Dielectron Measurements from the STAR BES-II Program: Status and Future Opportunities

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for the STAR Collaboration

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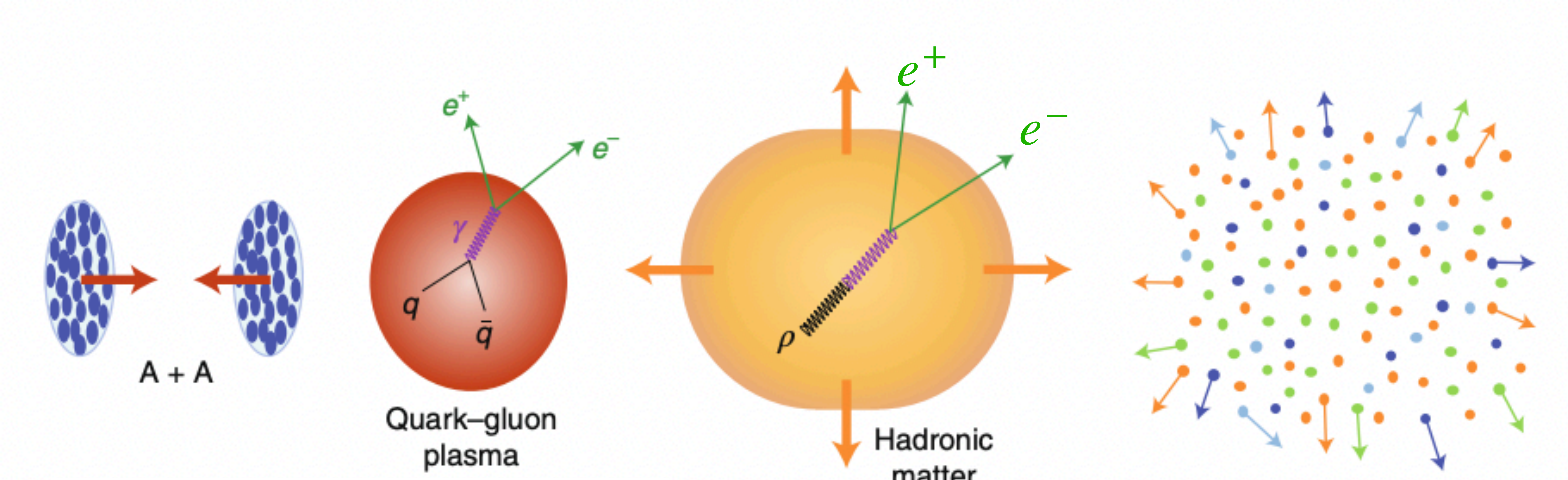
STAR

RICE

Outline

- Introduction
  - Dilepton mass spectrum
  - STAR BES-I
- STAR BES-II
- Future dielectron analysis with STAR BES-II
  - Low mass in-medium ρ yield
  - Temperature measurement
  - Electrical conductivity of medium
- Summary

Dilepton Probes

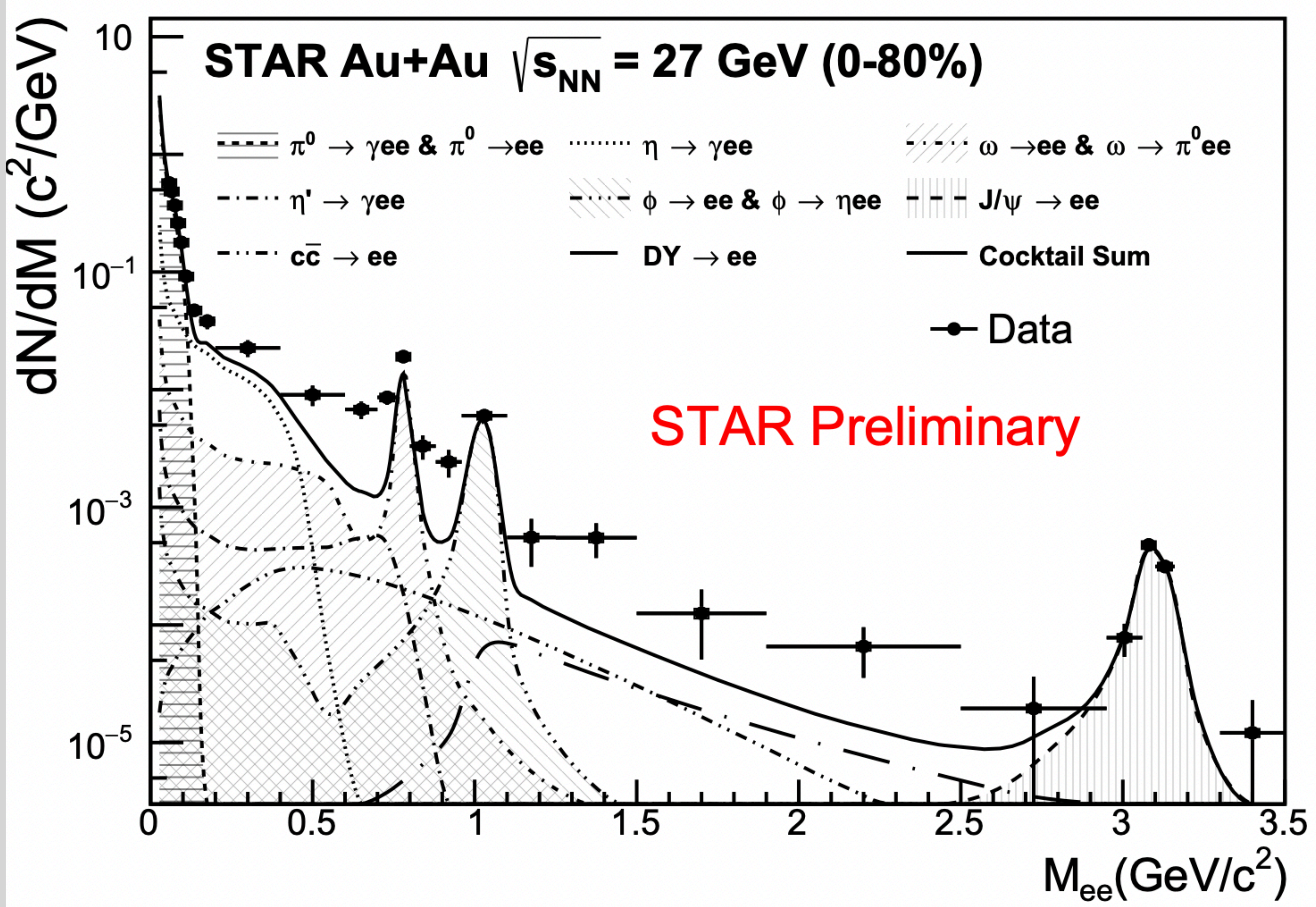


Ralf Rapp Nature Physics volume 15, pages 990–991 (2019)

Why dileptons?

- Dilepton pairs emitted from initial to final stages
- Leptons have no strong interaction with the hot QCD matter

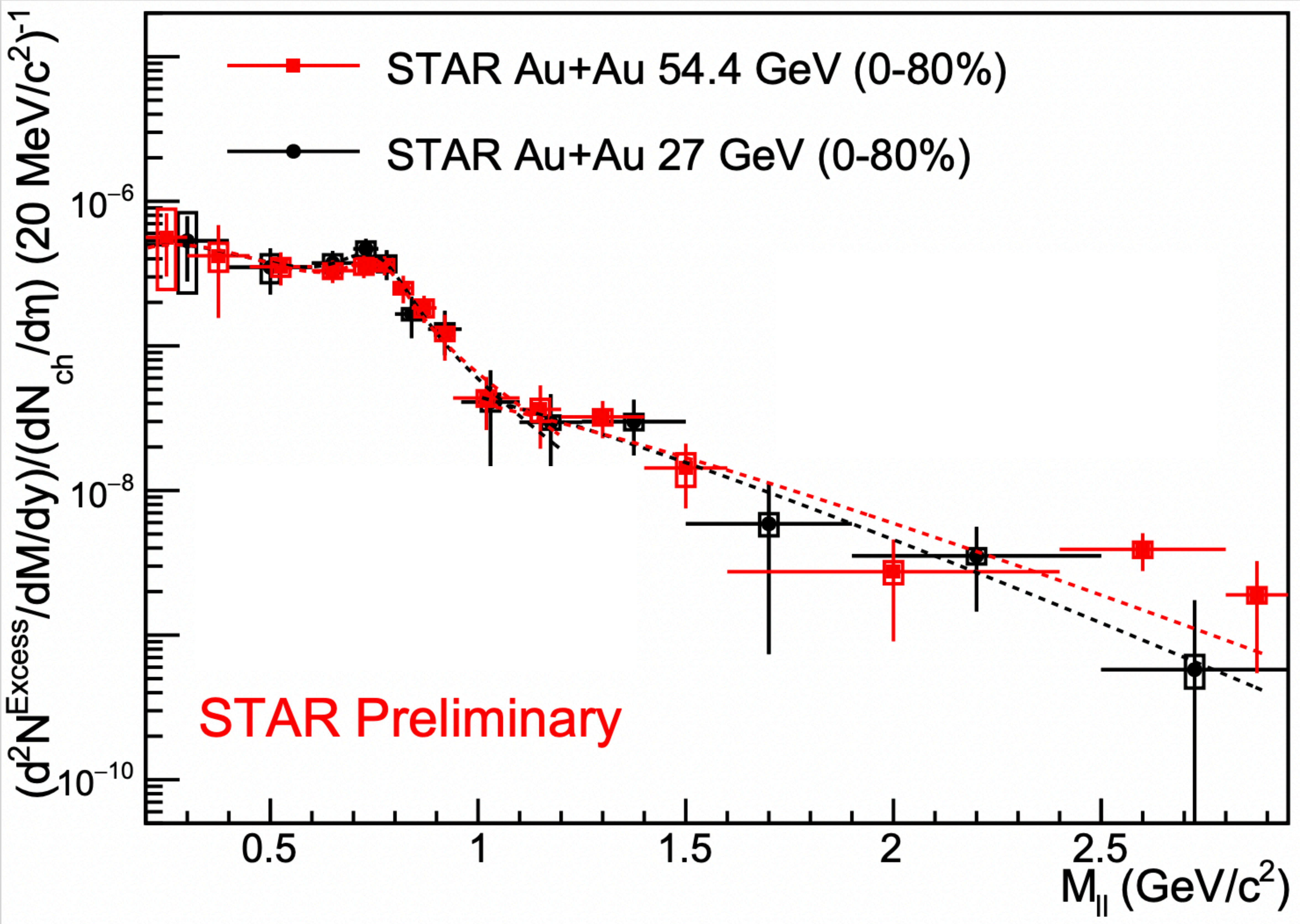
Dilepton Invariant Mass Spectrum



- Dilepton invariant mass spectrum
  - Signal:
    - In-medium ρ
    - QGP
  - Physics background
    - Light flavor hadron decays ($\pi^0, \eta, \omega, \phi, \eta'$)
    - Heavy flavor decay
    - Drell-Yan
    - Determined by simulation techniques

Interesting signal =
Data - Physics background

Dilepton Invariant Mass Spectrum



- Dilepton invariant mass spectrum
  - Signal:
    - In-medium ρ (Low Mass: $M_{ll} \leq M_{\phi}$)
      - Study effects on in-medium ρ production
        - Total baryon density Nucl.Phys.A 673, 357 (2000)
        - Temperature Phys. Rev. C 63, 054907 (2001)
        - Medium lifetime PLB 753, 586 (2016)
    - QGP (Intermediate Mass: $M_{\phi} < M_{ll} < M_{J/\Psi}$)
      - Temperature measurement
  - Physics background
    - Light flavor hadron decays ($\pi^0, \eta, \omega, \phi, \eta'$)
    - Heavy flavor decay
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Interesting signal =
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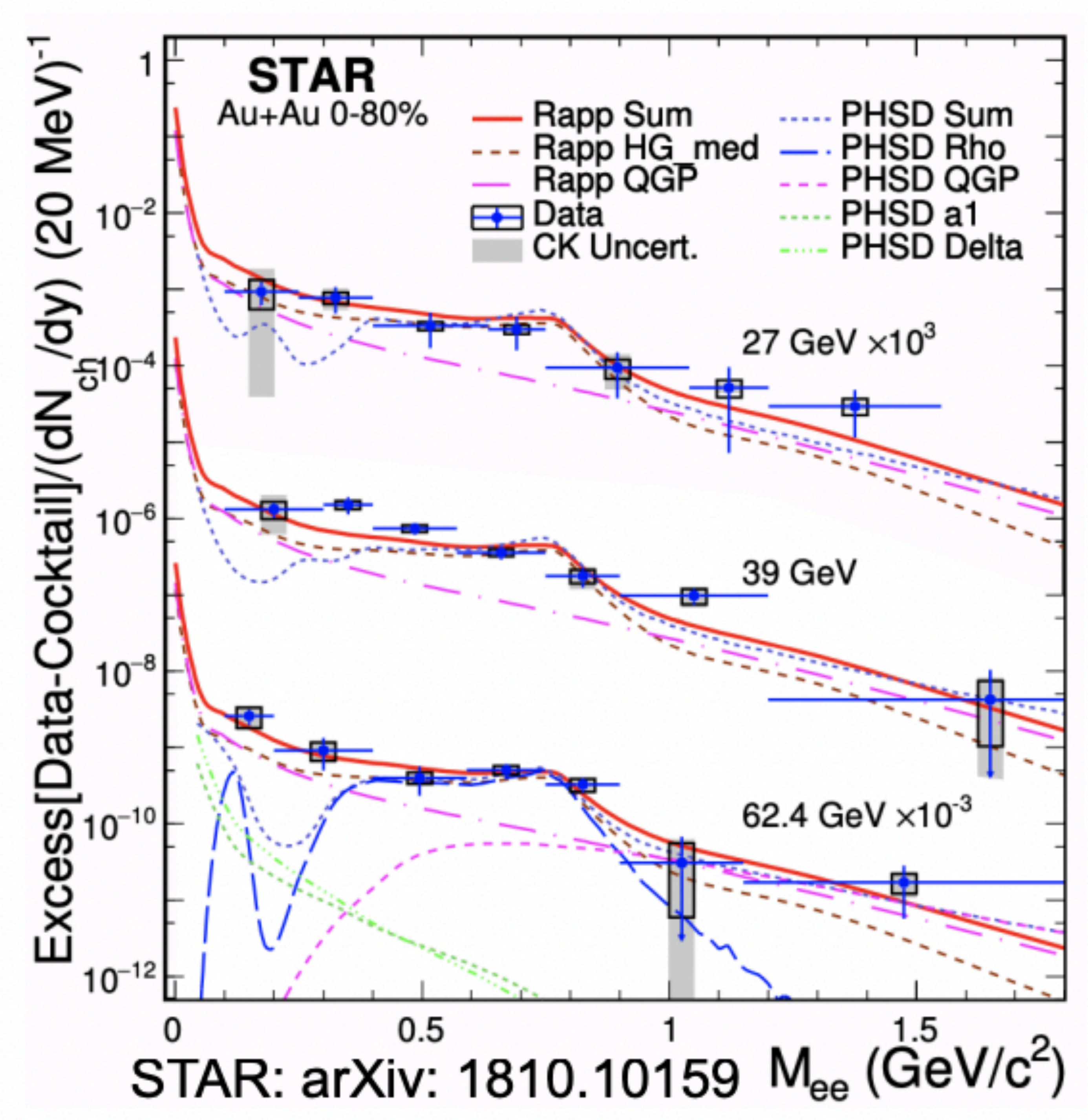
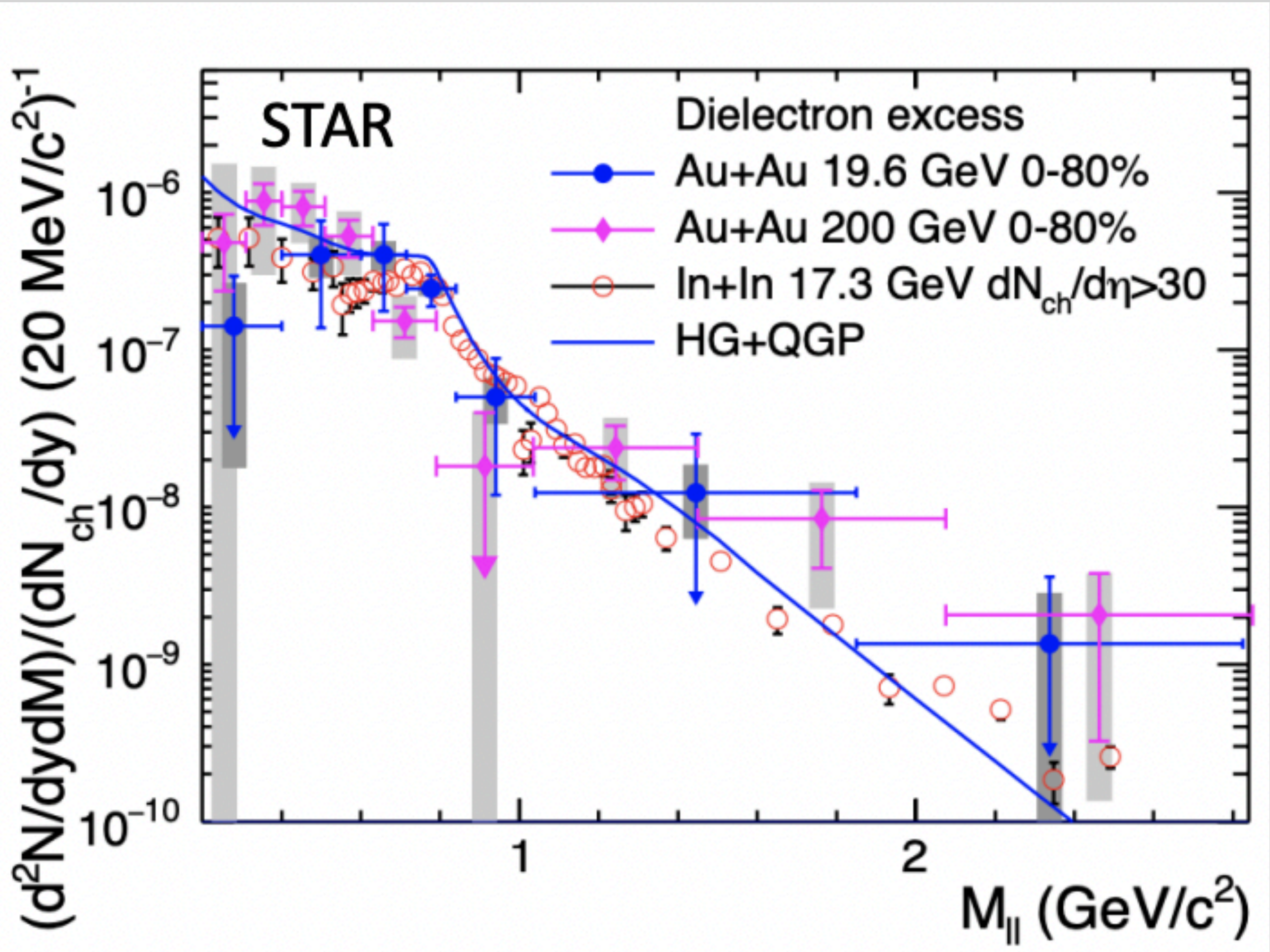
STAR BES-I Dielectron Analysis

STAR BES-I dielectron measurement



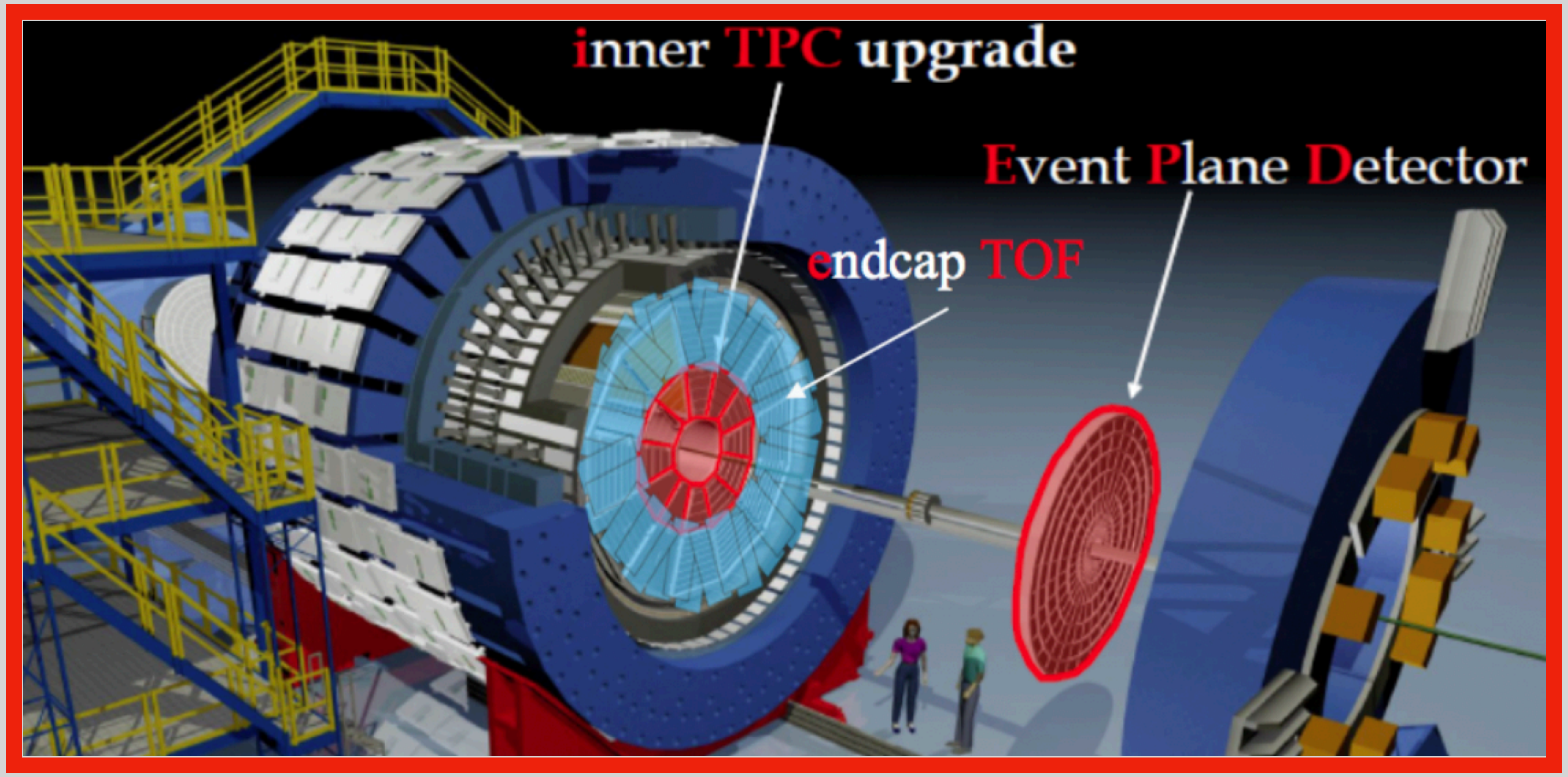


STAR: PLB750 (2015) 64, NA60: EPJ C 59 (2009) 607
Rapp: PRC 63 (2001) 054907, PRL 97, 102301 (2006) ;
PHSD: Phys. Rep. 308, 65 (1999), NPA 831, 215 (2009)

STAR BES-I:

- Experimental data can be well described by the in-medium ρ + QGP emission models
- Lack of statistics for temperature measurement at intermediate mass

STAR BES-II



STAR Beam Use Request 2019/2020 (SN696) https://drupal.star.bnl.gov/STAR/system/files/bur2018-final_0.pdf

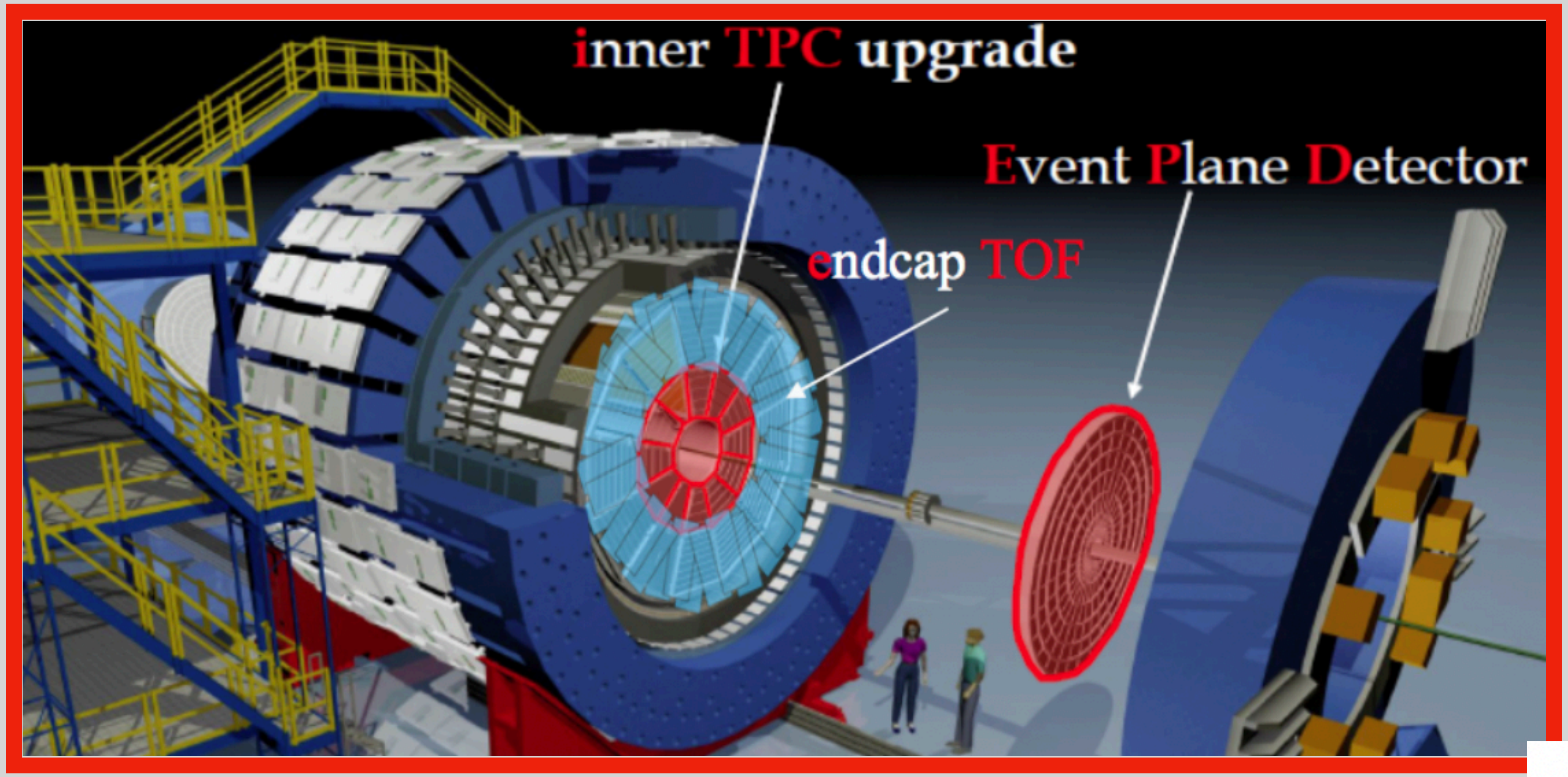
Inner TPC (iTPC) upgrade:

- Improve dE/dx resolution
- Extend η range from 1 to 1.5
- Reduce p_T cut off limitation from 135 MeV/c to 60 MeV/c

Event Plane Detector (EPD):

- Better trigger
- Reduce Beam Background

STAR BES-II



STAR Beam Use Request 2019/2020 (SN696) https://drupal.star.bnl.gov/STAR/system/files/b

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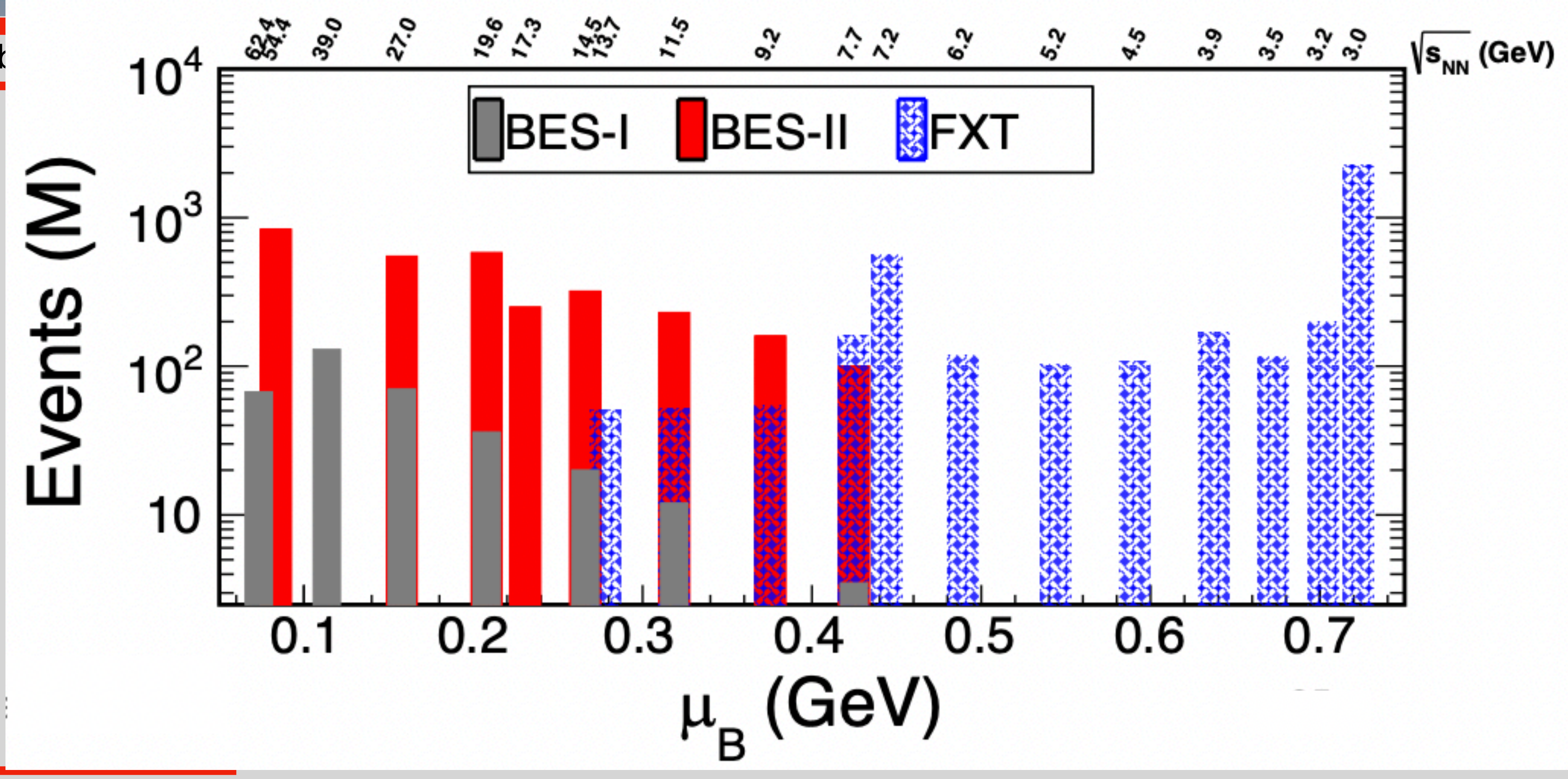
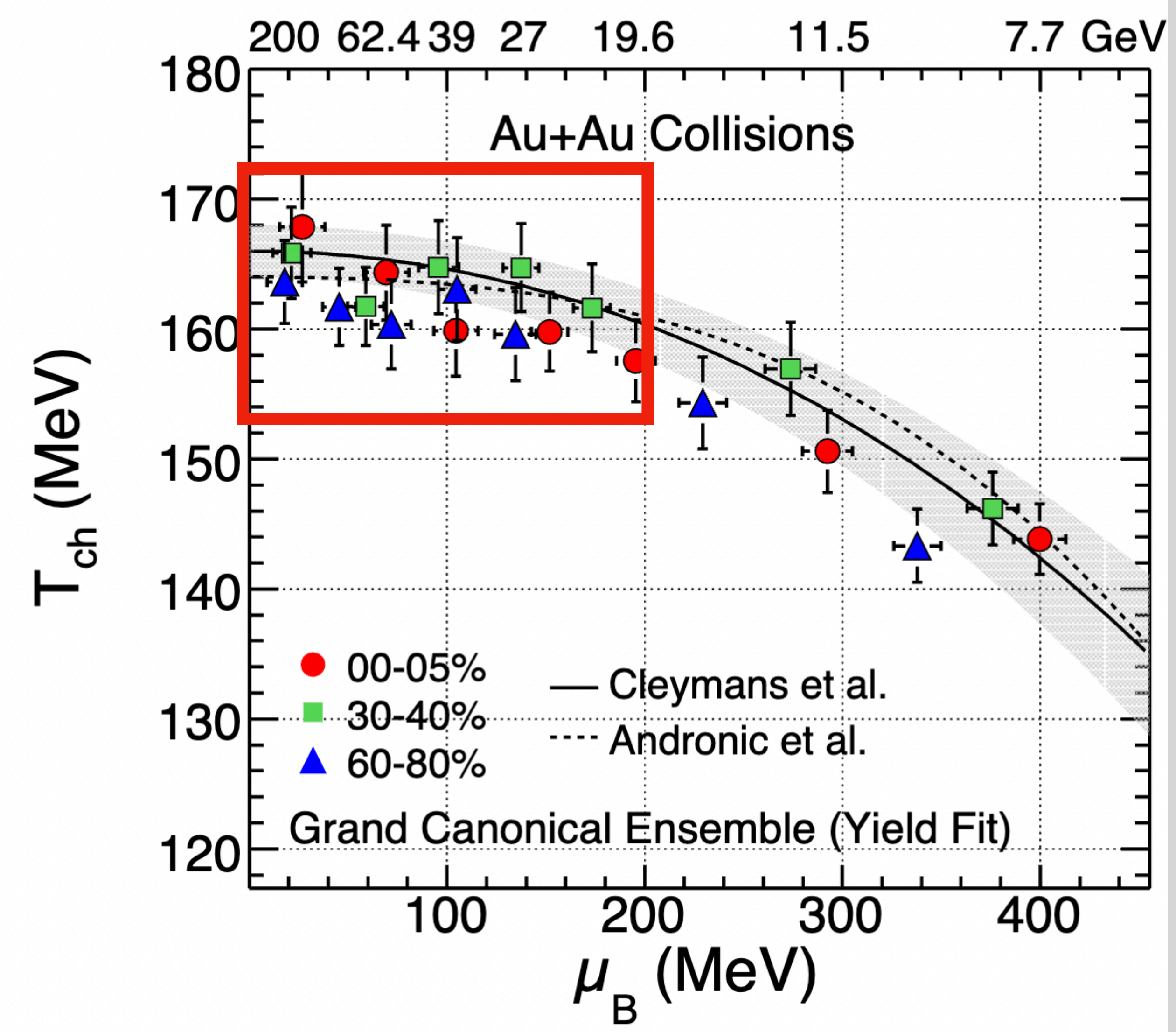
BES-II has > 10 times more statistics than BES-I

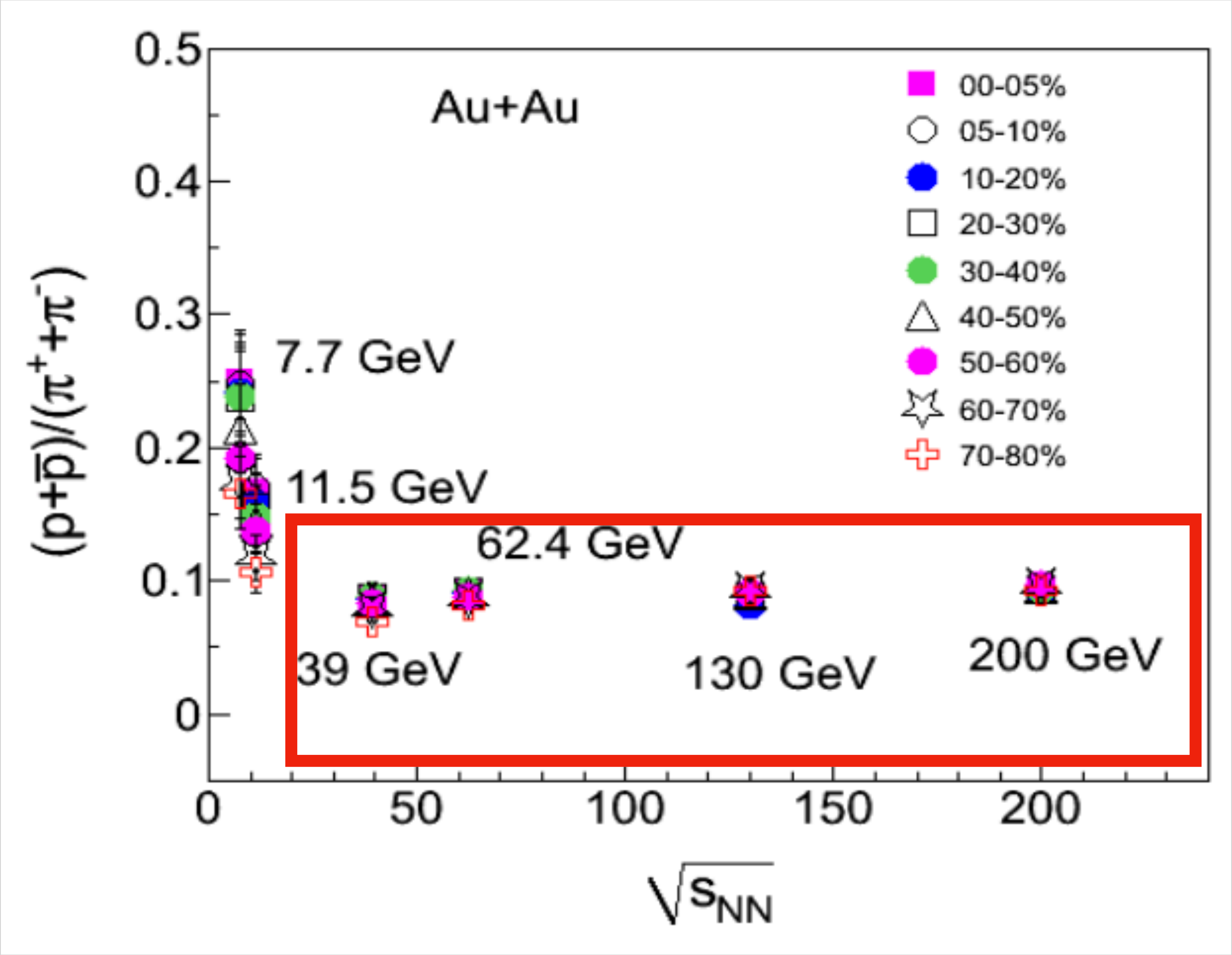
Collected Data



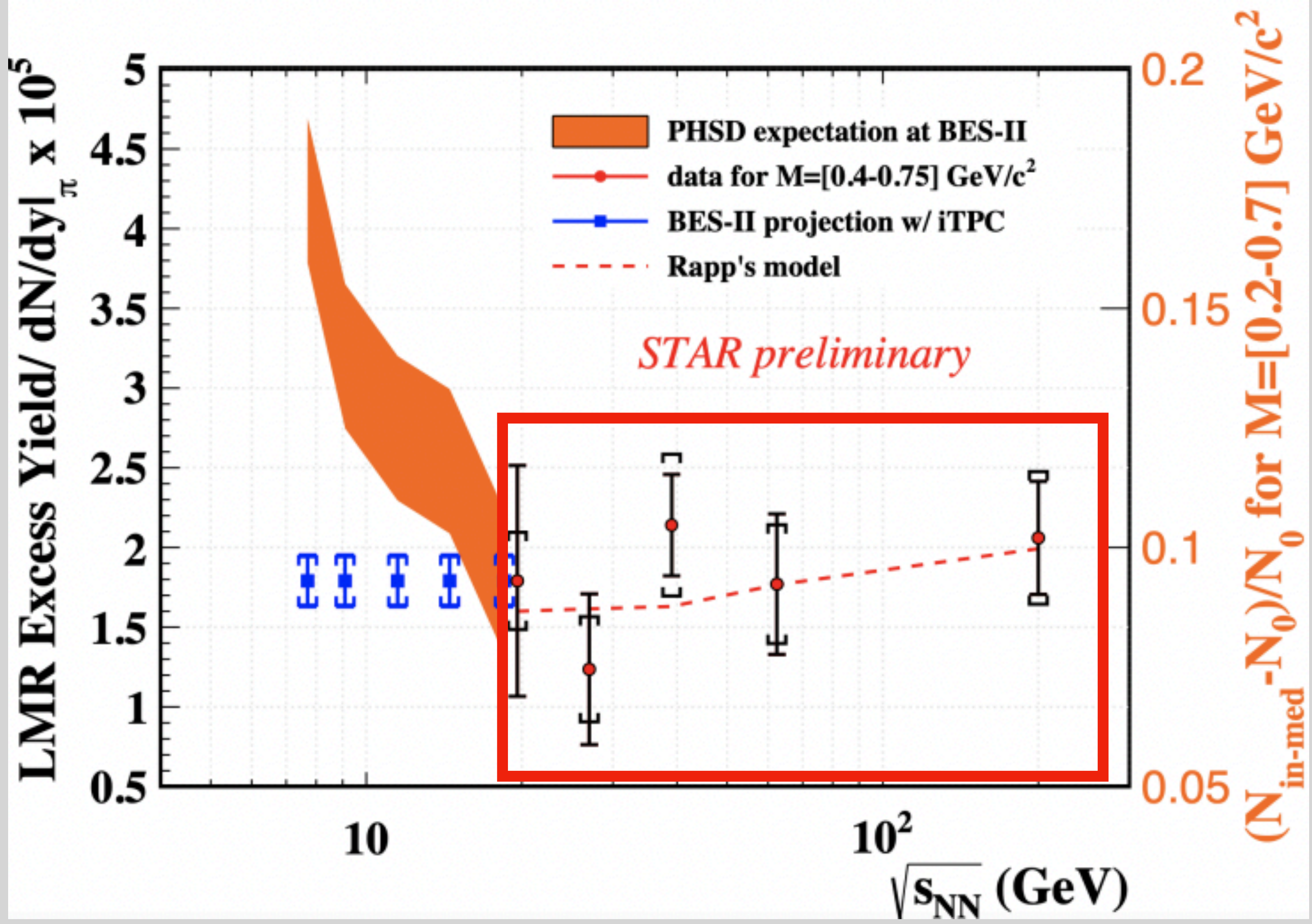
Low Mass In-medium ρ Yield



STAR: Phys. Rev. C 96, 044904 (2017)



F.Geurts ECT* 2018 Nov.



NPA 831, 215 (2009) PHSD: Phys. Rep. 308, 65 (1999)

- In-medium ρ yield is expected to be effected by medium temperature, total baryon density and medium lifetime
- For $\sqrt{s_{NN}} > 20\ GeV$, total baryon density and medium chemical freeze-out temperature are approximately constant.

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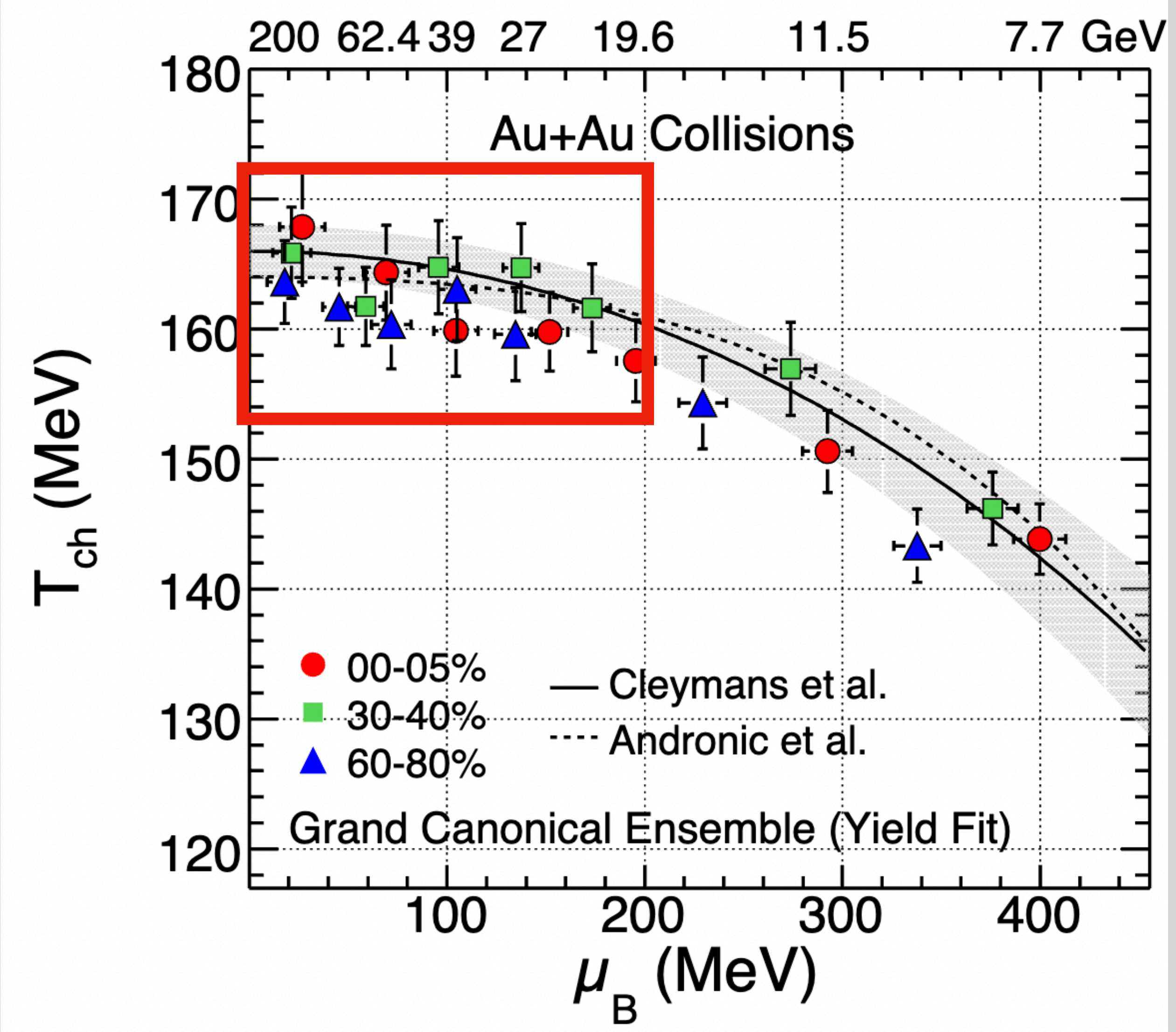

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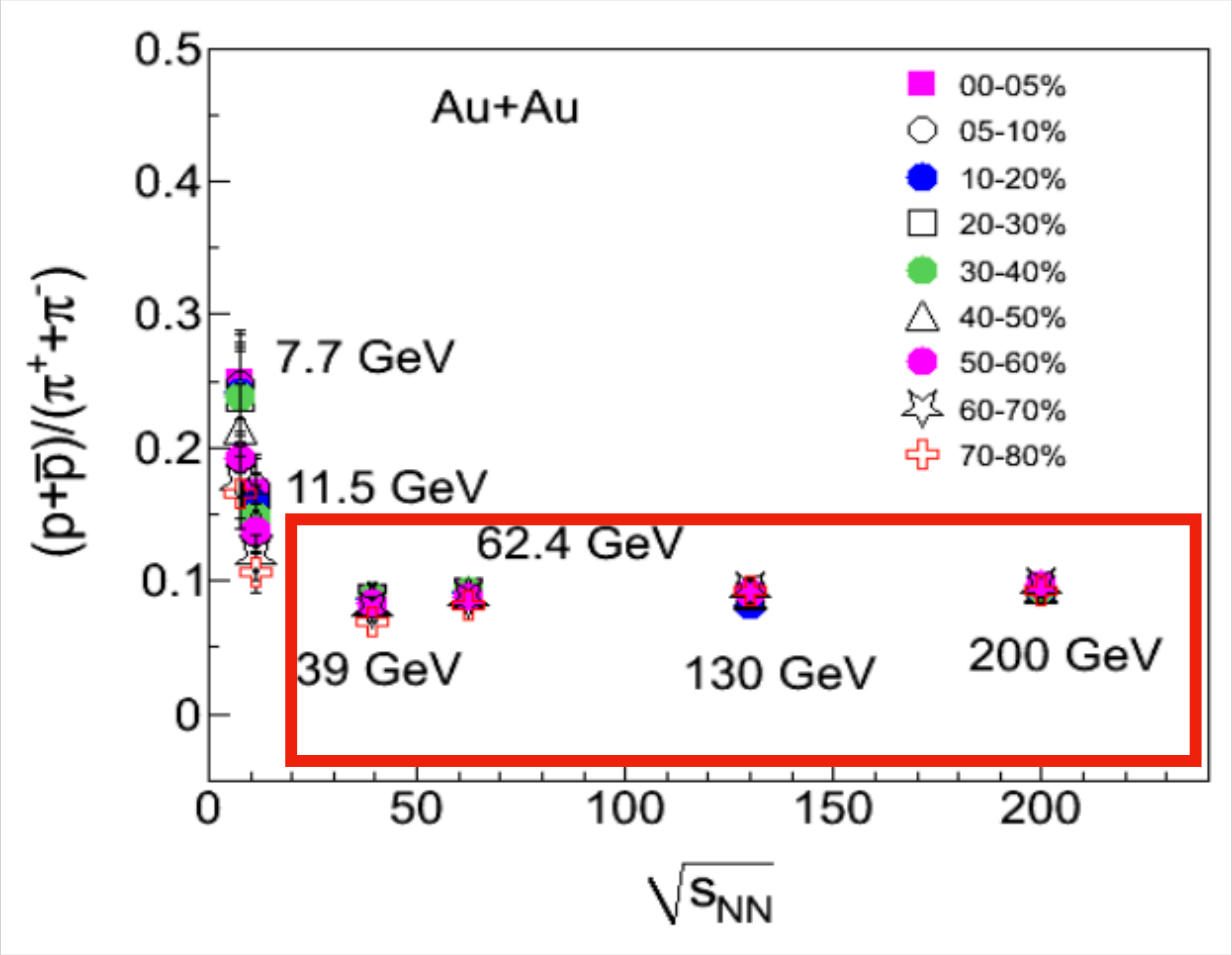

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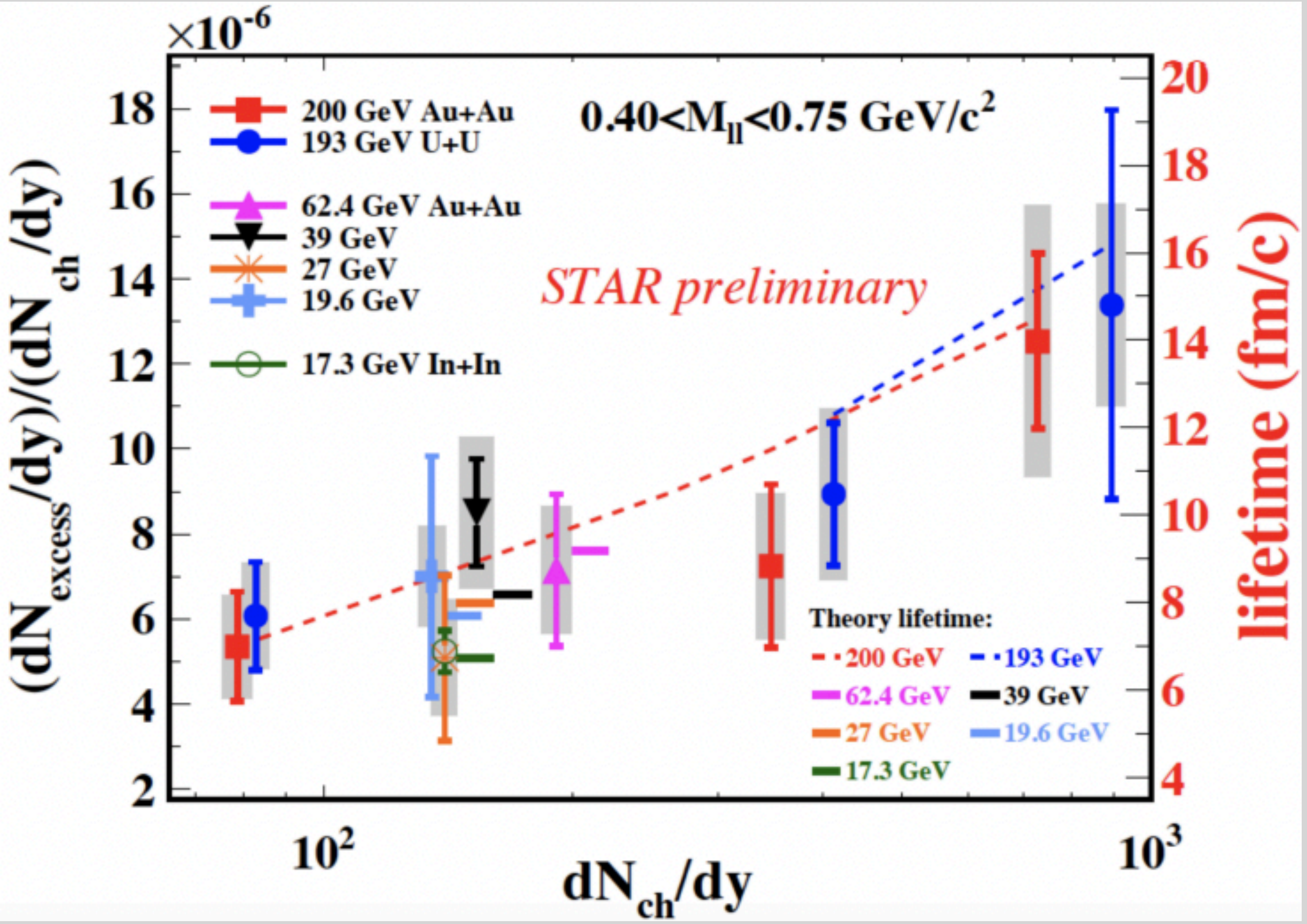

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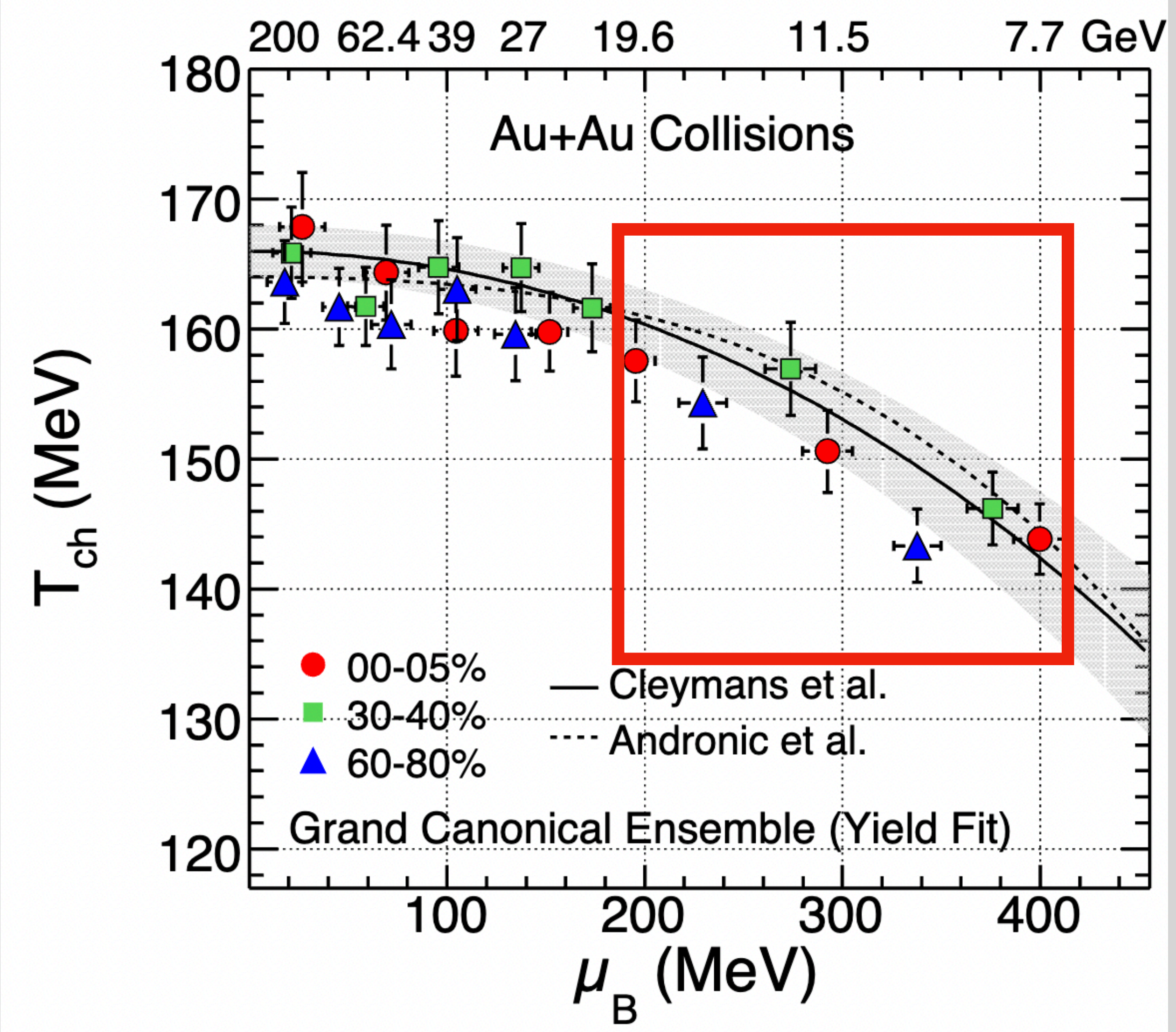
Low Mass In-medium ρ Yield



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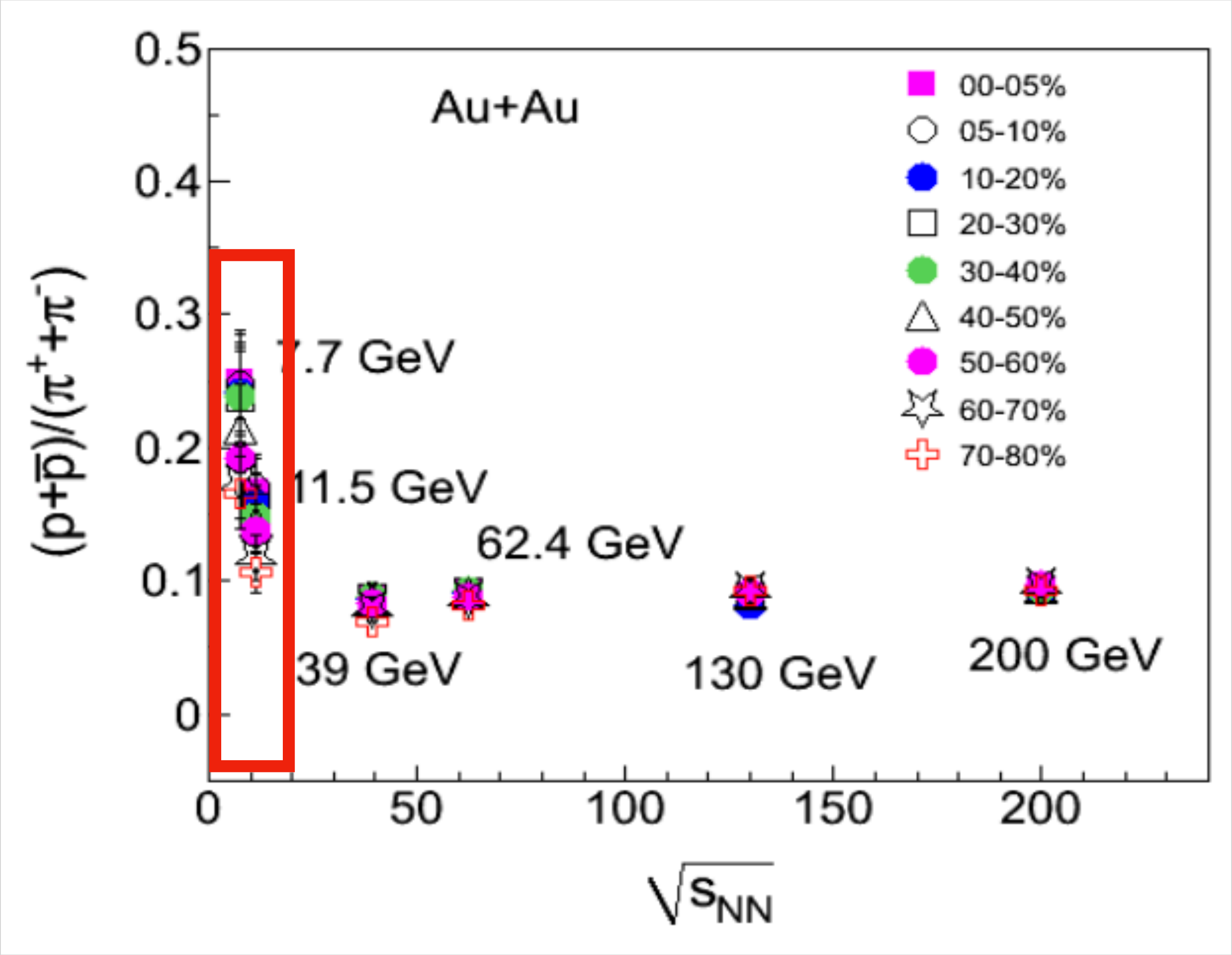

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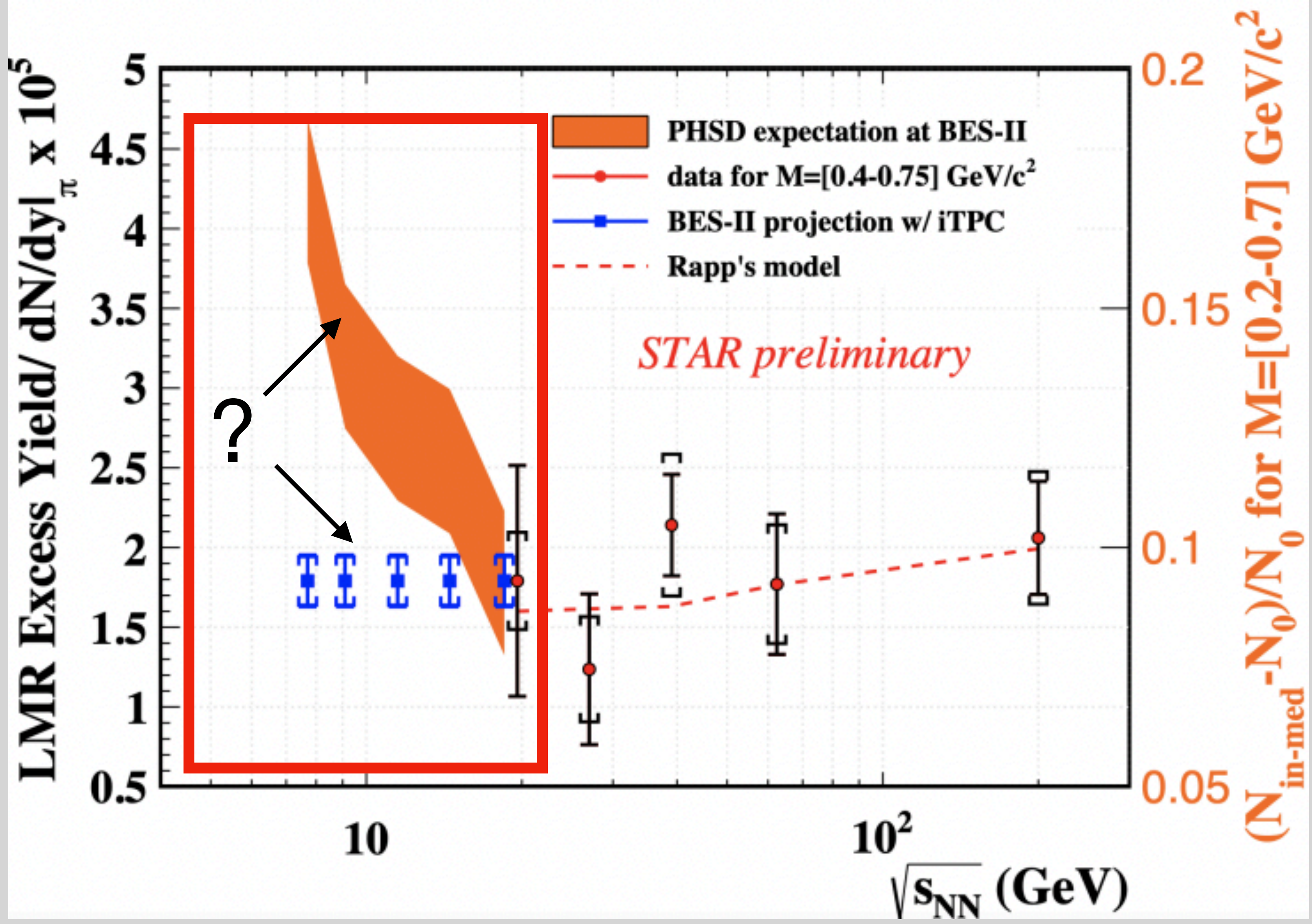

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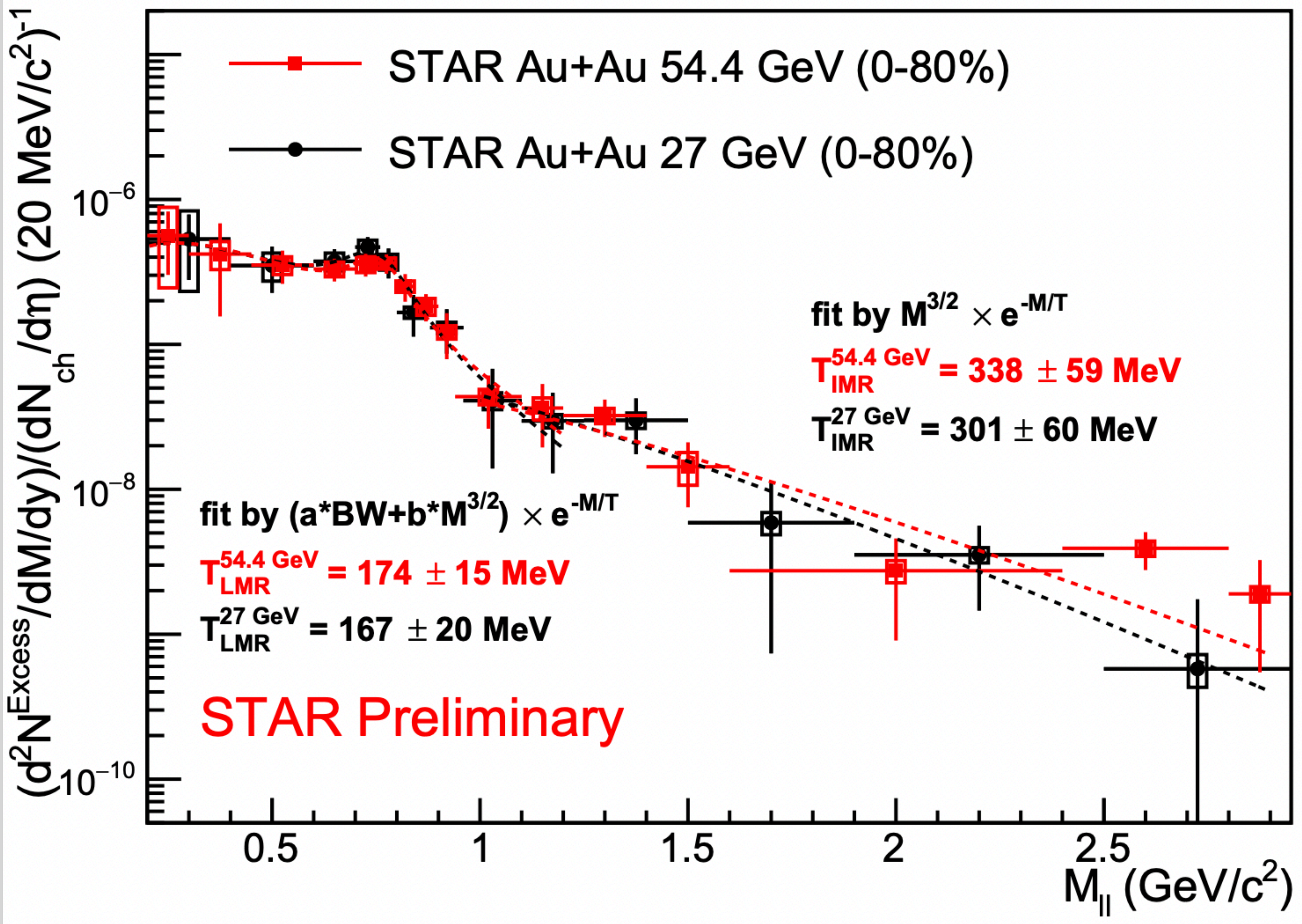
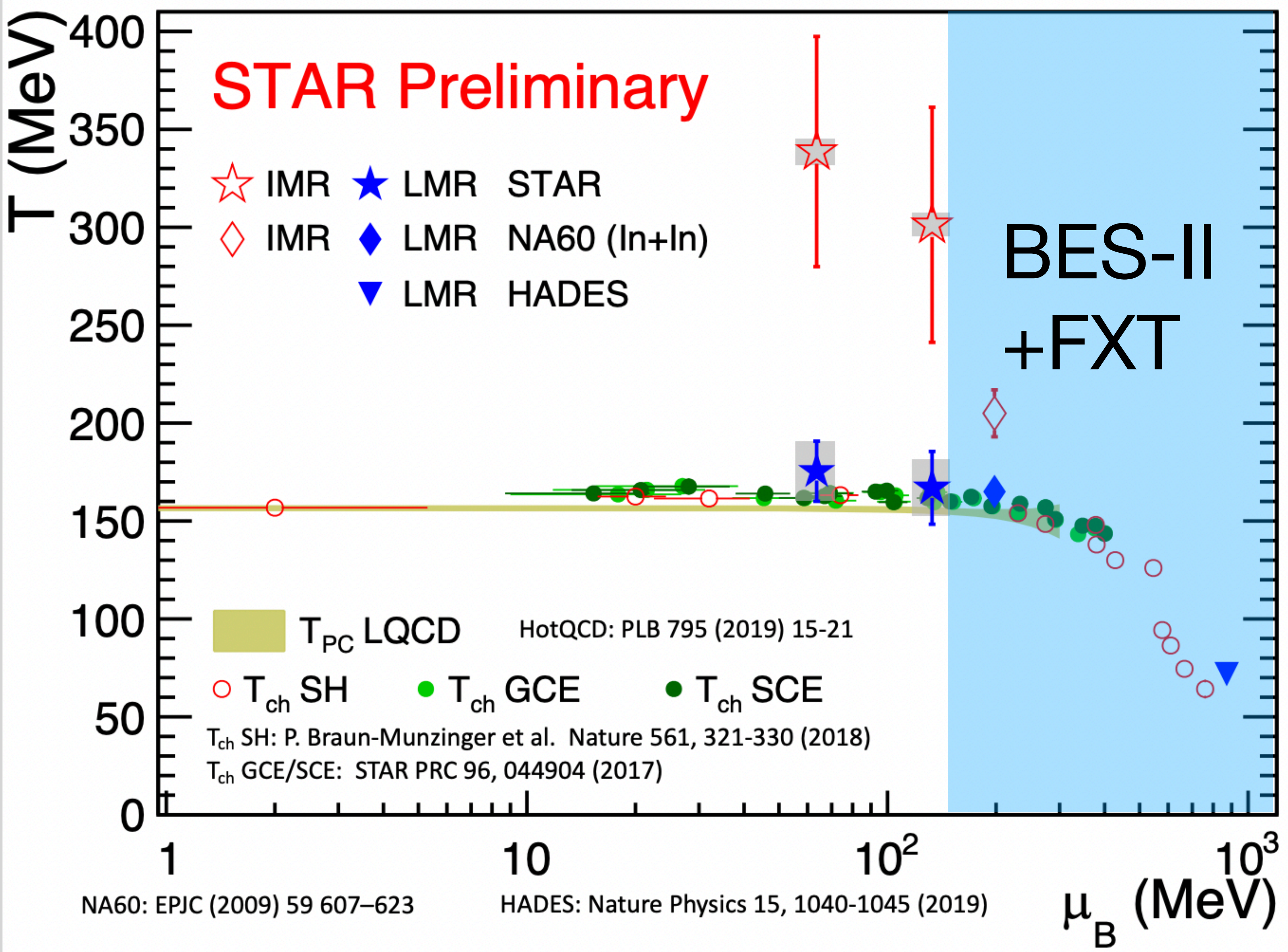
- For $\sqrt{s_{NN}} > 20\ GeV$, total baryon density and medium chemical freeze-out temperature are approximately constant.
- The experimental results show that dN_{ch}/dy-normalized in-medium ρ yield share the same tendency as the medium lifetime.
- BES-II provides a unique opportunity to study both the temperature and total baryon density effect.

Temperature Measurement





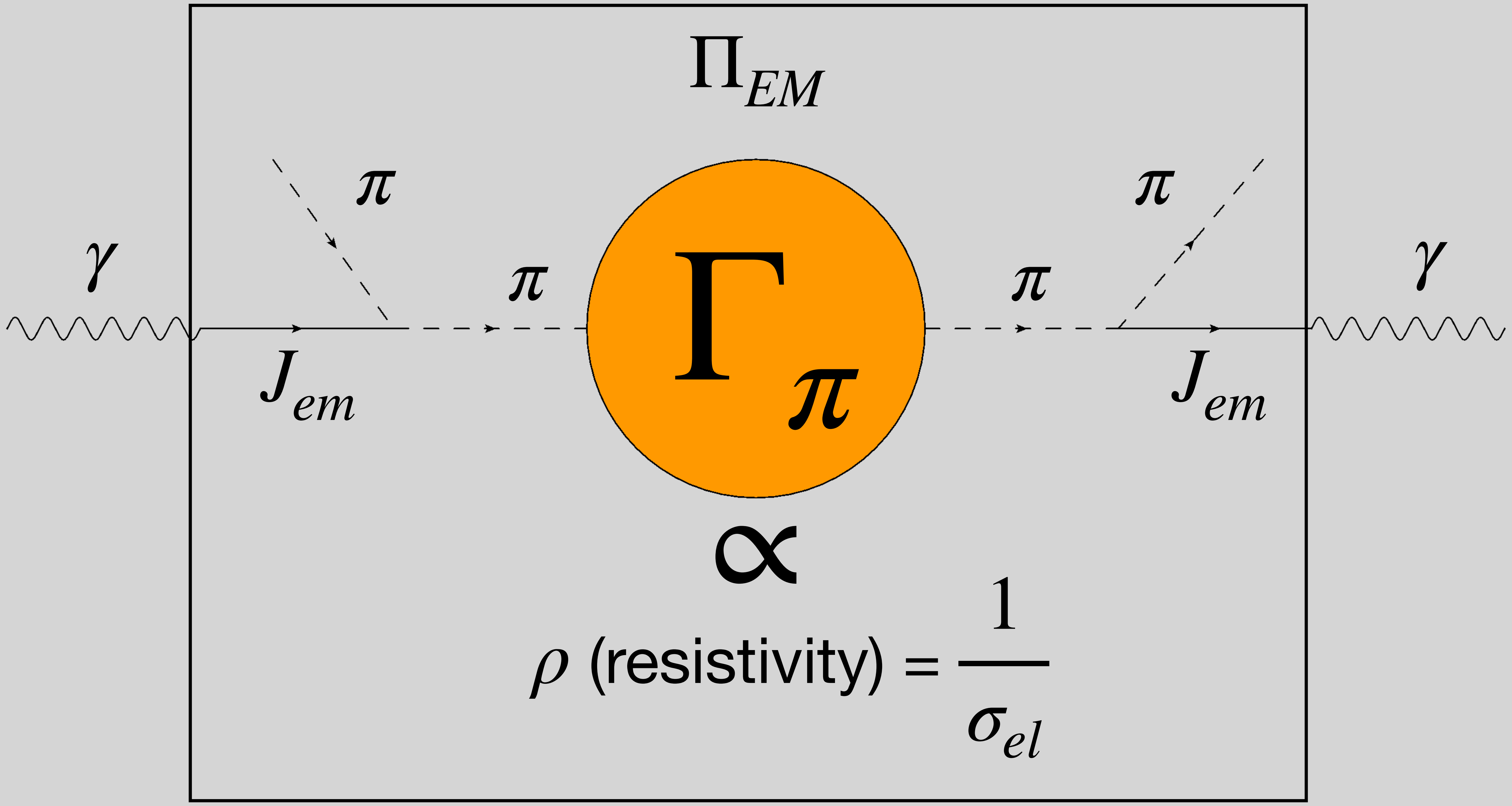
New Au-Au $\sqrt{s_{NN}} =$ 27, 54.4 GeV dielectron analysis:

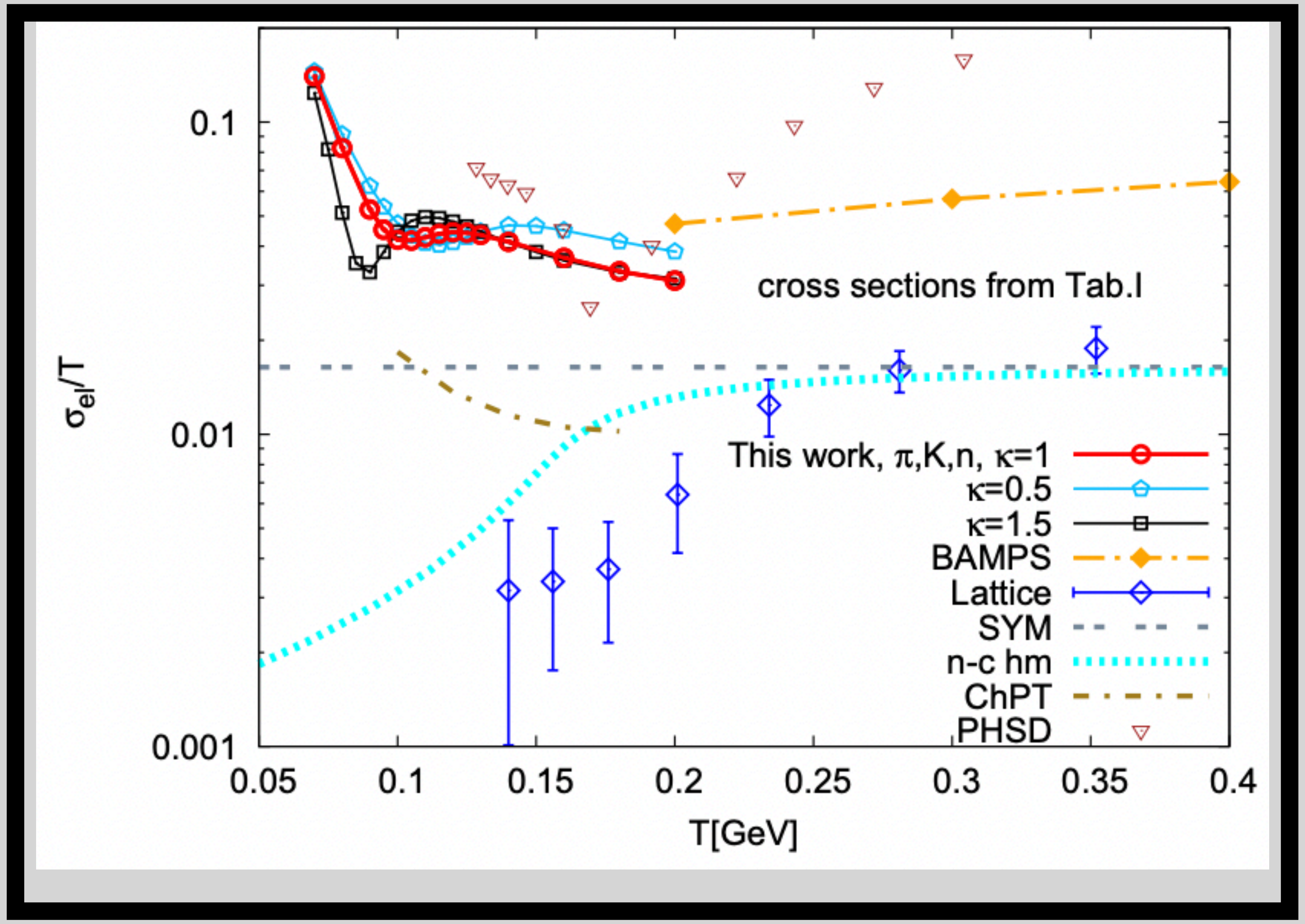
- Mass spectrum of thermal dileptons allows temperature measurement
- T from $M_\phi < M_{ll} < M_{J/\psi}$ is about 300 MeV, QGP dominant
- T from $M_{ll} \leq M_\phi$ is close to phase transition temperature

Goals for BES-II:

- Measurements of the temperature at higher μ_B

New Opportunity: Electrical Conductivity of the Medium

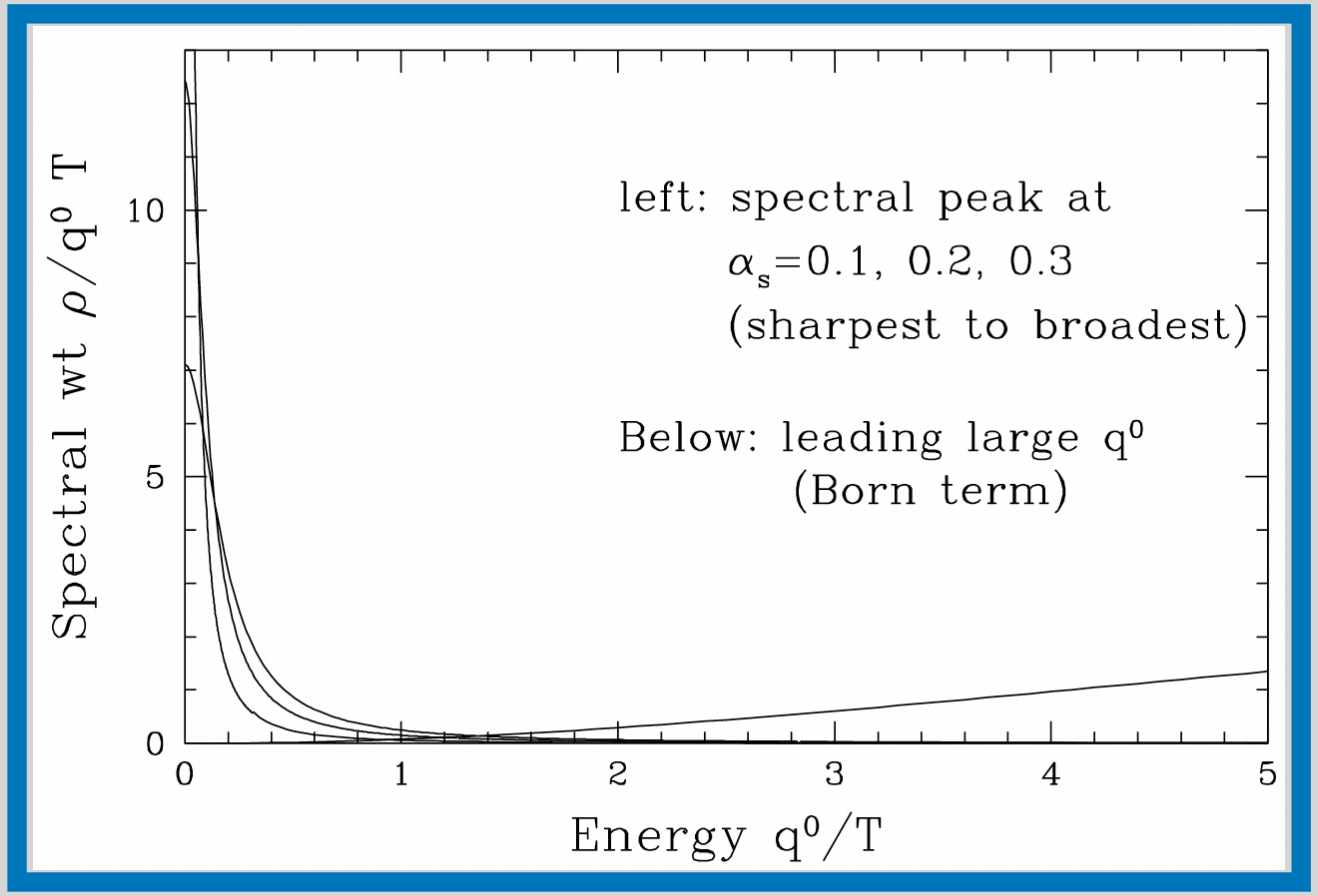




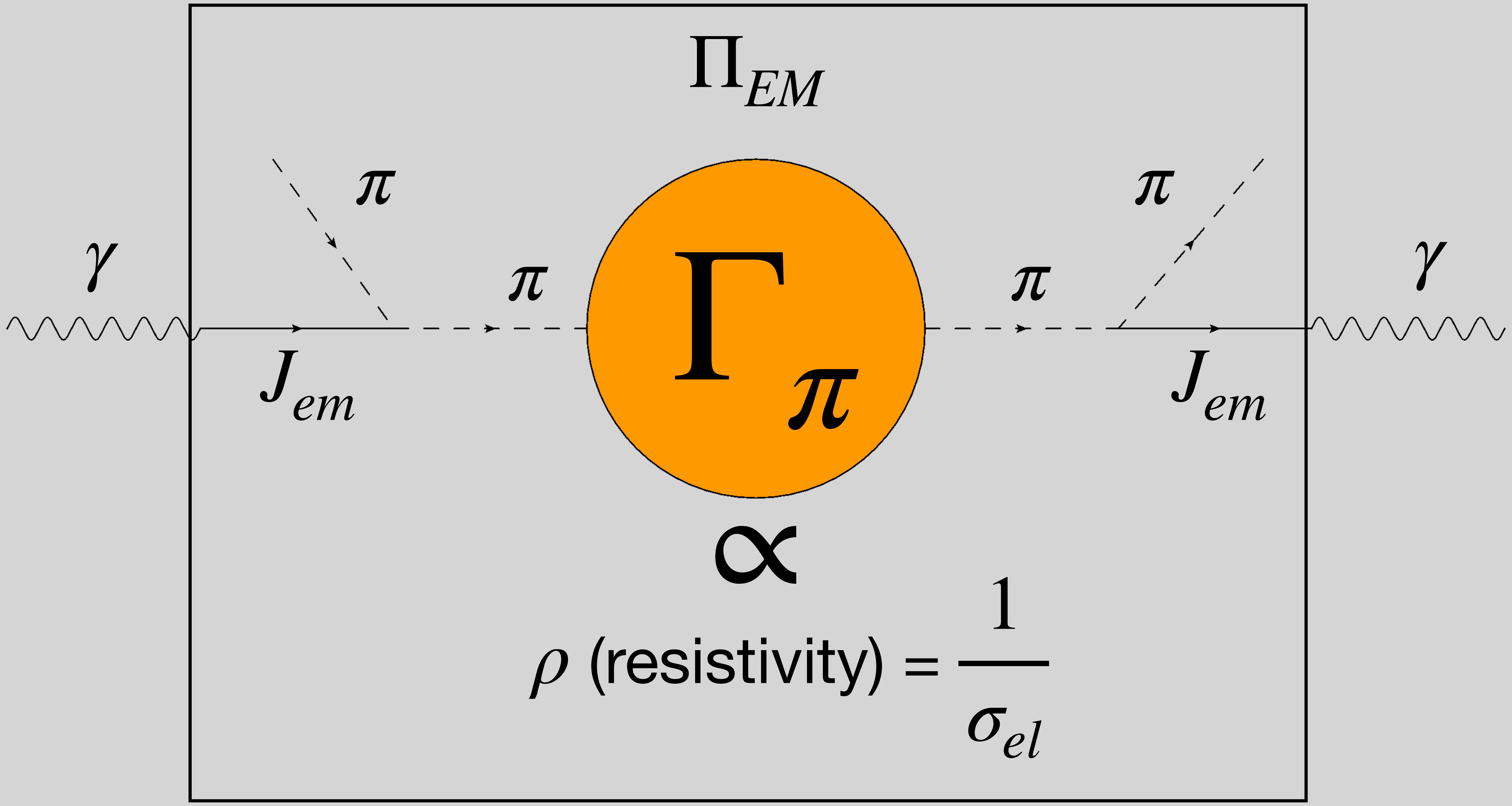
M. Greif, et. al. Phys. Rev. D 93, 096012 (2016)

- Different approaches show very different estimations of electrical conductivity(σ_{el}) of medium
  - σ_{el} as a transport coefficient is a very important quality for hot and dense nuclear matter
  - Experimental results may help us to constraint models

New Opportunity: Electrical Conductivity of the Medium



Moore & Robert arXiv:hep-ph/0607172



- Electrical conductivity: $\sigma_{el} = \frac{\langle eJ_i \rangle}{E_i} = -e^2 \lim_{q_0 \to 0} \frac{\delta}{\delta q_0} Im[\Pi_{EM}(q_0, q = 0, T)]$
- Dilepton emission rate: $\frac{dR_{l^+l^-}}{d^4q} = \frac{-\alpha_{EM}^2}{3\pi^3 M^2} f_B(q_0, T) g_{\mu\nu} Im[\Pi_{EM}^{\mu\nu}(M, q, T, \mu_B)]$
- The above connection brings up an opportunity to measure the electrical conductivity through dielectron mass spectrum. **As the resistivity increases, the transport peak melts, and dielectron spectrum extends to higher mass.**

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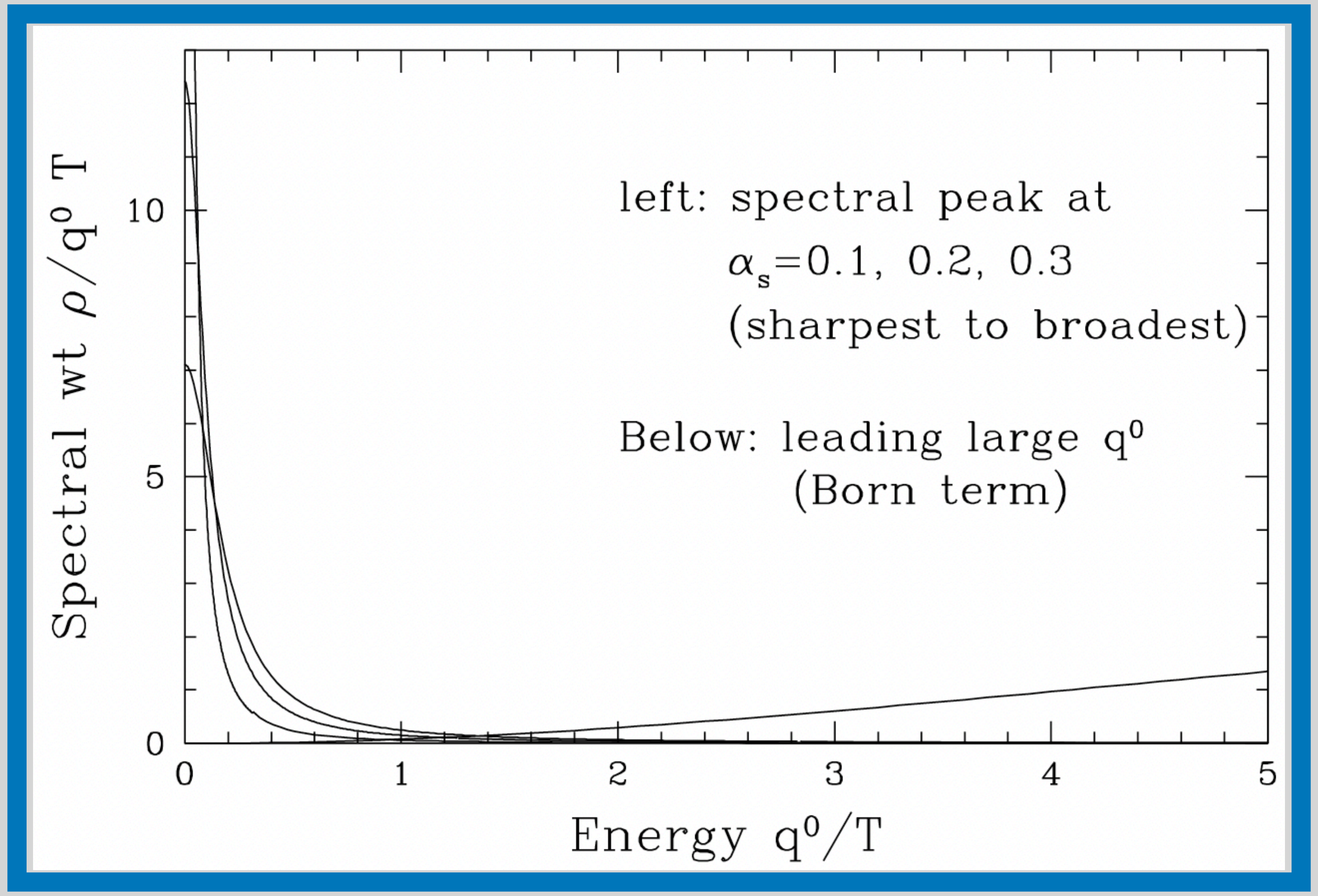

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Better chance to extract electrical conductivity at lower energy

⇒Detectors with lower p_T cut off limitation will benefit this measurement

- Electrical conductivity: $\sigma_{el} = \frac{\langle eJ_i \rangle}{E_i} = -e^2 \lim_{q_0 \to 0} \frac{\delta}{\delta q_0} Im[\Pi_{EM}(q_0, q = 0, T)]$
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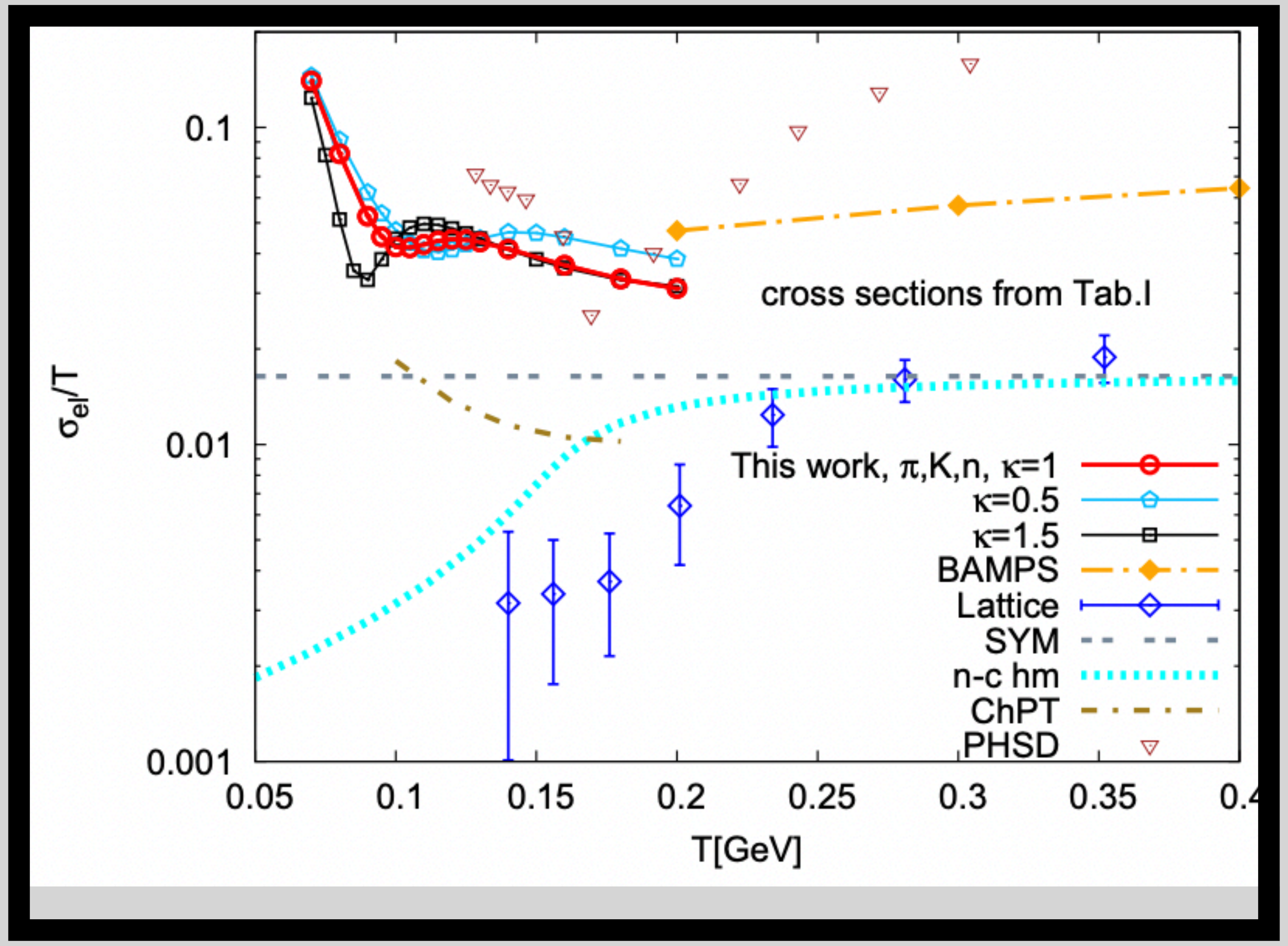

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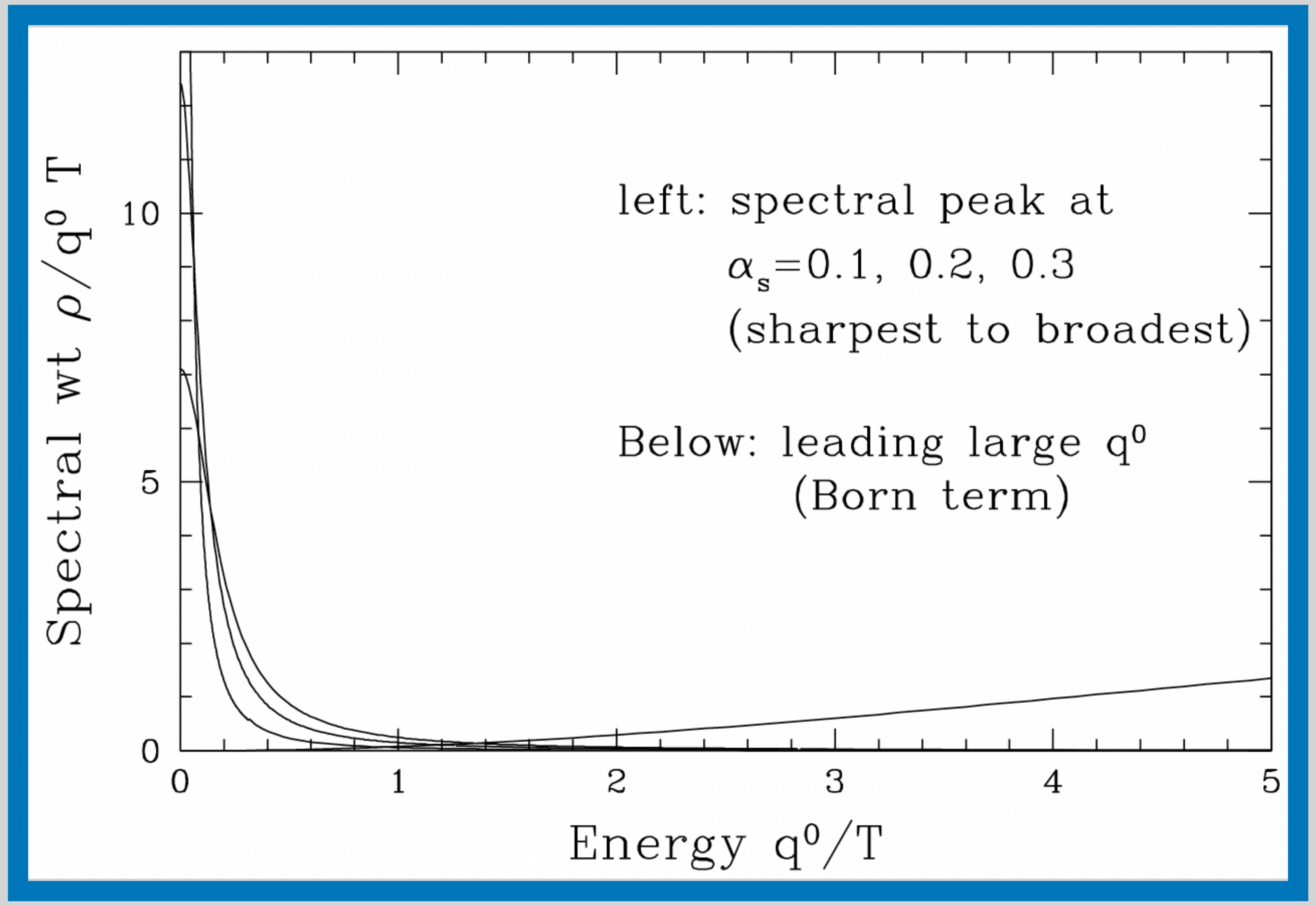

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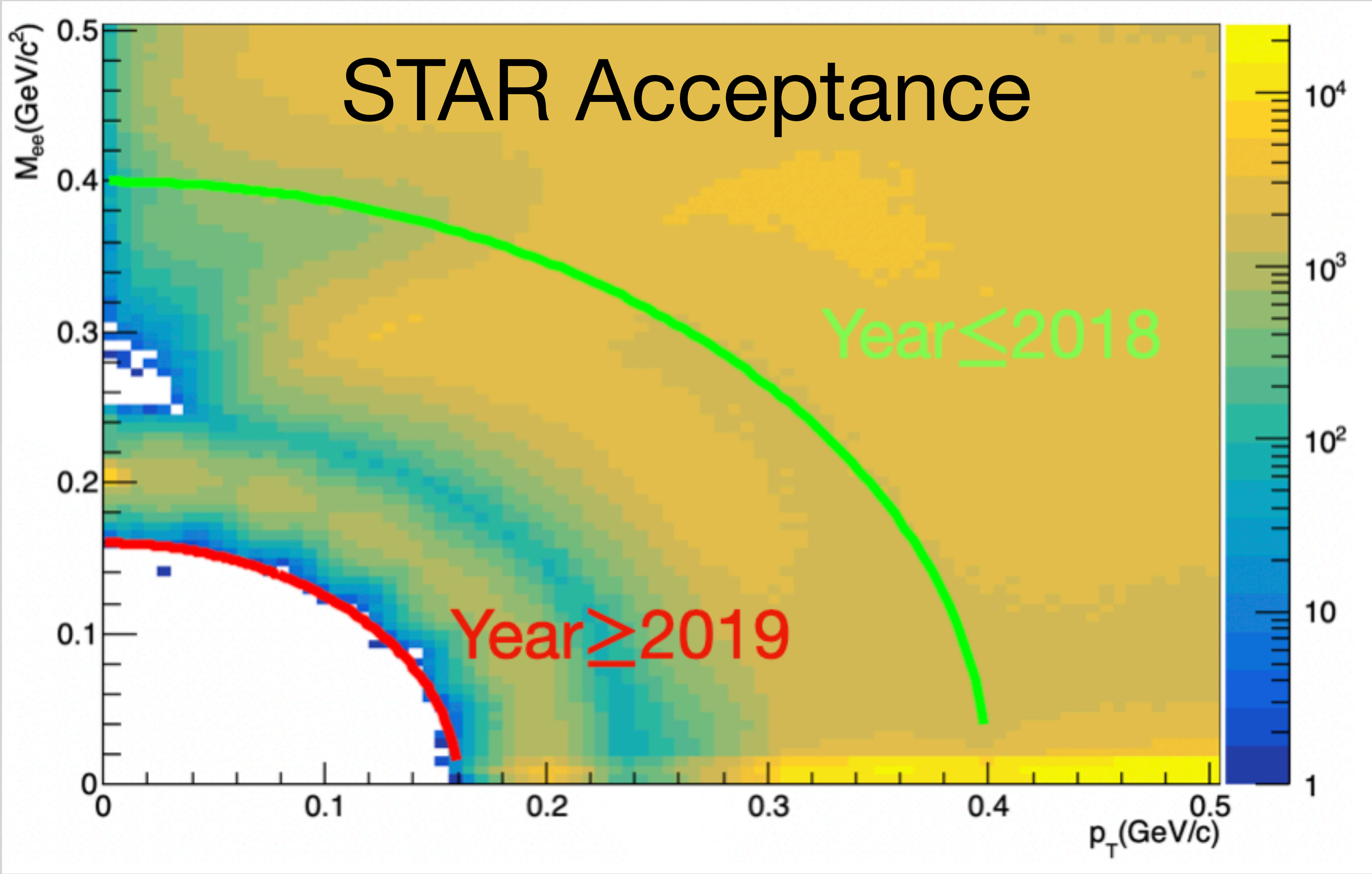
- Extend p_T^{ee} vs M_{ee} acceptance with iTPC upgrade
  - **Lower $(M_{ee}\ ,\ p_T^{ee})$ limitation after iTPC upgrade**



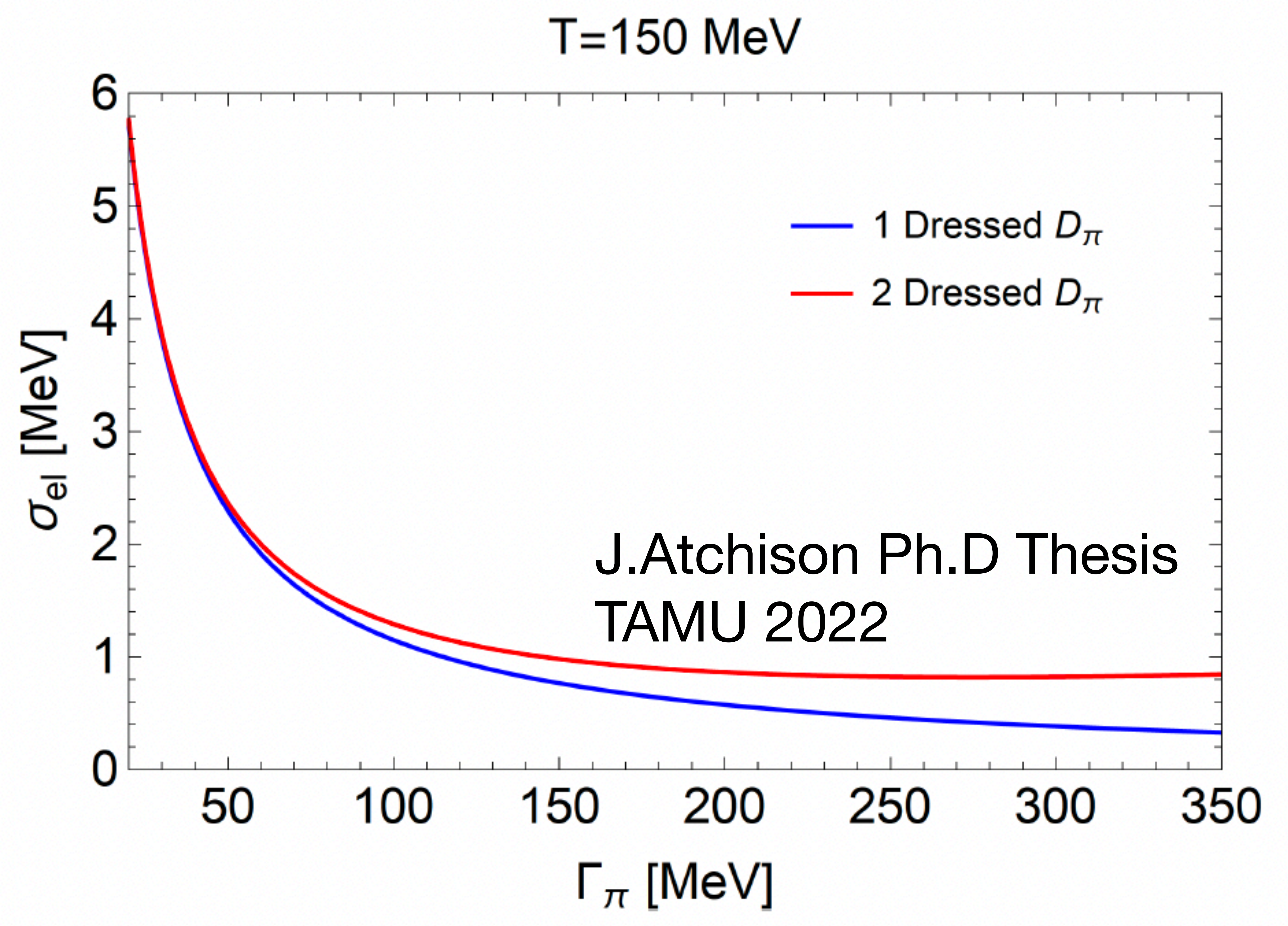
Summary

- New measurements in Au-Au collisions at $\sqrt{s_{NN}} =$ 27, 54.4 GeV:
  - Extract temperature from the hot medium
- STAR BES-II:
  - Detector upgrades with wider acceptance
  - $>$ 10 times more statistics than BES-I
  - Study total baryon density effect on in-medium ρ production
  - Temperature measurement at high μ_B range
  - Possible opportunity to study medium electrical conductivity through dilepton production

Thank You

Backup

Small width approximation for electrical conductivity



$$\sigma_{el} \approx \frac{2e^2}{3T} \int \frac{d^3\vec{k}}{(2\pi)^3} \frac{v_k^2}{\Gamma_\pi} \frac{e^{\frac{\omega_k}{T}}}{(-1 + e^{\frac{\omega_k}{T}})^2}$$

Thermal

$v_k = \dfrac{\omega_k}{k}$ pion velocity