Low transverse momentum dilepton production in heavy ion collisions

Lijuan Ruan
(*Brookhaven National Laboratory*)

Outline:

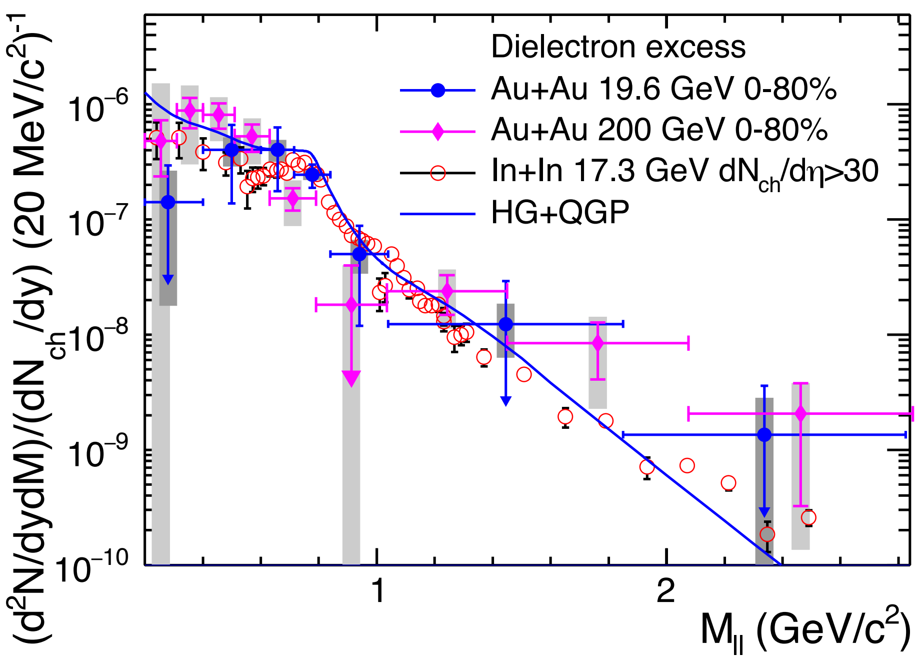
- How was it started?
- Recent results
- Future perspectives
- Summary

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

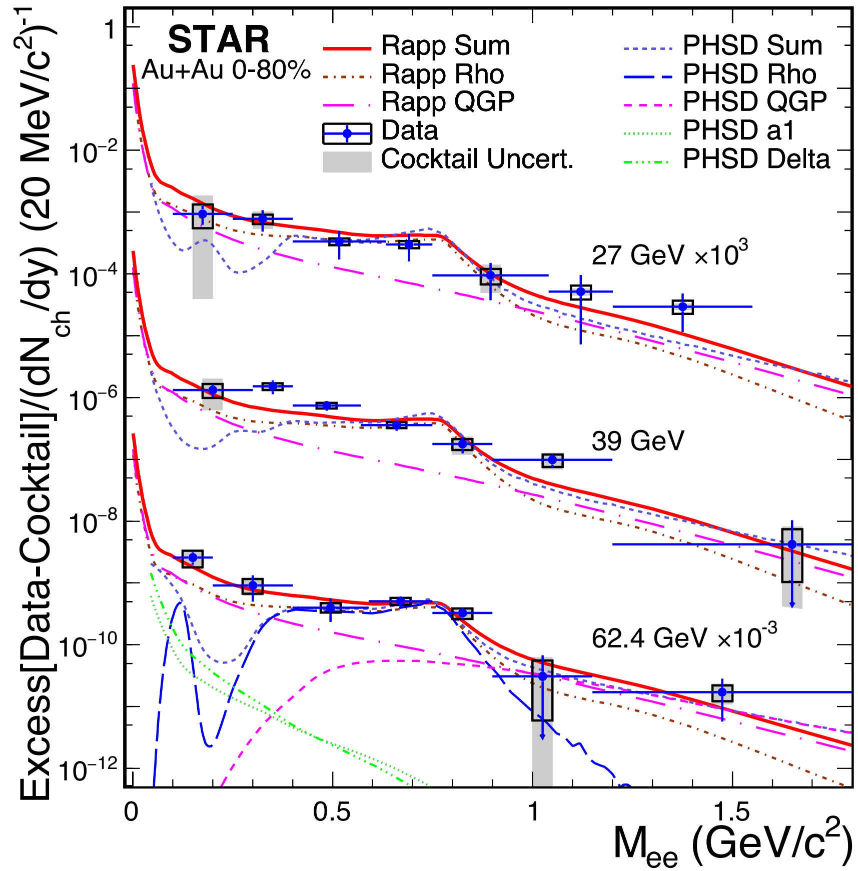
Office of Science U.S. DEPARTMENT OF ENERGY

Traditional: the dielectron excess spectrum

STAR: PLB750(2015)64

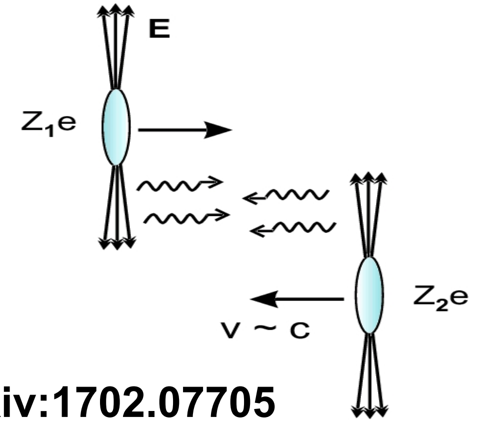


STAR: arXiv: 1810.10159, submitted to PRL

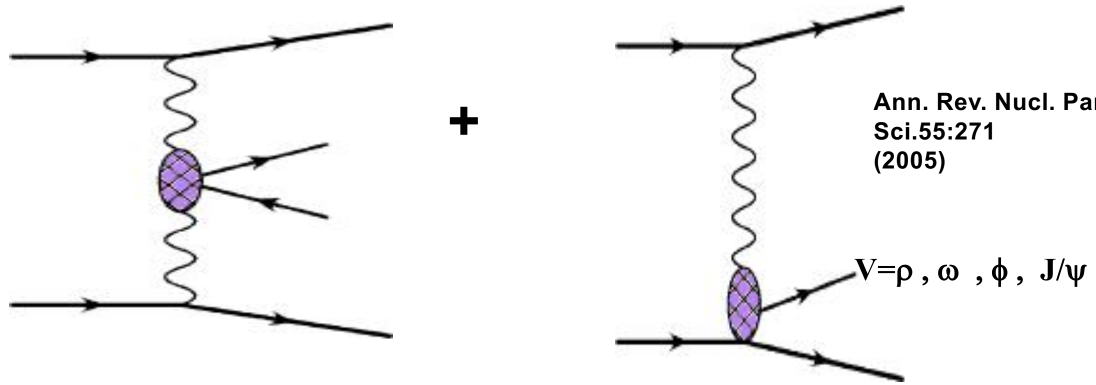


A broadened ρ spectral function consistently describes the low mass dielectron excess for all the energies 19.6-200 GeV.

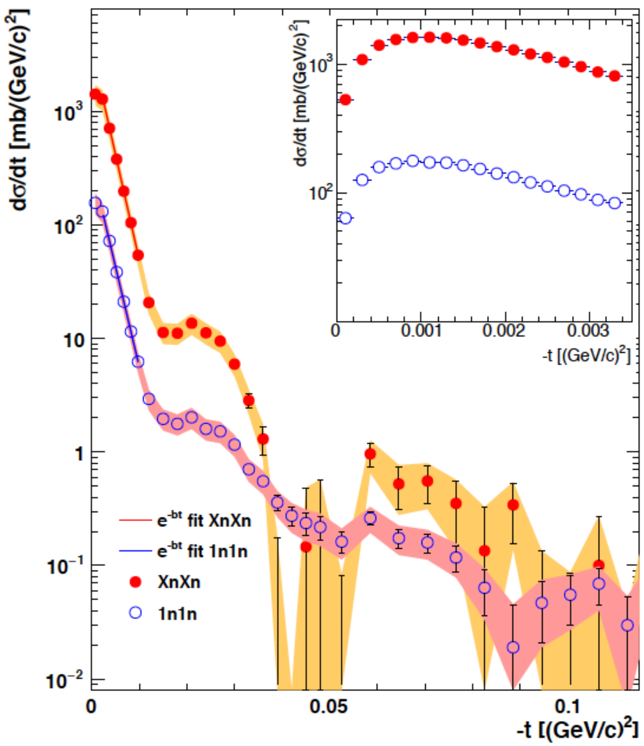
ρ and J/ψ in ultra-peripheral A+A collisions



=

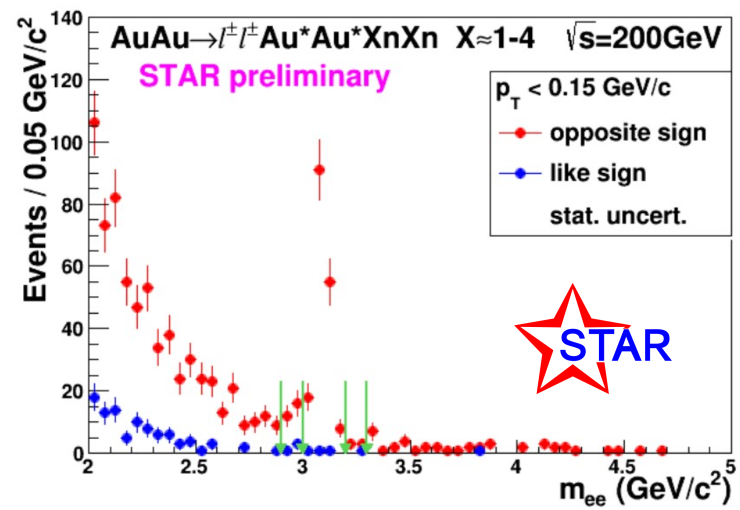


arXiv:1702.07705



Two-photon

photonuclear

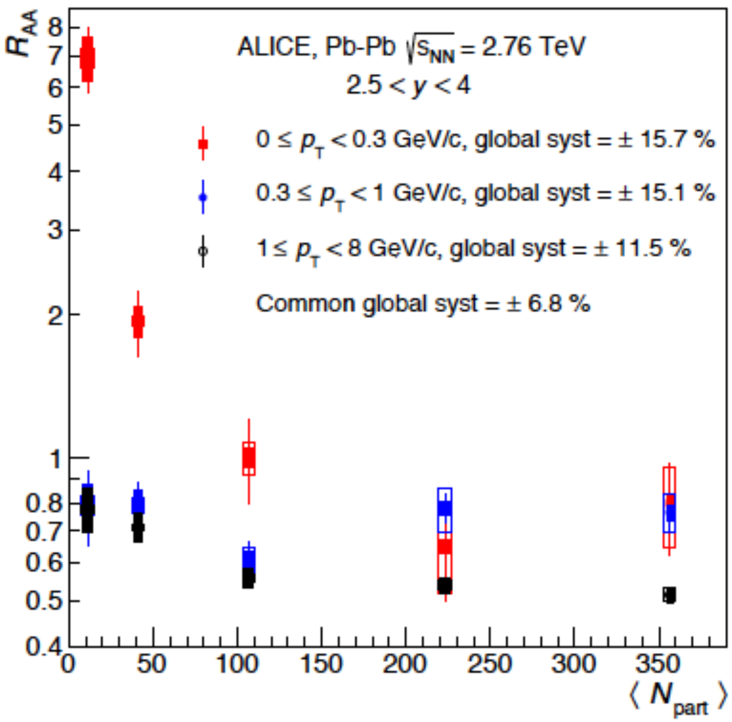


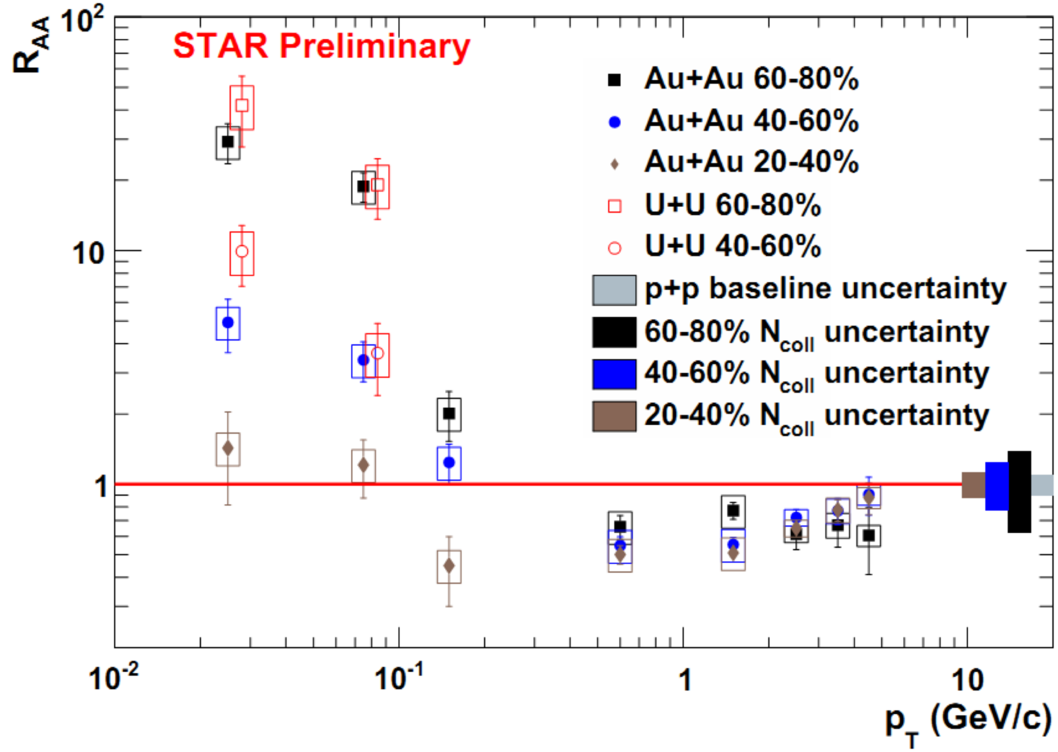
J/ψ signal

ρ: characteristic diffractive dips observed

Very low p_T J/ψ in heavy ion collisions

PRL116(2016)222301

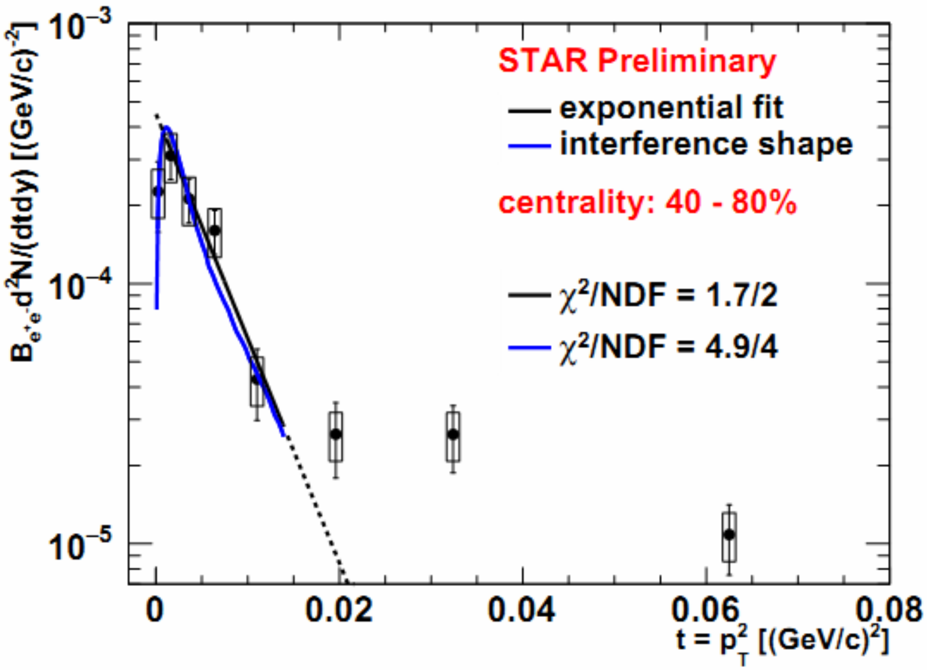


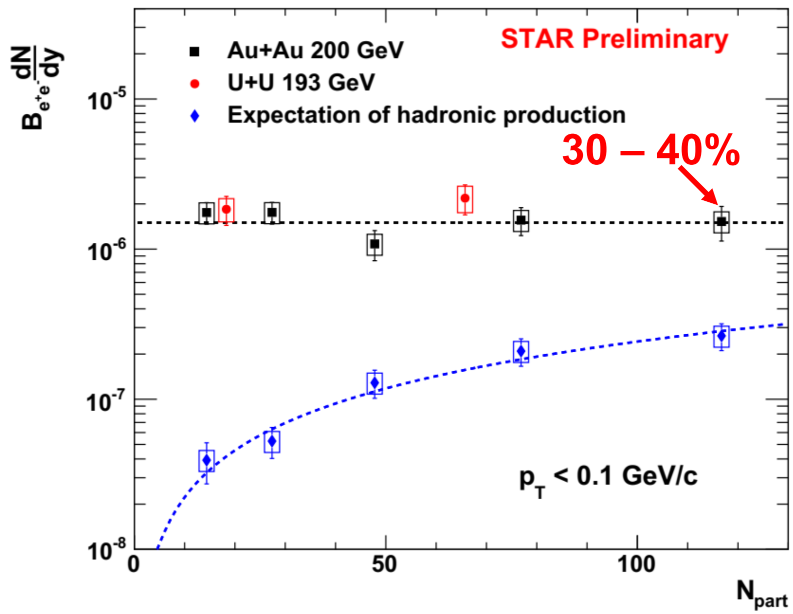


Large enhancement of J/ψ yield observed in peripheral A+A collisions!

Prominent centrality and p_T dependence.

J/ψ yield :$t=p_T^2$ and centrality dependence



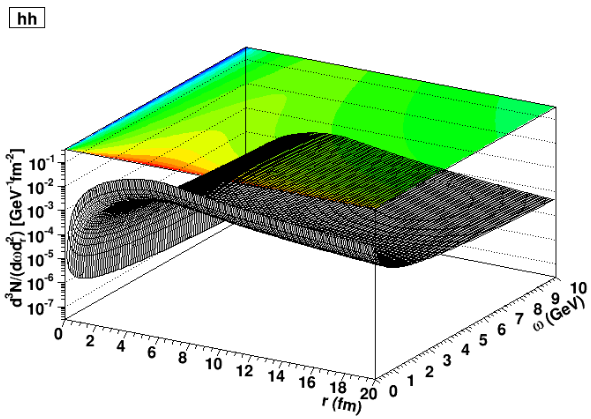


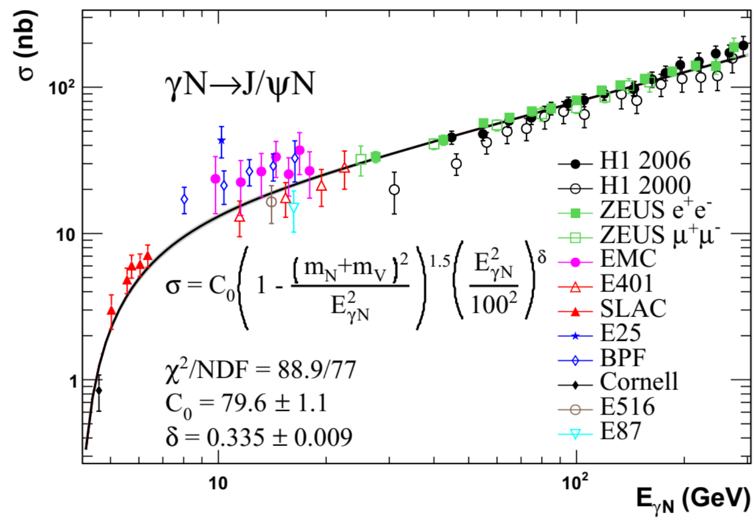
Slope parameter consistent with the size of the Au nucleus. Interference structure observed. Coherent photon-nucleus interactions!

No significant centrality dependence of the excess yield!

Calculation of photoproduction in hadronic collisions

- “Photon distribution function” induced by ions?
  - ✓ Equivalent Photon Approximation



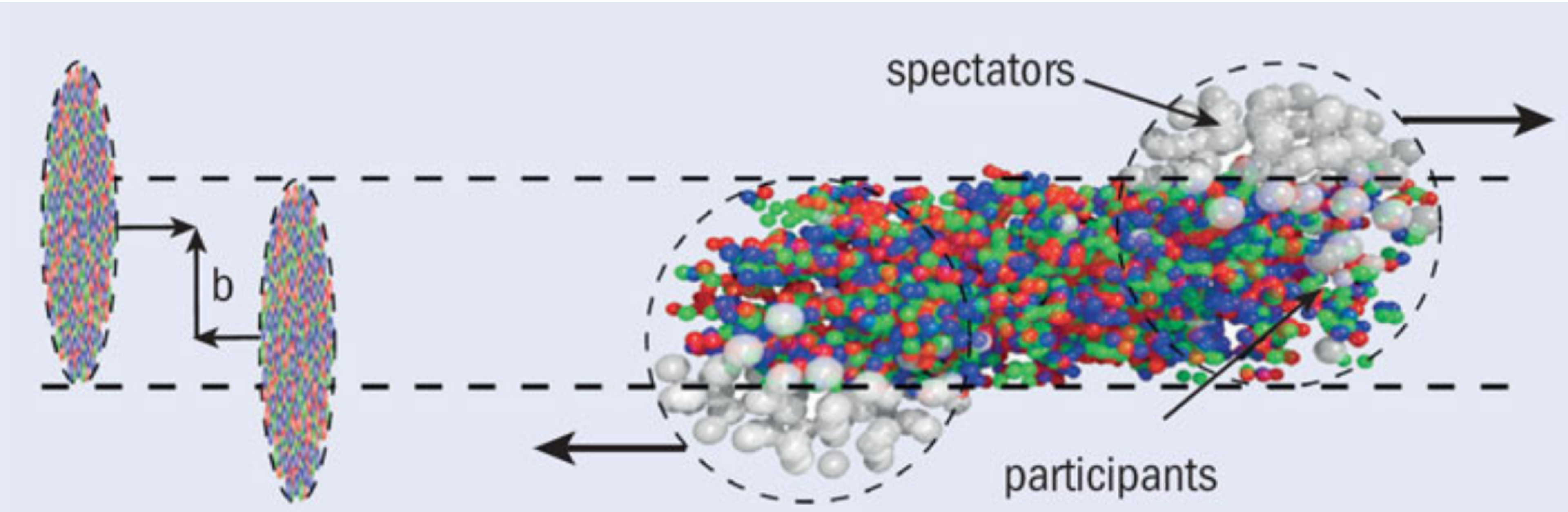


W. Zha et al., PRC 97 (2018) 044910

- Initial geometry?
  - ✓ Glauber model
- Microscope cross sections?
  - ✓ J/ψ cross section in γ+p convoluted with Glauber +VMD
- Possible disruption by the hadronic collisions?

Wangmei Zha, ATHIC2018, USTC

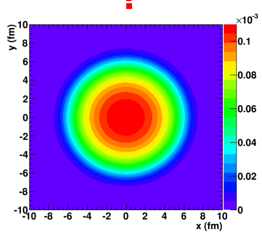
Possible disruption from overlap region?



Photon emitter:

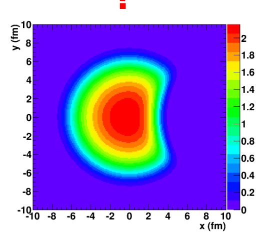
Pomeron emitter:

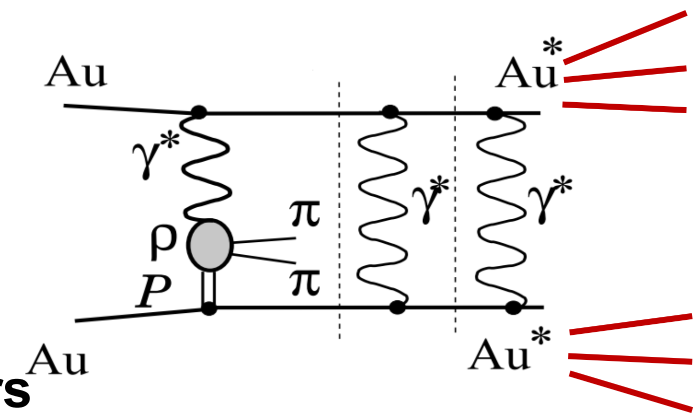
?



or

?





How coherence keep? --- Time scale matters

Collision (production) time > GeV

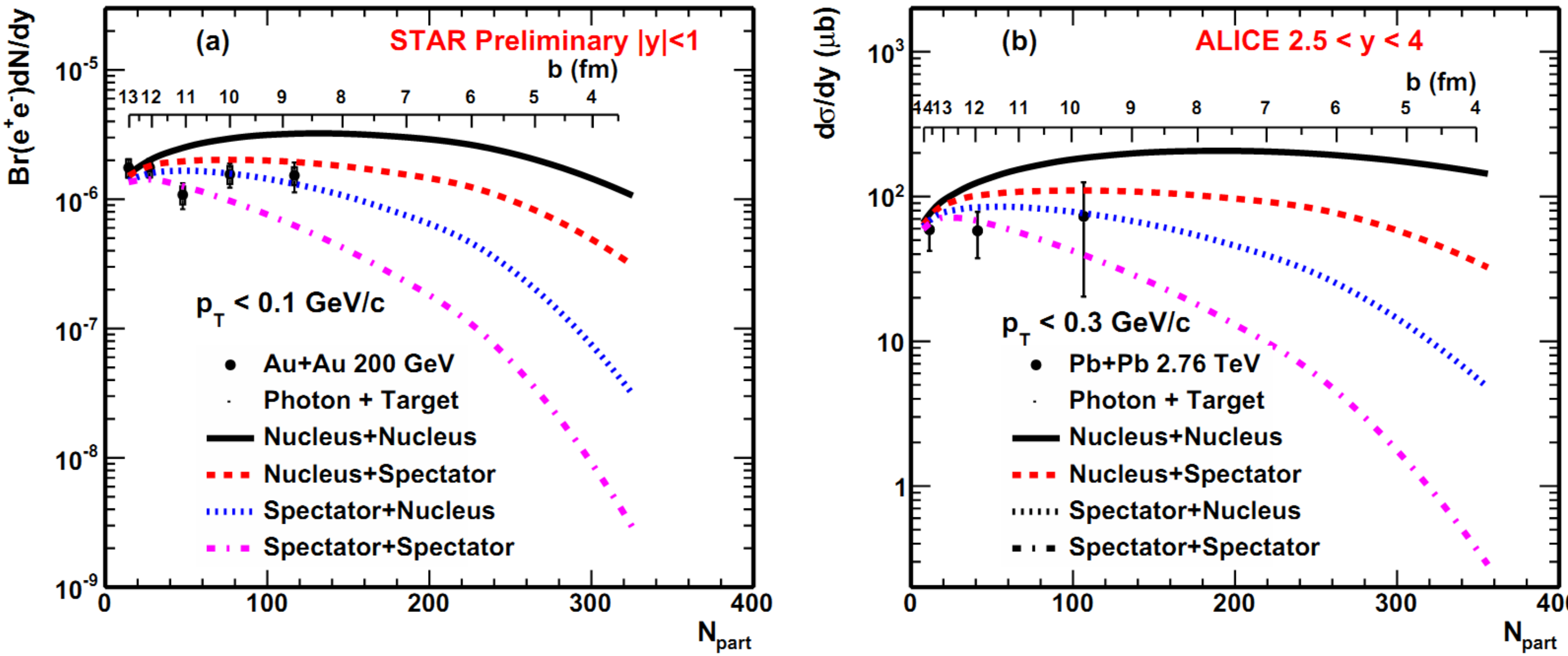
Fragment of spectator and nucleus excitation ~ MeV

PRC 77 (2008) 34910

Wangmei Zha, ATHIC2018, USTC

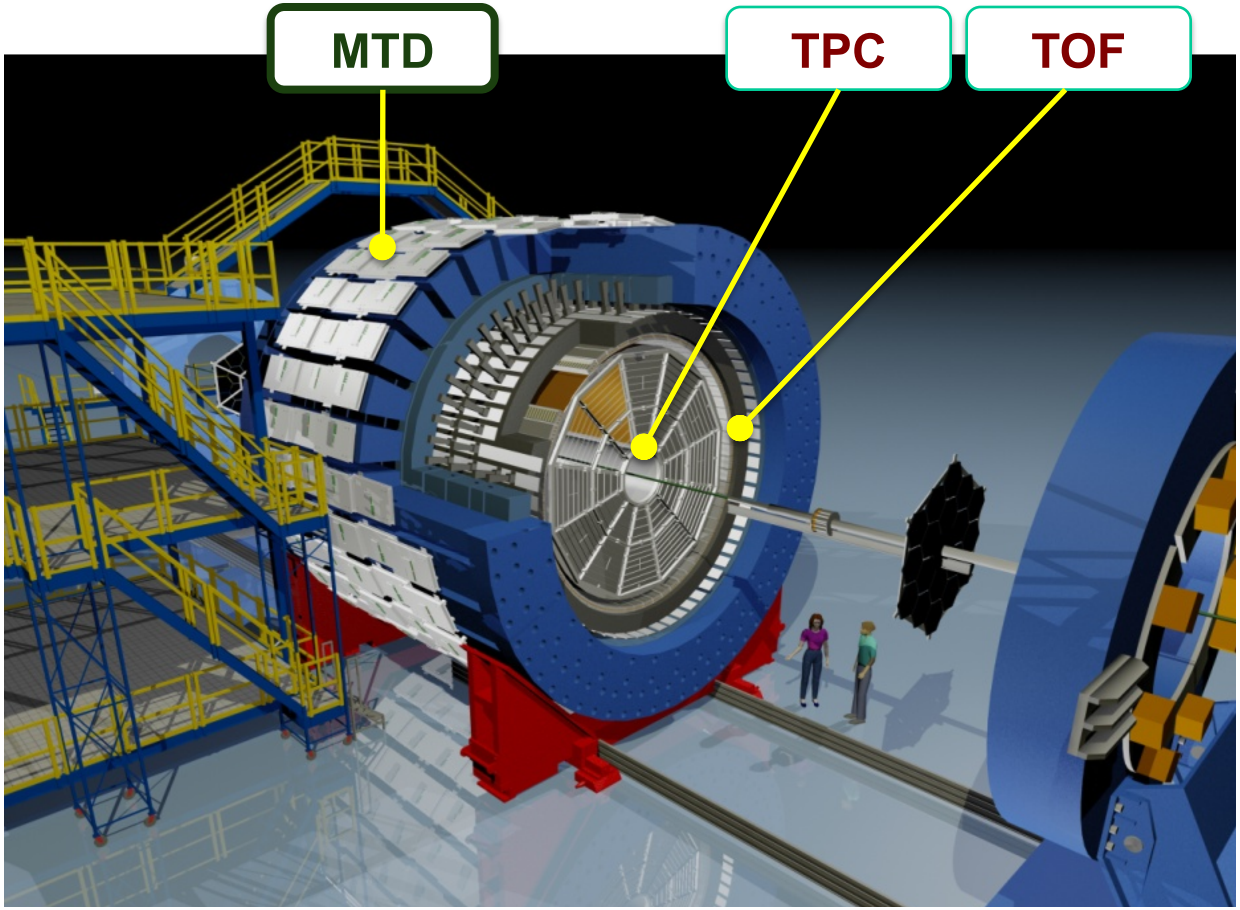
Calculations with different scenarios

W. Zha et al., PRC 97 (2018) 044910
Wangmei Zha, ATHIC2018, USTC



- All scenarios describe the data in peripheral collisions!
- Nuclues+Nucleus: overestimate the data in semi-central collisions.
- Spectator+Spectator: under predict the data in semi-central collisions.
- To distinguish the different scenarios, measurements at central collisions are needed!

The STAR (Solenoidal Tracker at RHIC) Detector



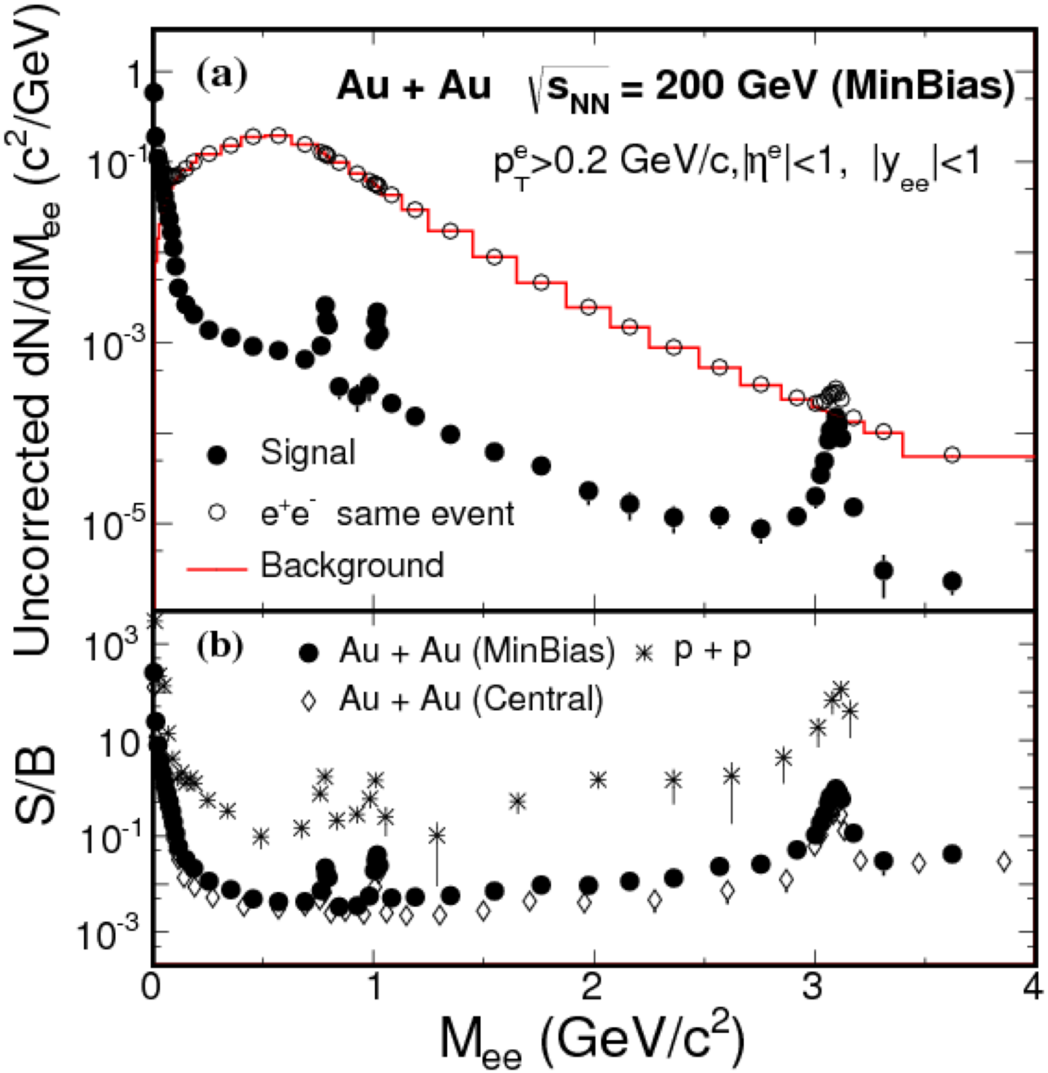
Time of Flight Detector (TOF) & Muon Telescope Detector (MTD): Multi-gap Resistive Plate Chamber (MRPC), gas detector, avalanche mode

TOF: has **precise timing** measurement, <100 ps timing resolution

MTD: provide **trigger capabilities** in heavy ion collisions and **muon identification** with **precise timing and position** information

Time Projection Chamber (TPC): Measure ionization energy loss (dE/dx) and momentum

Inclusive dielectron invariant mass distribution



At M_{ee}=0.5 GeV/c^2,
S/B =1/10 in proton+proton,
=1/250 in head-on Au+Au

A good measurement requires low material budget to control background and high statistics data sample

Mee < 1 GeV/c^2 Like sign background
Mee >= 1 GeV/c^2 Mixed event background

Cocktail components

Cocktail components:

e+e- pairs from light flavor meson and heavy flavor decays (charmonia and open charm correlation):

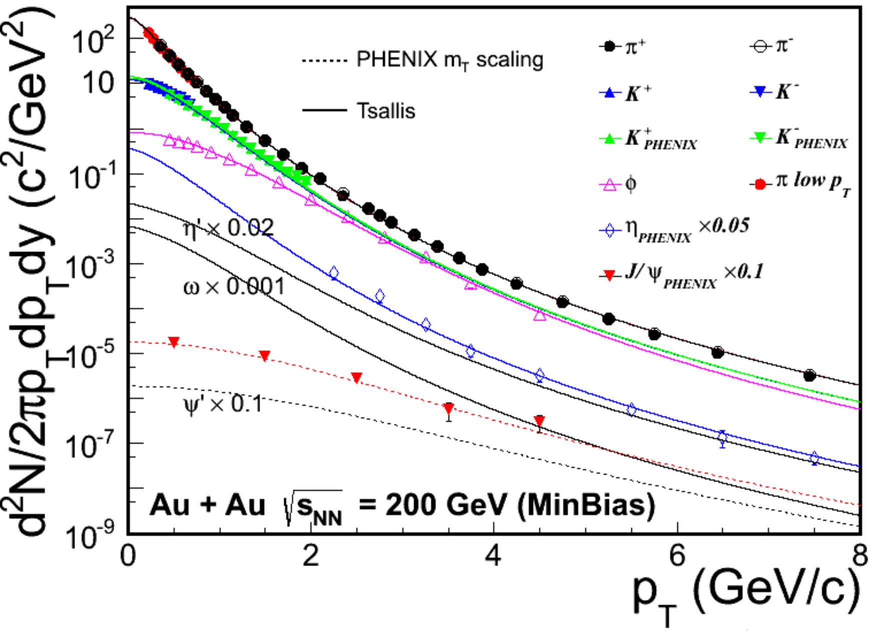
Pseudoscalar meson Dalitz decay: π^0, η, η' → γe^+e^-

Vector meson decays: ρ^0, ω, ϕ → e^+e^-, ω → $\pi^0 e^+e^-$, ϕ → ηe^+e^-

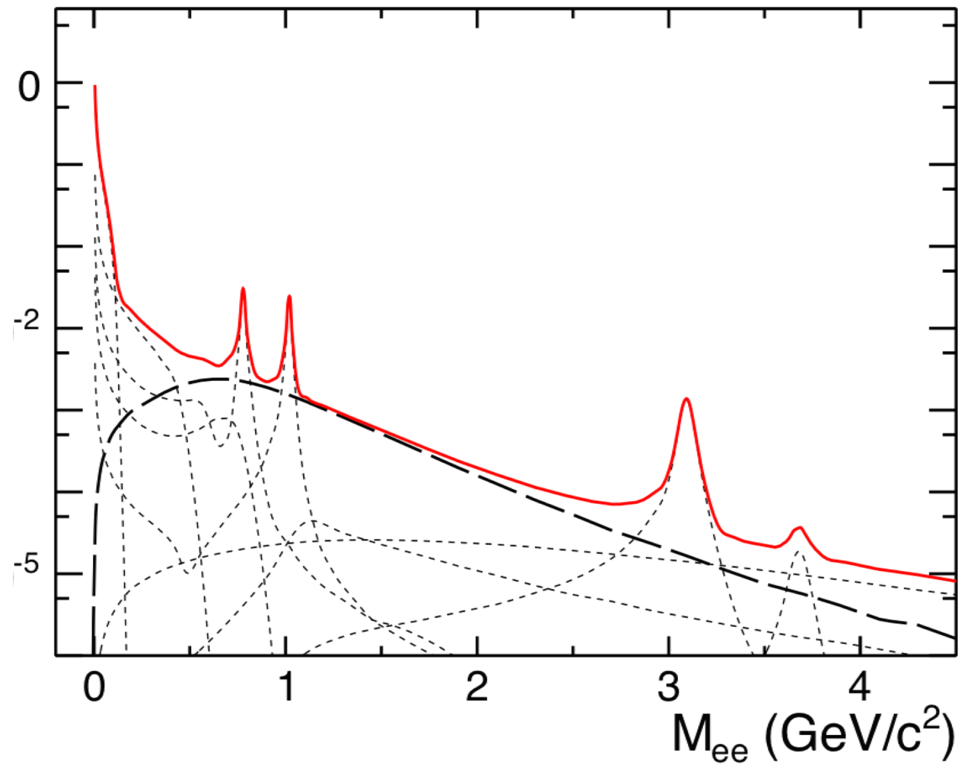
Heavy flavor decays: J/ψ → e^+e^-, ccbar → e^+e^- X, bbbar → e^+e^- X

Drell-Yan contribution

Cocktail simulation

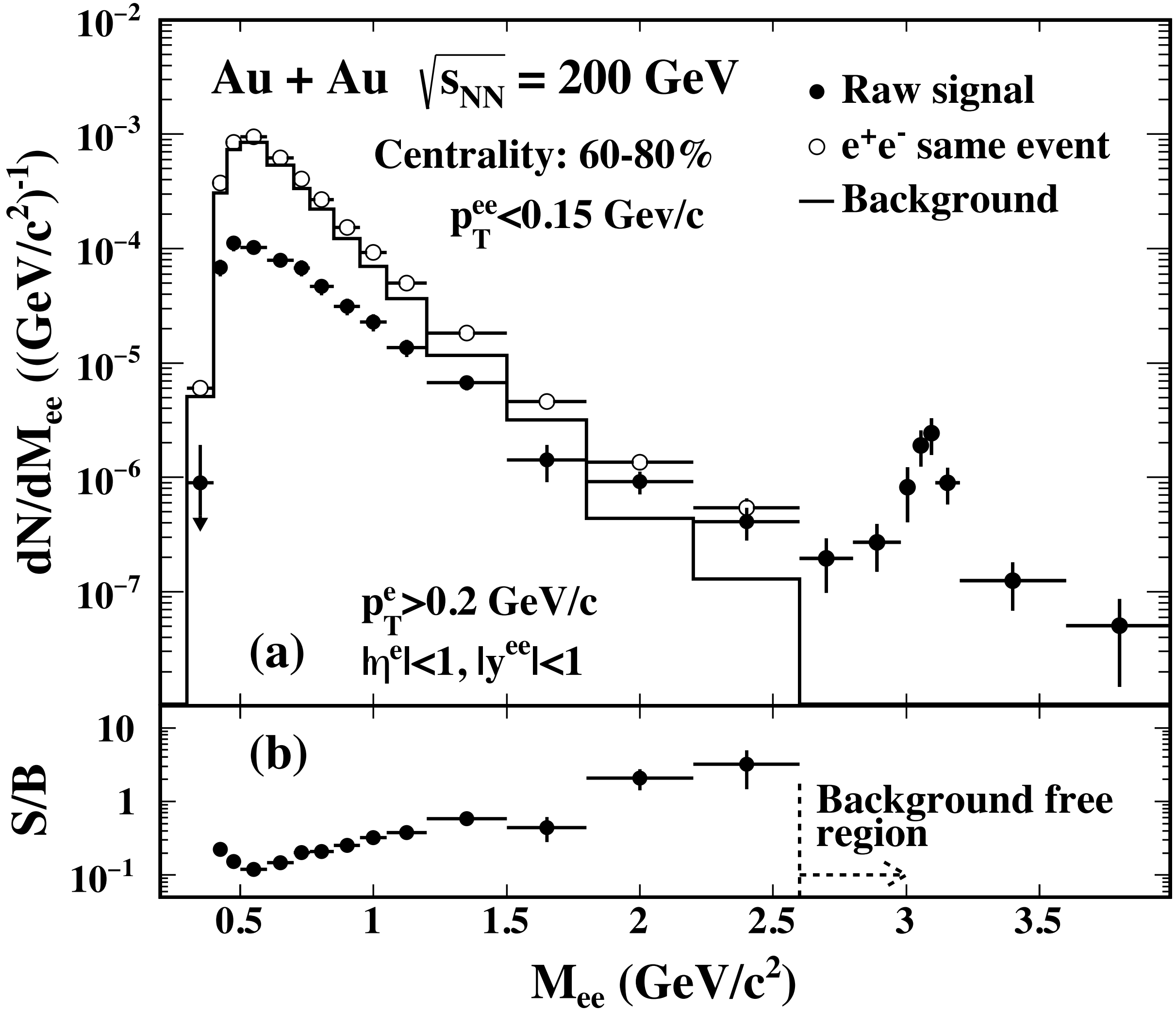


PHENIX Collaboration, Phys. Rev. C 81, 034911 (2010)
STAR Collaboration, Phys. Rev. Lett. 92, 112301 (2004)
STAR Collaboration, Phys. Lett. B 612, 181 (2005).
STAR Collaboration, Phys. Rev. Lett. 97, 152301 (2006)
Z. Tang et al. Phys. Rev. C 79, 051901 (2009)



Electron-positron mass spectrum from known hadronic sources without hot, dense medium contribution.

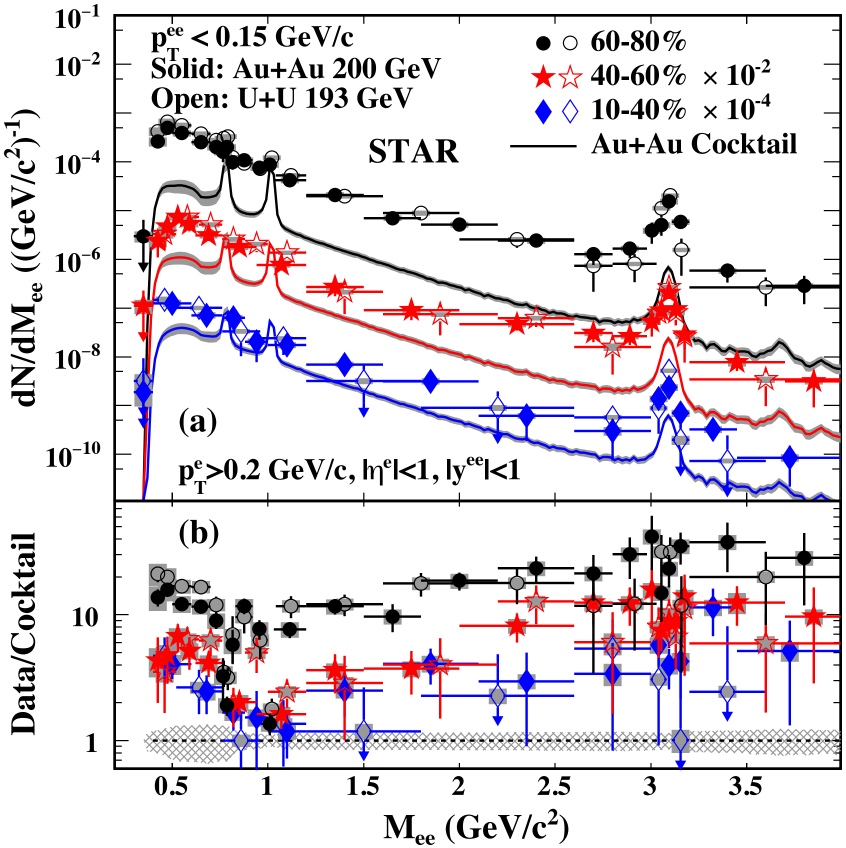
Low p_T e^+e^- signal

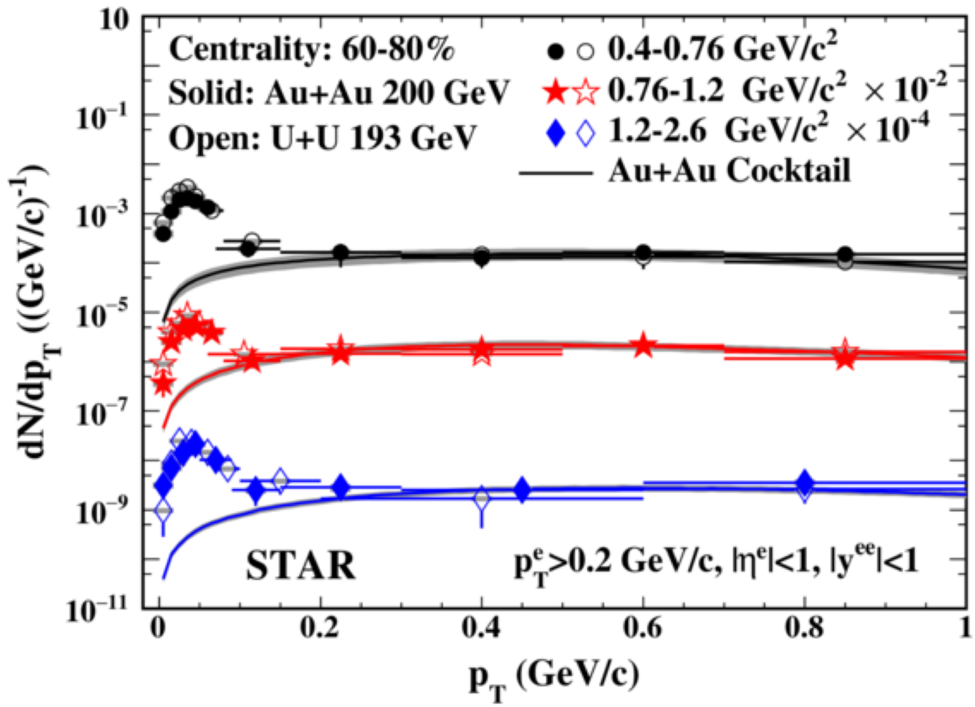


BROOKHAVEN NATIONAL LABORATORY

Very low p_T electron-positron production

STAR: Phys. Rev. Lett. **121** (2018) 132301

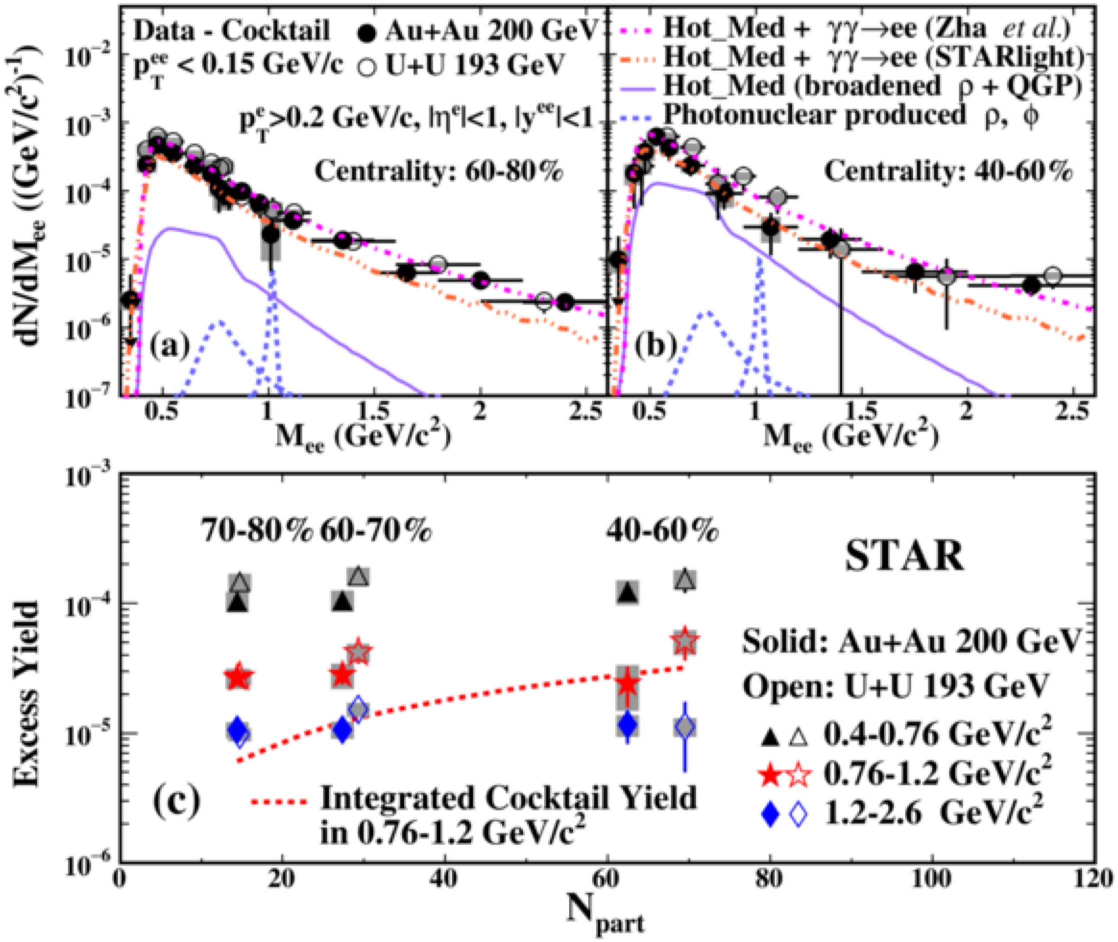




The excess is large at low p_T.

Very low p_T electron-positron excess

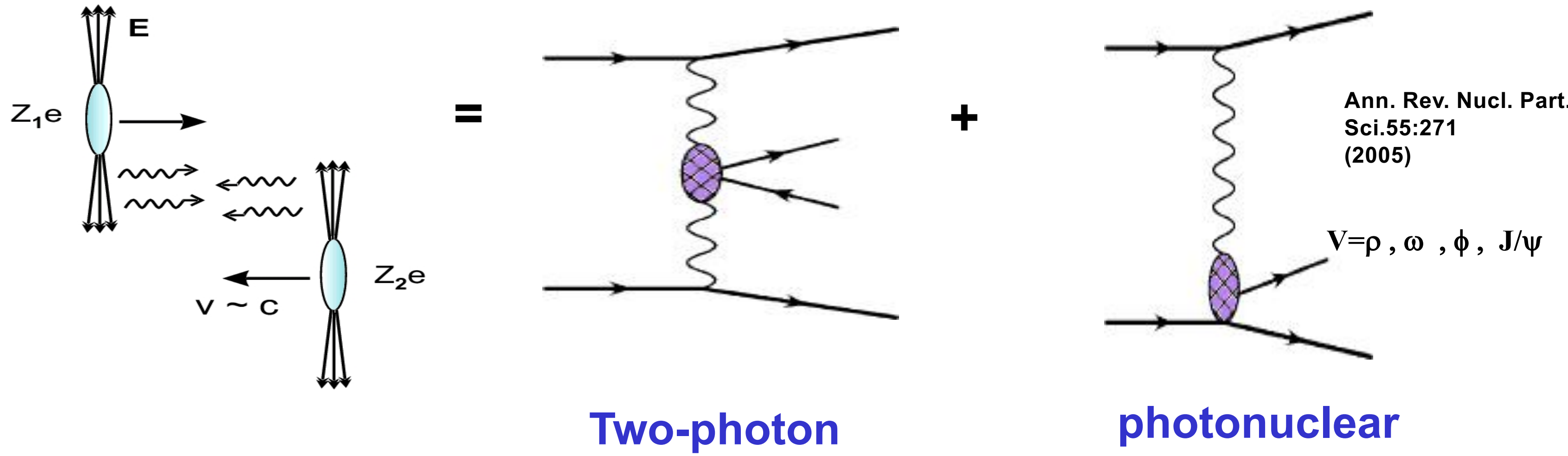
STAR: Phys. Rev. Lett. 121 (2018) 132301



The excess: no significant centrality dependence

Coherent photon-photon process describes the excess.

Coherent photonuclear and two-photon processes



Studied extensively in ultra-peripheral collisions

We see this in heavy ion collisions too!

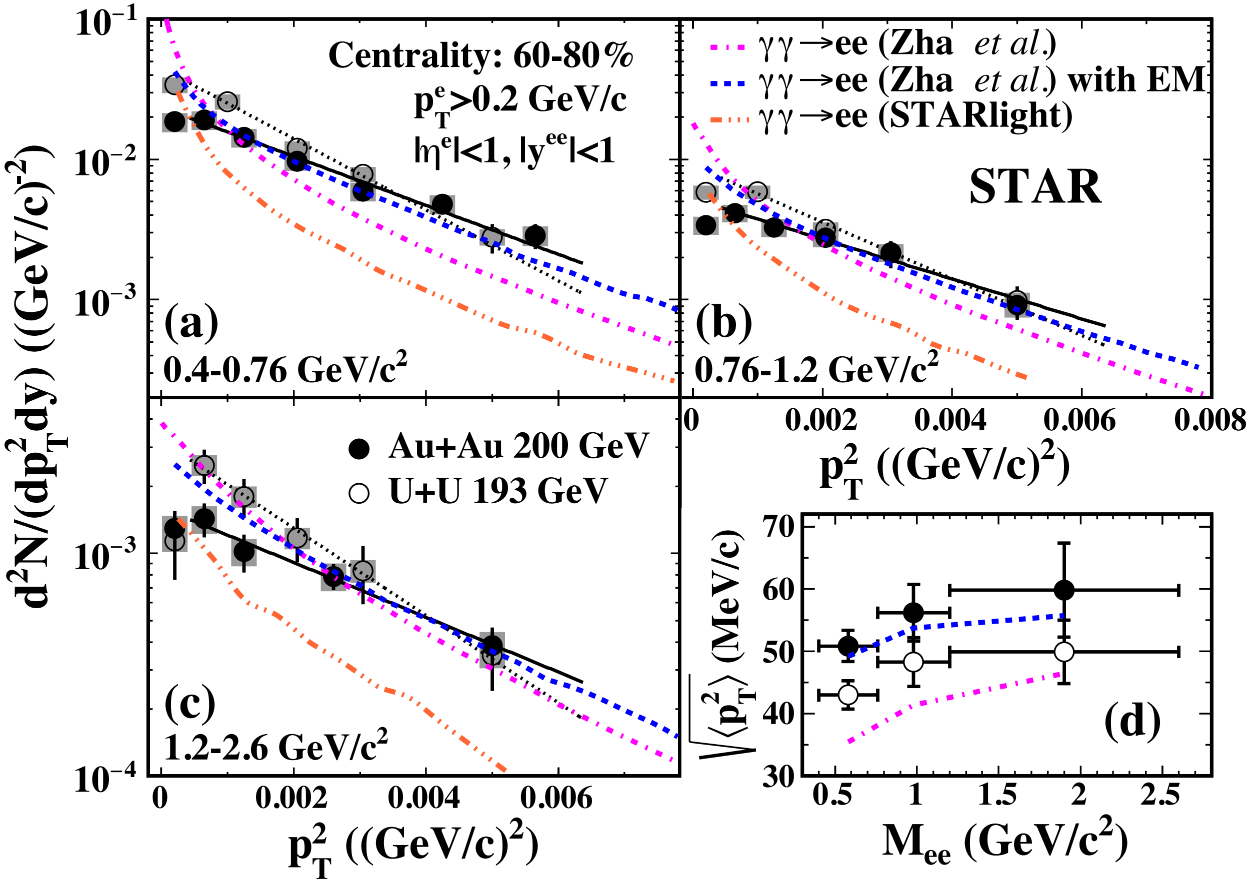
How is the J/ψ from coherent photonuclear process affected by hot and cold QCD matter!

A new tool to study enriched multi-body dynamics on the strong QCD force!

How are the electron and positron pairs from photon-photon process affected by the medium?

p_T^2 distribution

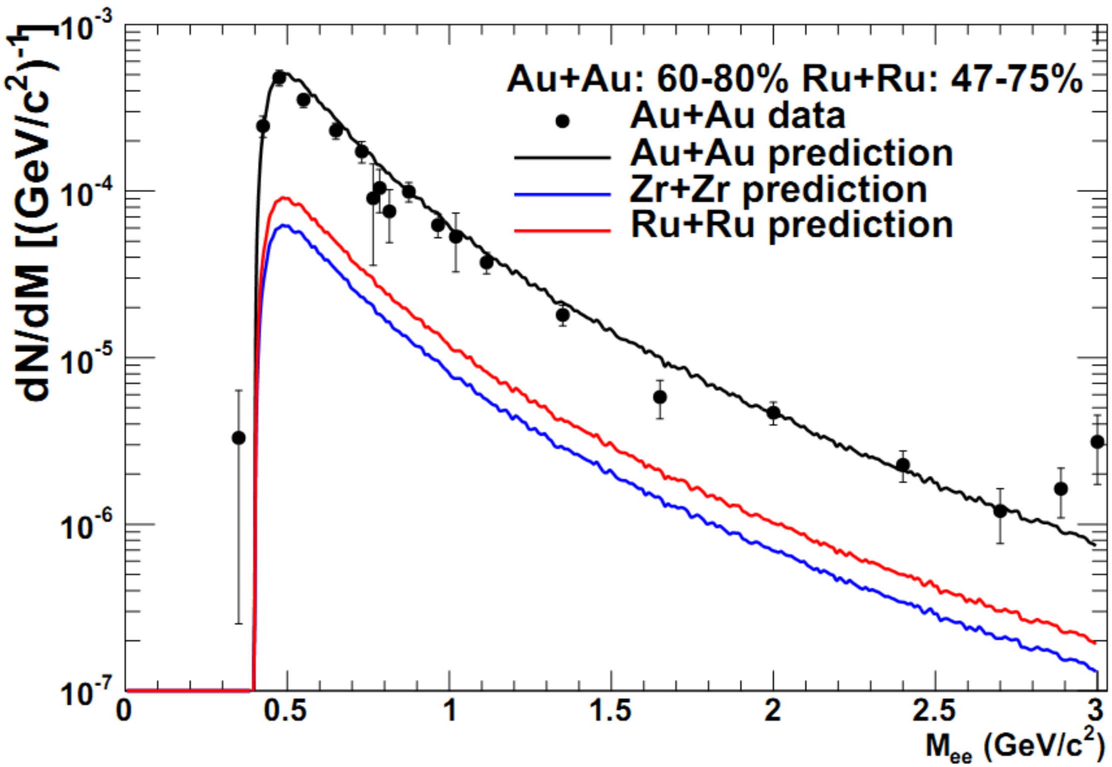
STAR: Phys. Rev. Lett. 121 (2018) 132301



p_T^2 distribution is sensitive to magnetic field effect (eBL~30 MeV/c, B~10^{14}T, L~ 1fm)

Towards isobar collisions taken in 2018

W. Zha etal., arXiv:1810.02064



Au: Ru: Zr ≈ 7.9 : 1.5 :1

Isobaric collisions:
Same A different Z

$^{96}_{40}Zr+^{96}_{40}Zr$, $^{96}_{44}Ru+^{96}_{44}Ru$

Coherent photon-photon interactions ~ Z^4

Further constrain the initial EM fields in heavy ion collisions.

Au+Au: 700M
Zr+Zr: 3.0B
Ru+Ru 3.0B

Difference between
Au and Ru: 17.8σ
Au and Zr: 19.3σ
Ru and Zr: 3.7σ

What is the next step at STAR

Experimentally:

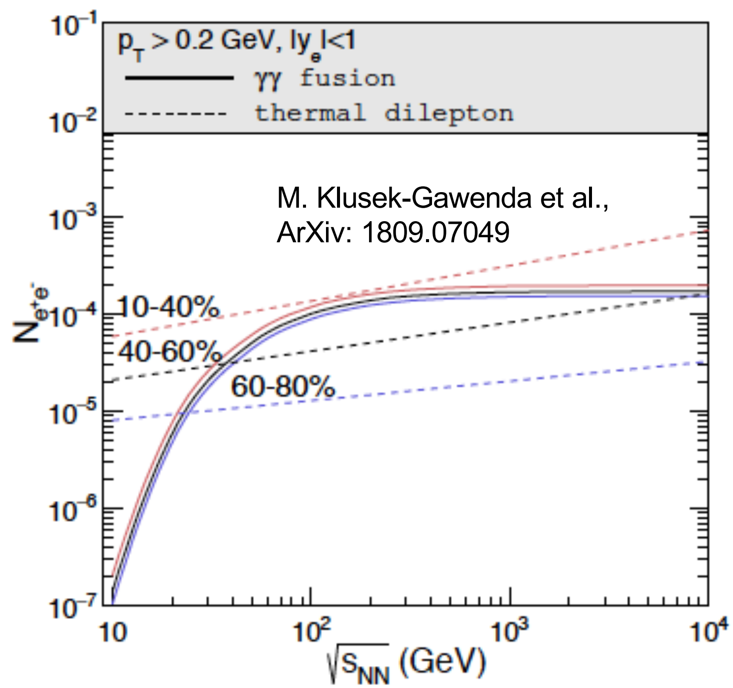
- UPC collisions → to constrain initial production model

- System size and energy dependence (isobaric collisions, 54 and 27 GeV Au+Au) → to constrain the B field evolution. The effective B field and pathlength the dilepton traverse should depend on collision system size, and energy.

- 200 GeV Au+Au is the best data sample to study the above effect.
  1) Initial production increases as a function of Z^4
  2) Initial production over thermal (S/B) is largest

Call for a coherent theoretical calculation taking into account the photoproduction, cold and hot QCD medium effects, and their space-time evolutions!

The 200 GeV Au+Au data beyond 2021+, together with advanced theoretical calculations, will enable a quantitative understanding of the magnetic field evolution in heavy ion collisions!



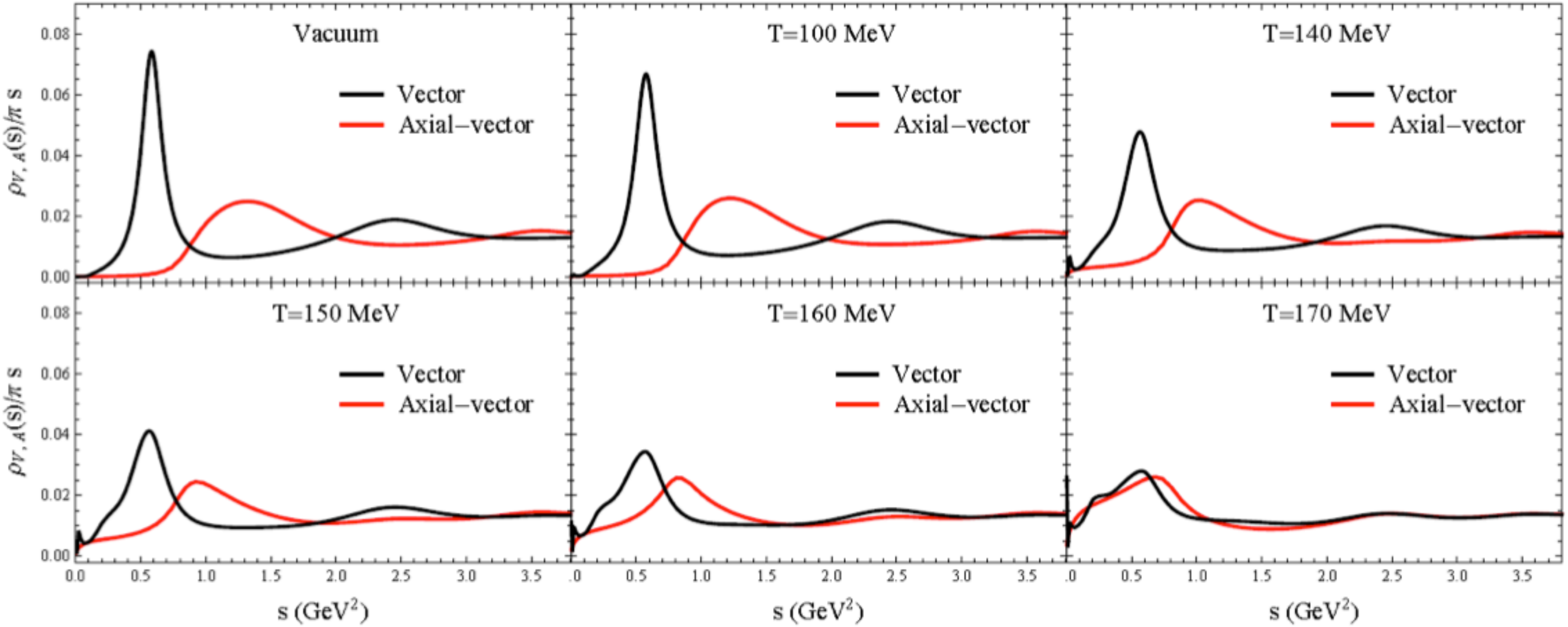
What is the connection to typical dilepton program at STAR?

The future electron-positron program (2021+)

To link electron-positron measurements to chiral symmetry restoration need more precise measurement at $\mu_B = 0$:

- Lattice QCD calculation is reliable at $\mu_B = 0$.

- Theoretical approach: derive the a1(1260) spectral function by using the broadened rho spectral function, QCD and Weinberg sum rules, and inputs from Lattice QCD; to see the degeneracy of the rho and a1 spectral functions (Hohler and Rapp 2014).



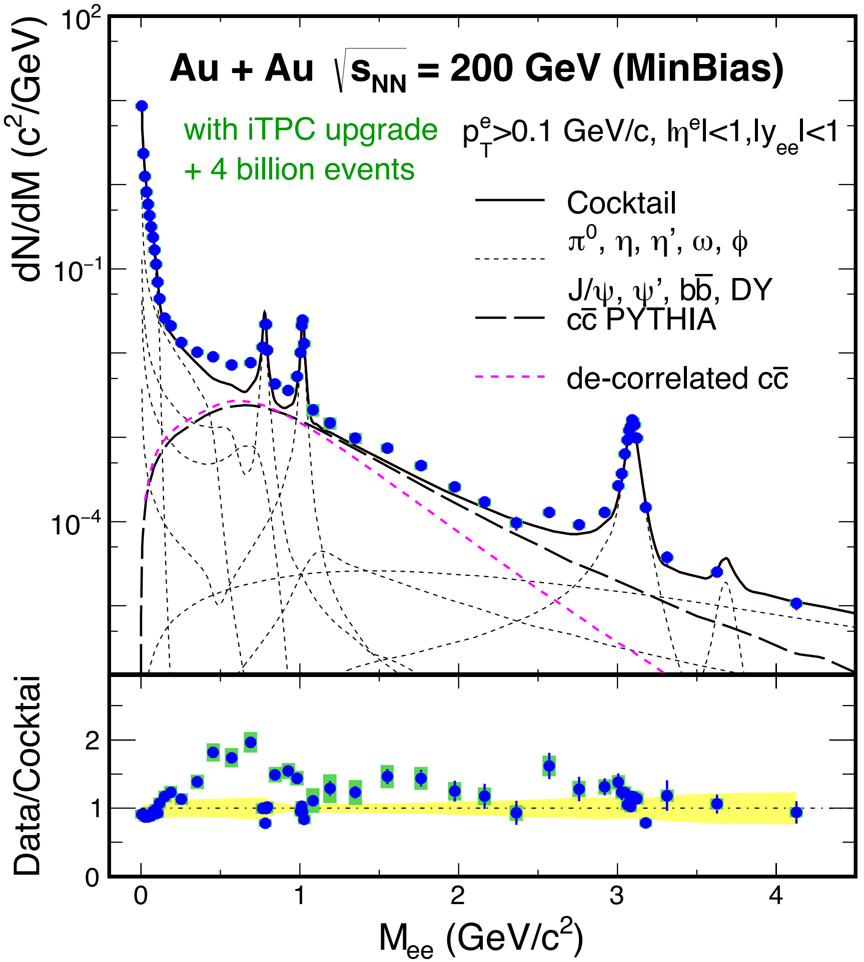
The future electron-positron program (2021+)

Beyond 2021+

Mid-rapidity: e^+e^- measurement at μ_B~0

Connection to chiral symmetry restoration

Thermal radiation from QGP: The slope in the intermediate mass region represents the true average temperature T of the medium.



Low-mass electron-positron emission depends on T, total baryon density, and life time, and enables systematic life-time measurements.

What is the connection

Thermal dilepton measurements in the intermediate mass region will constrain T_0, t_0.
Low p_T dielectron production constrains initial EM field.

The above two will put a constraint on magnetic field evolution in hot, dense medium

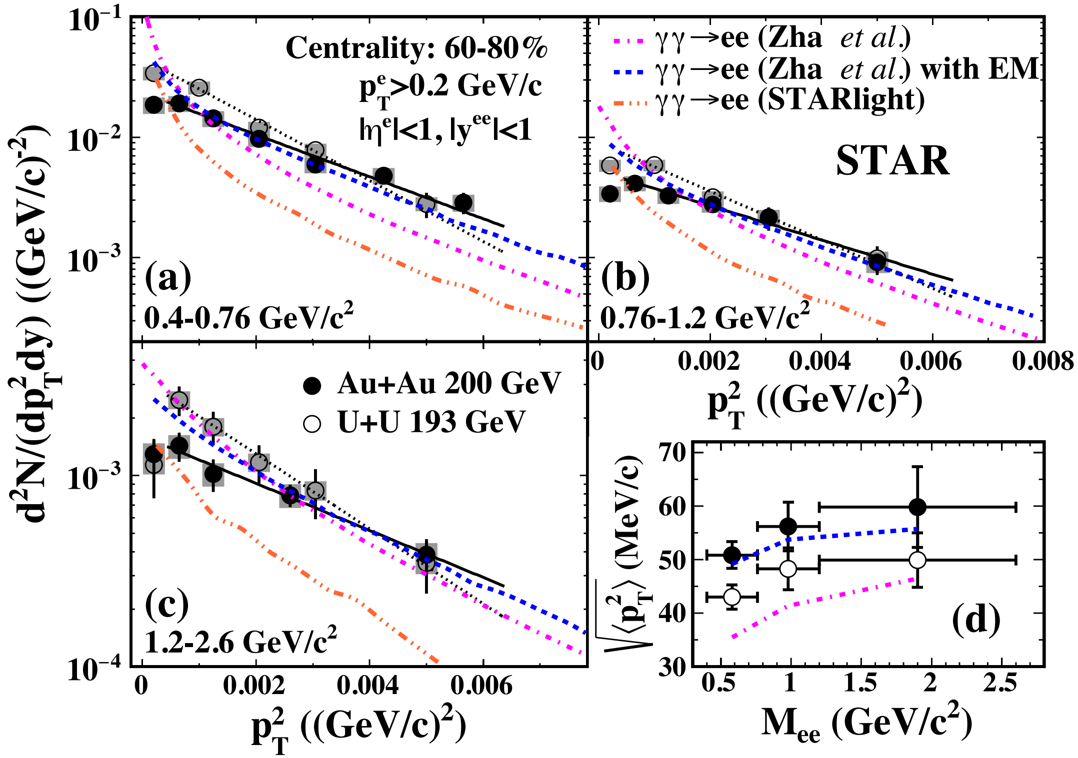
The p_T distributions of produced dilepton could be sensitive to this magnetic field evolution.

Theoretical efforts are needed and critical!

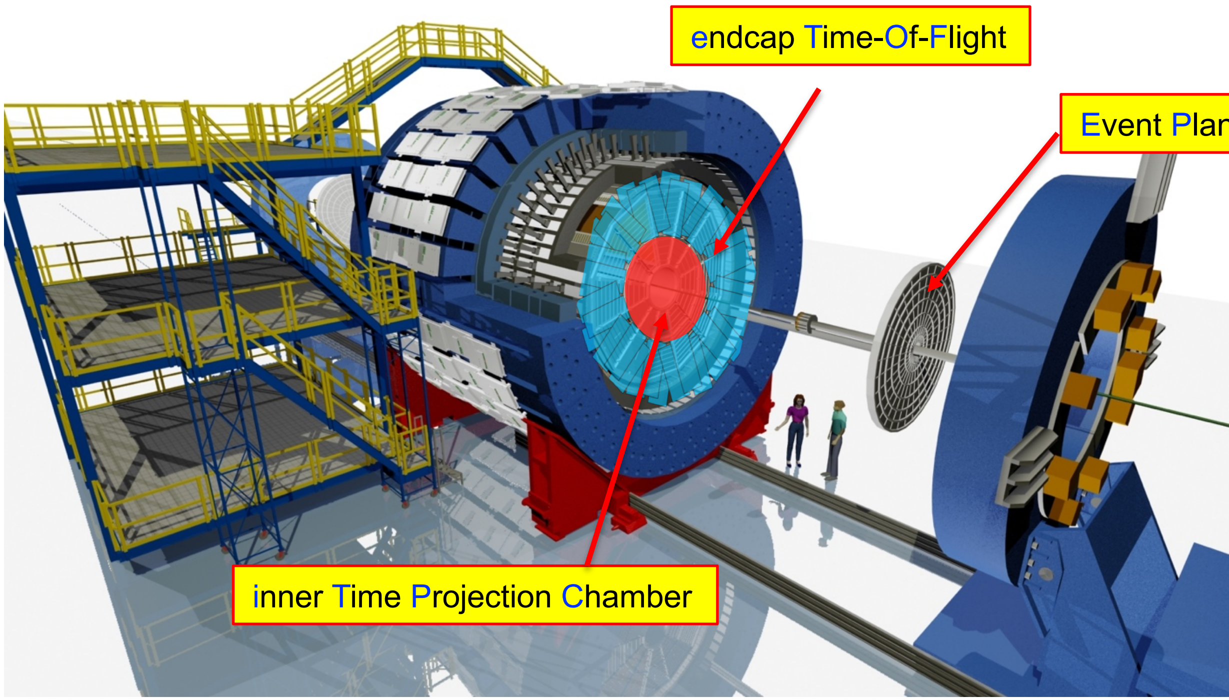
Summary

STAR measured dielectrons from light-light scattering in peripheral heavy ion collisions.

The current model with initial photon-photon process describes the low-p_T dielectron production yields but fails to reproduce the p_T distributions

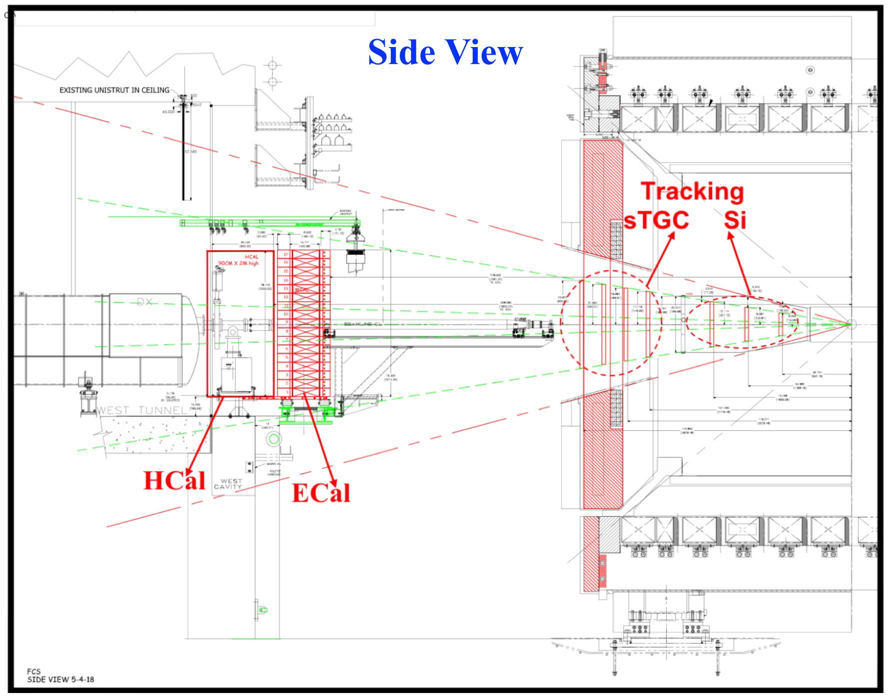


Upgrade plan for BES II



iTPC upgrade	EPD upgrade	eTOF upgrade
Continuous pad rows Replace all inner TPC sectors	**Replace Beam Beam Counter**	**Add CBM TOF modules and electronics (FAIR Phase 0)**
$\|\eta\|<1.5$	**$2.1<\|\eta\|<5.1$**	**$-1.6<\eta<-1.1$**
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**

STAR forward upgrade for 2.5 < η < 4



Calorimetry:
Electromagnetic and Hadronic

Tracking:
Silicon detectors and
small-strip Thin Gap Chambers (sTGC)

pp, pA and AA data taking in FY2021/22 and parallel with sPHENIX data taking period

AA physics at 200 GeV for 2023-2025:
Constrain 3D hydro evolution
Temperature dependent η/s
Rapidity dependent vorticity

Successful technical review on Nov 19, 2018, BNL

Outlook

In 2009-2018, qualitative:

- A broadened ρ spectrum function consistently describes the low mass electron-positron excess in A+A collisions

In 2019-2021, start to be quantitative:

- Beam Energy Scan II (7.7-19.6 GeV) will provide a unique opportunity to quantify the effect of Chiral Symmetry Restoration via total baryon density effect on the ρ broadening.

In 2021+, indispensable mission with 200 GeV Au+Au data:

- Measure the temperature and lifetime of hot, dense medium
- Provide input for the community to establish connection between dilepton observables and chiral symmetry restoration
- Gain a quantitative understanding of magnetic field evolution in heavy ion collisions.
- Solve photon puzzle