Electro-magnetic Probes at the Electron-Ion Collider

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Outline:

- **EM probes in heavy ion collisions**
- **Very low-p_T J/ψ measurement**
- **Anything similar at the EIC?**
- **Summary**

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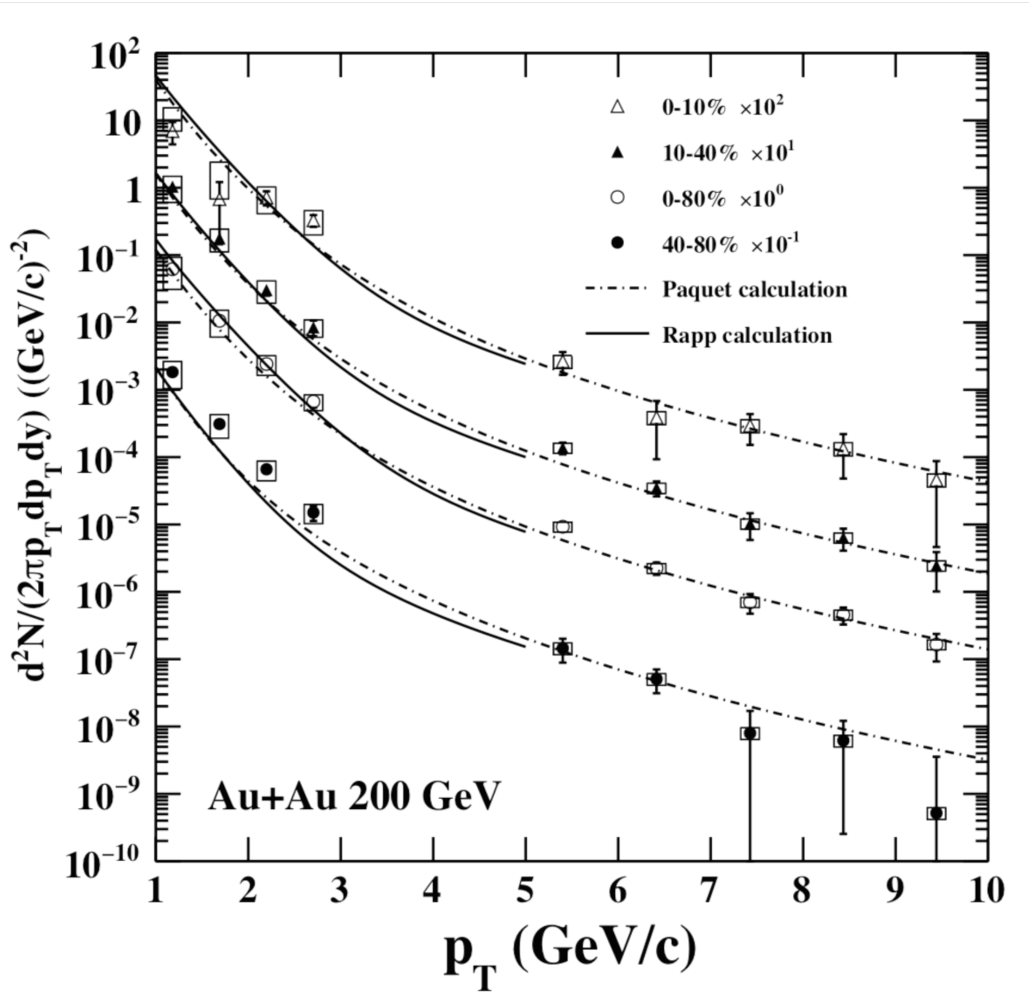
Introduction: why I am here?

Salvatore Fazio: we would like to invite you to give a talk. Present recent progress at the EIC beyond the scope of the White paper.

LR: not an expert at all. I am going to talk about something recent, ask whether this physics can be carried at the EIC.

STAR Preliminary results are from S. Yang et al., QM2015 on dielectrons and R. Ma, T. Todoroki, and W. Zha et al., SQM2016 on quarkonium.

EM probe: photon emission



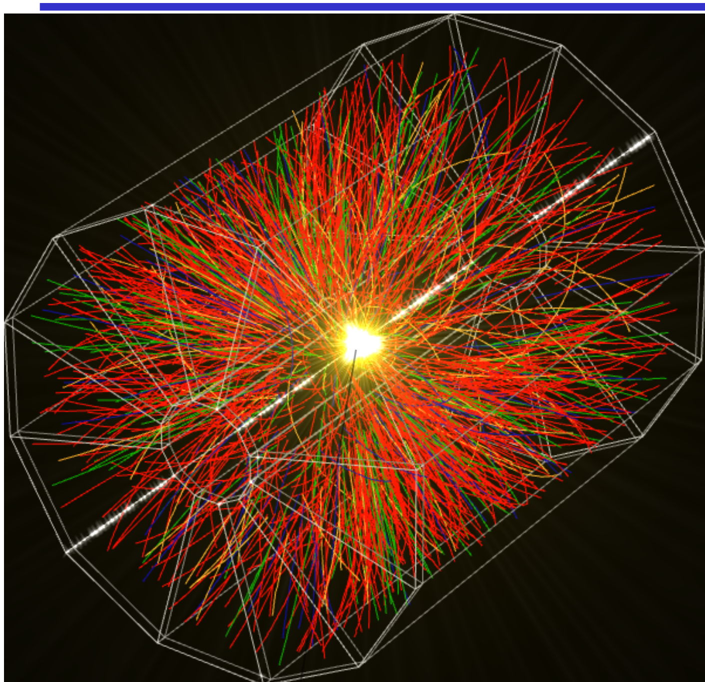
Quark-Gluon Plasma emission spectrum:
photon energy a few 10^9 electron volts

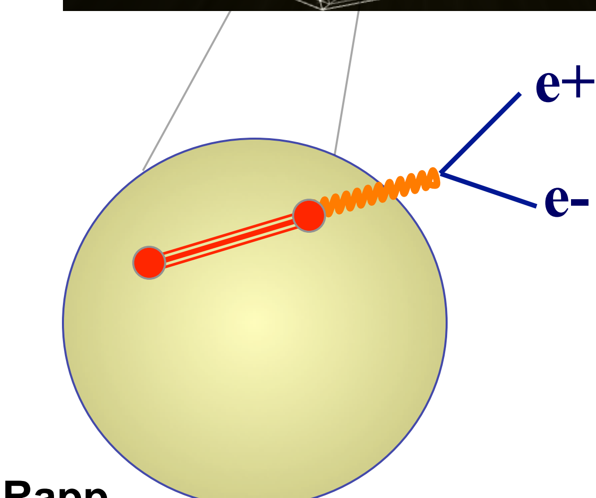
Sun emission spectrum:
Photon energy a few electron volts.

Hottest matter in the universe: a few trillion degree Celsius!

STAR Collaboration, arXiv: 1607.01447, submitted to PLB.

EM probe: electron-positron tomography





- In our method, we detect electron and positron pairs from quark-antiquark annihilation.
- Electron-positron pairs are penetrating probes and can provide information deep into the system and early time.
- Using electron-positron tomography, we would like to study the symmetry of the Quark-Gluon Plasma.

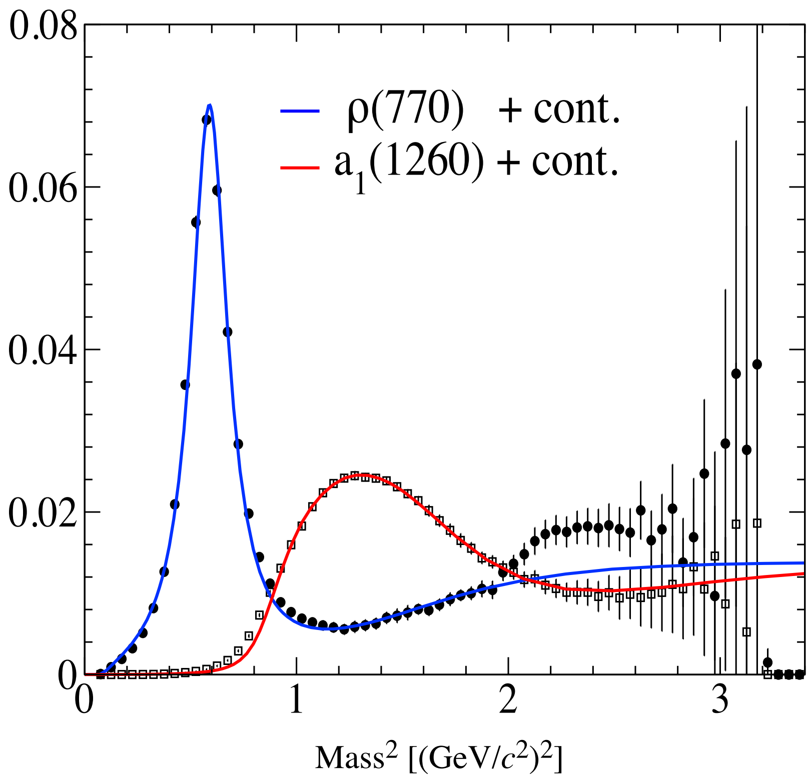
Spontaneous chiral symmetry breaking

Microscopic picture:

- quark condensate: left-handed quark and right-handed antiquark attract each other through the exchange of gluons. Generate 99% of visible mass in the universe.

- electron condensate: electrons attract each other through the vibration of the crystal at low temperature. Generate superconductivity in the metal.

ρ and a1 resonance (spectrum function) in vacuum



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

Spontaneous chiral symmetry breaking: mass distributions are different

Chiral symmetry restoration: mass difference disappears

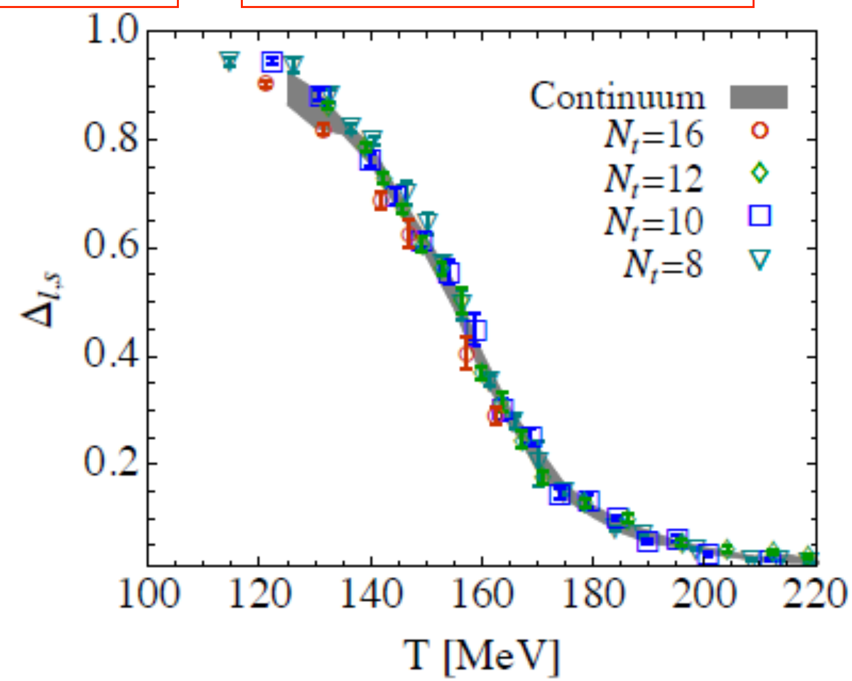
Is chiral symmetry restored in Quark-Gluon Plasma?

Early universe	Chiral symmetry	Quark Gluon Plasma
The world we live	Spontaneous chiral symmetry breaking	Particles we observe

In the Quark-Gluon Plasma,
which is hot and dense,
is chiral symmetry restored?

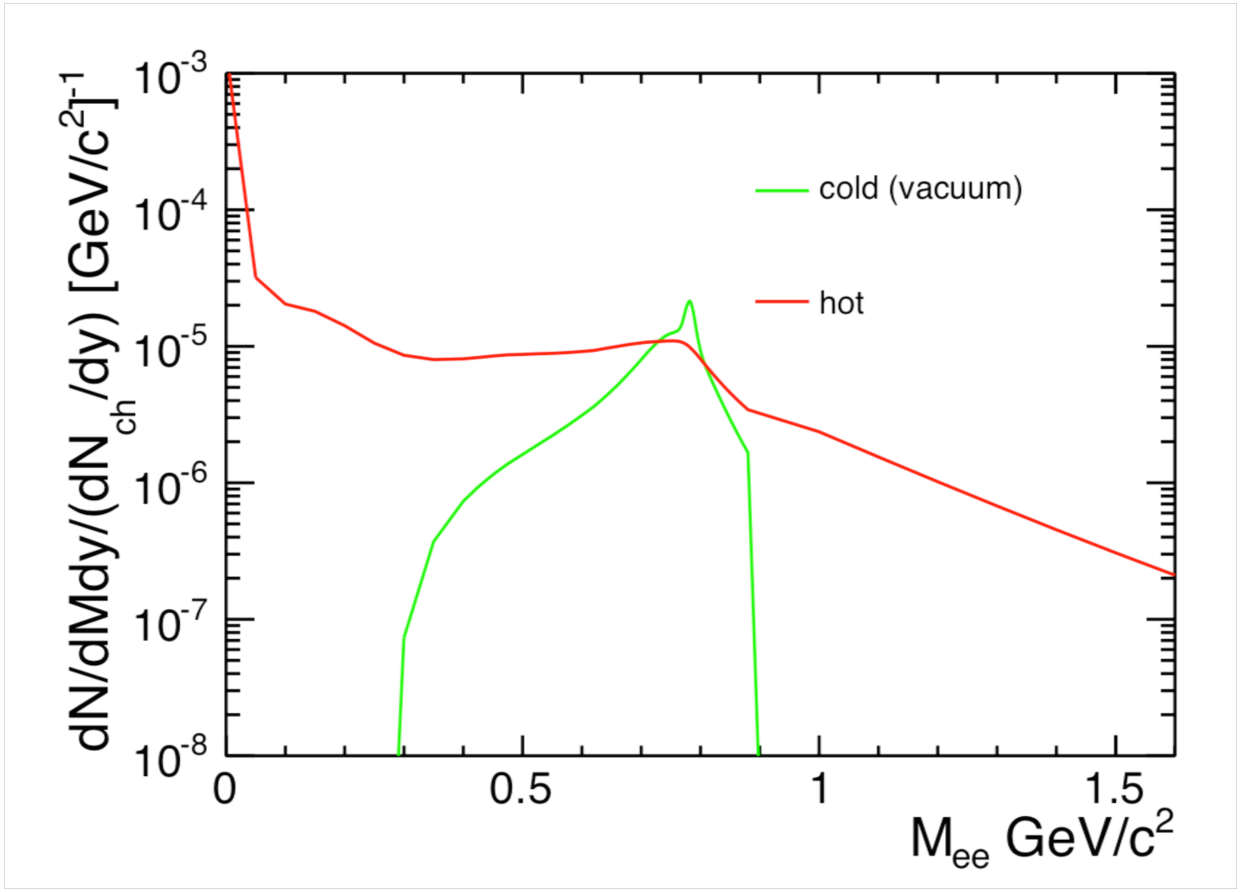
T_c= 155 MeV

Do we have experimental observable?



$\Delta_{l,s}$: subtracted chiral condensate
Z. Fodor, Lattice 2010

The ρ resonance mass spectrum function

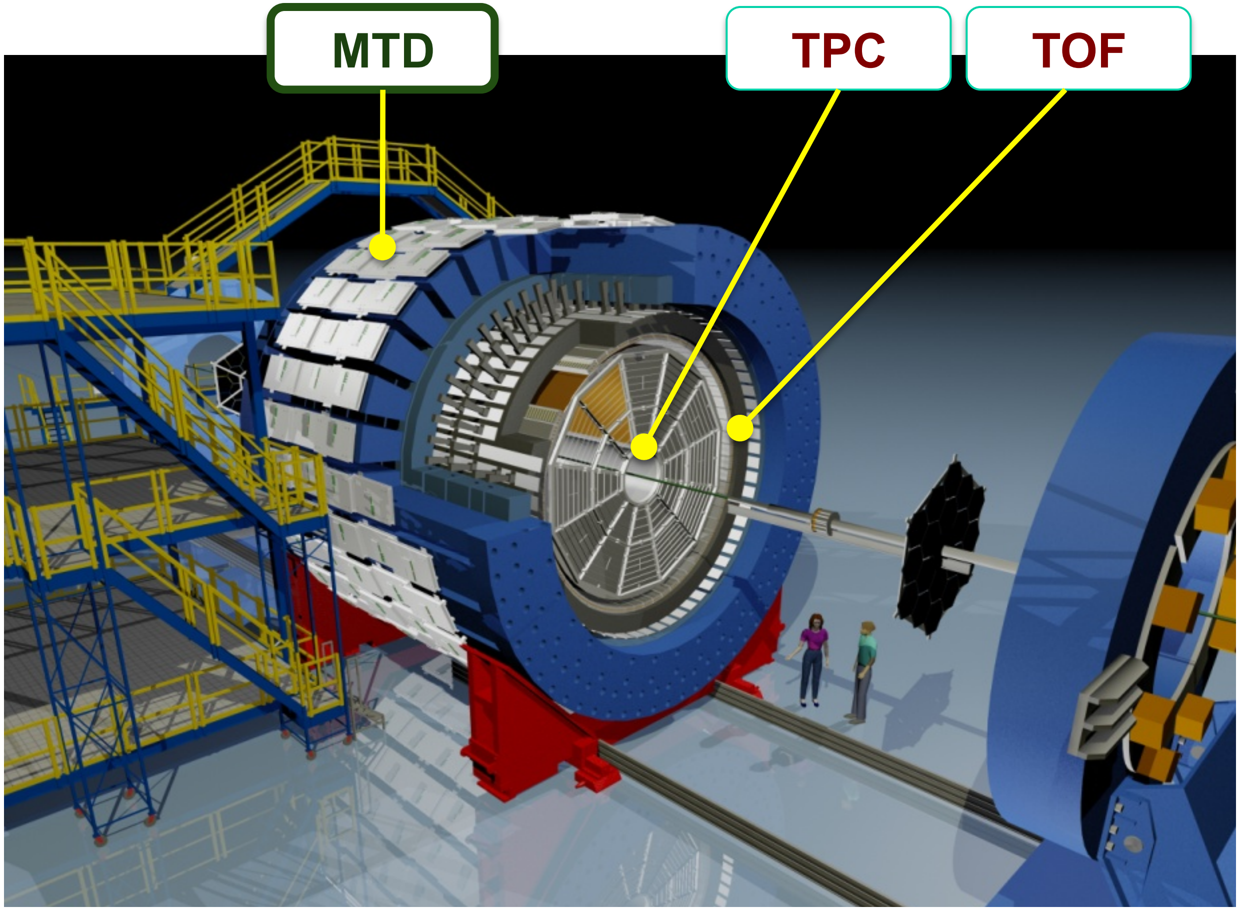


Observable for chiral symmetry restoration:

a broadened ρ spectral function and ultimately the peak structure disappears!

Model: Rapp & Wambach, priv. communication
Adv. Nucl.Phys. 25, 1 (2000); Phys. Rept. 363, 85 (2002)

The STAR (Solenoidal Tracker at RHIC) Detector



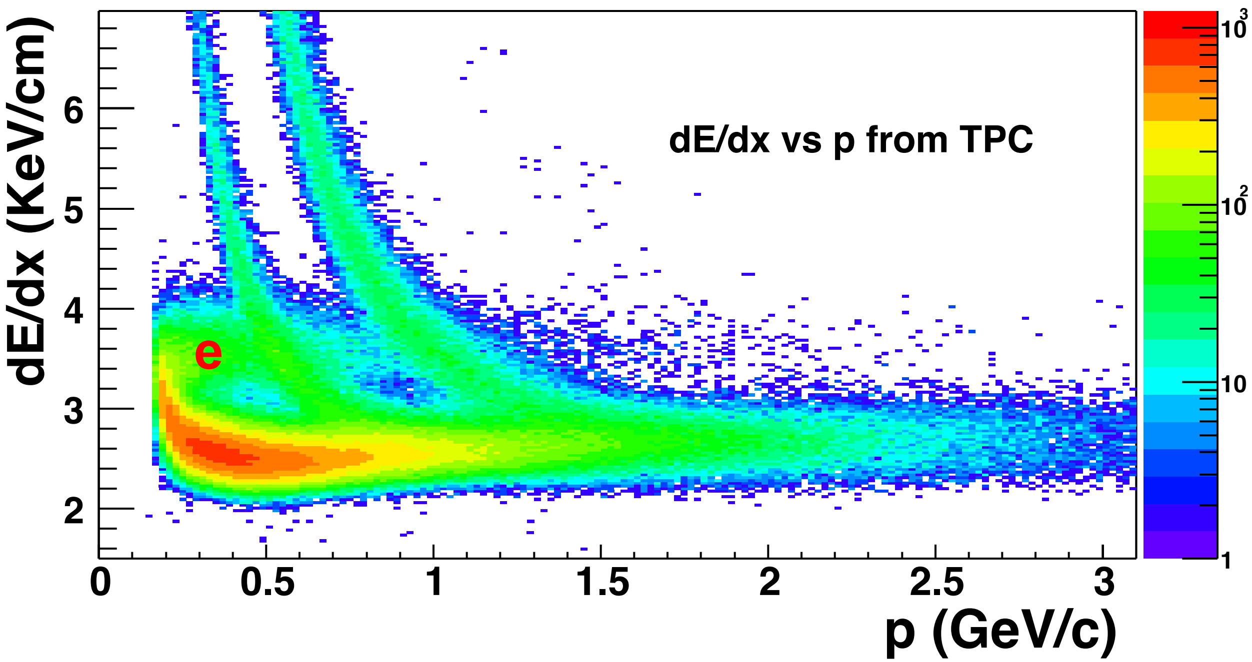
Time of Flight Detector (TOF) & Muon Telescope Detector (MTD):
Multi-gap Resistive Plate Chamber (MRPC), gas detector, avalanche mode

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

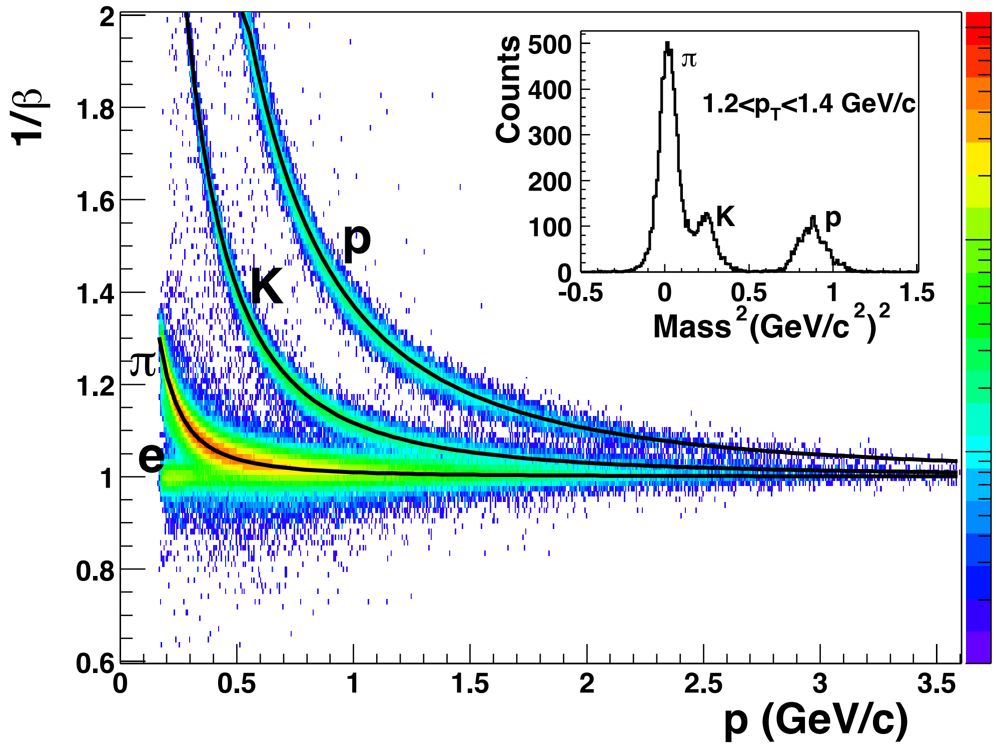
Particle identification



Electrons are highly contaminated by other particles.

Need new experimental tool to clearly identify electrons!

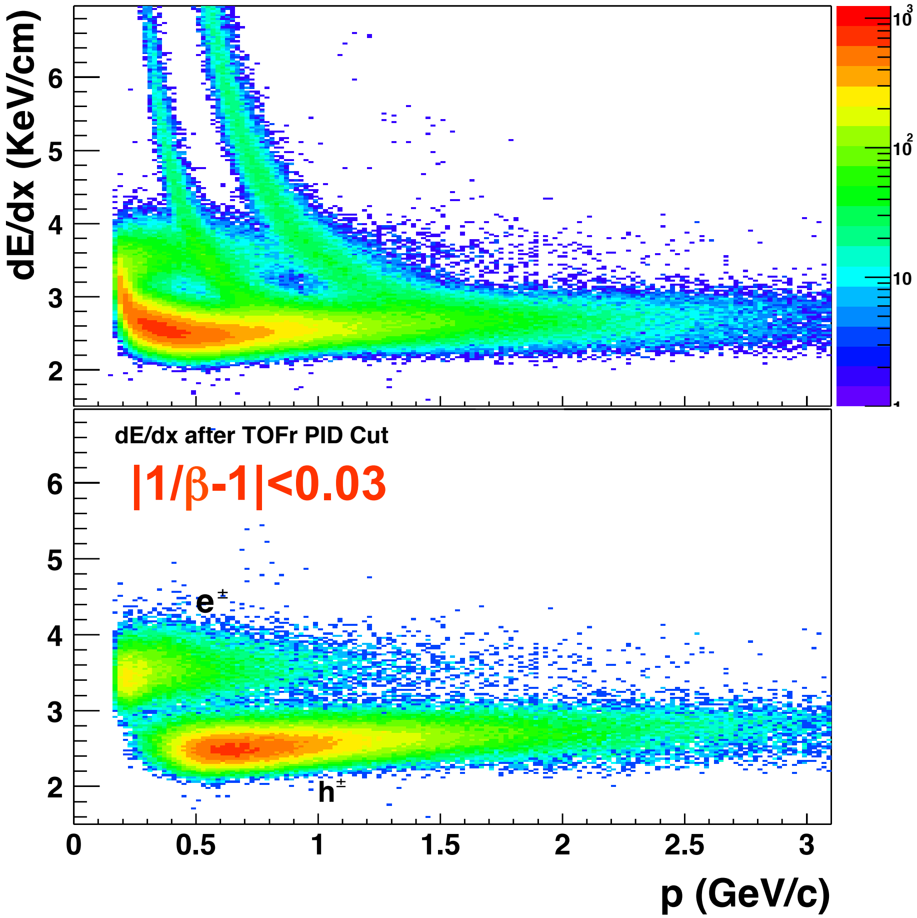
Particle identification from Time of Flight Detector



STAR Collaboration, PLB616(2005)8

Hadron identification: proton up to 3 GeV/c, kaon and pion up to 1.6 GeV/c

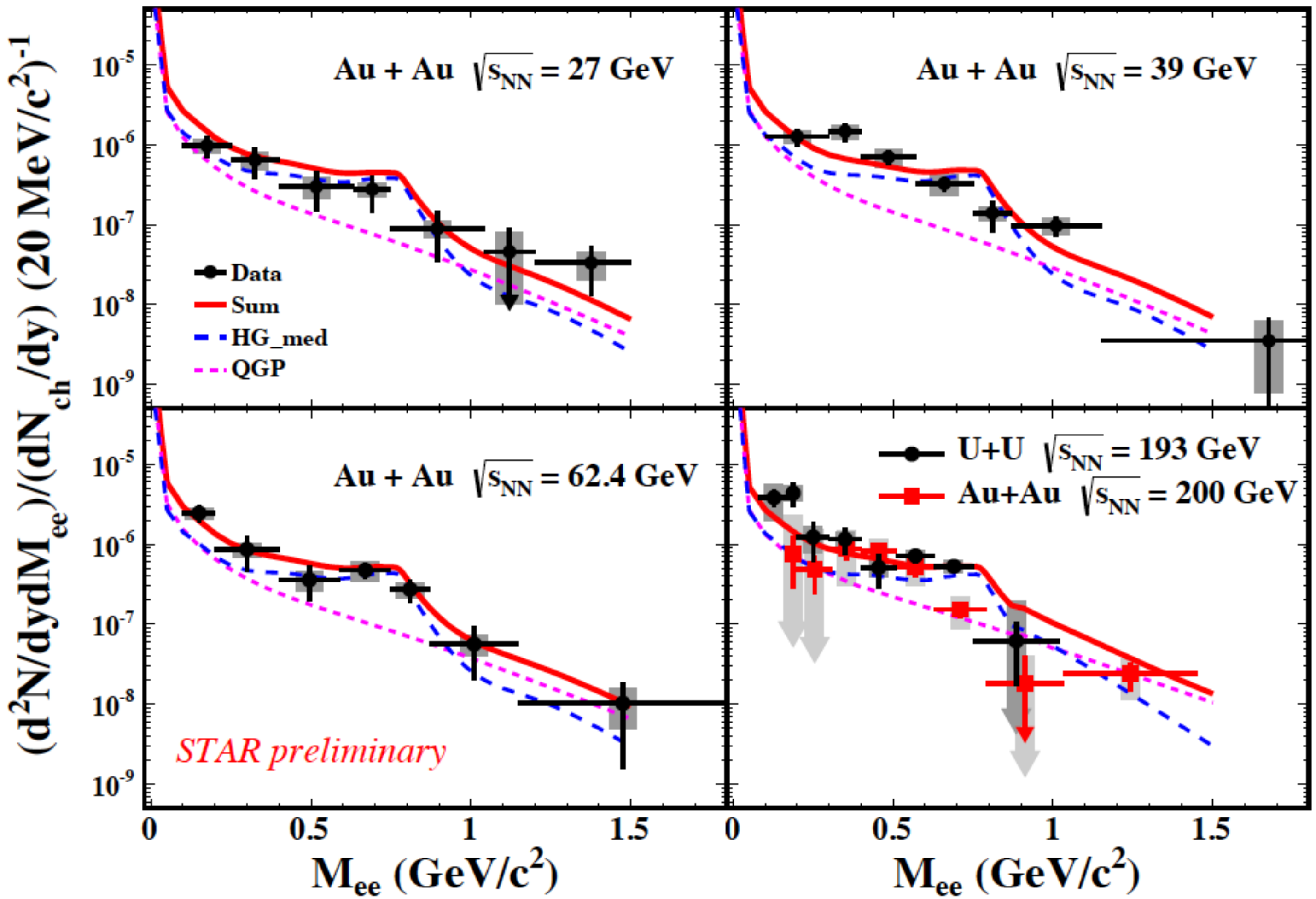
Electron identification



STAR Collaboration, PRL94(2005)062301

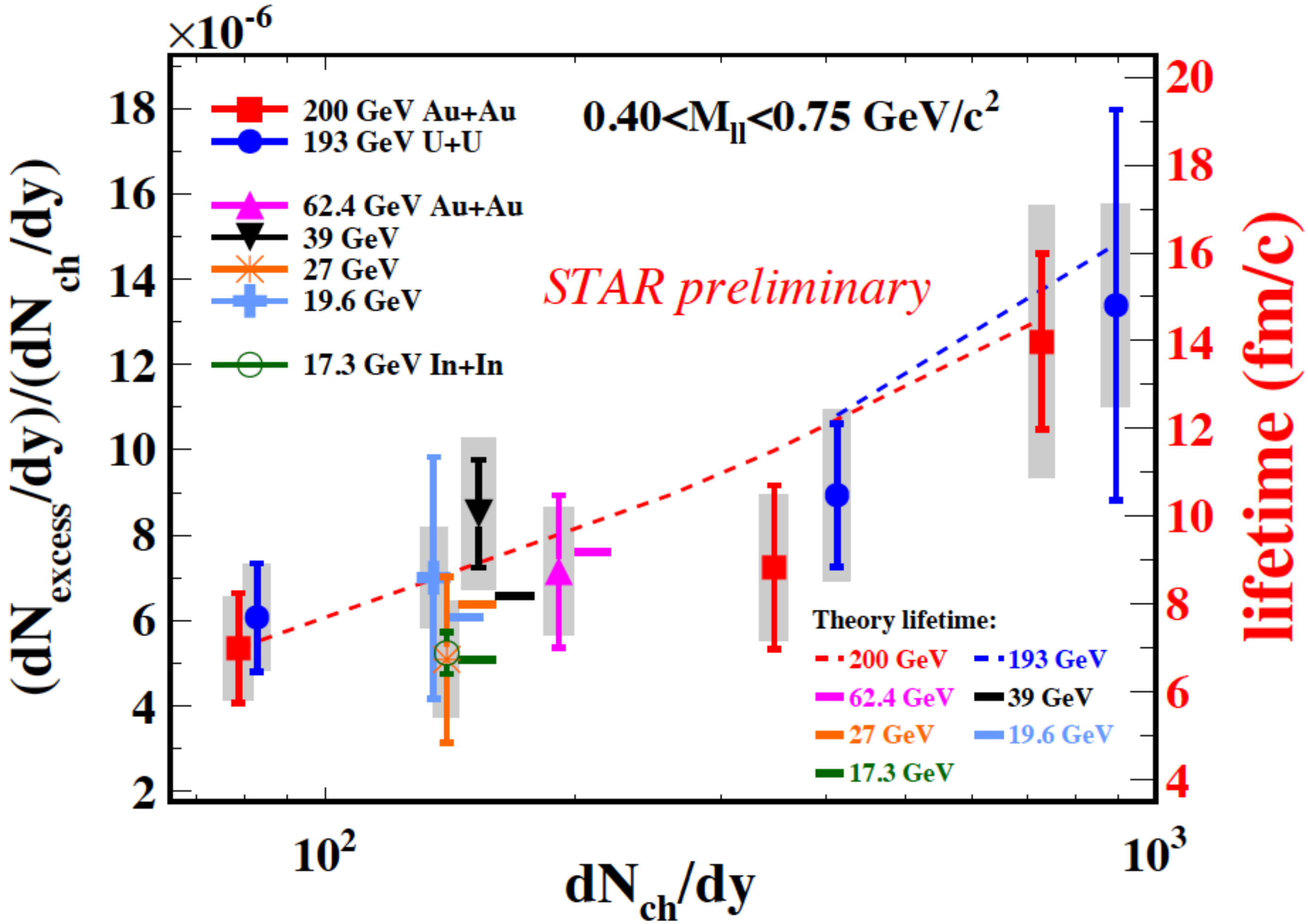
Combining information from the TPC and TOF, we obtain clean electron samples at p_T<3 GeV/c.

The ρ resonance spectrum function: broadened



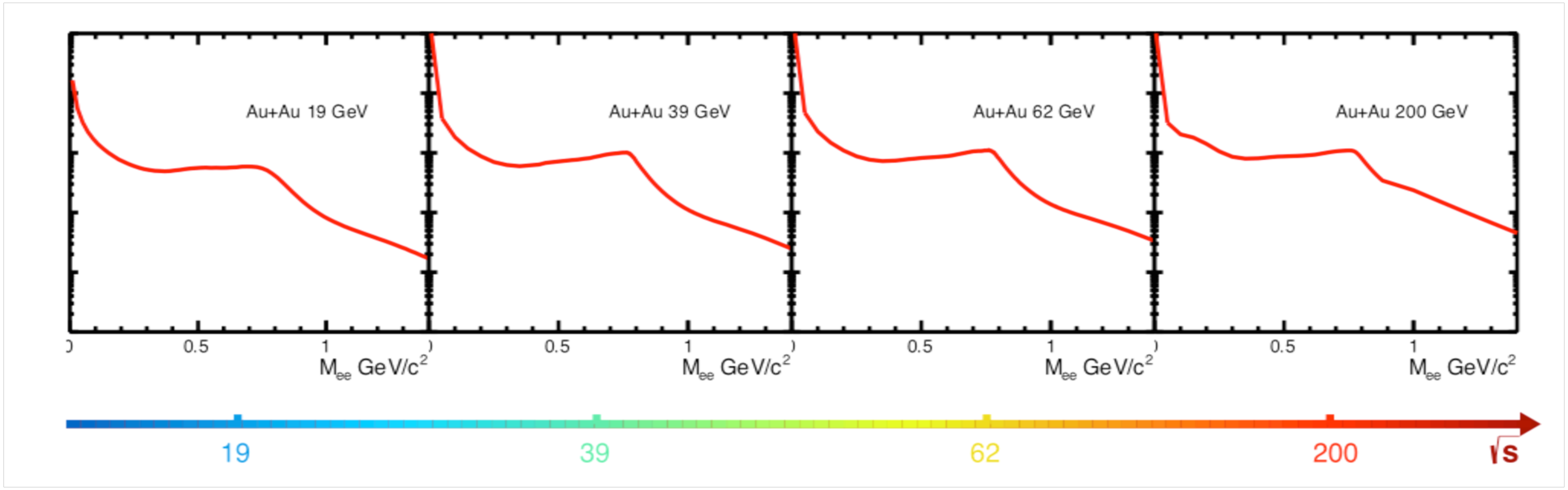
A broadened ρ spectrum function consistently describes the low mass electron-positron excess for all the energies 19.6-200 GeV.

The low mass measurements: lifetime indicator



Low-mass electron-positron production, normalized by dN_{ch}/dy, is proportional to the life time of the medium from 17.3 to 200 GeV.

The contribution from hot, dense medium



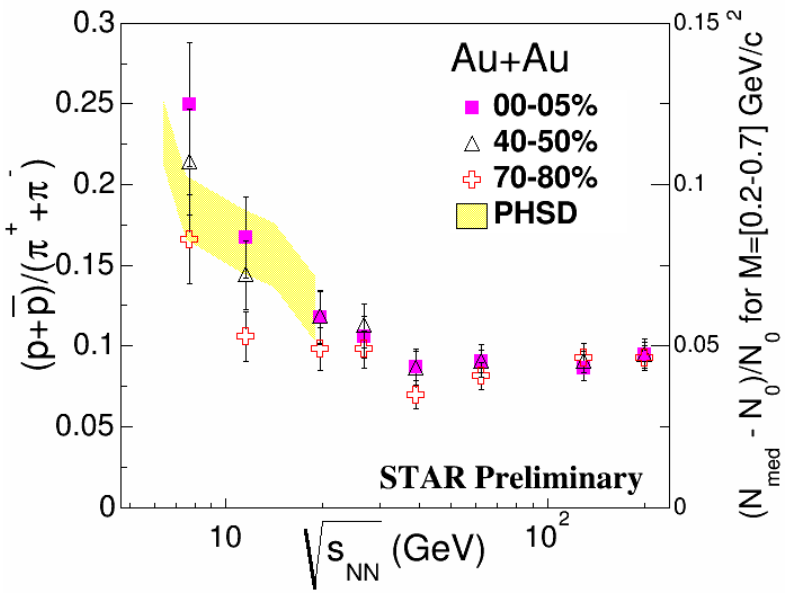
The electron-positron spectrum from hot, dense medium is consistent with a broadened ρ resonance in medium.

The production yield normalized by dN_{ch}/dy is proportional to lifetime of the medium from 17.3 to 200 GeV. Why?

The contribution from hot, dense medium from 17.3 to 200 GeV

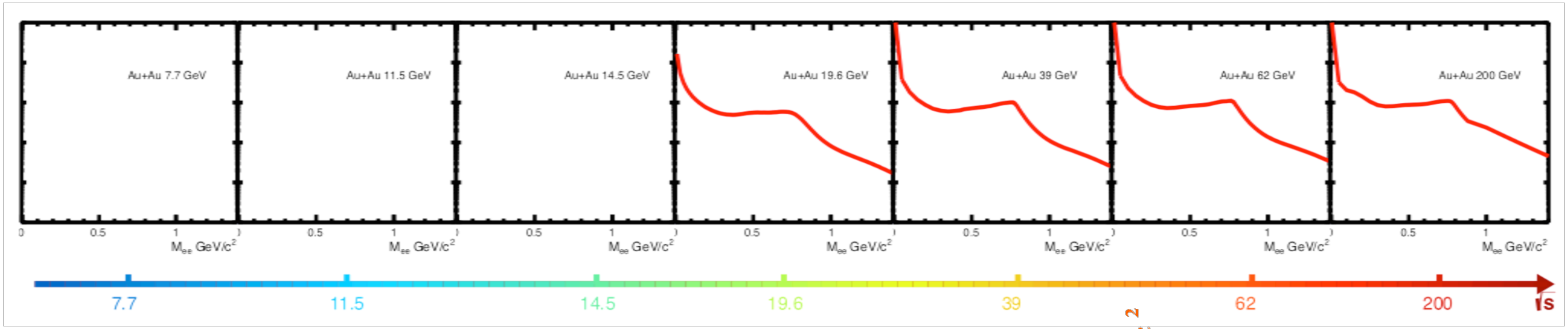
Low-mass electron-positron emission depends on T, total baryon density, and lifetime

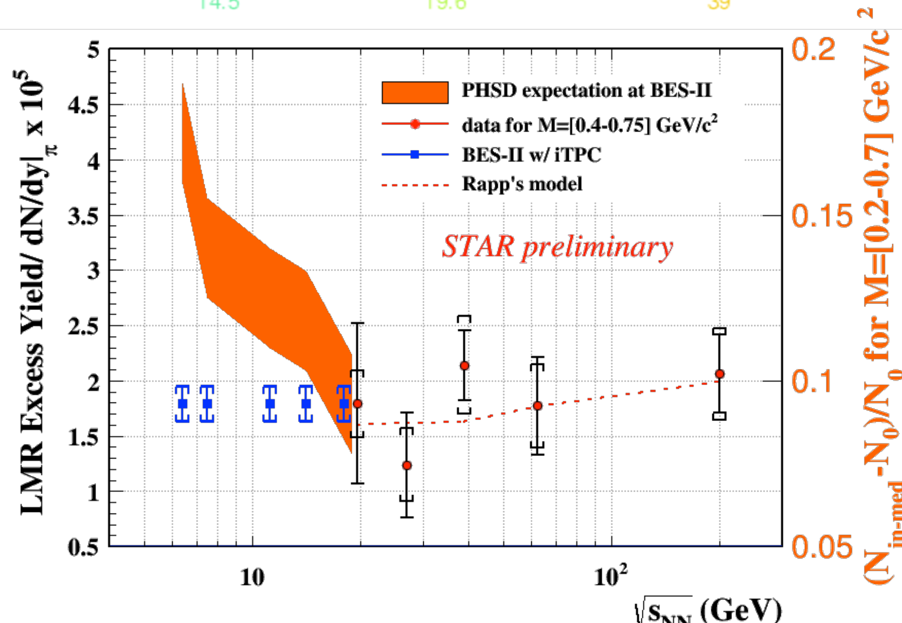
Coupling to the baryons plays an essential role to the modification of ρ spectral function in the hot, dense medium.



Normalized low-mass electron-positron production, is proportional to the life time of the medium from 17.3 to 200 GeV, given that the total baryon density is nearly a constant and that the emission rate is dominant in the Tc region.

Probe total baryon density effect
7.7 GeV to 19.6 GeV (RHIC beam energy scan II)

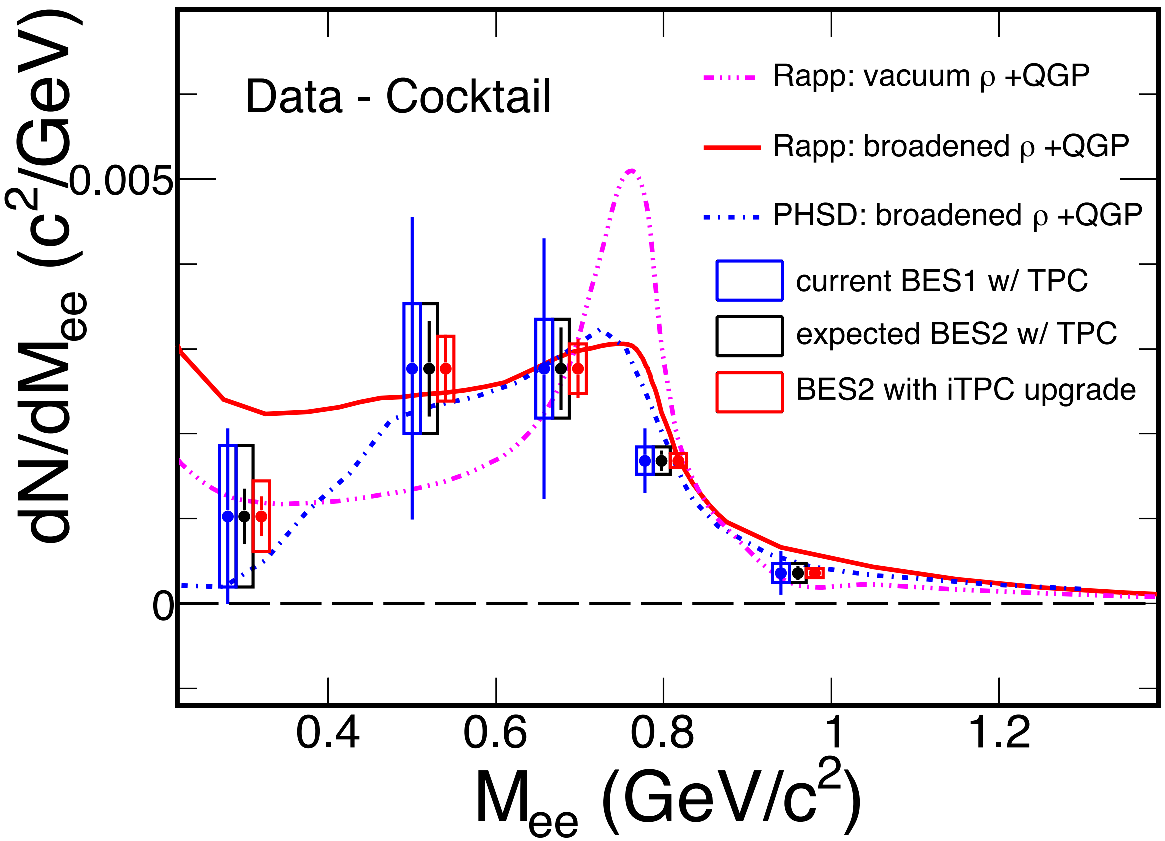




Broader and more electron-positron excess down to 7.7 GeV collision energy?

Beam Energy Scan II provides a unique opportunity to quantify the total baryon density effect on the ρ broadening!

Distinguish the mechanisms of rho broadening



Knowing the mechanism that causes in-medium rho broadening and its temperature and baryon-density dependence is fundamental to our understanding and assessment of chiral symmetry restoration in hot QCD matter !

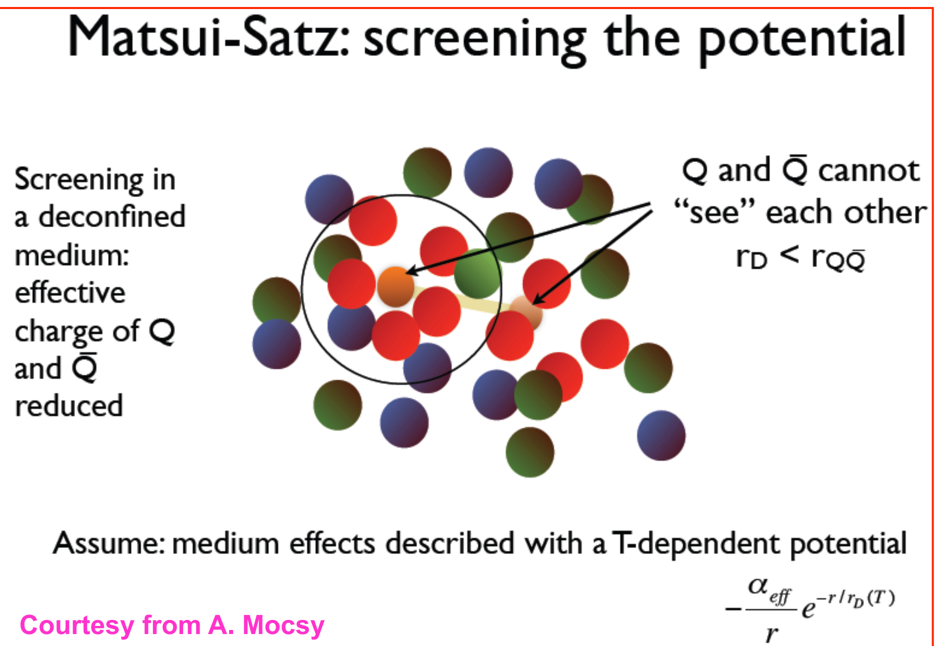
Turn off hot medium effect: electron-positron pair at the EIC? Understanding the rho modifications in cold nuclear matter (e+A versus e+p) is fundamental!

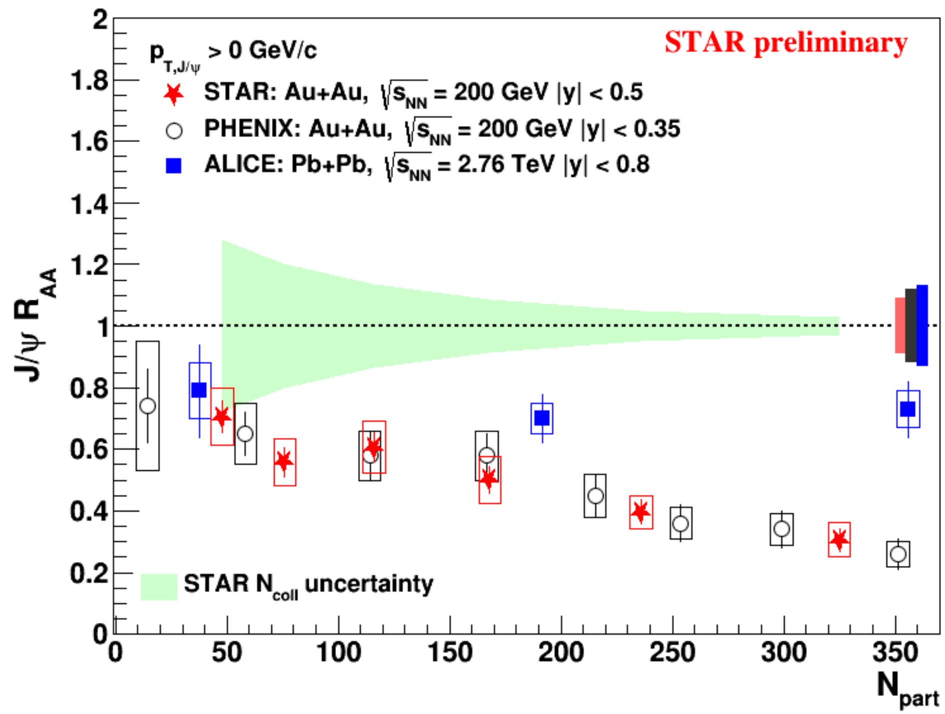
EM probe: quarkonium

Different quarkonium states: heavy but small, different dissociation temperature

J/ψ through its dileptonic decay: indicator of deconfinement of quarks and gluons

color screening





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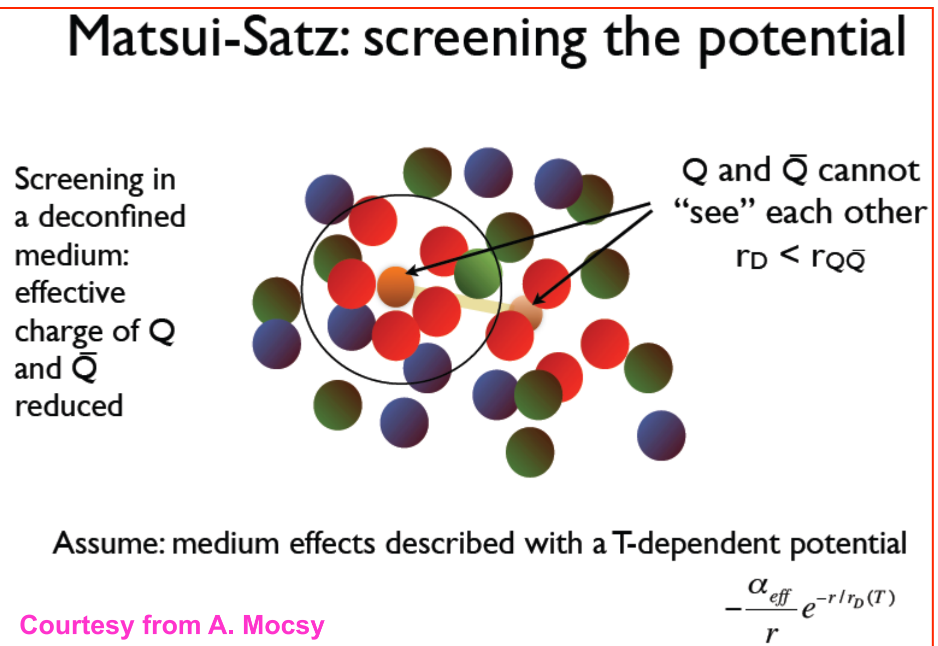

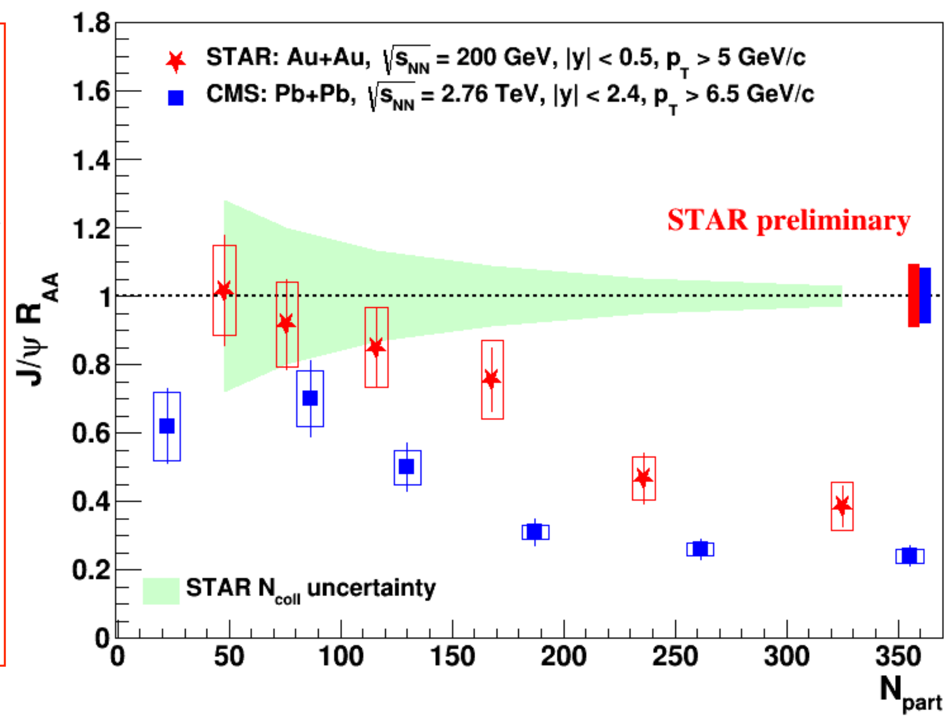

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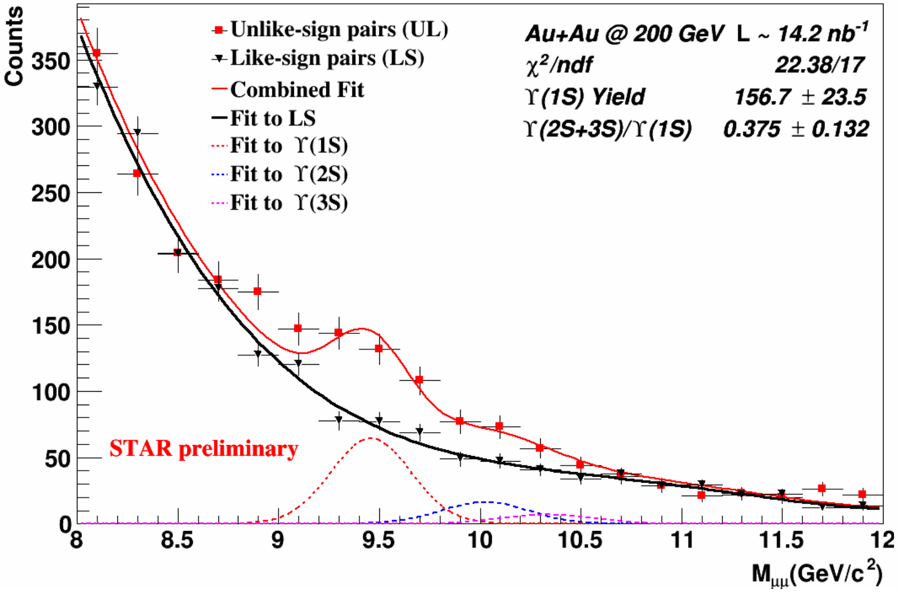
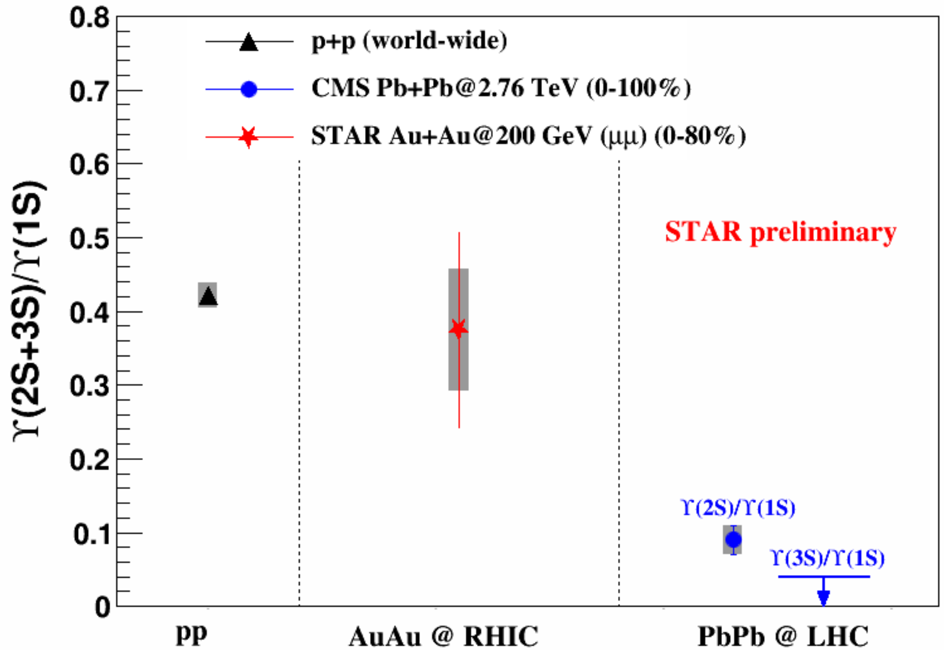




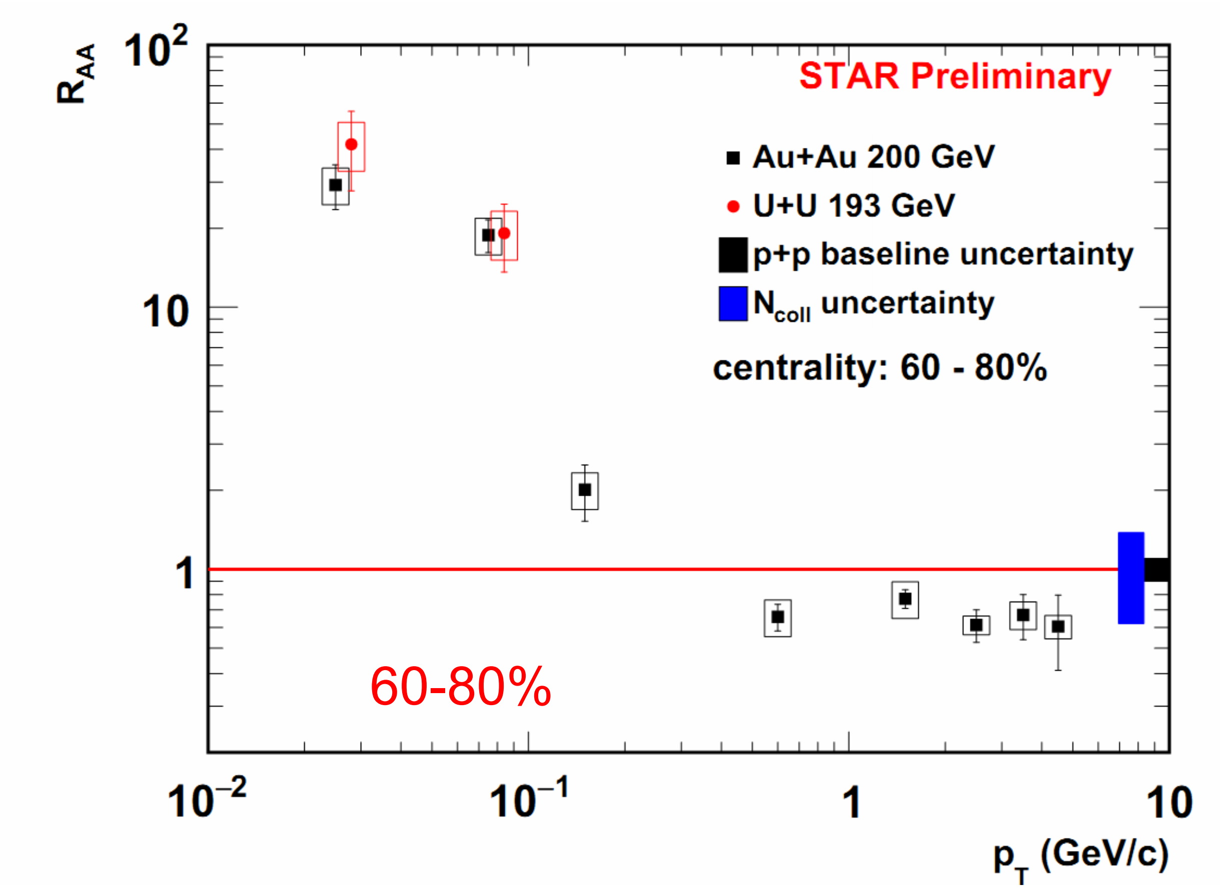
0.28, 0.56, 0.78 fm for ϒ(1S), ϒ(2S), ϒ(3S).

Negligible contribution from b and bbar recombination at RHIC

A better probe to study color-screening feature of QGP.

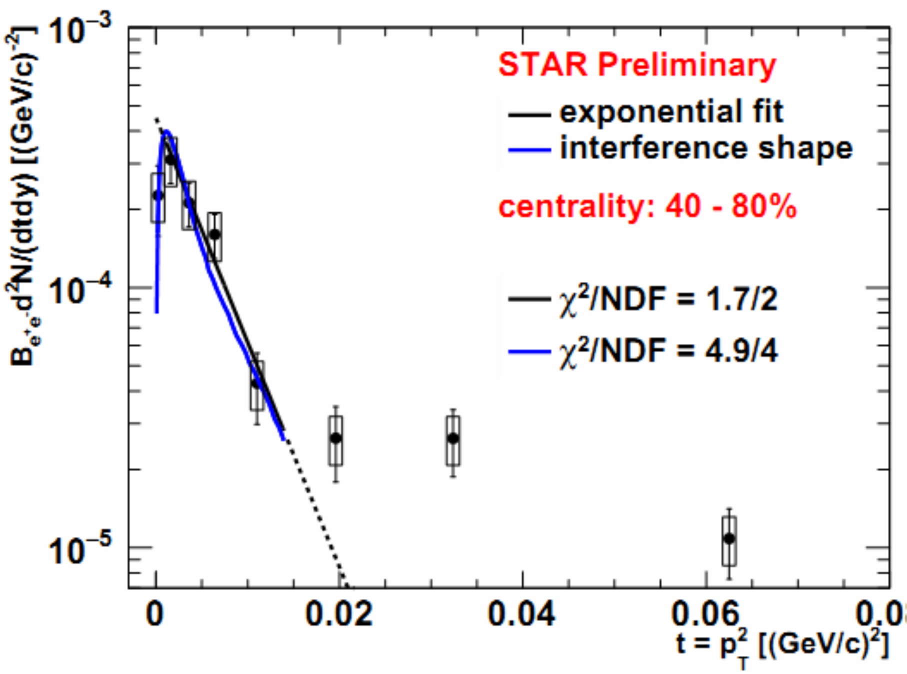
A hint of ϒ(2S+3S) less suppressed at RHIC than at LHC!

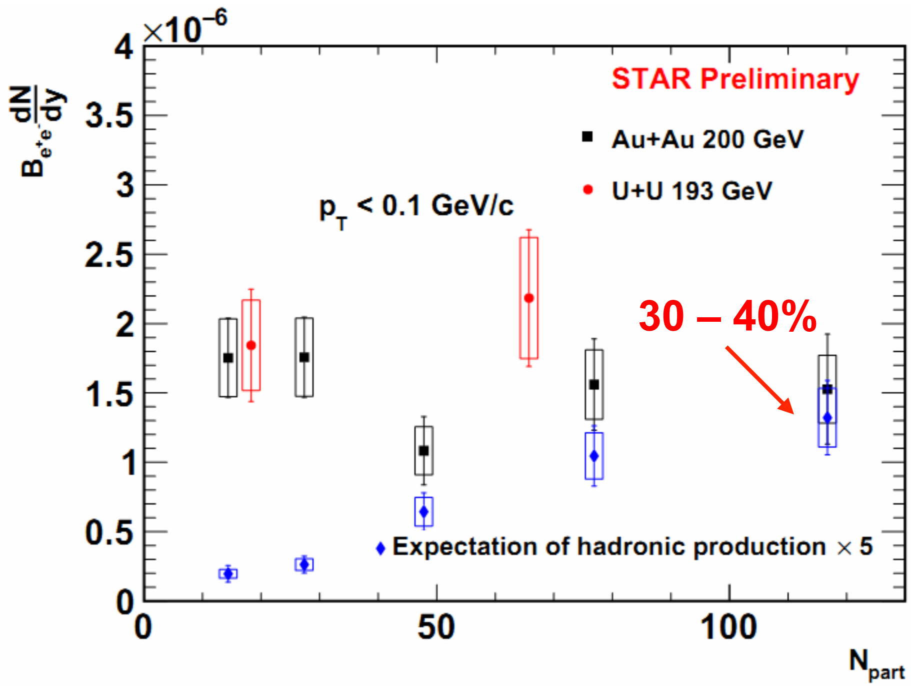
Very low pt J/ψ: largely enhanced!



Significant enhancement of J/ψ yield observed: R_{AA}~ 20 at p_T < 0.1 GeV/c for peripheral collisions (60 – 80 %) Au+Au and U+U !

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



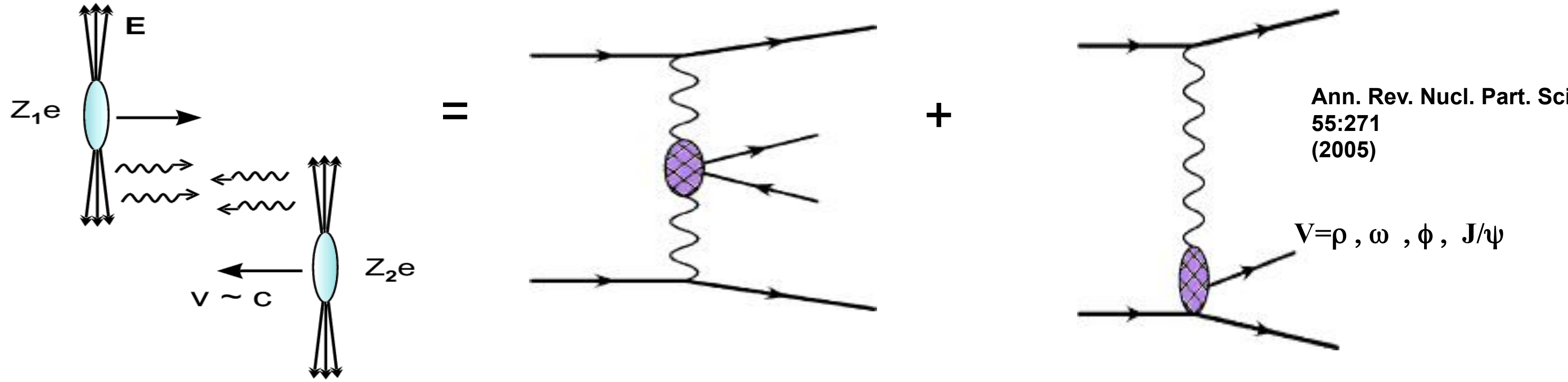


Slope parameter consistent with the size of the Au nucleus. Interference structure observed. Coherent photon-nucleus interactions?

No significant centrality dependence of the excess yield! Interplay between photon flux cancellation in the overlapped area and the distance of the spectators of the two nuclei?

Simulations ongoing and need theoretical inputs!

Coherent photonuclear and two-photon processes



Two-photon photonuclear

Studied extensively in ultra-peripheral collisions

How is the J/ψ from coherent photonuclear process affected by hot and cold QCD matter! Why do we still be able to observe these J/ψs?
A new tool to study enriched multi-body dynamics on the strong QCD force!

EIC serves as an ideal factory to study the cold QCD matter effect.
Study the very low p_T J/ψ production as a function of multiplicity and system size (by varying nucleus type). Is it feasible?

Summary

EM probes at EIC:

Turn off the hot, medium effect on the electron-positron pair production: Understanding the rho modifications in cold nuclear matter (e+A versus e+p) is fundamental!

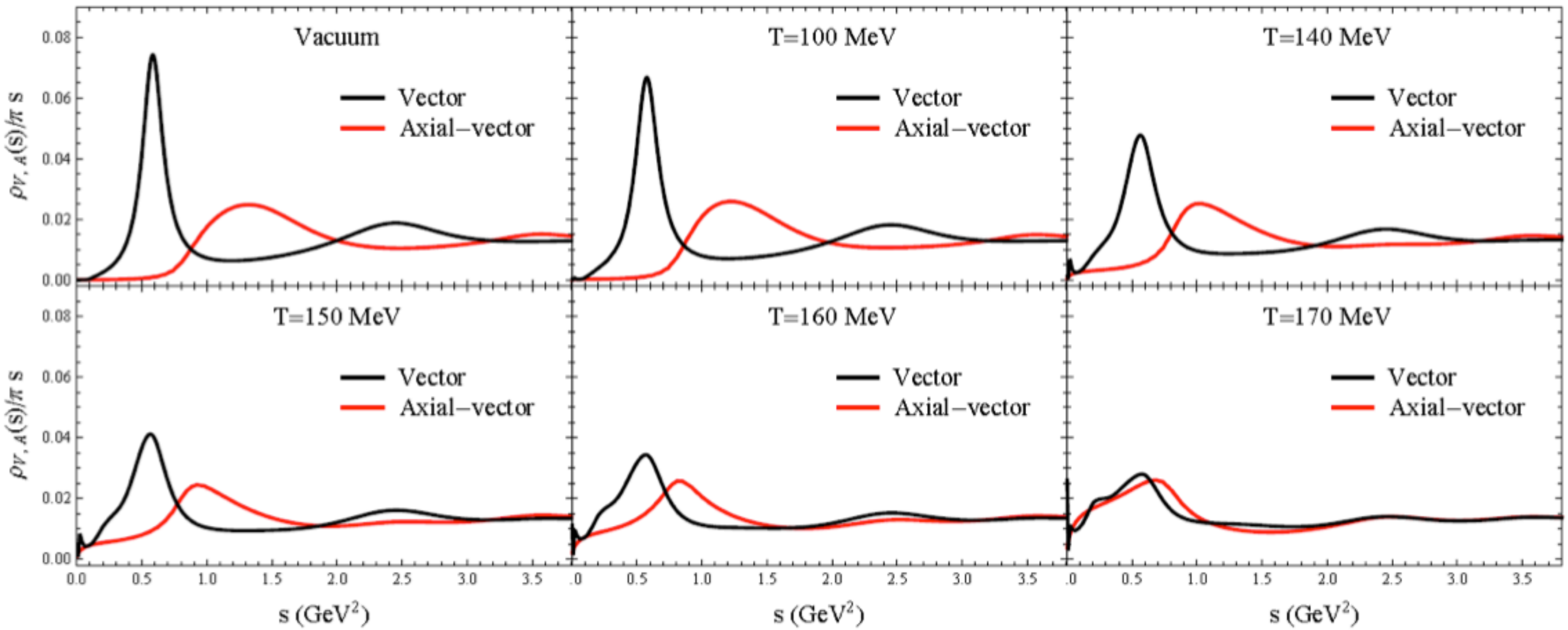
Very Low-p_T J/ψ might be an important messenger on the multi-body dynamical effect on the strong QCD force! EIC will serve as an ideal factory to study the cold QCD effect on it: Study the p_T^2, multiplicity, and system size dependences in e+A collisions and also compare the measurements in e+A to those in e+p one (R_{eA}).

Backup

The future electron-positron program

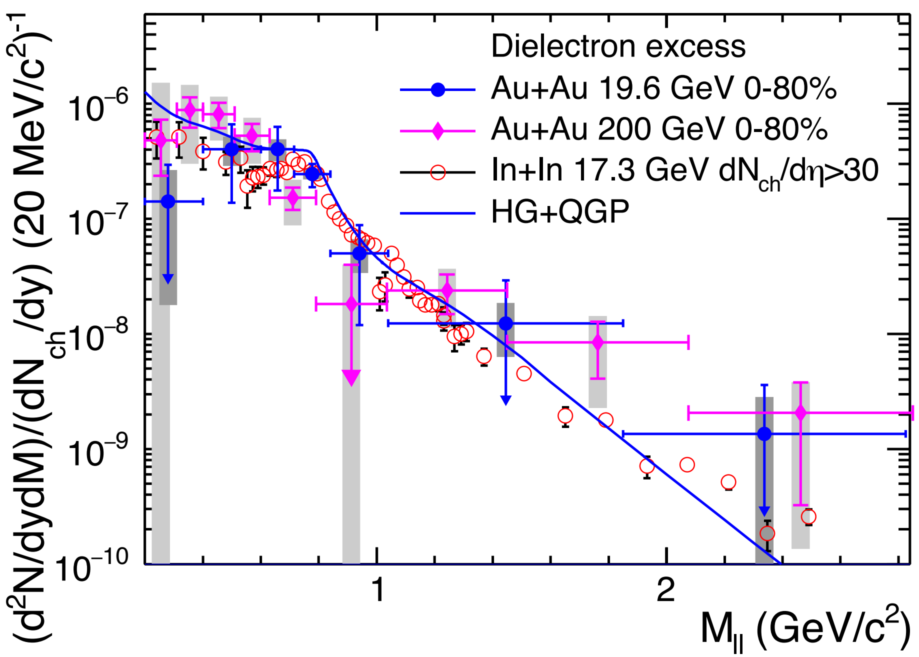
To link electron-positron measurements to chiral symmetry restoration need more precise measurement at $\mu_B = 0$:

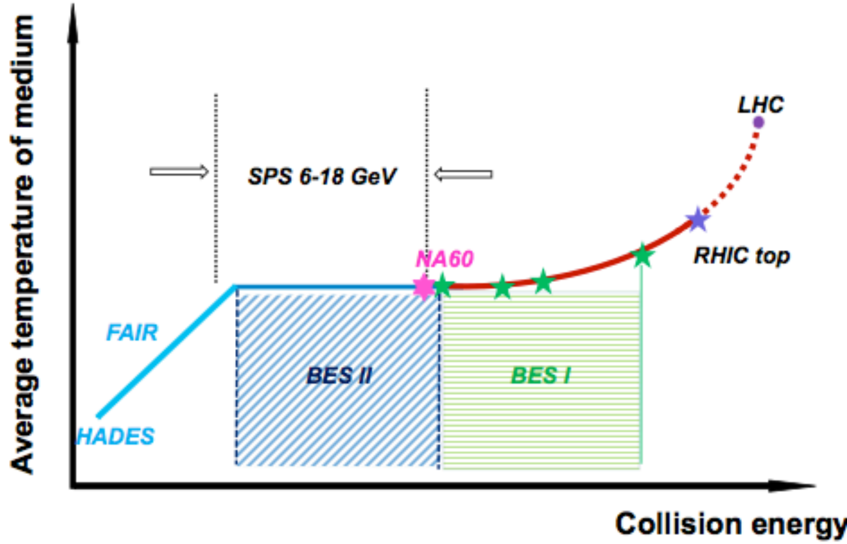
- Lattice QCD calculation is reliable at $\mu_B = 0$.
- Theoretical approach: derive the a1(1260) spectral function by using the broadened rho spectral function, QCD and Weinberg sum rules, and inputs from Lattice QCD; to see the degeneracy of the rho and a1 spectral functions (Hohler and Rapp 2014).

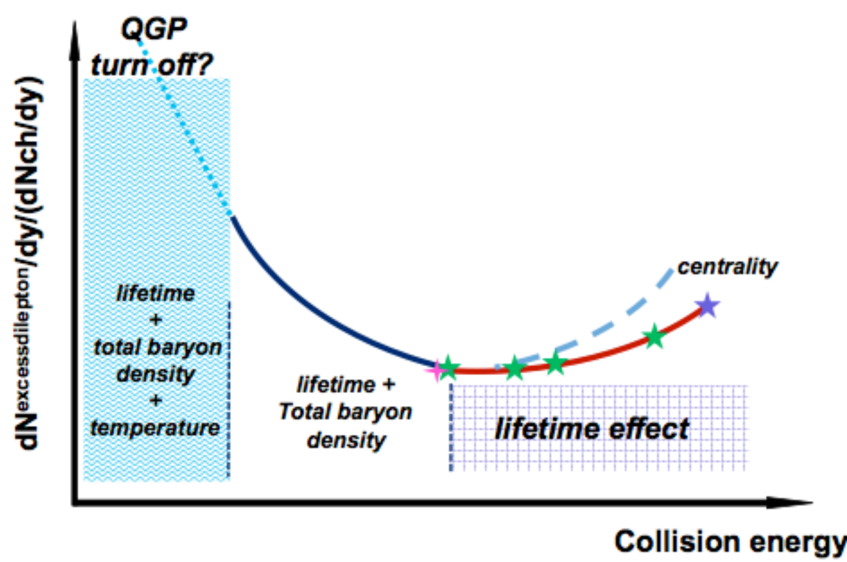


The future electron-positron program

- **The slope in the intermediate mass region represents the true average temperature T of the medium.**

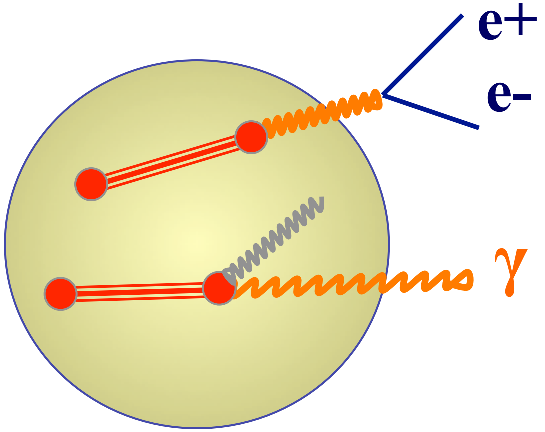


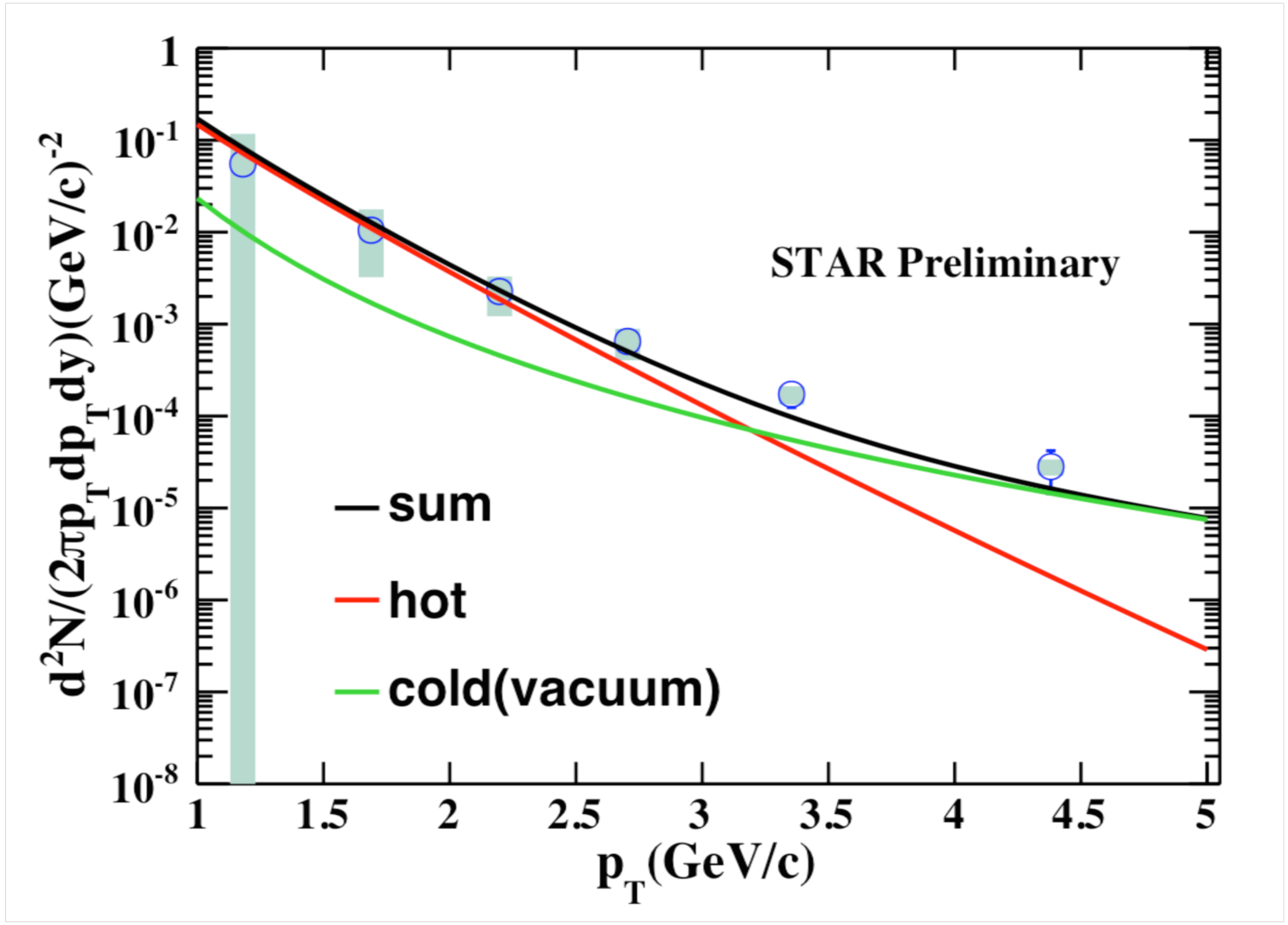




- **Low-mass electron-positron emission depends on T, total baryon density, and life time, and enables systematic life-time measurements.**

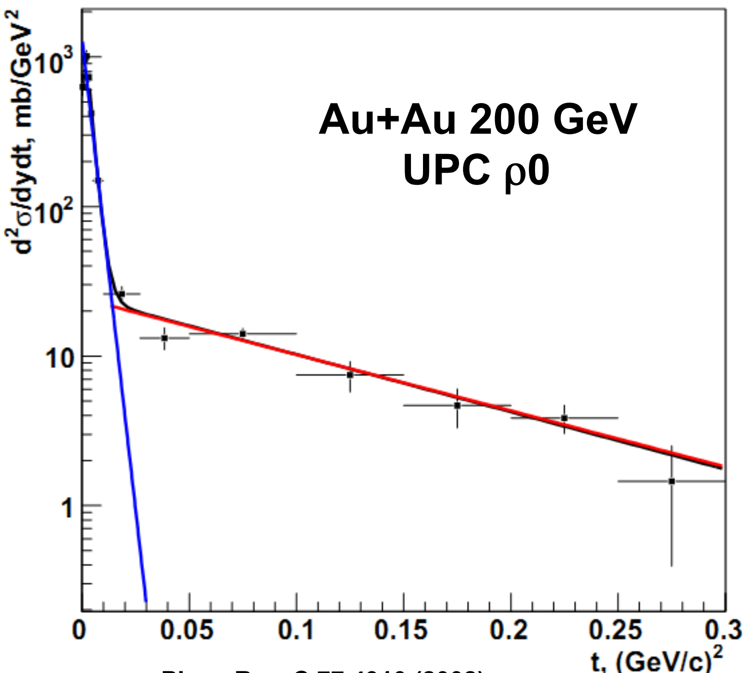
Photon emission





Hot contribution observed in the photon energy spectrum!

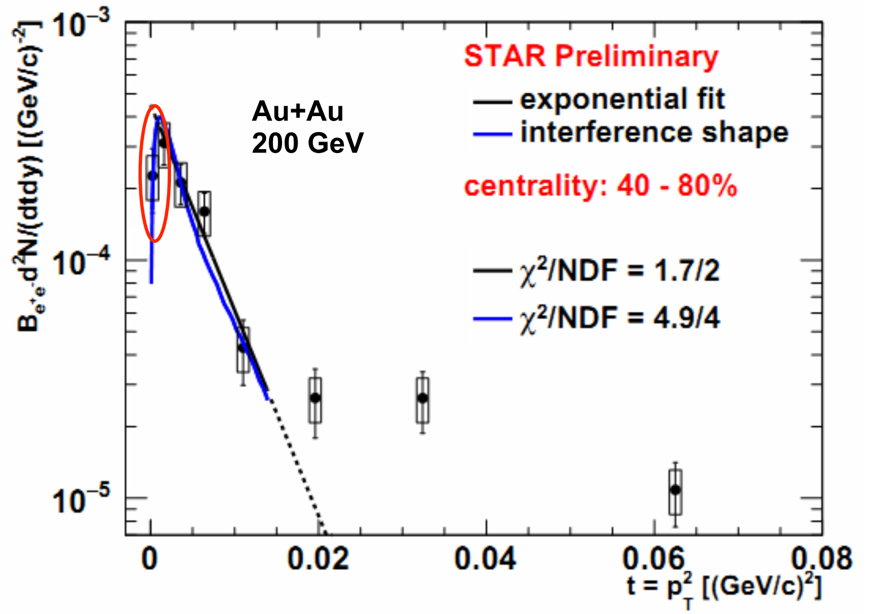
J/ψ dN/dt distribution for Au+Au 40-80%



Phys. Rev. C 77 4910 (2008)

ρ0 cross-section as a function of the momentum transfer squared from STAR UPC measurements.

The slope from the exponential fit reflects the size and shape of target.



Similar structure to that in UPC case!

Indication of interference!

Interference shape from calculation for UPC case PRL 84 2330 (2000)

Similar slope parameter!

Slope from STARLIGHT prediction in UPC case – 196 (GeV/c)$^{-2}$

Slope w/o the first point: 199 ± 31 (GeV/c)$^{-2}$