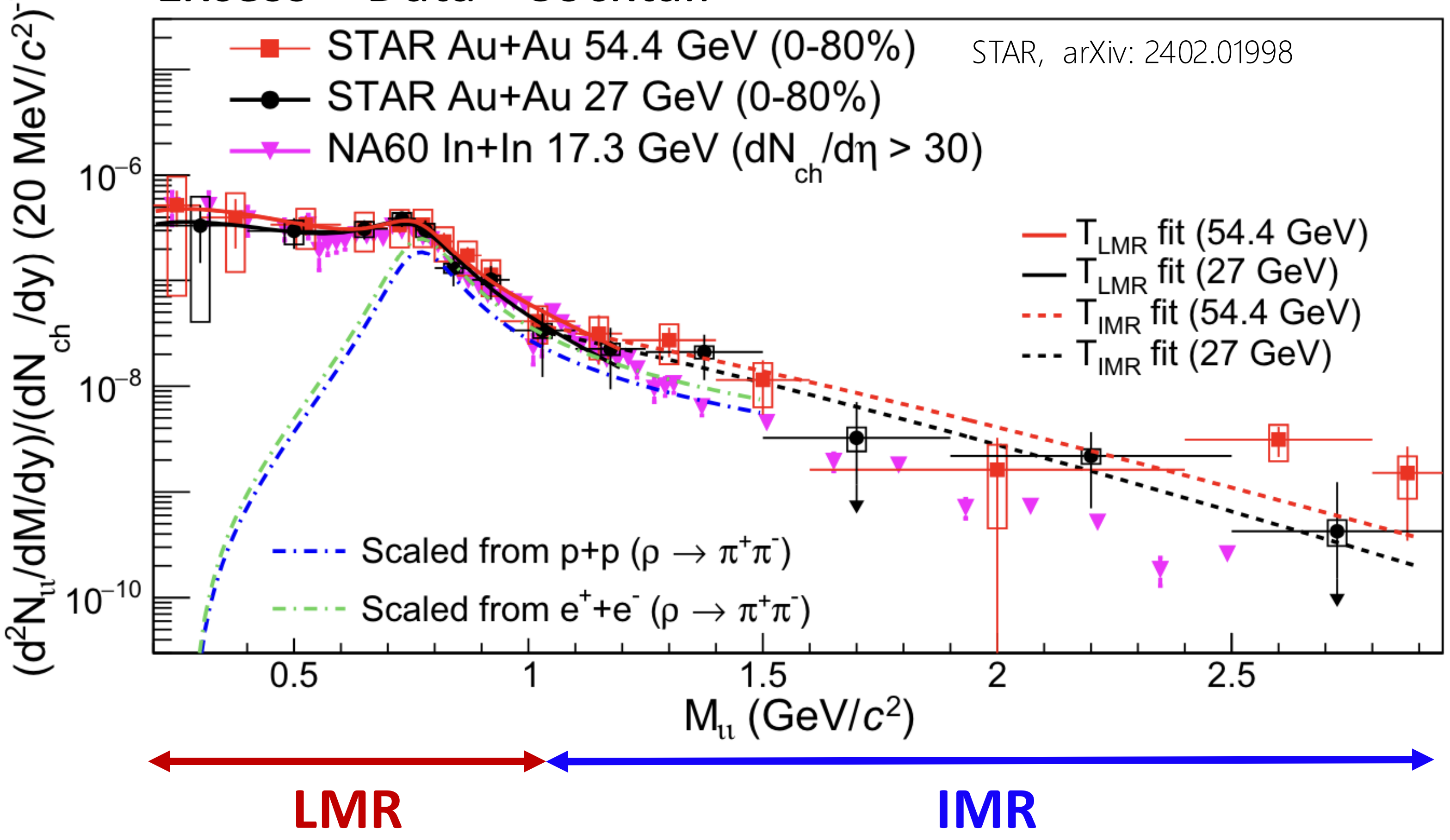
Dielectron spectra @ 27 and 54.4 GeV



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

Excess yield

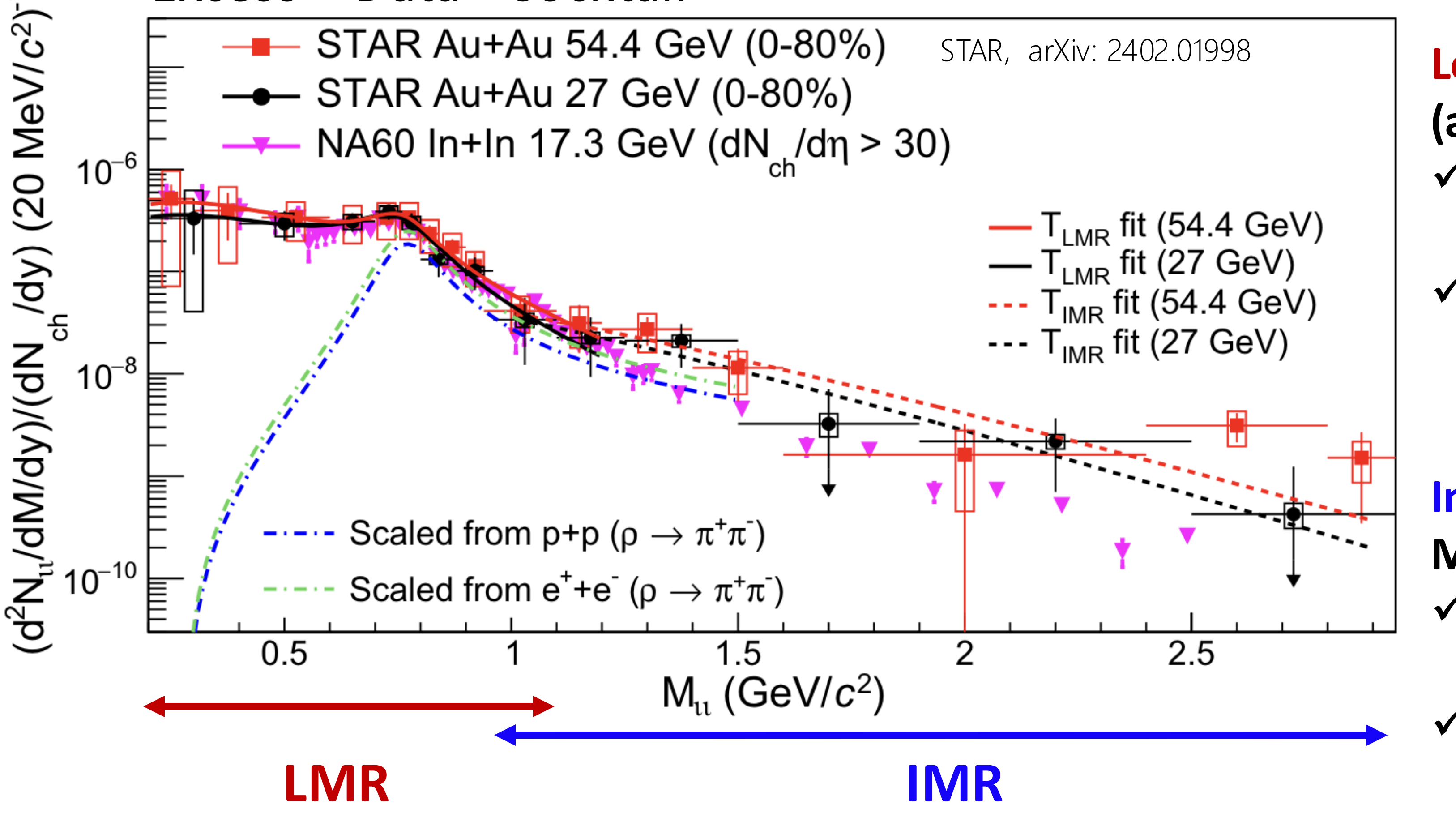
Excess = Data - Cocktail



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

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

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

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

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

Low mass region:

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

✓ Similar T compared to lower collision data.

✓ T_{LMR} ~ Pseudo Critical temperature T_{pc} (156 MeV)

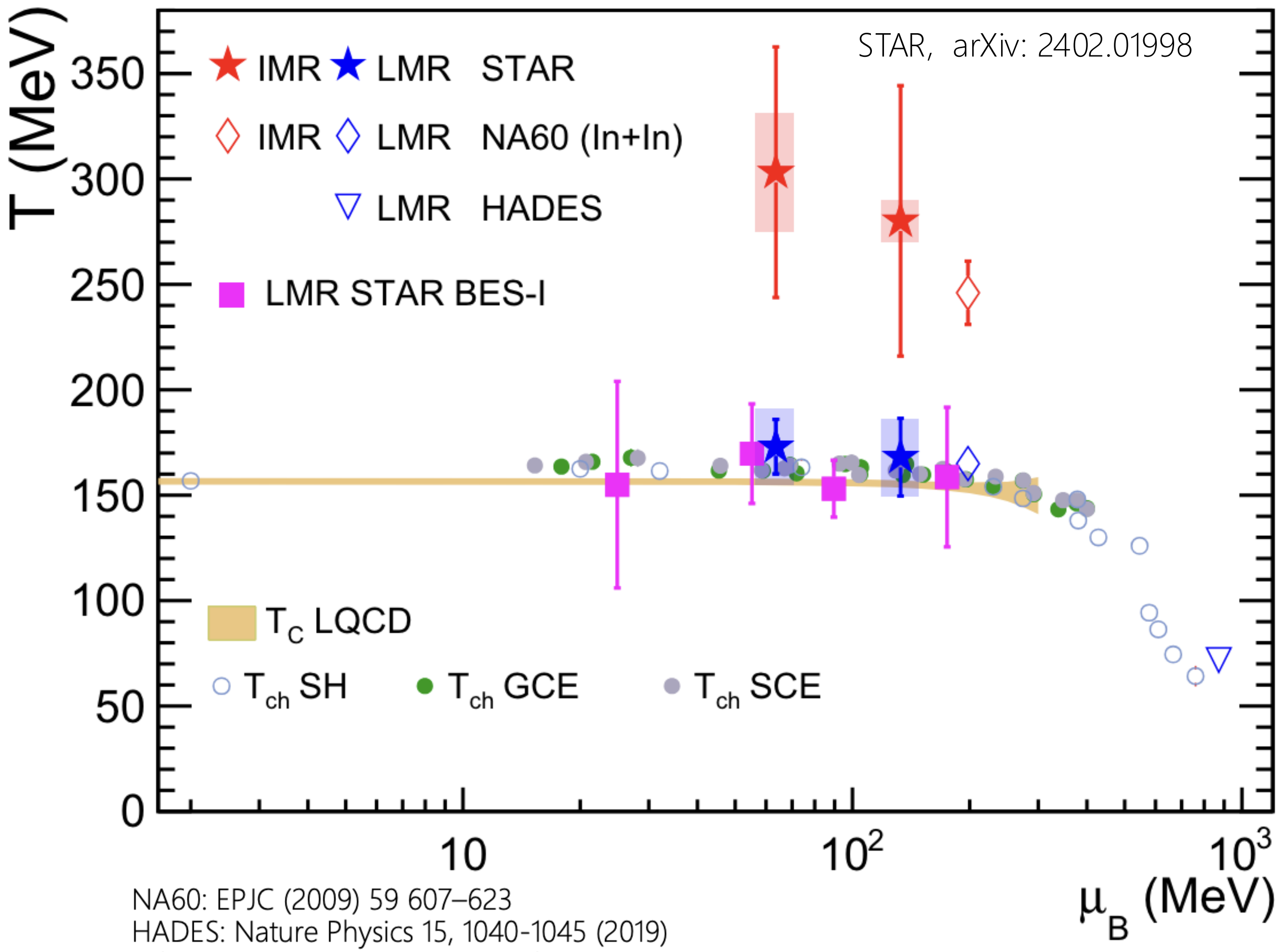
Intermediate mass region:

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

✓ QGP thermal radiation is predicted to be the dominant source

✓ T_{IMR} is higher than the pseudo critical temperature T_{pc} (156 MeV)

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:

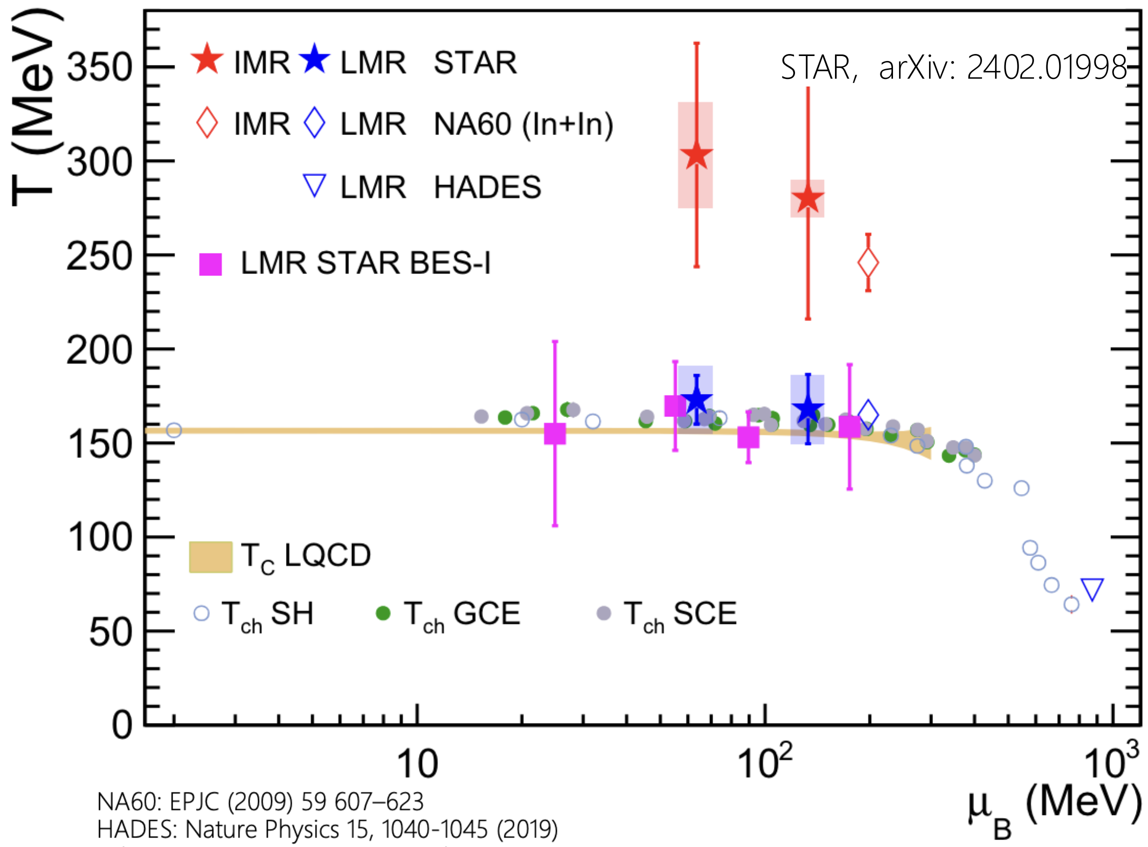
- ✓ T_{LMR} is close to the T_{pc} and T_{ch}
- ✓ Emitted form the hadronic phase, dominantly around the phase transition

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

Temperature at high μ_B region



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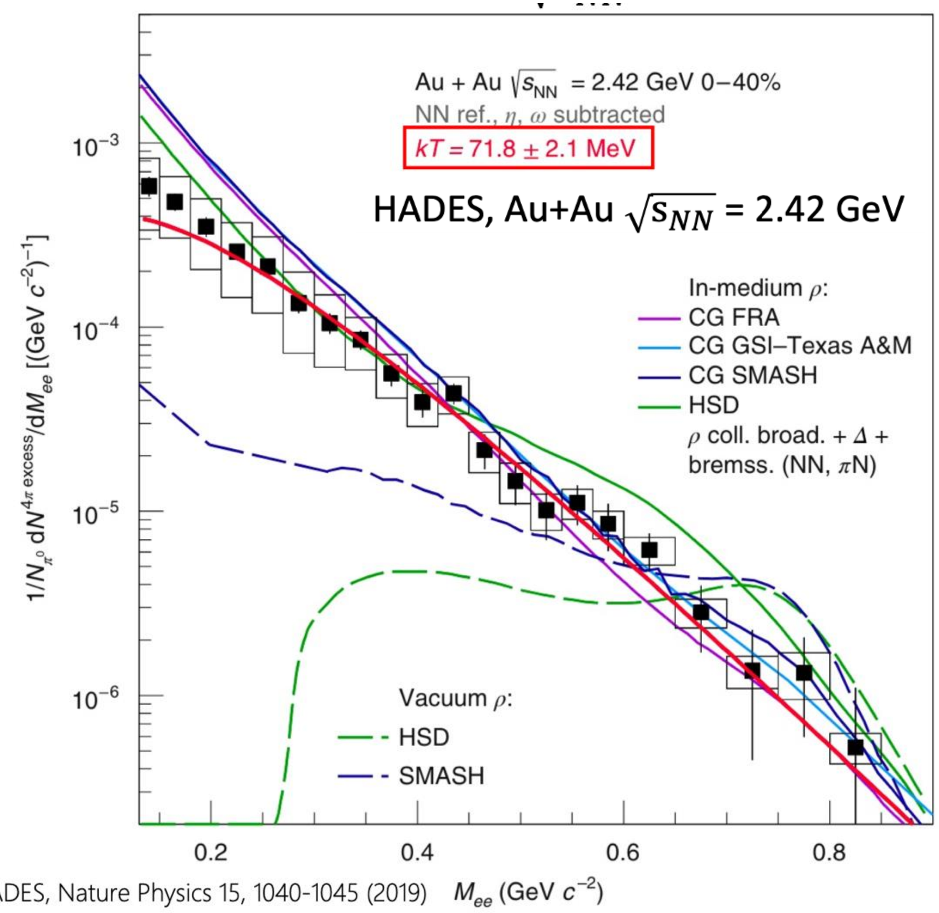
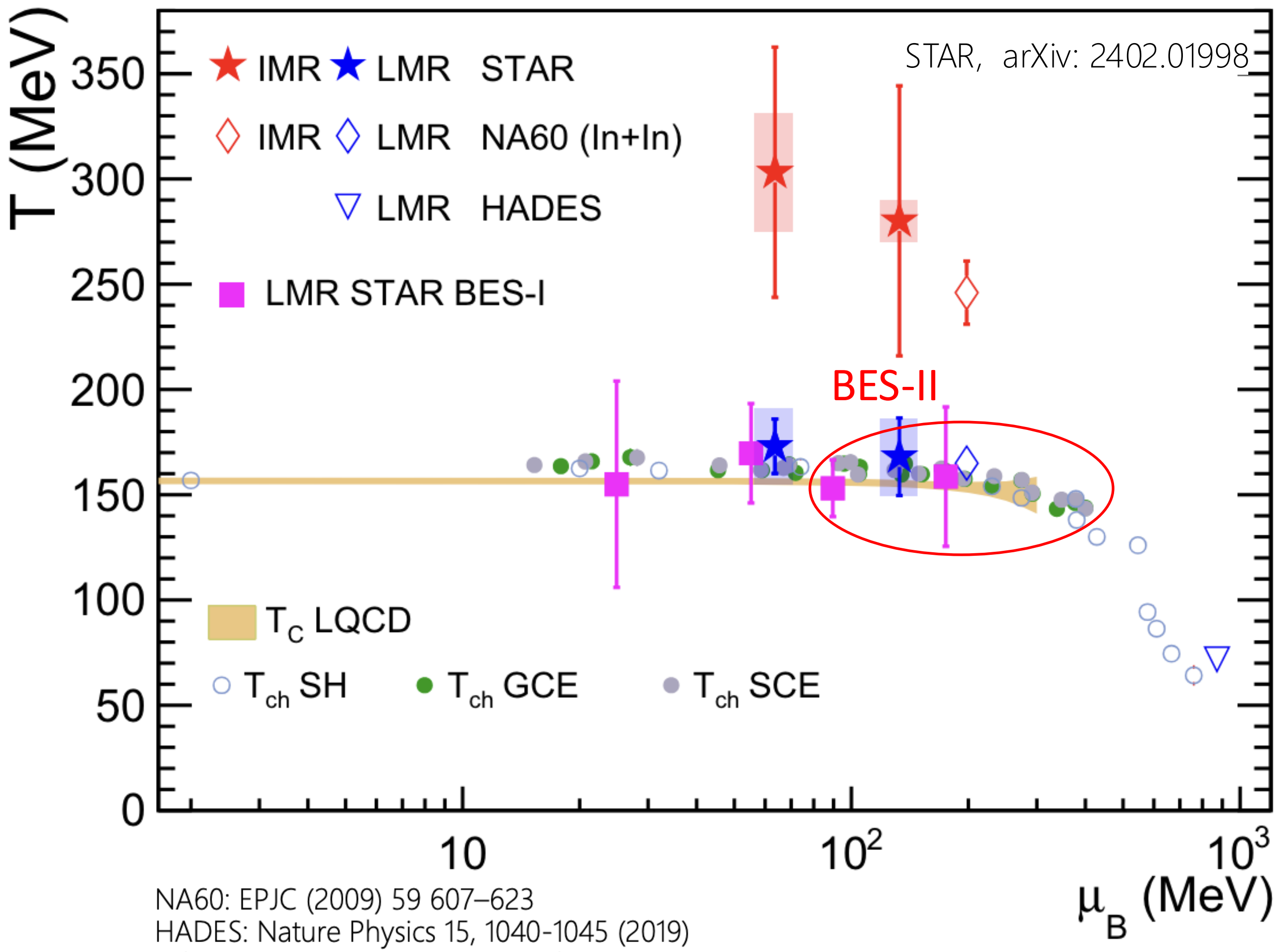


HADES, Nature Physics 15, 1040-1045 (2019)

- ✓ High baryon density, μ_B ~ 700-900 MeV
- ✓ In-medium ρ melt via frequent scattering with surrounding baryons
- ✓ T_{LMR} ~ 71.8 MeV, much lower than that at RHIC and SPS

Dielectron measurements with STAR BES-II and isobar data



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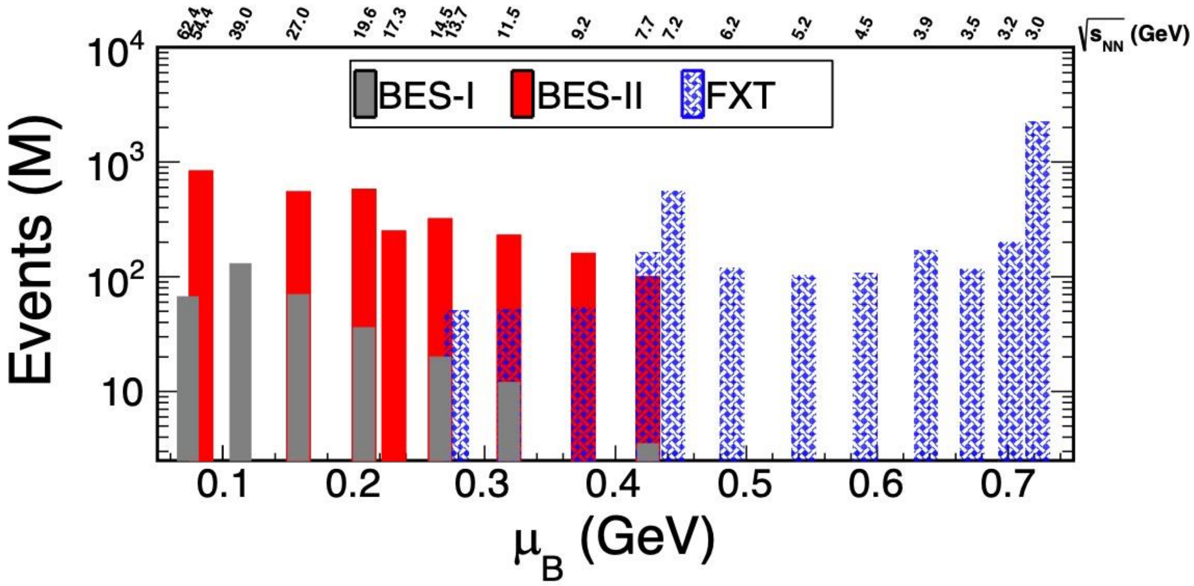
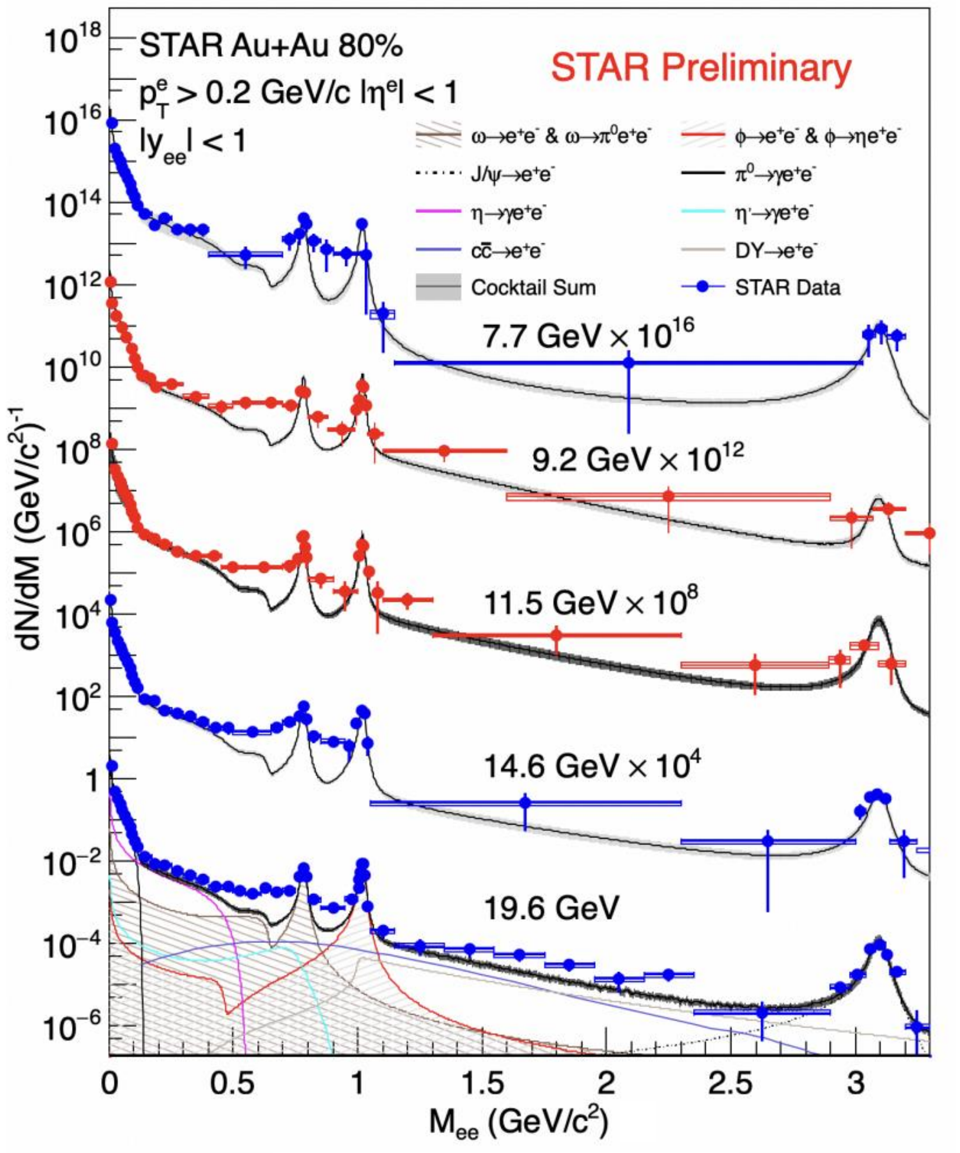
Tch SH: P. Braun-Munzinger et al. Nature 561, 321-330 (2018)
Tch GCE/SCE: STAR PRC 96, 044904 (2017)

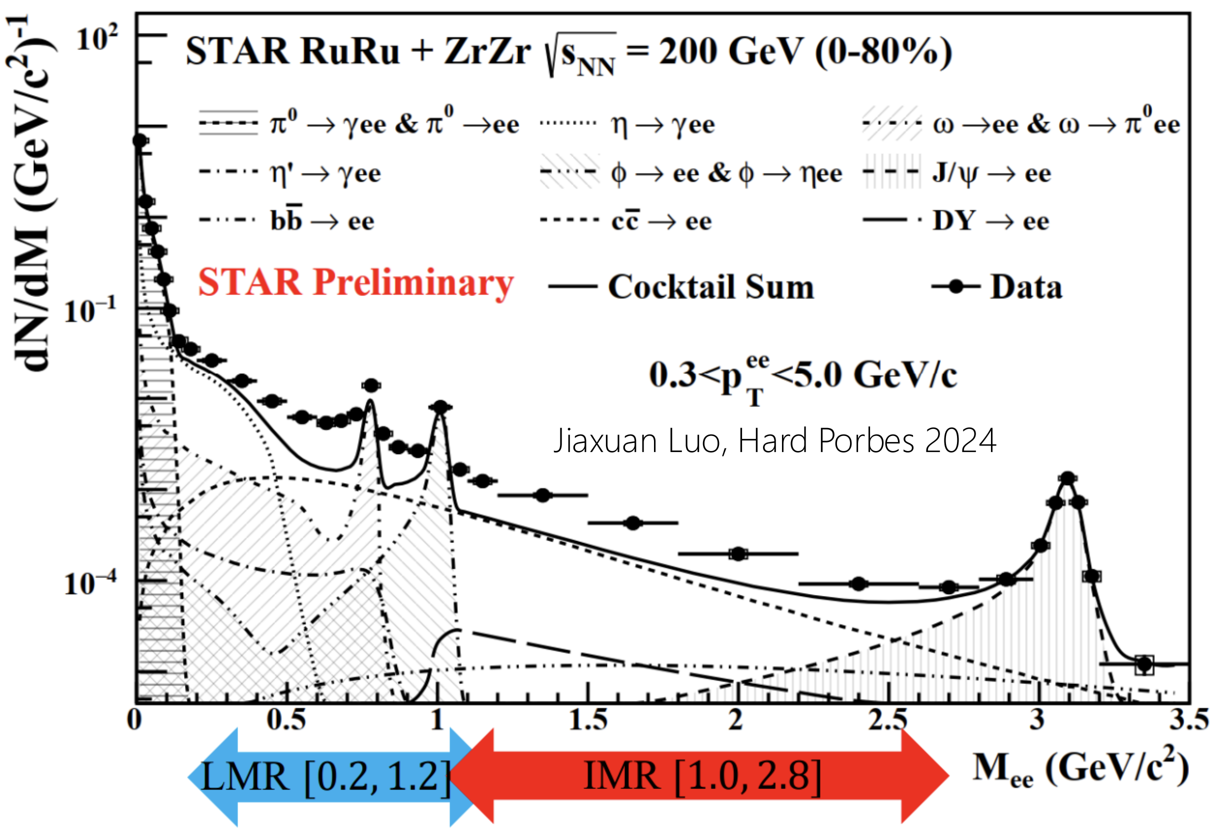
- ✓ BES-II and FXT data will cover the large gap between the STAR and HADES data
- ✓ High statistic dataset with isobar collisions at 200 GeV.
  - Ru+Ru ~ 2B events
  - Zr+Zr ~ 2B events



Mass spectra



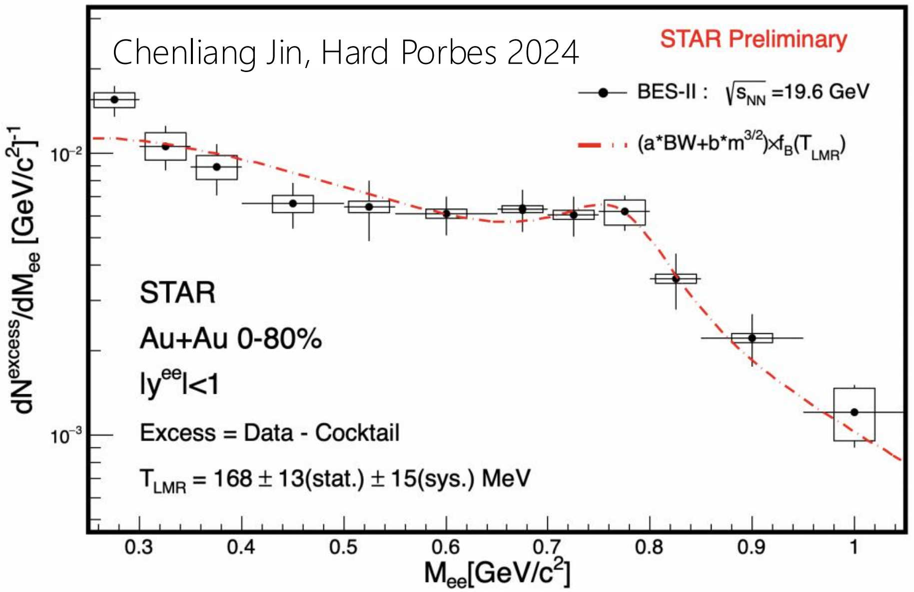
Chenliang Jin, Hard Porbes 2024

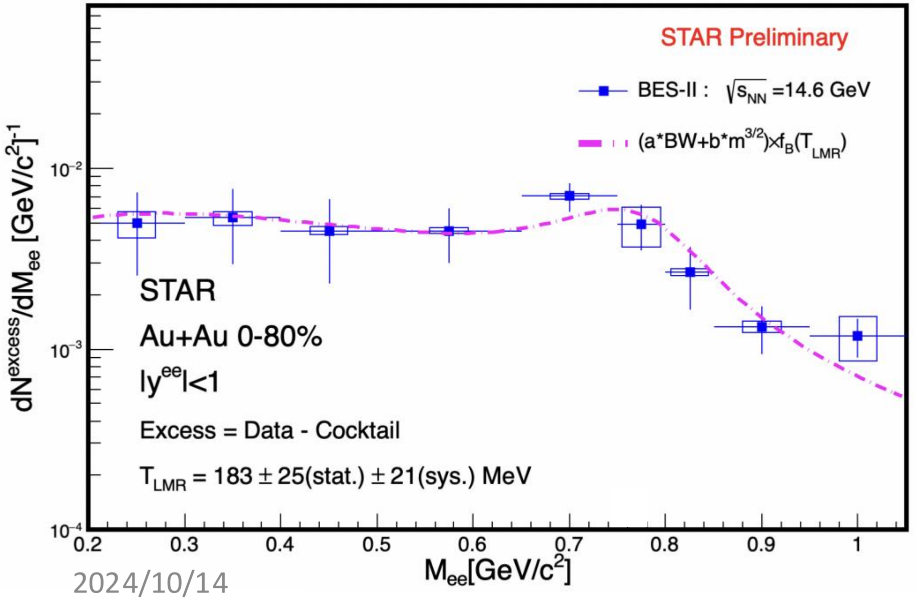


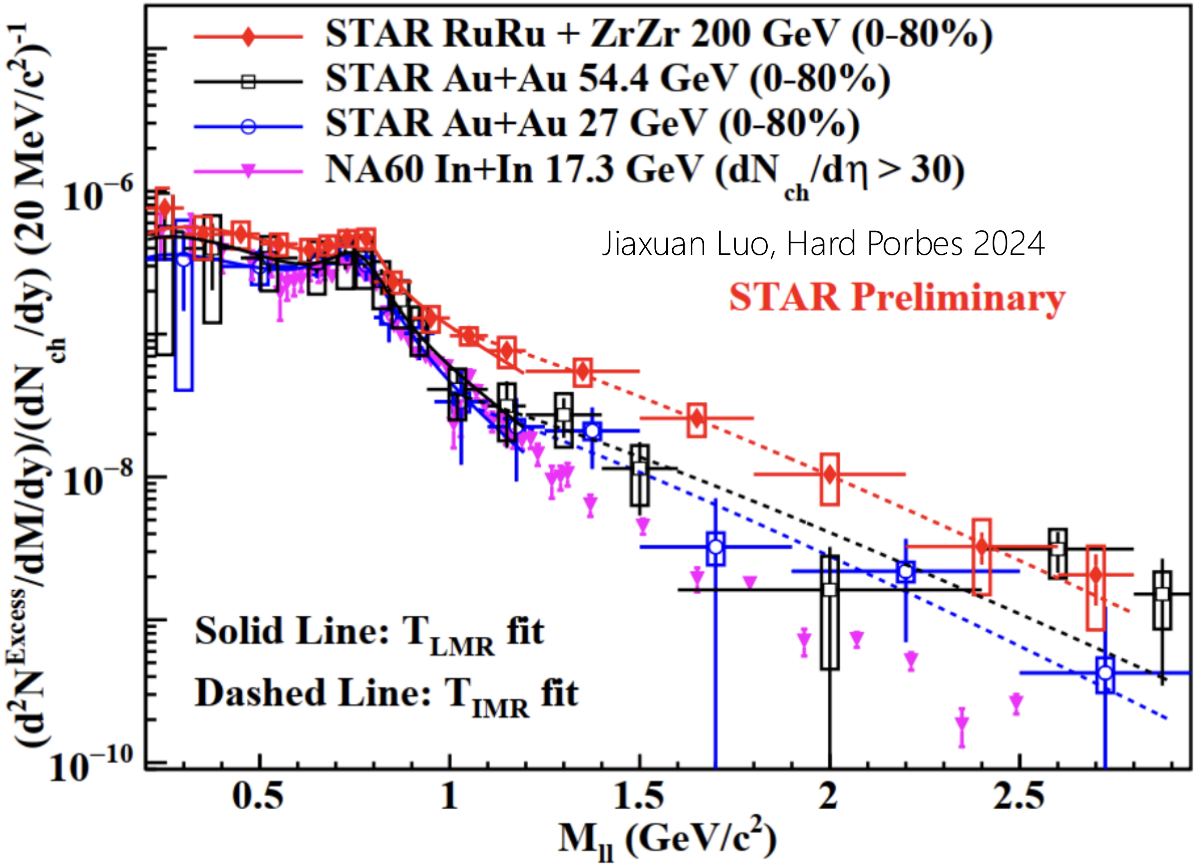
Jiaxuan Luo, Hard Porbes 2024

- ✓ Mass spectra obtained in BES-II and isobar data
- ✓ Excess yield observed
- ✓ Same fitting method compared to 27 and 54.4 GeV

Excess yield spectra







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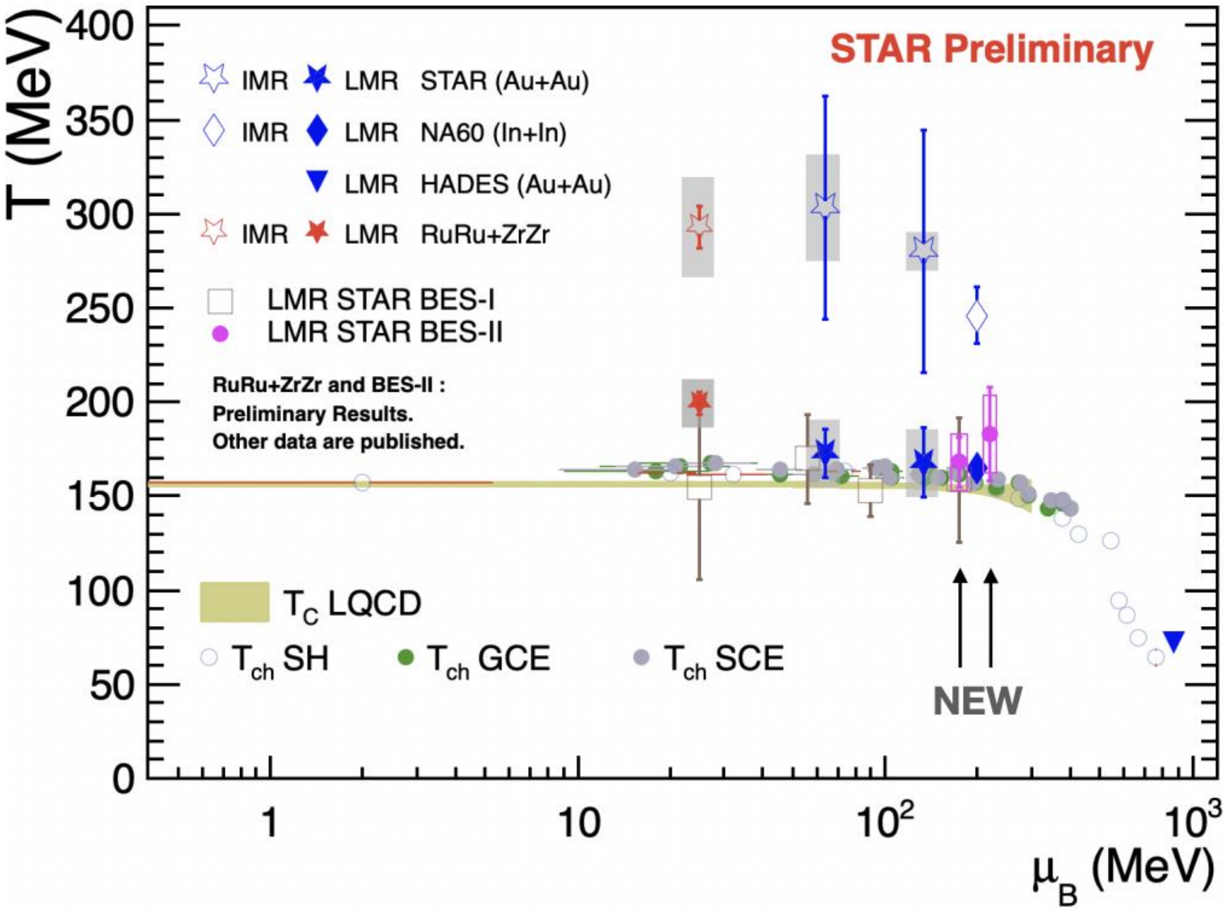
Temperature extraction

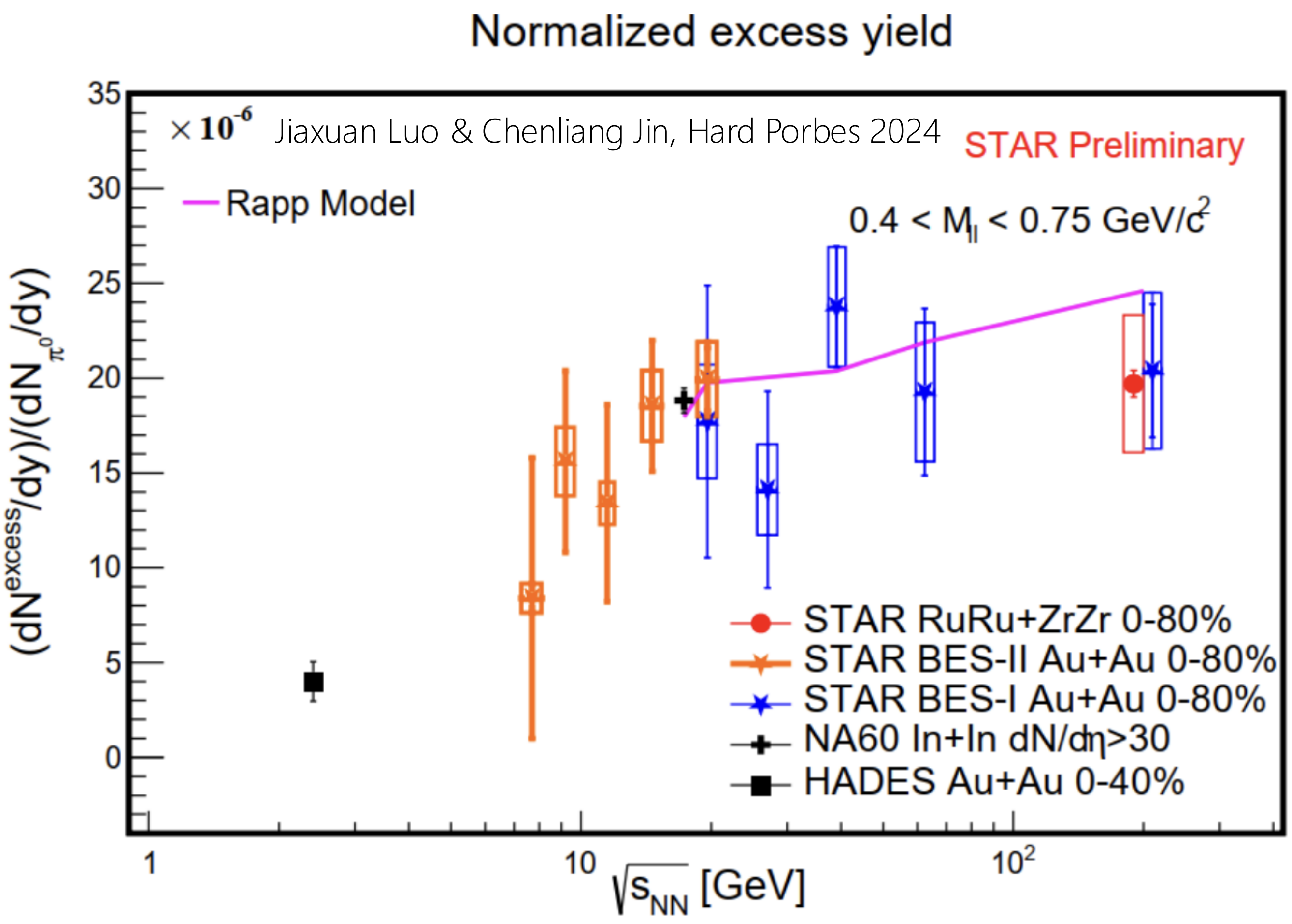
Jiaxuan Luo & Chenliang Jin, Hard Porbes 2024



- ✓ Low collision energy:
  - ✓ T_{LMR} ~ T_{PC}
  - ✓ Indicate the thermal radiation from hadronic gas is mainly produced around the phase transition.
- ✓ 200 GeV isobar:
  - ✓ T_{LMR} is higher than T_{PC}
  - ✓ Hint of higher QGP contribution
  - ✓ T_{IMR} ~ 4.3σ higher than T , strong evidence for the existence of QGP

STAR: Phys. Rev. C 107, L061901 (2023)
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)
STAR: Phys. Lett. B 750, 64 (2015)
NA60: EPJC 59, 607–623 (2009)

Integral of normalized excess yield



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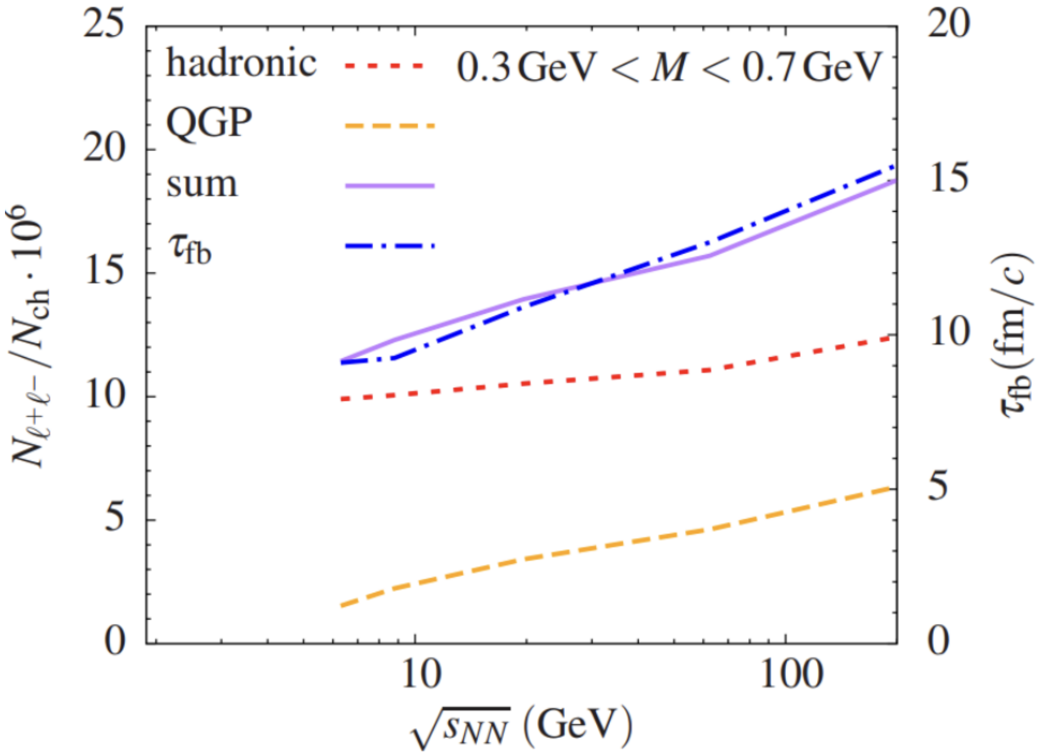
R. Rapp, Phys. Rev. C 63, 054907 (2001)
H. van Hees and R. Rapp:
Phys. Rev. Lett. 97, 102301 (2006). Phys.Lett.B 753 (2016) 586-590

STAR: Phys. Lett. B 750, 64 (2015)
NA60: EPJC 59, 607–623 (2009)

- ✓ Normalized by π^0 to cancel the volume effect
- ✓ Hint of decreasing trend from high to low collision energies



R. Rapp and H. van Hees : Phys.Lett.B 753 (2016) 586-590

Summary & Outlook

Dielectron invariant mass spectra measurement:

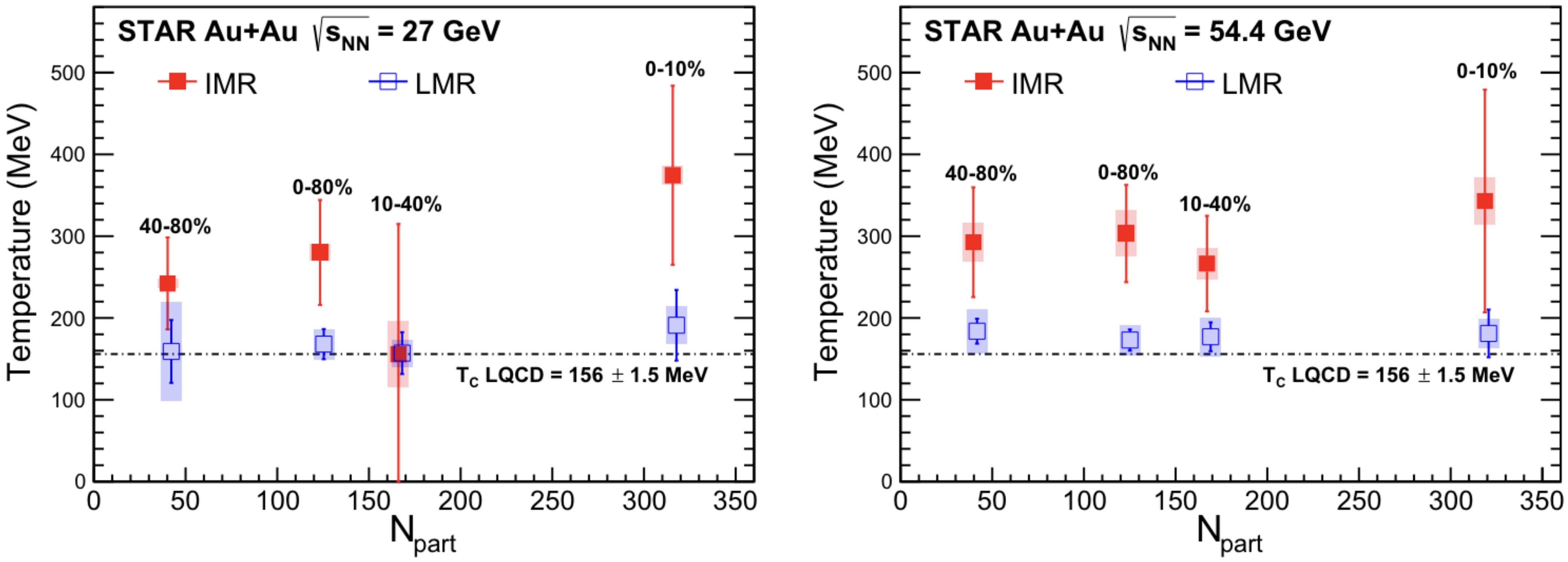
- ✓ Excess yield in wide collision range
- ✓ Hints of decreasing trend of integrated excess yield
- ✓ T_{IMR}: Higher than T_{pc}, T_{ch} and T_{LMR}
- ✓ T_{LMR}: Hint of higher QGP contribution at higher energies

Outlook:

- ✓ Comparison with theory calculation to constrain models and further physics interpretation at higher baryon density region
- ✓ Opportunity for other topics with electromagnetic probe:
  - ✓ Azimuthal anisotropy

Temperature v.s. N_{part}

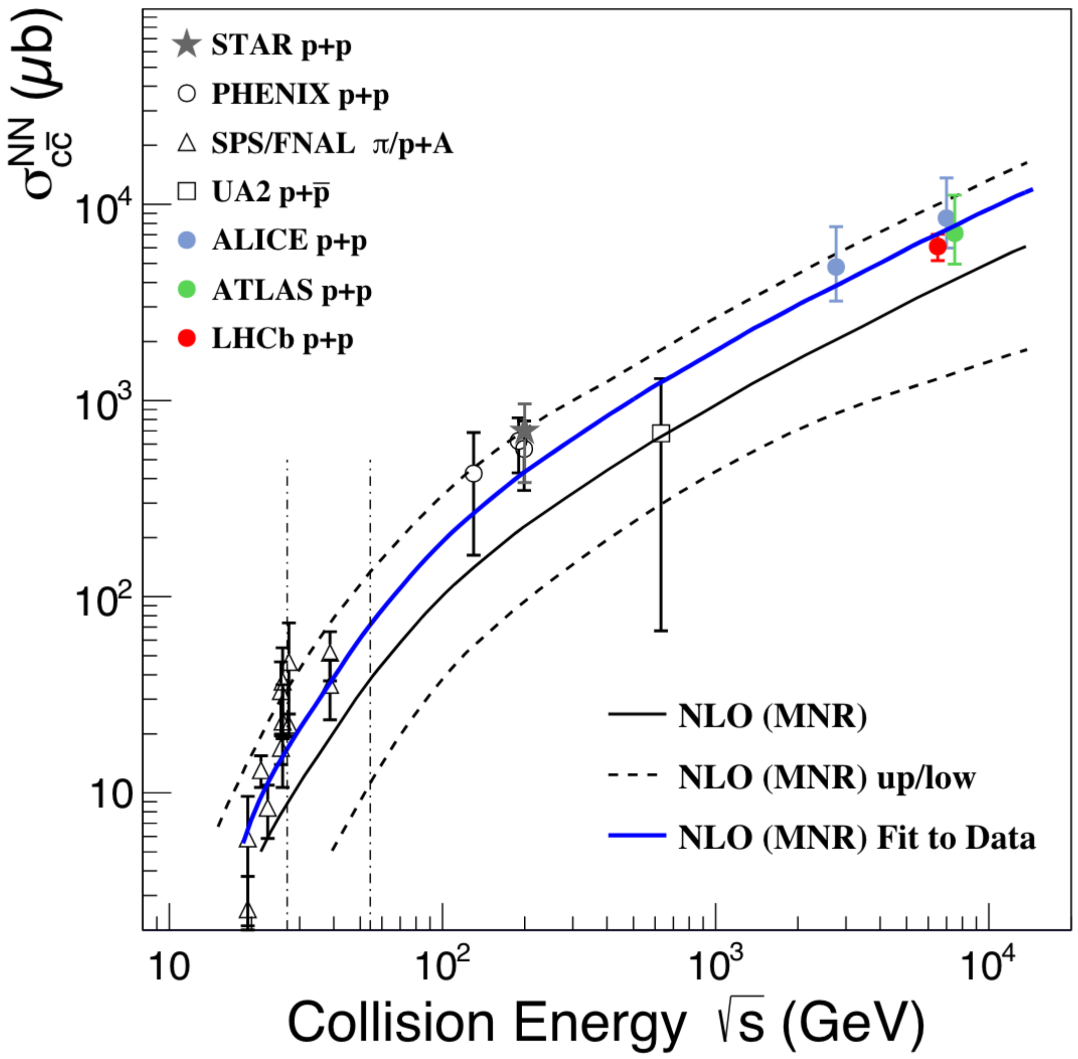
STAR, arXiv: 2402.01998



No clear centrality dependence in both mass regions

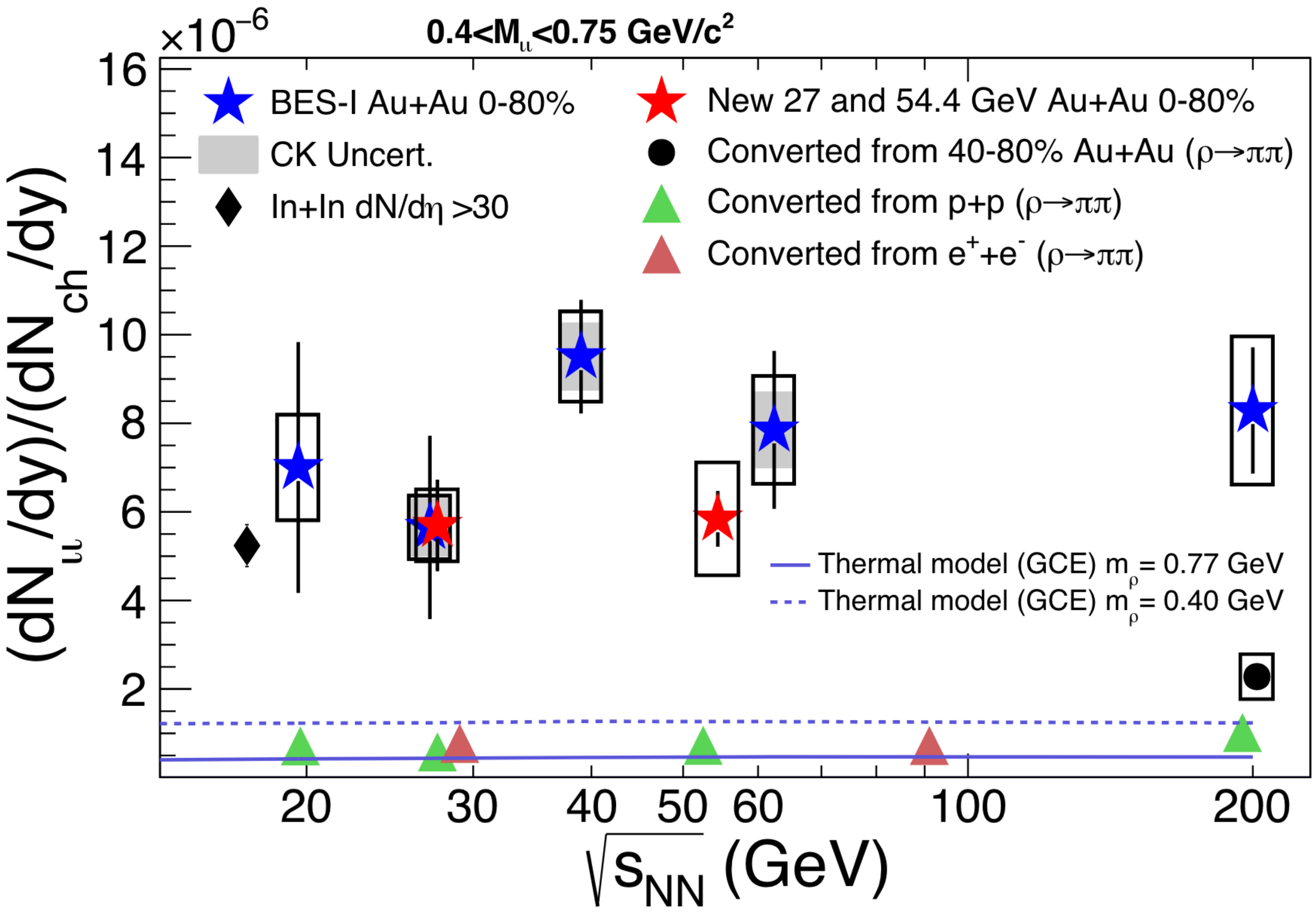
- ✓ Temperature from low mass region is around the pseudo critical temperature
- ✓ Temperature from intermediate mass region is higher than that in low mass region

Backup



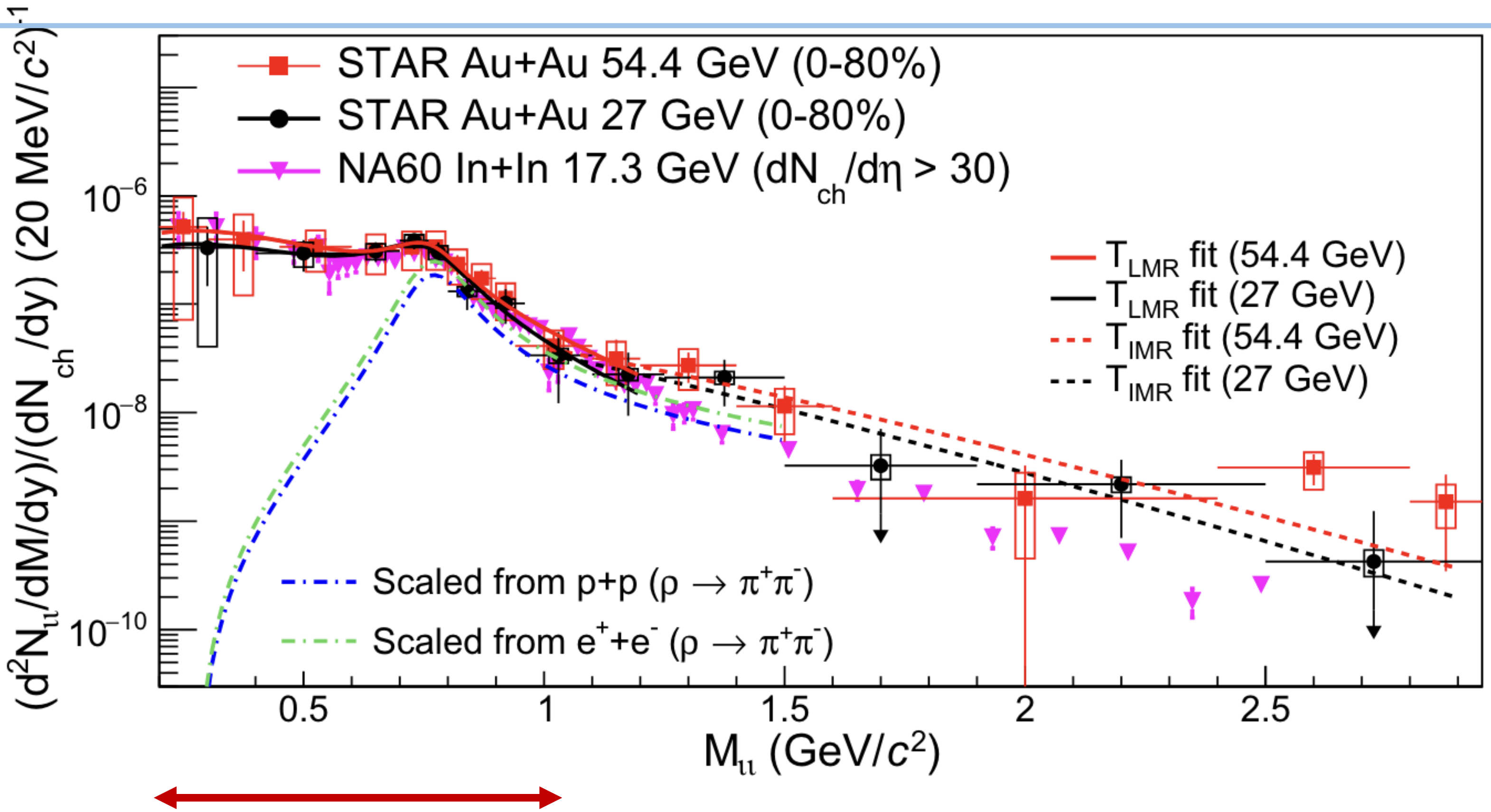
STAR p+p
PHENIX p+p
SPS/FNAL π/p+A
UA2 p+p̄
ALICE p+p
ATLAS p+p
LHCb p+p
NLO (MNR)
NLO (MNR) up/low
NLO (MNR) Fit to Data
$\sigma_{c\bar{c}}^{NN}$ (μb)
Collision Energy $\sqrt{s}$ (GeV)
10
10^2
10^3
10^4

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)

Backup



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