The Electromagnetic Probes at RHIC-STAR

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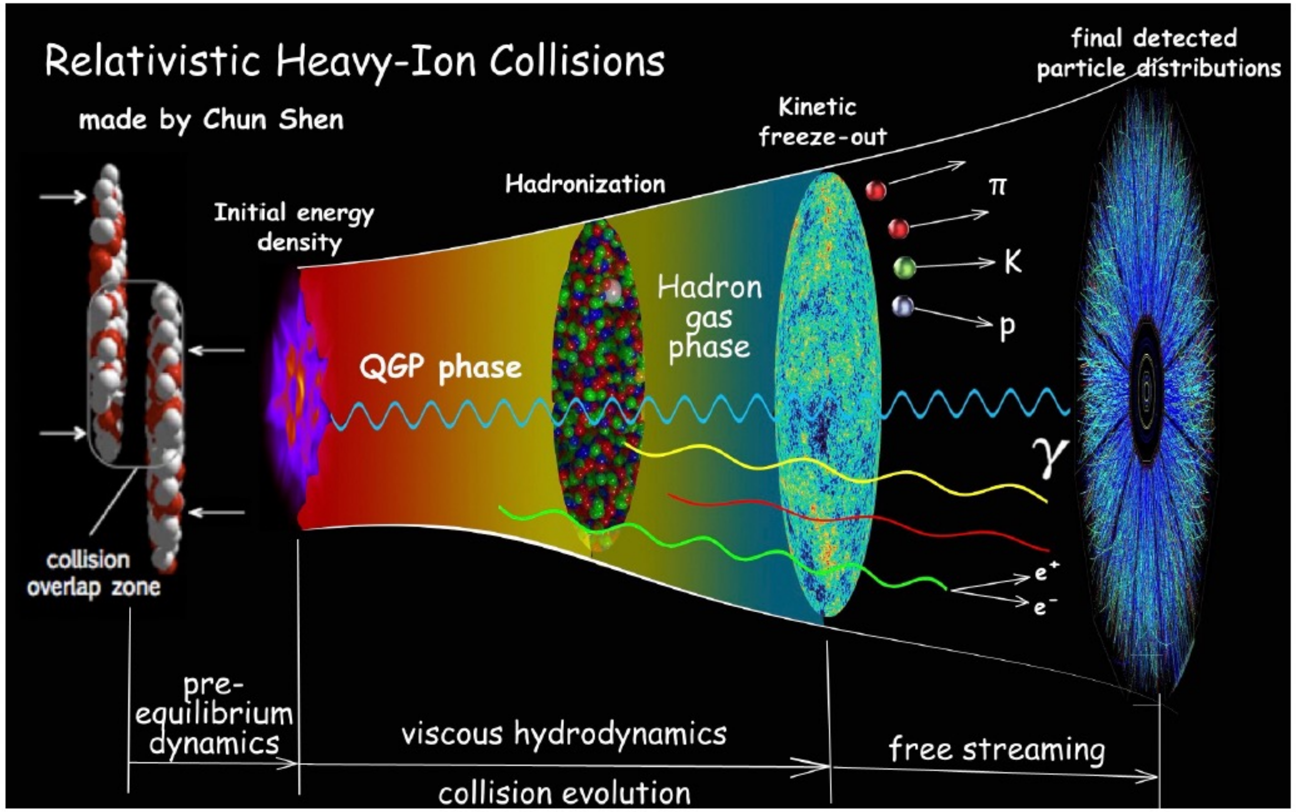
Outline

- Introduction
- Dileptons
- Direct photons
- Photon-induced dilepton productions
- Summary

Why EM probes?



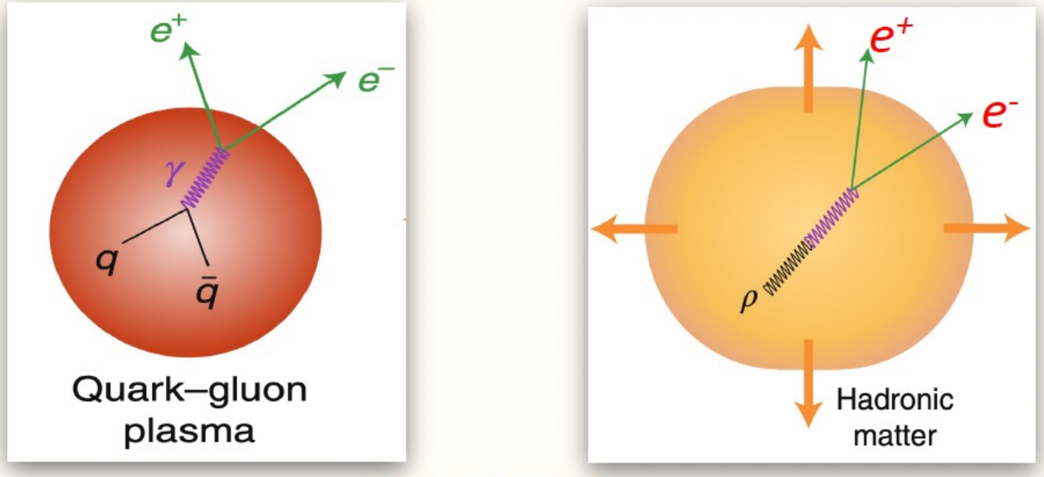
EM probes:

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

Why dileptons?

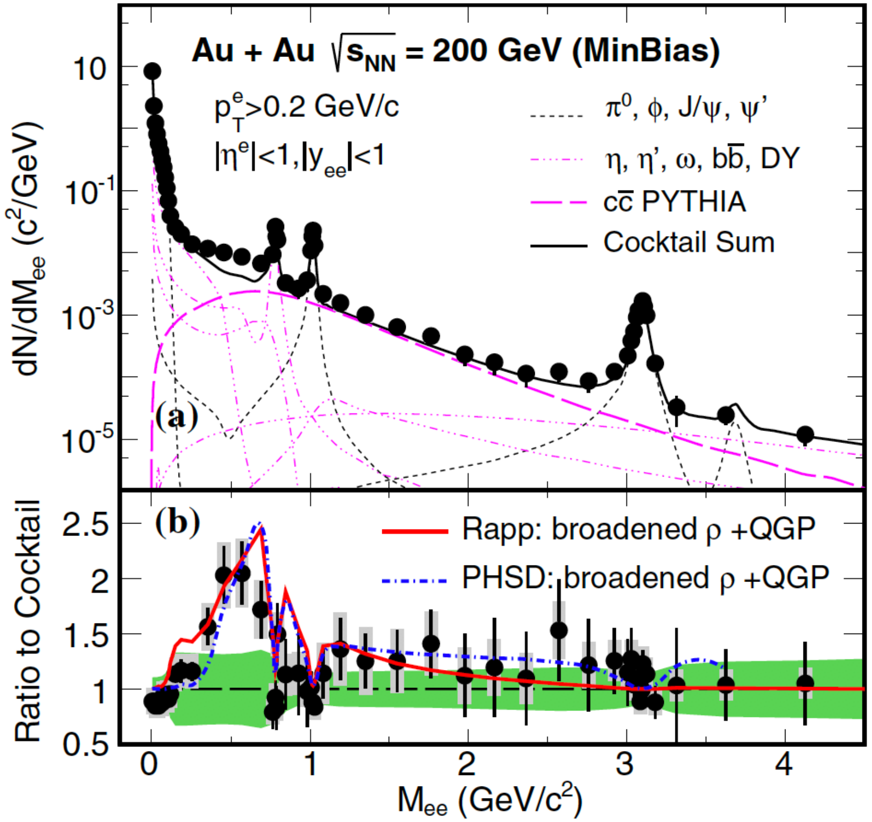
Dileptons:

- Temperature w/o distortion by blue-shift effects
- Connection between chiral symmetry restoration and in-medium ρ modification
- Only observable to directly access in-medium spectral function



Courtesy of Ralf Rapp

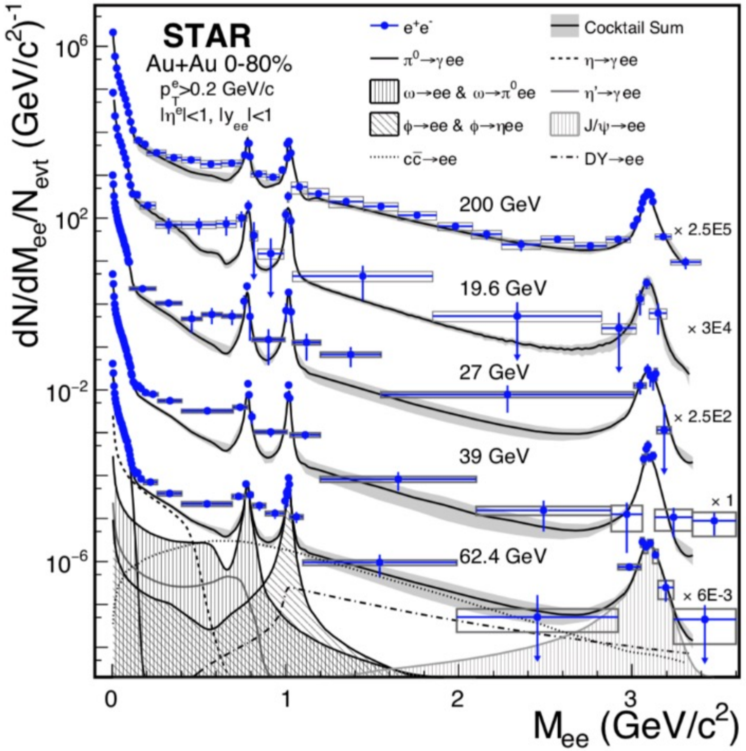
QGP: $M^{3/2} * e^{-M/T}$ **In-med. ρ: Relativistic Breit-Wigner * $e^{-M/T}$**

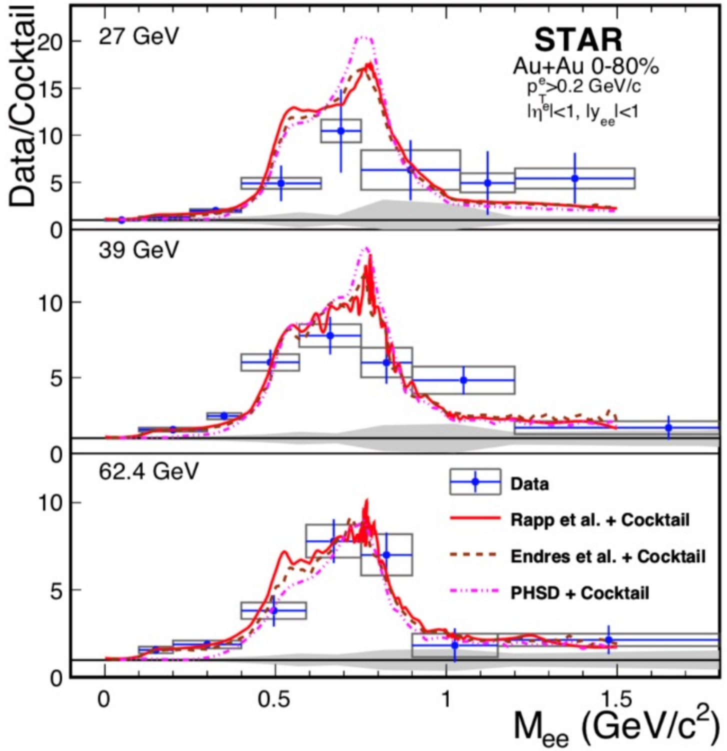


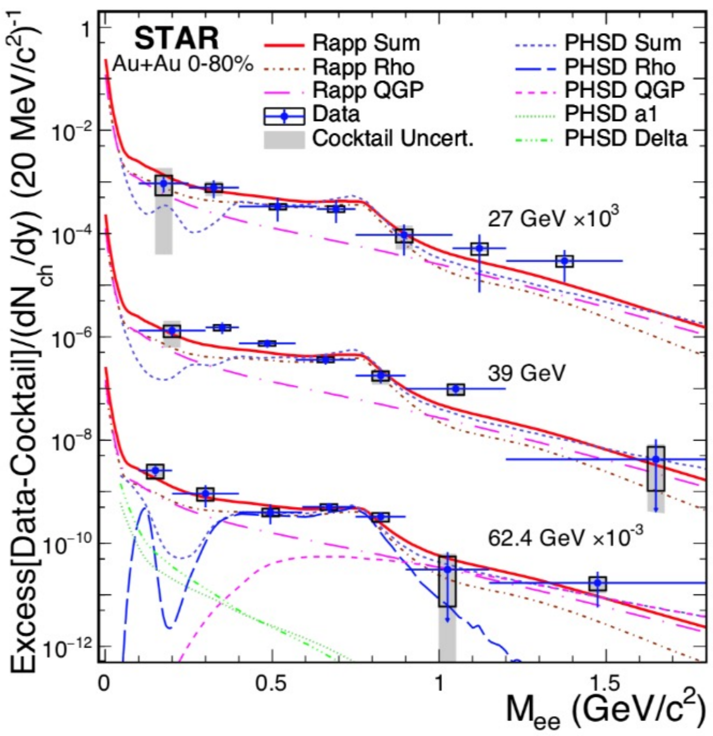
STAR: PRL 92, 092301 (2004), Rapp: PLB 753, 586 (2016)

Dielectron in Beam Energy Scan Phase I

arXiv:1810.10159; Phys. Lett. B 750,64-71(2015); Phys. Rev. Lett. 113,022301 (2014)







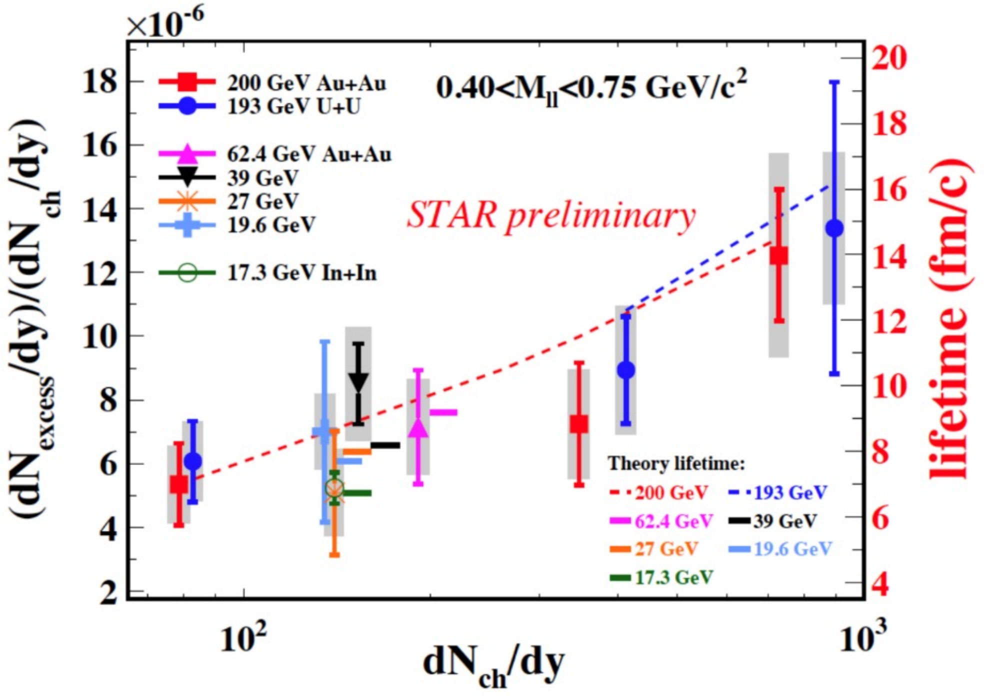
- **Low mass excesses are consistent with ρ broadening scenario from RHIC top energy down to 19.6GeV**

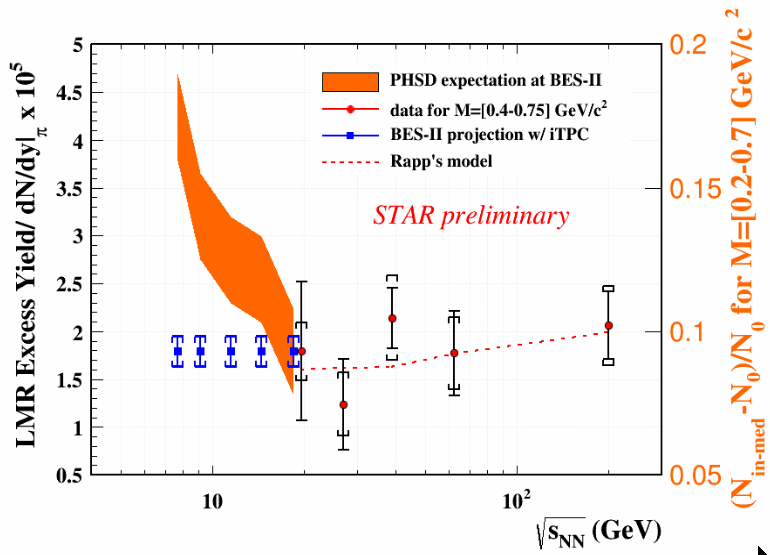
- **Hard to extract T_{eff}**

    200 GeV: High yield of heavy flavor quark semi-leptonic decay

    19.6–62.4 GeV: lack of statistics

Why dilepton in low energy region?





Total baryon density increases

Constant total baryon density

Low-mass e^+e^- emission is effected by T, total baryon density, lifetime

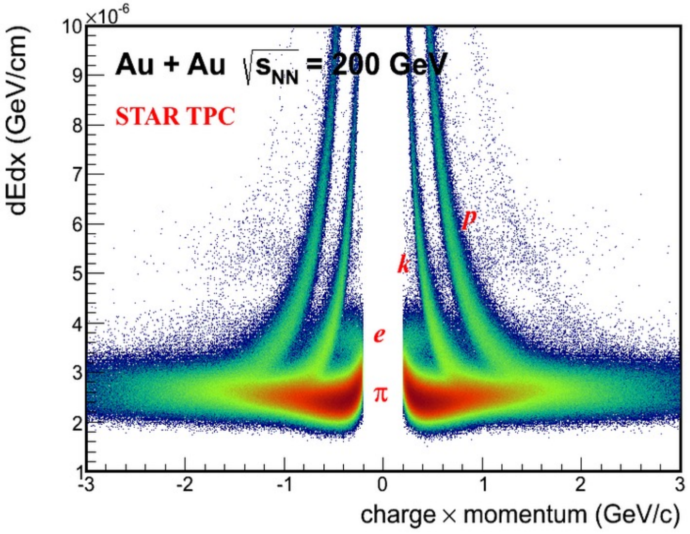
- Emission rate is dominant in the T_c region
- More clear pictures of the excess versus lifetime and total baryon density

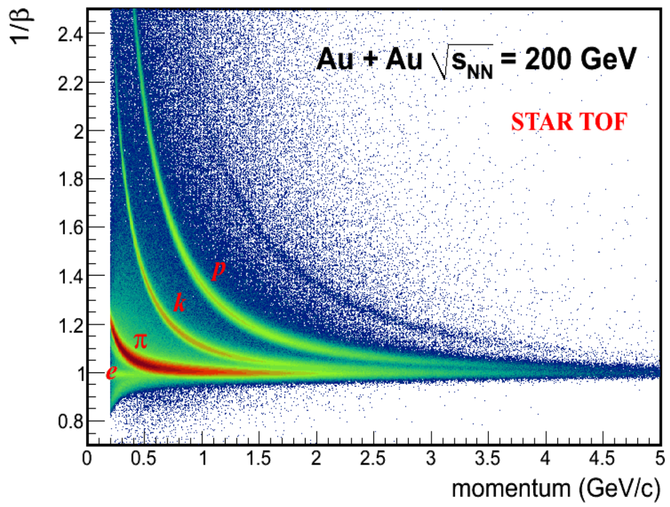
Higher precision measurements in BES-II at STAR

Year	Energy	Events
2018	27 GeV	500M
2017	54.4 GeV	875M
2011	27 GeV	68M
2010	39 GeV	132M
2010	62.4 GeV	62M

Particle identification at STAR

In HHICs

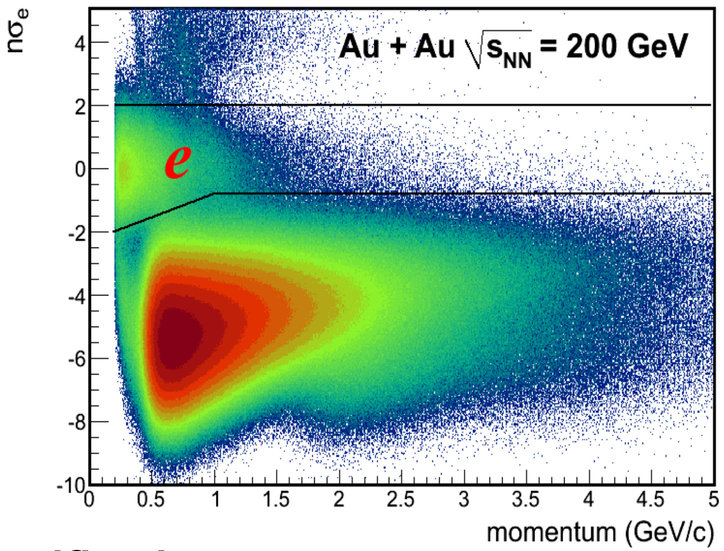




Chinese STAR group contribute to the eID/muID:

- TPC: FDU+SDU+SINAP
- TOF: FDU+SINAP+THU+USTC
- MTD: THU+USTC

Require β close to speed of light



Electron identification: TPC+TOF

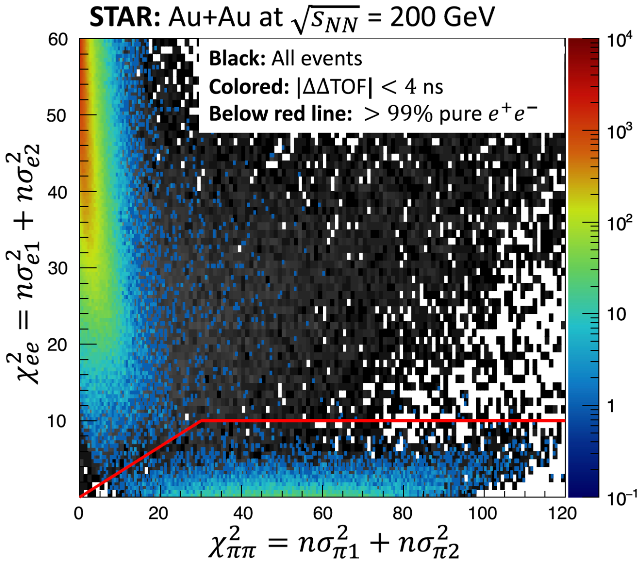
STAR, Phys. Rev. Lett. 94, 062301 (2005)

Muon identification: TPC or TPC+MTD

J.D.Brandenburg, Nucl. Phys. A 982, 192 (2019)

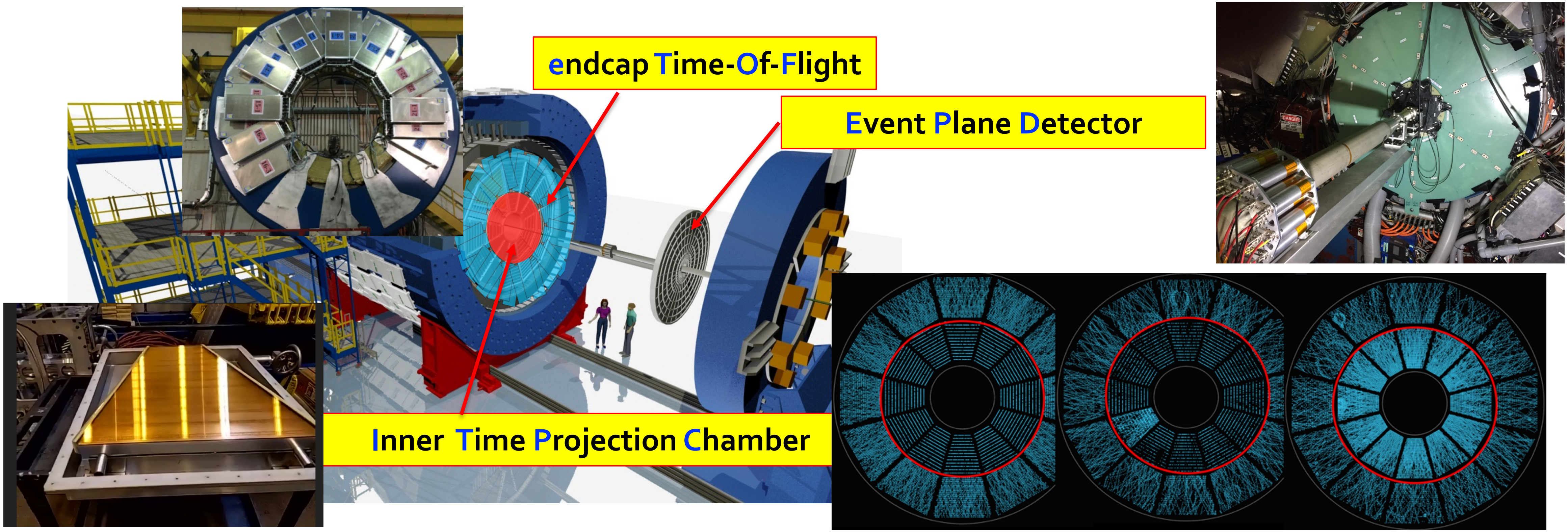
T.C.Huang, et.al., NIM.A 833, 88-93 (2016)

In UPCs



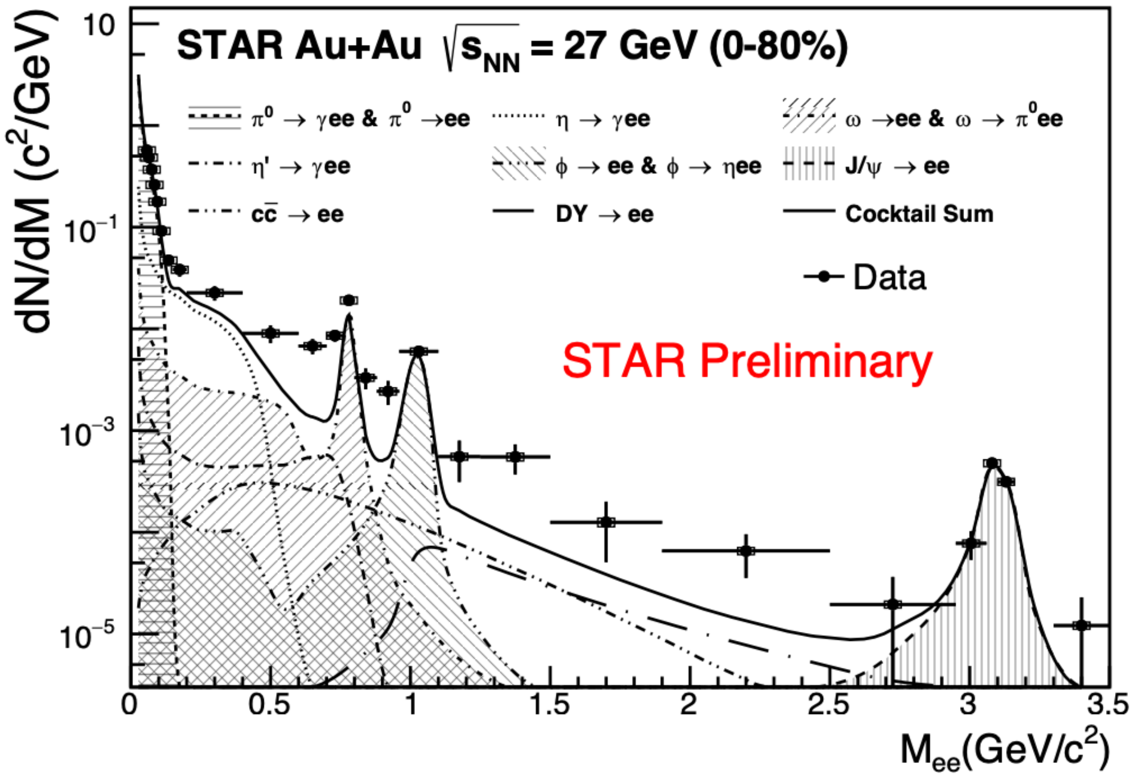
dielectron pair:>99% purity

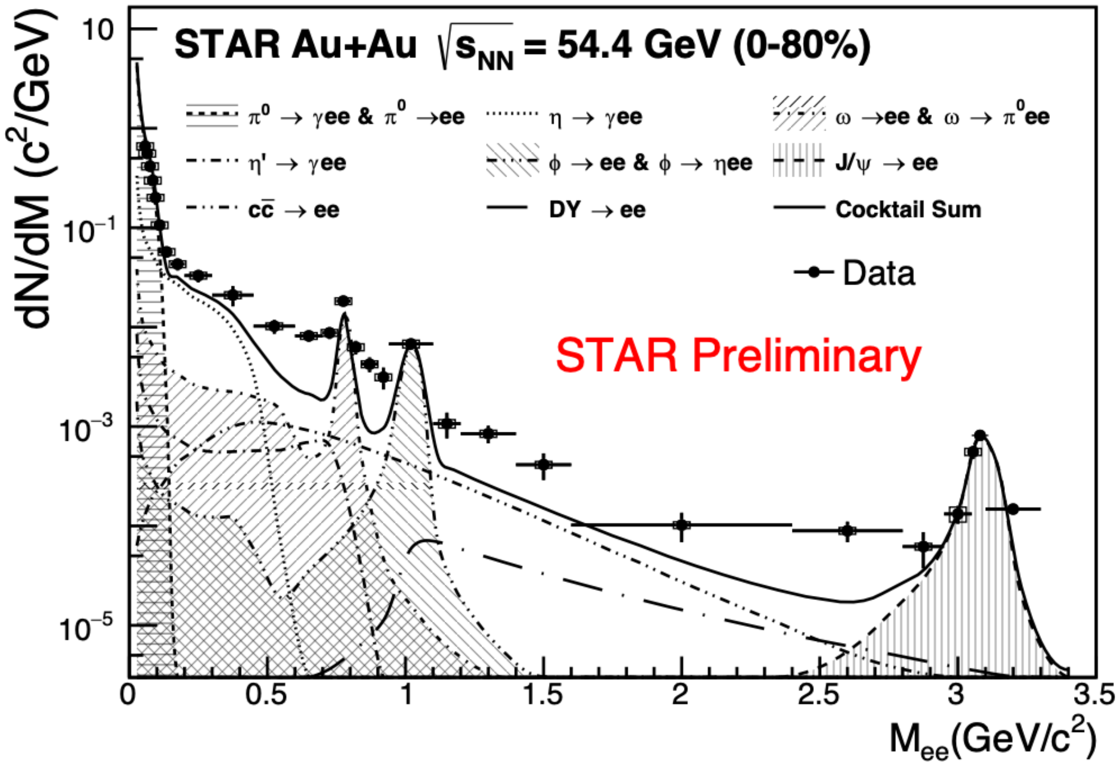
Detector upgrades commissioned by Run19 for Beam Energy Scan Phase II



iTPC upgrade	EPD upgrade	eTOF upgrade
$\|\eta\|<1.5$	$2.1<\|\eta\|<5.1$	$-1.6<\eta<-1.1$
p_T >60 MeV/c	Better trigger & b/g reduction	Extend forward PID capability
Better dE/dx resolution Better momentum resolution	Greatly improved Event Plane info (esp. 1st-order EP)	Allows higher energy range of Fixed Target program
Fully operational in 2019	Fully operational in 2018	Fully operational in 2019

Dielectron spectrum at 27 and 54.4GeV Au+Au

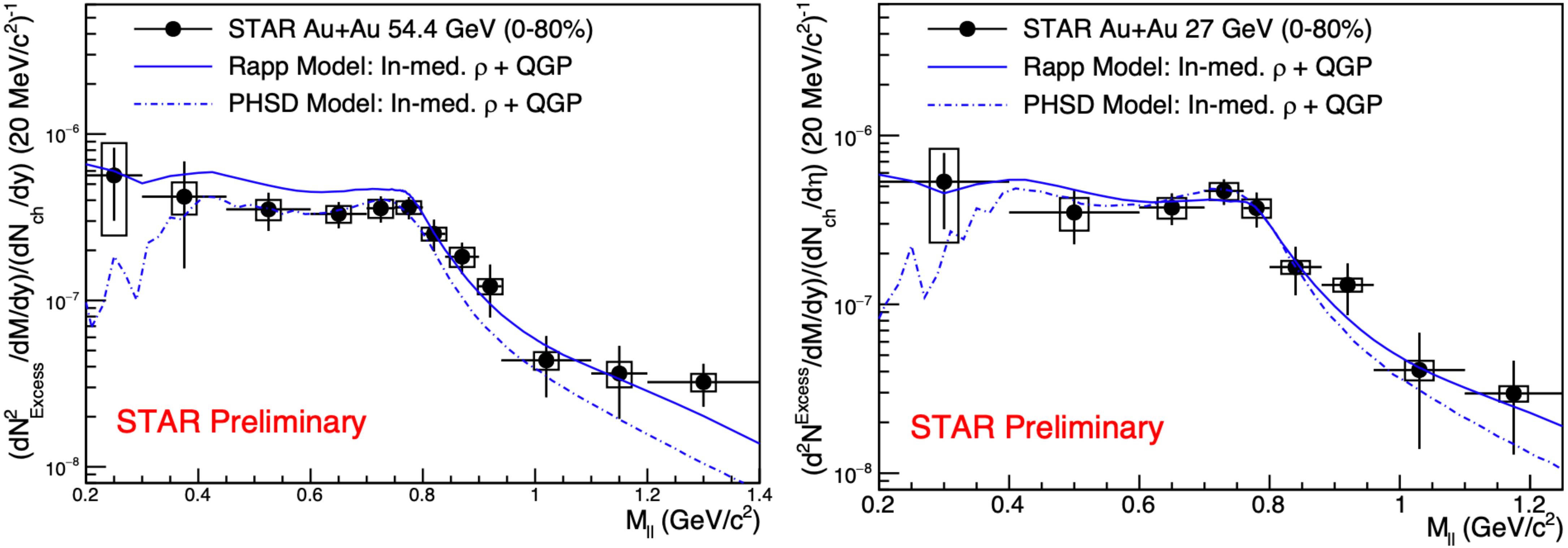




Clear enhancement compared to ρ excluded cocktail simulation in LMR and IMR

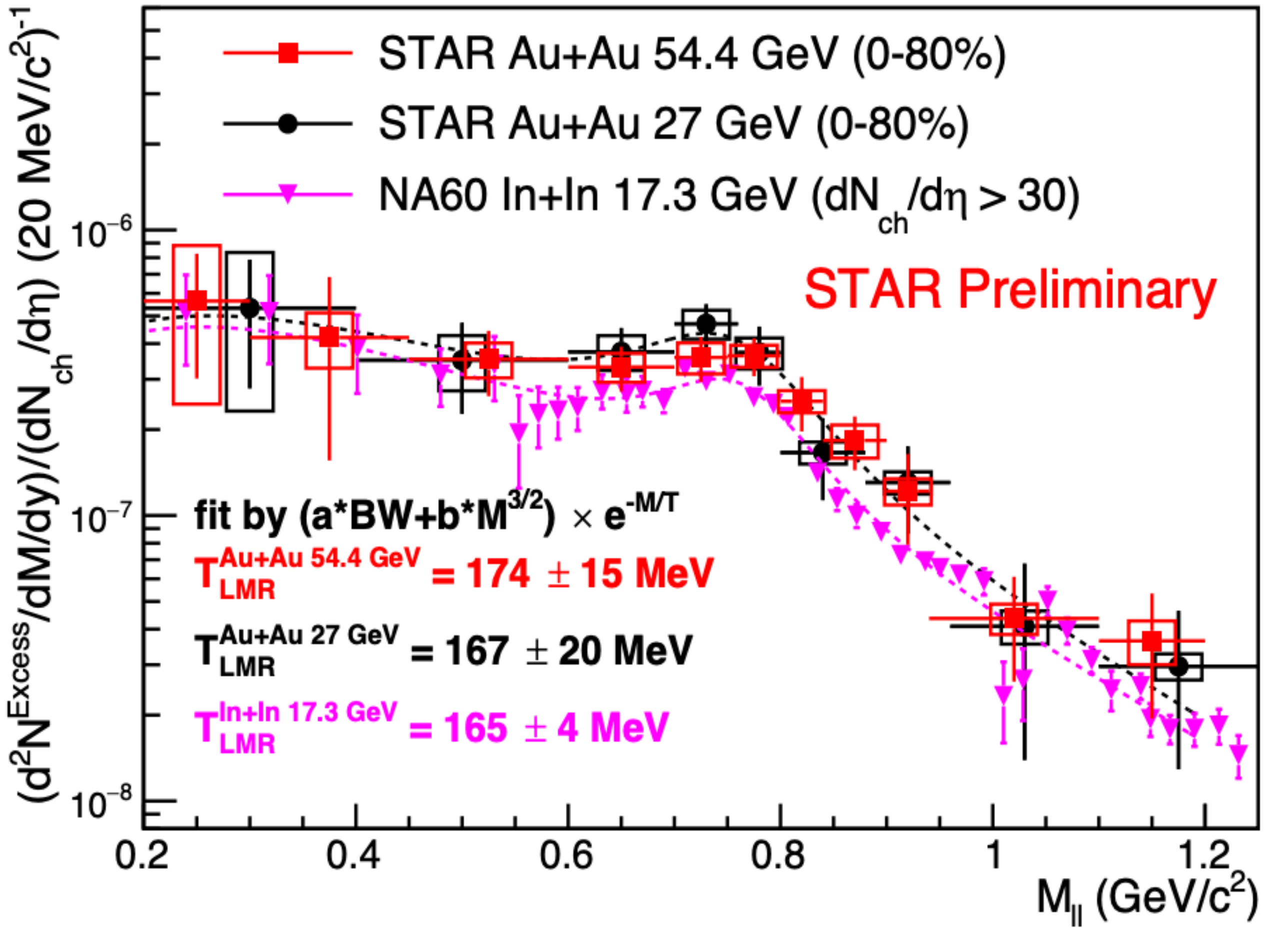
Excess in low mass region

Excess = data - cocktail



- Both models can well describe 27 GeV in ρ mass region
- Rapp model describes data well but overestimate 54.4 GeV for 0.5< M_{ee} <0.9 GeV/c^2
- PHSD model describes data well but underestimate 54.4 GeV for M_{ee} > 0.9 GeV/c^2

Thermal dileptons in low mass

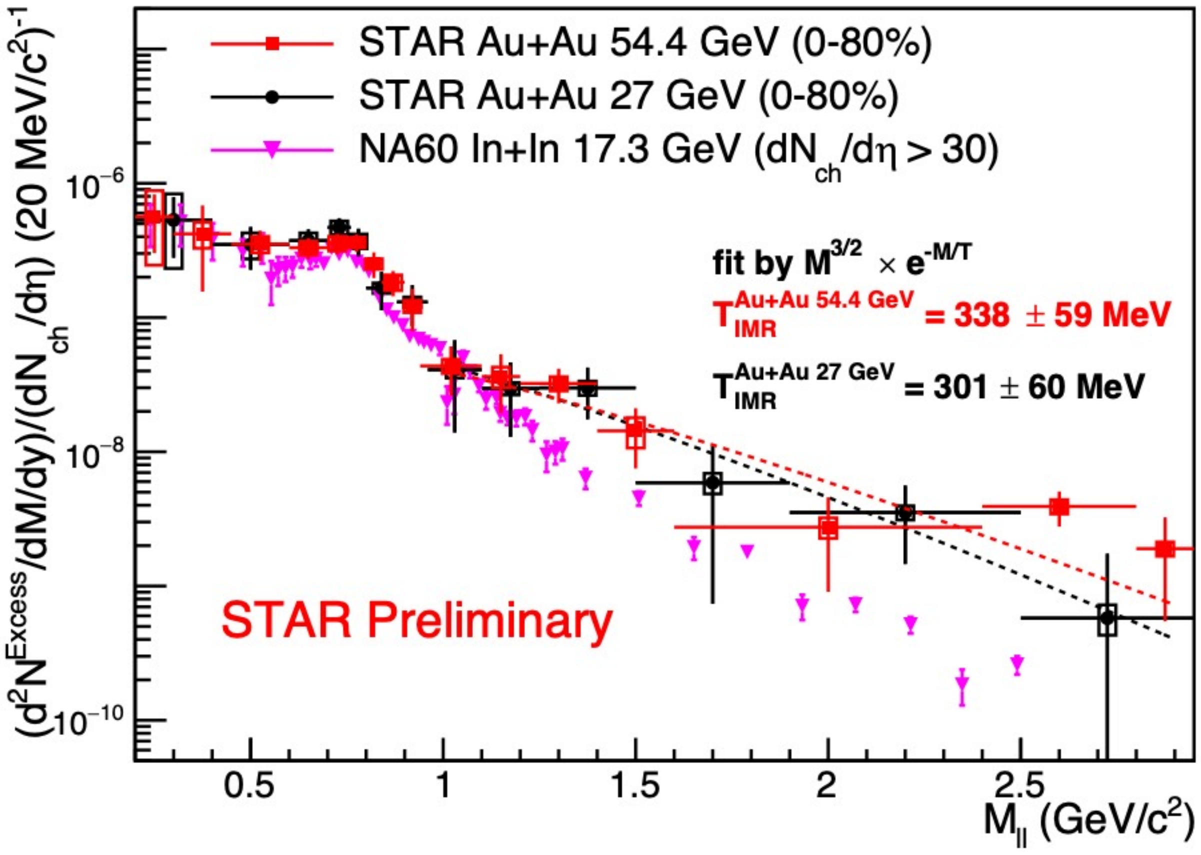


NA60: EPJC (2009) 59: 607–623
HotQCD: PLB 795 (2019) 15-21

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

- Excess dielectron spectra of 27 and 54.4 GeV Au+Au collisions and NA60 In+In collisions are similar
- T is similar despite significant differences in collision energy and system size
- T extract from low mass region around the pseudo critical temperature T_{pc} (156 MeV)

Thermal dileptons in low + intermediate mass

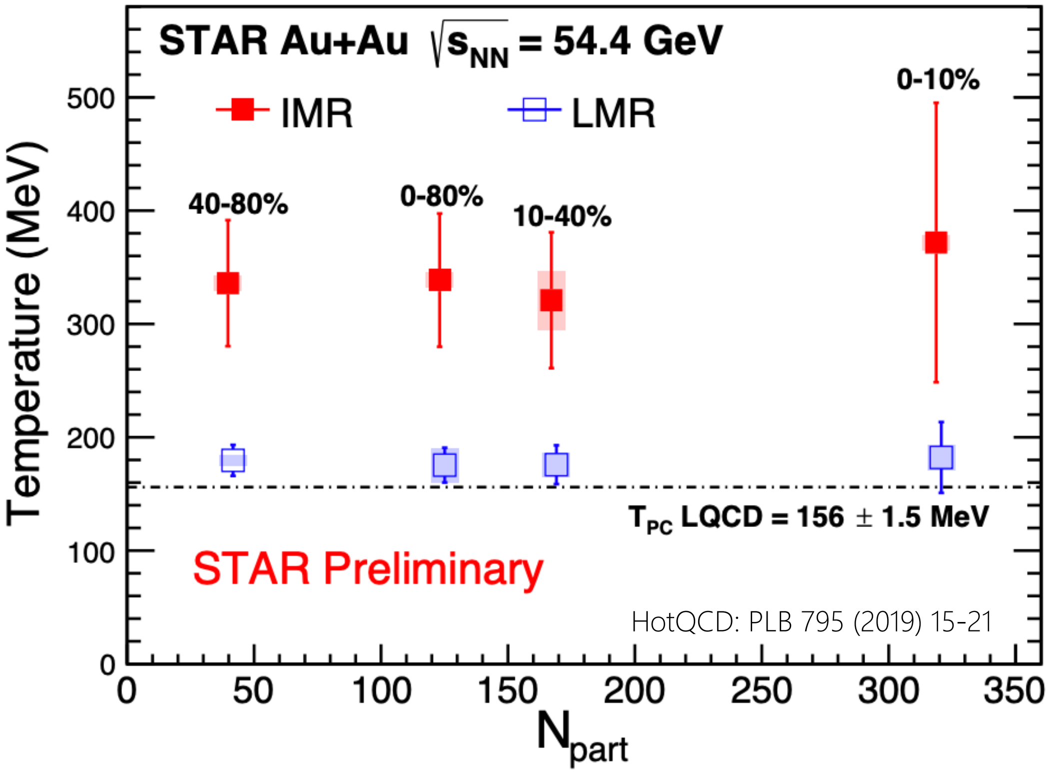


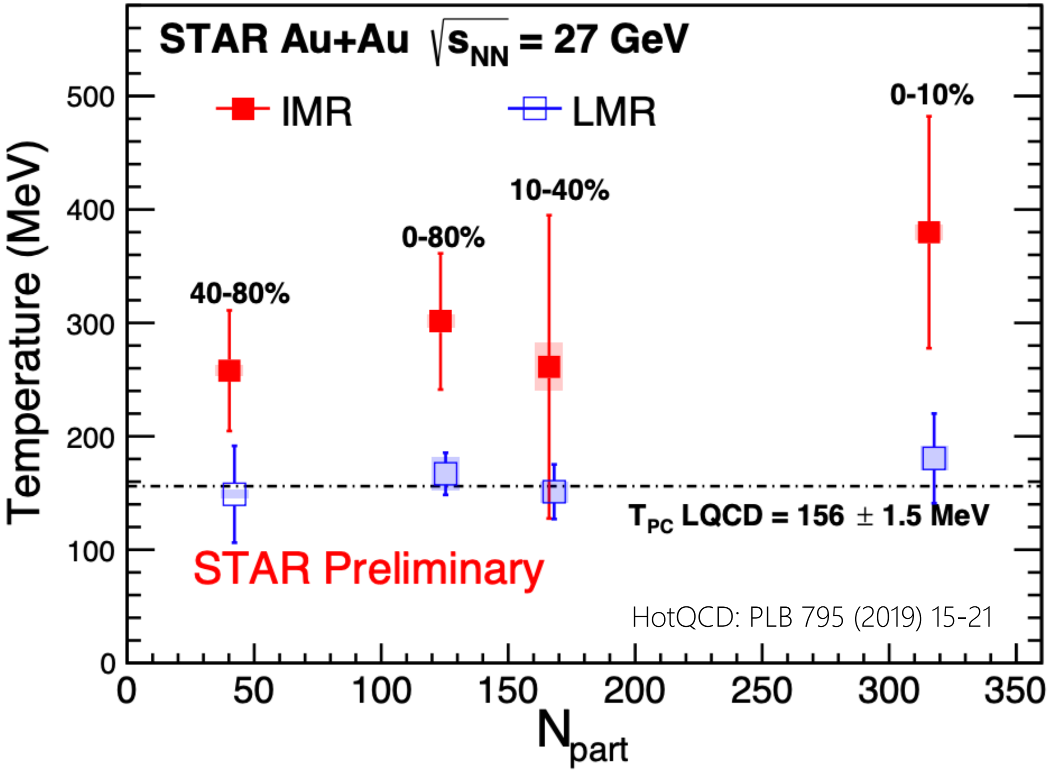
fitting function: $M^{3/2} * e^{-M/T}$

- Thermal dielectrons is the major source in IMR
- T in 27 and 54.4 GeV are consistent with each other
- $T > T_{pc}$ (156 MeV): emission dominantly from QGP
- QGP is hotter at RHIC than that in NA60 (205+/-12 MeV)

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

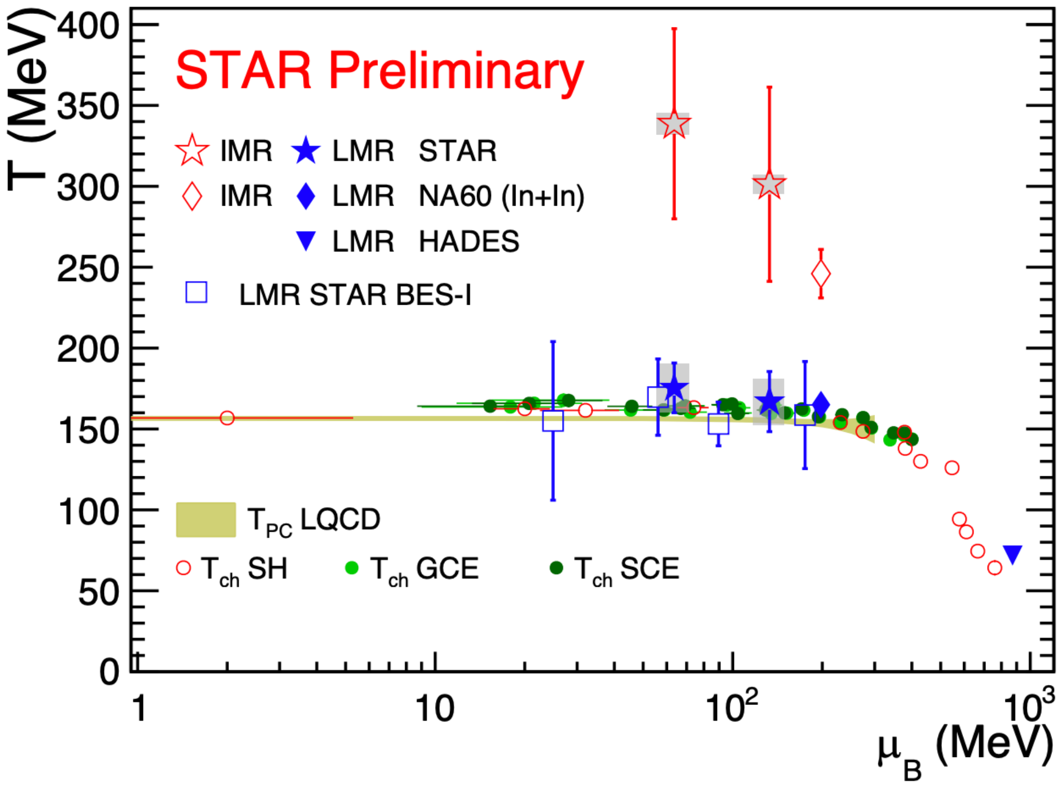
Temperature v.s. N_{part}





- No clear centrality dependence
- T in LMR is close to phase transition temperature (T_{pc})
- T in IMR is higher than that in LMR

Temperature v.s. μ_B



T_{LMR}:

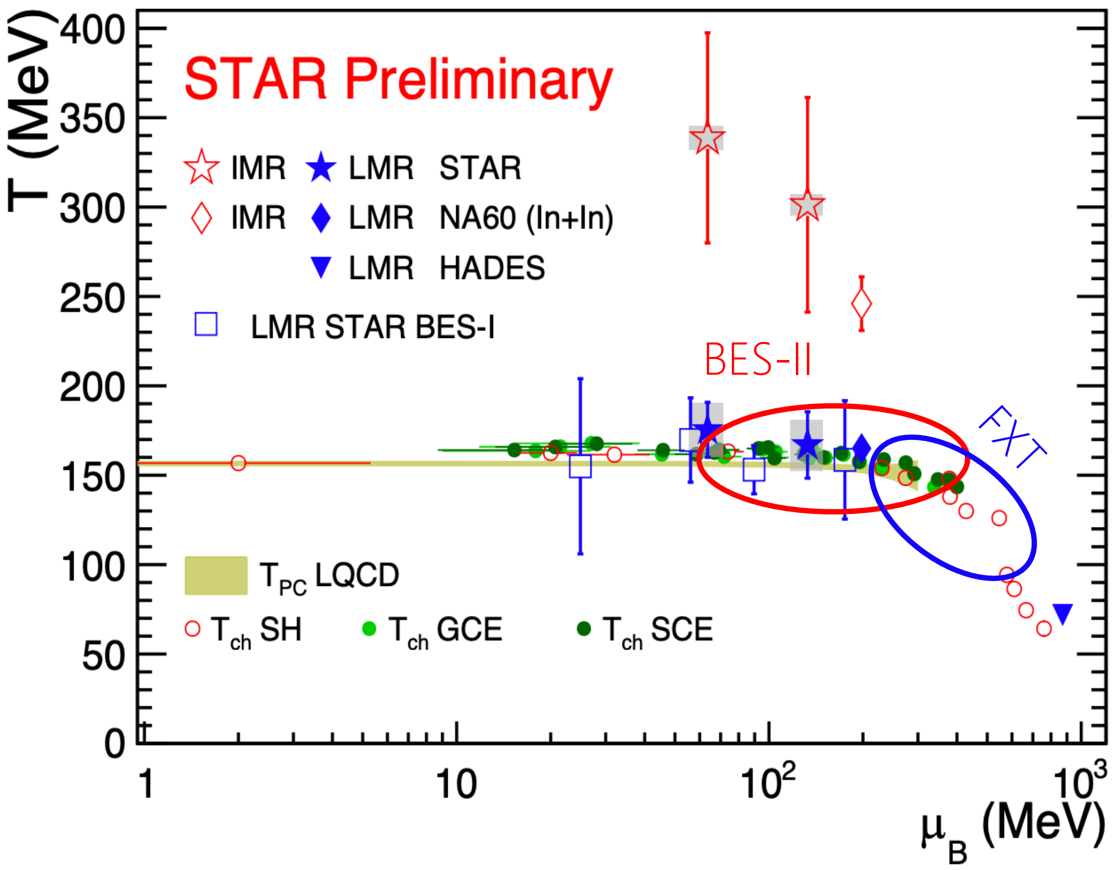
- Close to T_{ch} and T_{pc}
- Dielectrons dominantly emitted around phase transition

T_{IMR}:

- Higher than T_{LMR}, T_{ch} and T_{pc}
- Dielectrons dominantly emitted from QGP phase

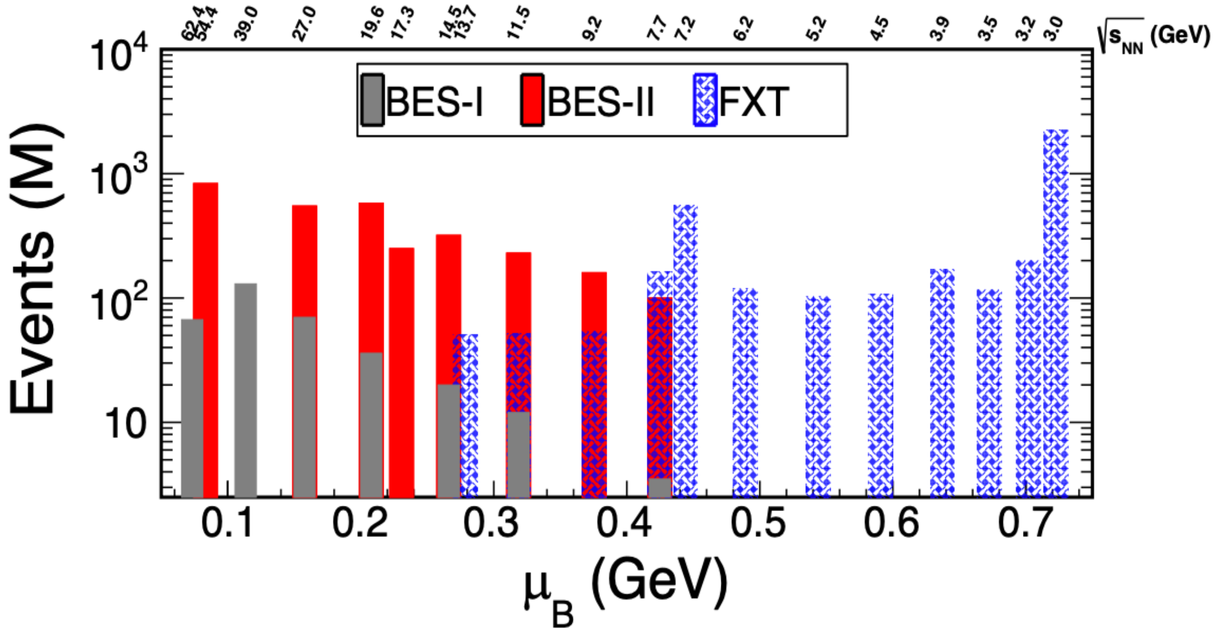
NA60: EPJC (2009) 59 607–623
HADES: Nature Physics 15, 1040-1045 (2019)
Tch SH: P. Braun-Munzinger et al. Nature 561, 321-330 (2018)
Tch GCE/SCE: STAR PRC 96, 044904 (2017) c

Future in lower energies of BES-II



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) c

- High statistic data sample between 7.7 GeV and 19.6 GeV in STAR BES-II
- Enhanced tracking and particle identification capabilities with iTPC and eTOF upgrades

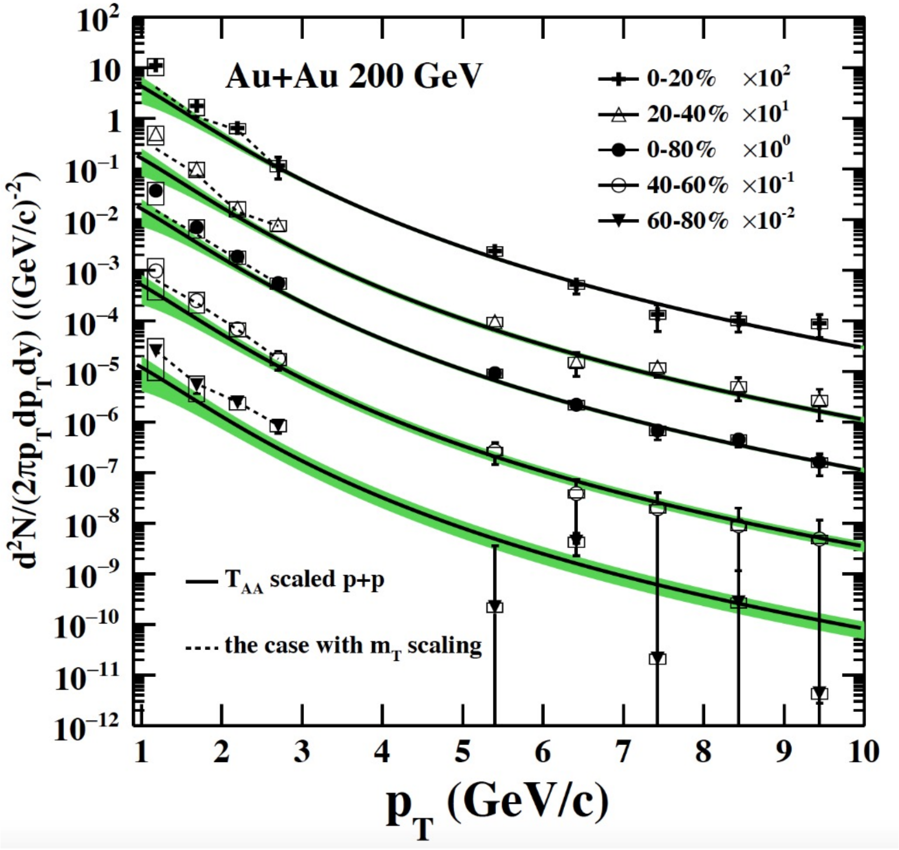


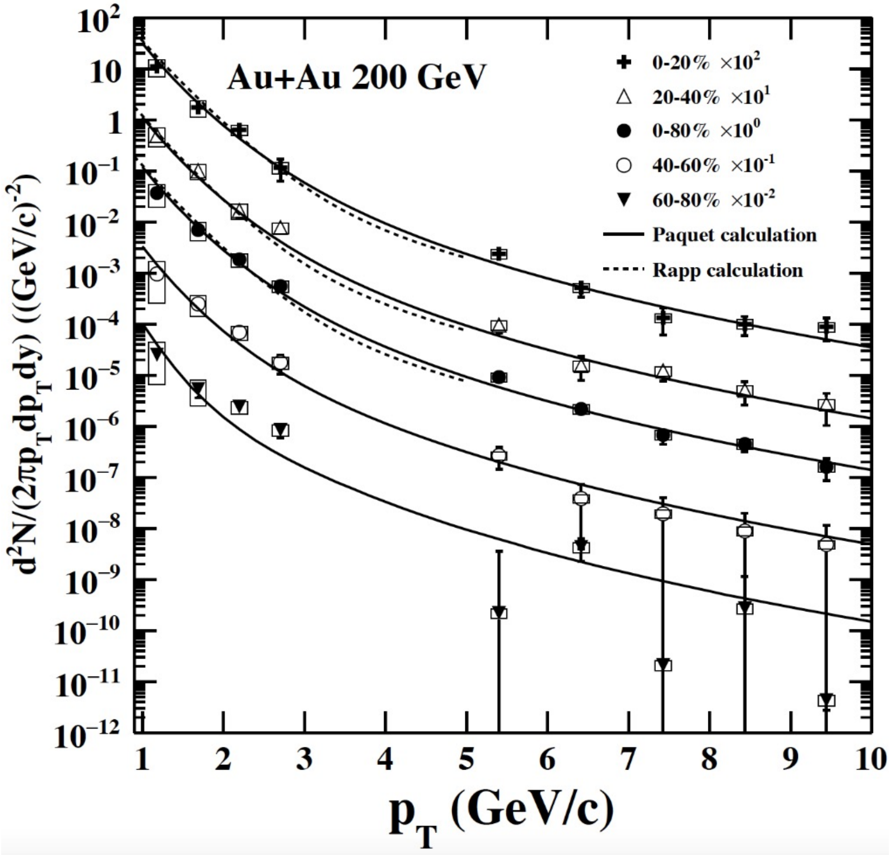
- **Overlapped with NICA region between 7-11GeV**
- **But lower statistics**

Direct Virtual Photon at RHIC Top Energy

Thermal photons can be observed

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





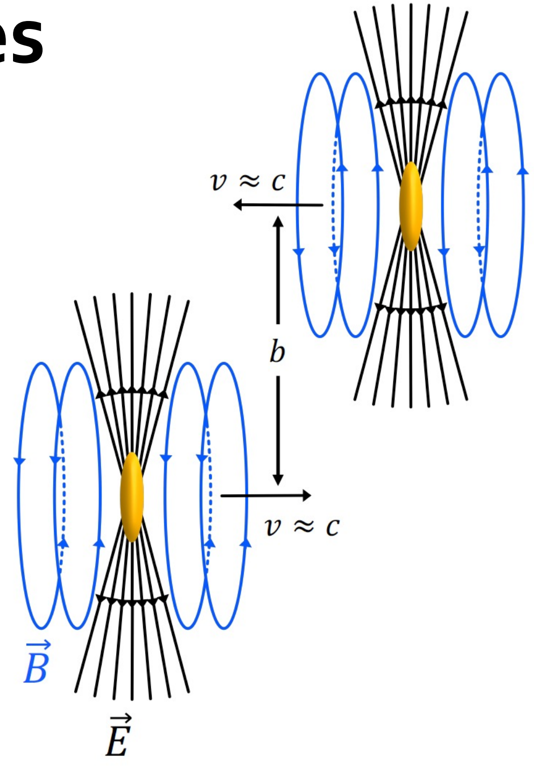
Model calculations:

- Consistent with the yield within uncertainties except some bins in 60-80%
- Simultaneously describe both dielectron and direct virtual photon yields

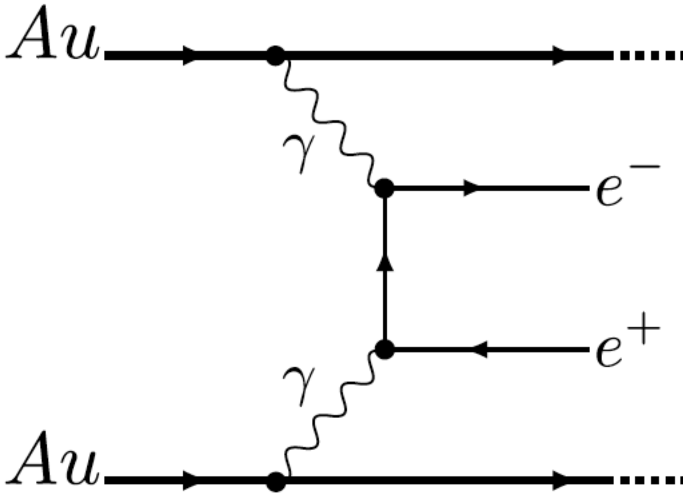
Internal conversion method：

- Depend on dielectron study
- Limited by statistics

Photon-induced dileptons as new probes



- EM fields is highly compressed in HICs
- Equivalent to quasi-real photons moving alone the beam direction
- These photons may then interact with the other nucleus/photons



$\gamma\gamma \to l^+l^-$

In UPC

- Provide baseline for EM field and final effect study
- Novel way to constrain the nuclear charge radius

In HHIC

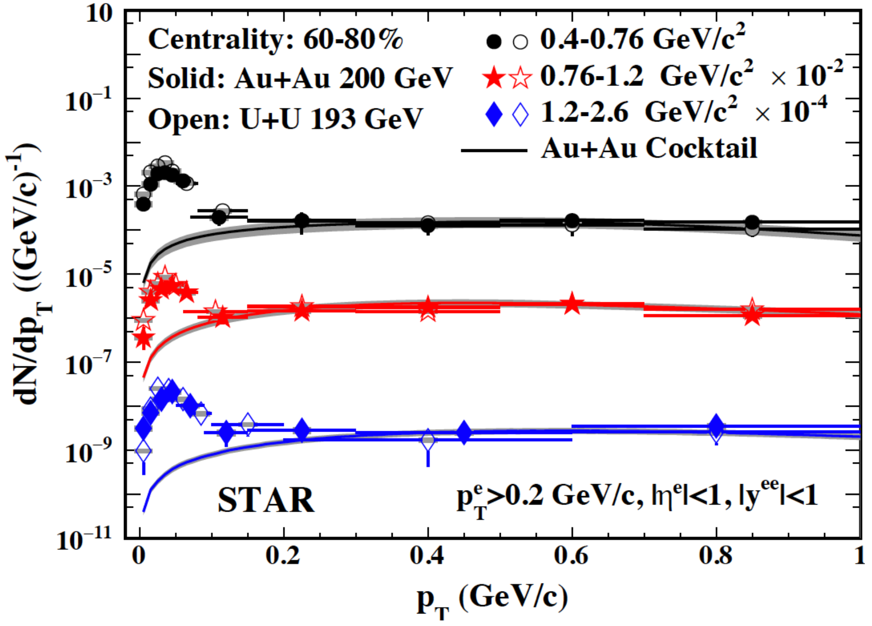
- Study extreme magnetic field and potential medium effect

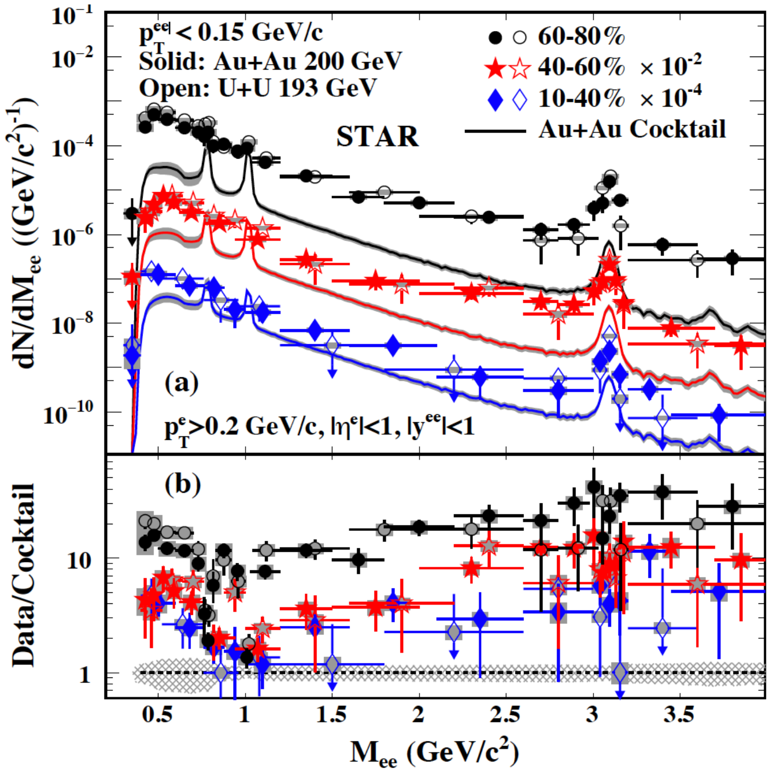
$\gamma\gamma \to e^+e^-$

Photon-induced e^+e^- at STAR

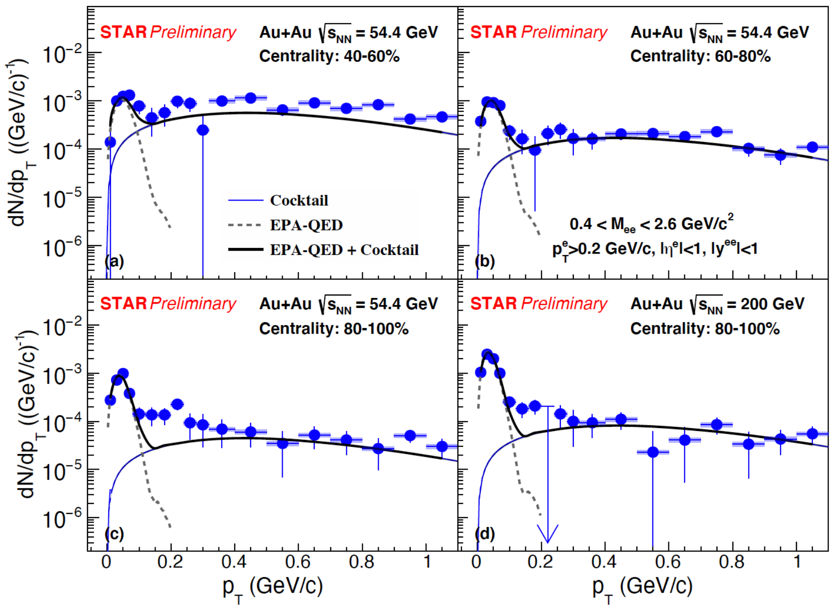
Phys. Rev. Lett. 121, 132301 (2018)

200GeV Au+Au and U+U



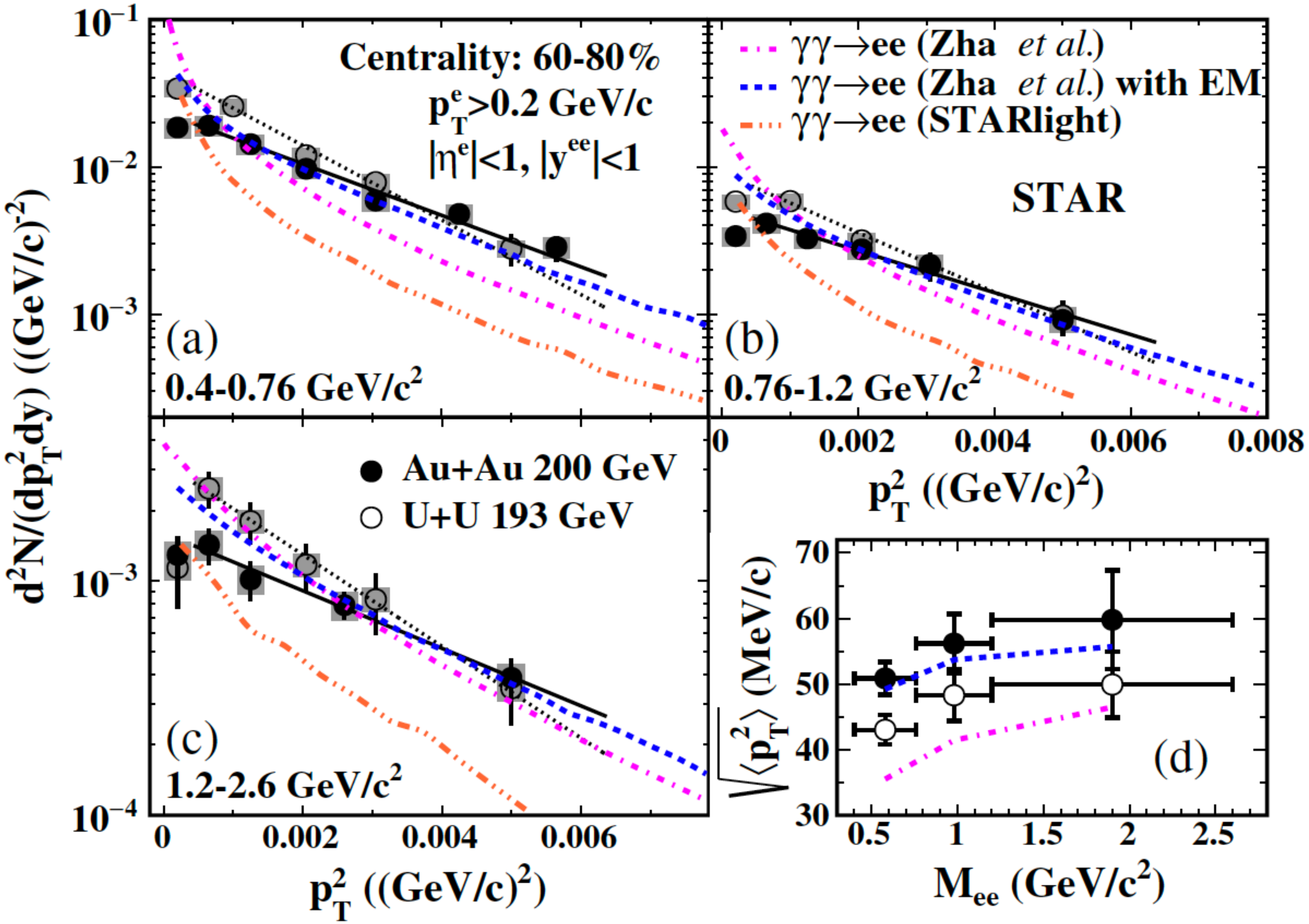


54.4GeV Au+Au



- Significant enhancement
- Excesses concentrate below $p_T \approx 0.15$ GeV/c
- Coherent photon-photon interactions in HHICs

Affected by Strong Magnetic Field ?



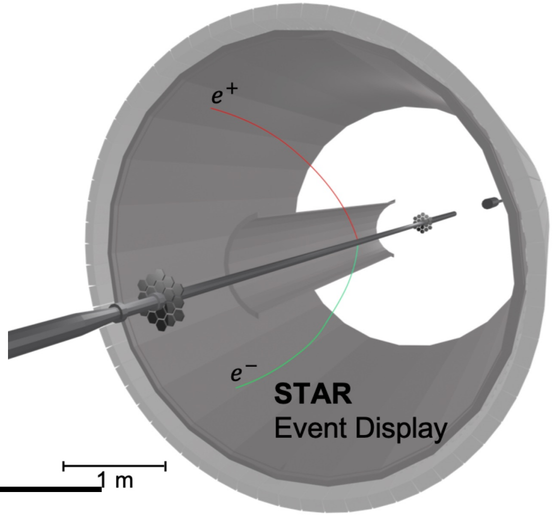
$\langle p_T^2 \rangle$ higher than QED expectation

Phys. Rev. Lett. 121, 132301 (2018)

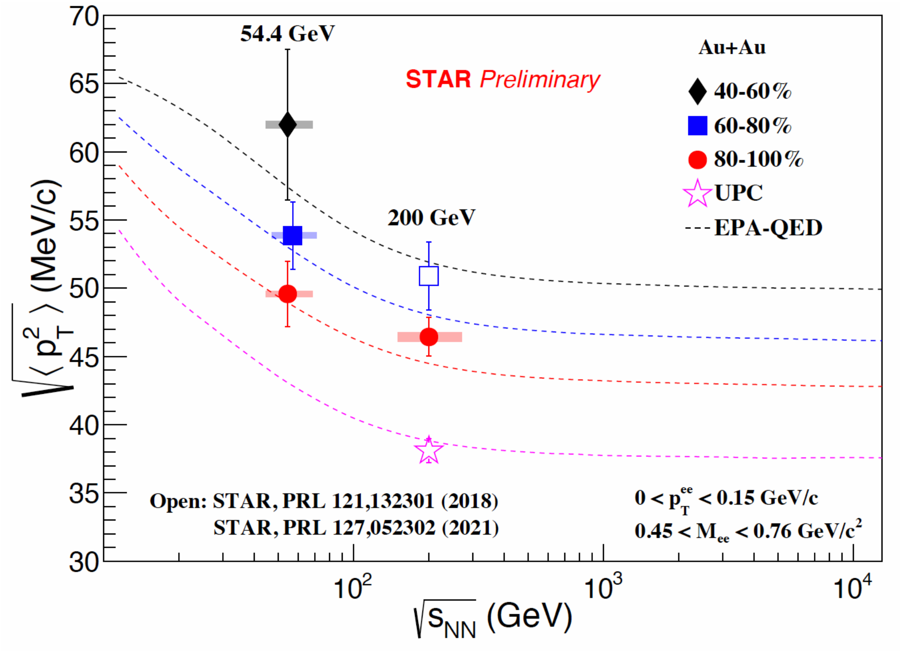
Breit-Wheeler Process as baseline

Phys. Rev. Lett. 127, 052302 (2021)

1. Observe 6085 exclusive e^+e^- pairs from data collected in 2010 at STAR
2. No vector meson contribution visible
3. Energy spectrum
4. Photon transverse polarization & spatial distribution



Energy and Centrality Dependence of $\sqrt{\langle p_T^2 \rangle}$

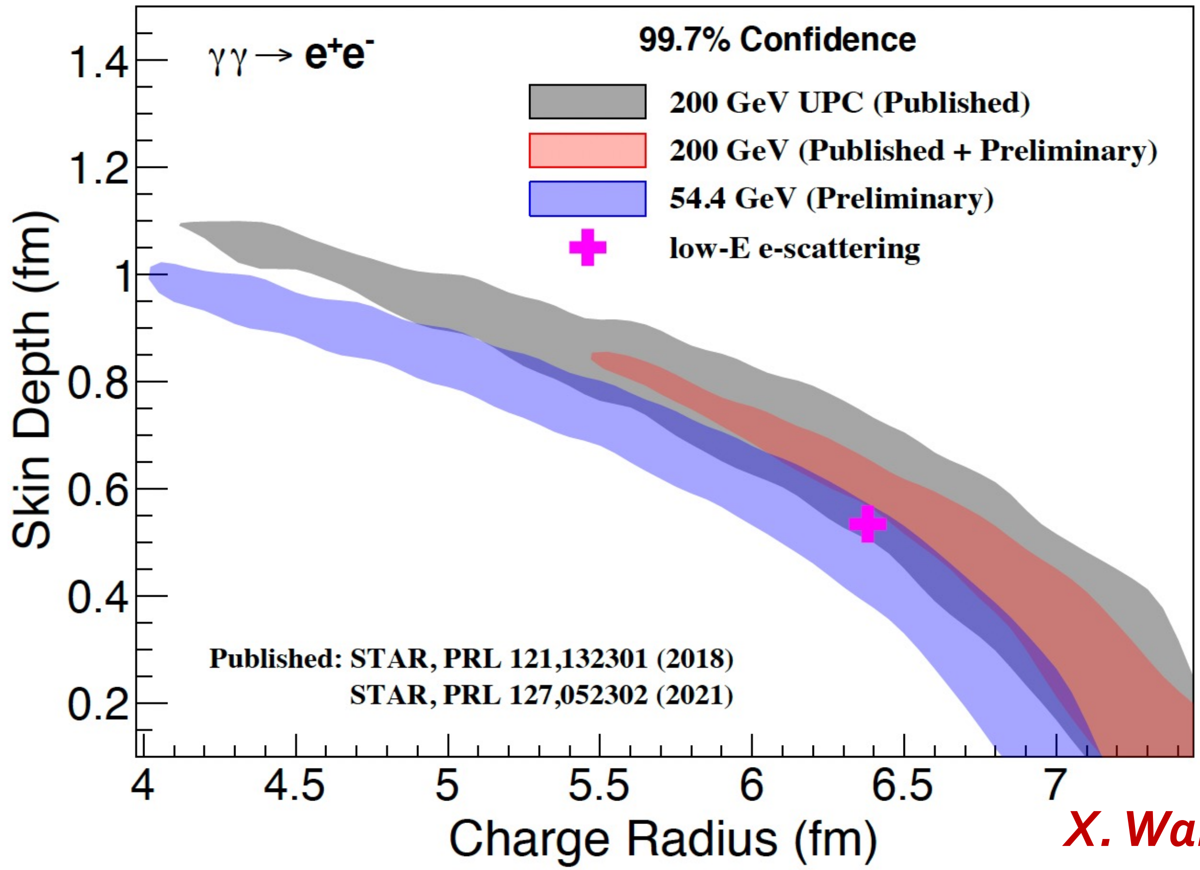


- $\langle p_T^2 \rangle$ sensitive to p_T broadening
- Decreases from semi-peripheral to peripheral collisions

  Initial state effect: Impact parameter dependence
- Energy dependence (3.7σ compared to 200 GeV QED)

  And/or final state effect (1.8σ)?

Application to Nuclear Charge Radius Measurements



X. Wang, STAR talk@ QM2022

- **200 GeV vs 54.4 GeV:**
  energy dependence of charge distribution?

Low energy scattering: R=6.38 fm, d=0.535 fm
R. C. Barrett and D. F. Jackson, Nuclear Sizes and Structure (Oxford University Press, 1977)

- **Low-energy scattering vs RHIC (3σ difference):**
  energy dependence of charge distribution and/or final state effect?

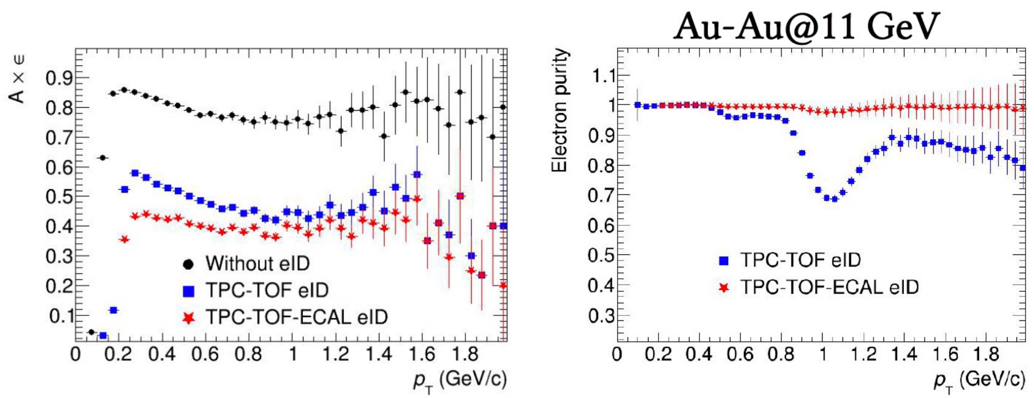
Summary

RHIC-STAR	200GeV Au+Au	193GeV U+U	200GeV Ru+Ru	200GeV Zr+Zr	62GeV Au+Au	54.4GeV Au+Au	39GeV Au+Au	27GeV Au+Au	19.6GeV Au+Au
Rho broadening	√	√			√	√	√	√	√
Thermal dilepton						√		√	
Thermal photon	√								
Photon-induced dilepton	√	√	√	√		√			

√ BES-I
√ BES-II

EM probes at MPD

- **Large statistics**
- **Good PID especially in high pT with ECal**
- **Direct photon measurement capability**
- **Nice energy region**



Thank you for your attention!