Beam energy dependence of dilepton productions at RHIC-STAR

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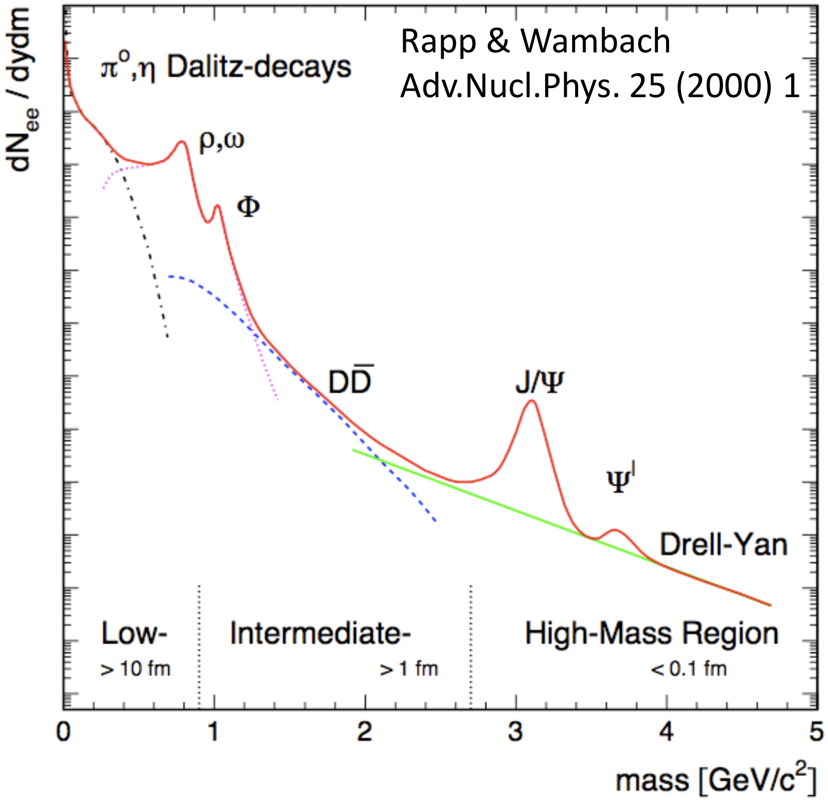
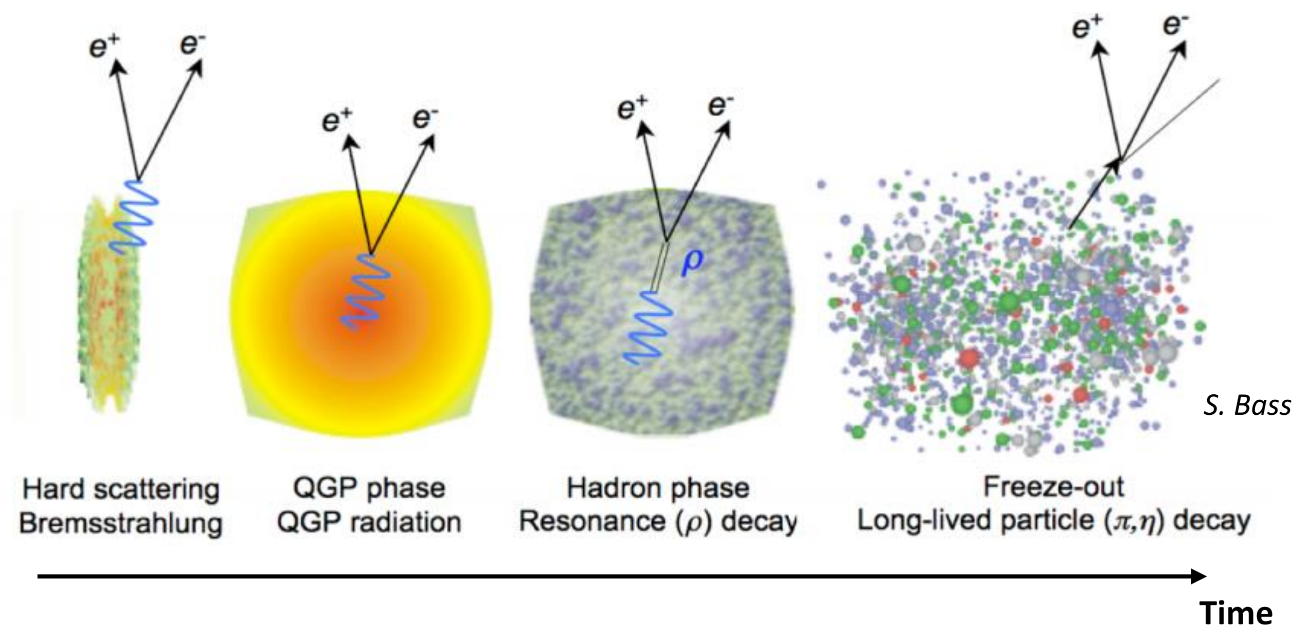
Outline

- Introduction and motivation
- Dielectron production at RHIC top energy
- Dielectron production from RHIC BES-I
- Prospects for Run18-19 and BES-II
- Summary

Introduction: EM penetrating probes





LMR	Chiral symmetry restoration Vector meson production: in-medium effect
IMR	Heavy quark correlation QGP thermal radiation
HMR	Heavy quarkonia production Drell-Yan

Electromagnetic probes =>

Do not participate in strong interactions.

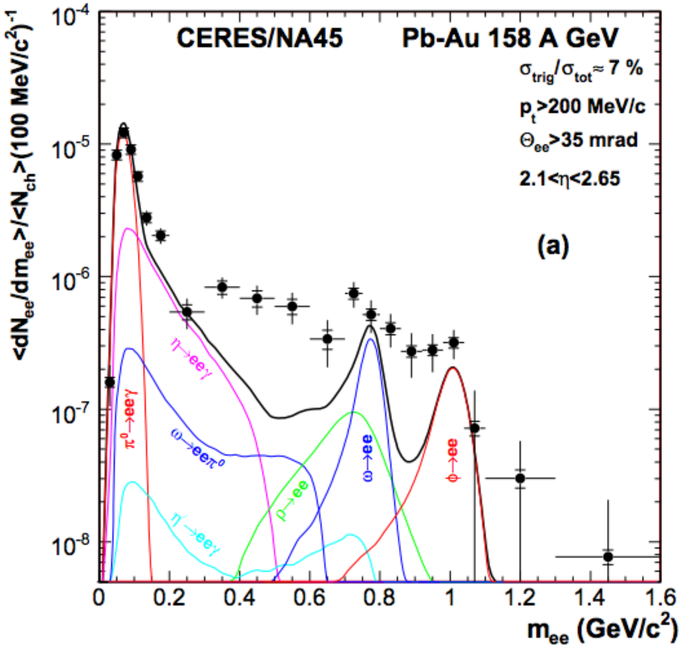
Bring undistorted information as where produced.

Penetrate medium properties.

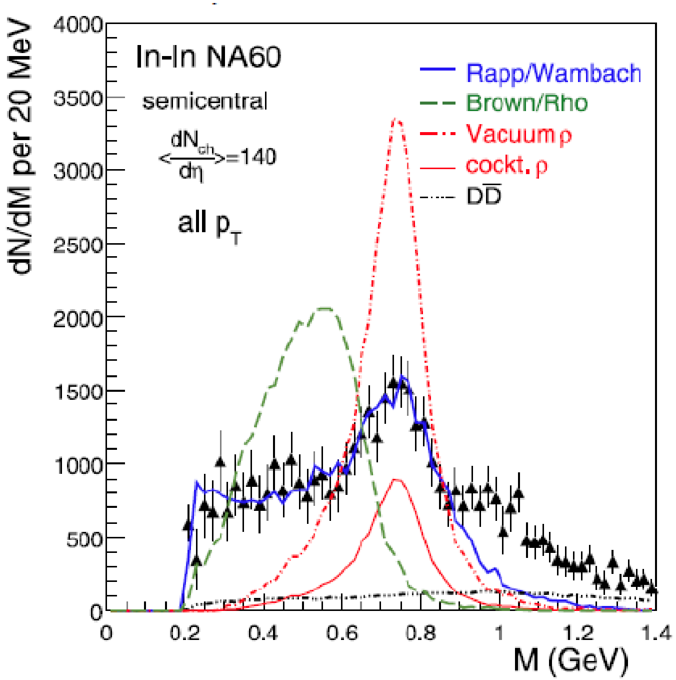
Challenge: Time-space integrated from every stages.

Continuum at IMR.

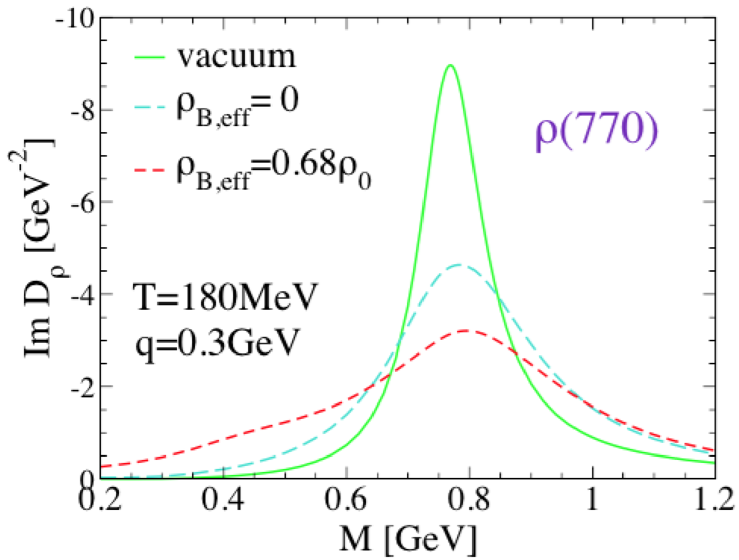
Introduction: in-medium modifications



PLB 666 (2008) 425



EPJ C61 (2009) 711



Rapp, Wambach, van Hees
arXiv:0901.3289

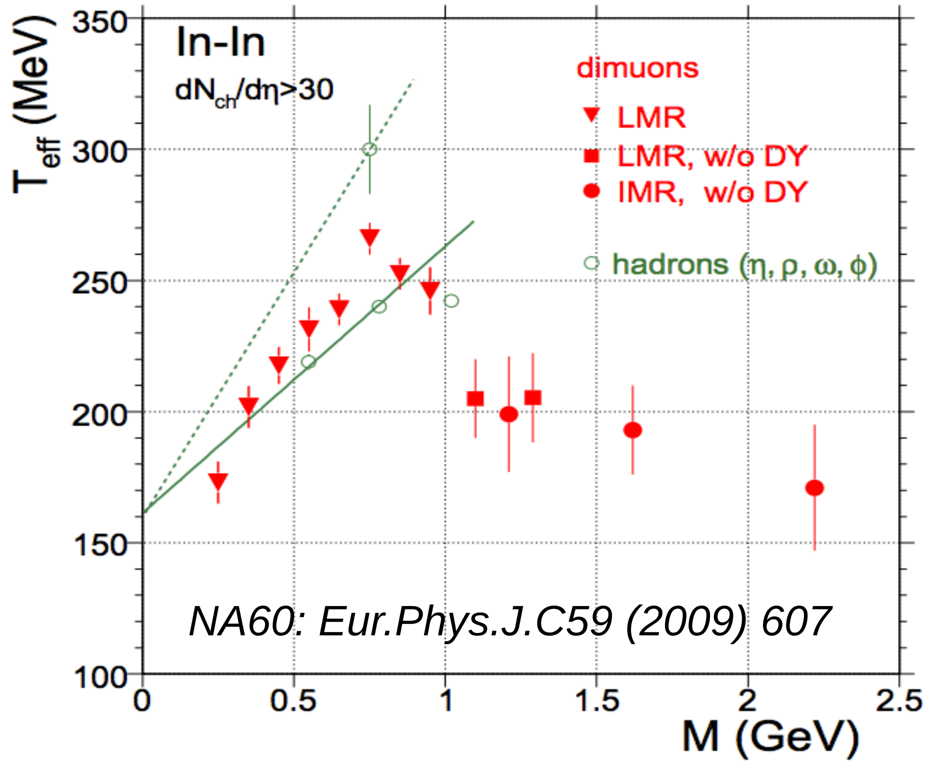
Low mass excess was observed in previous experiments.

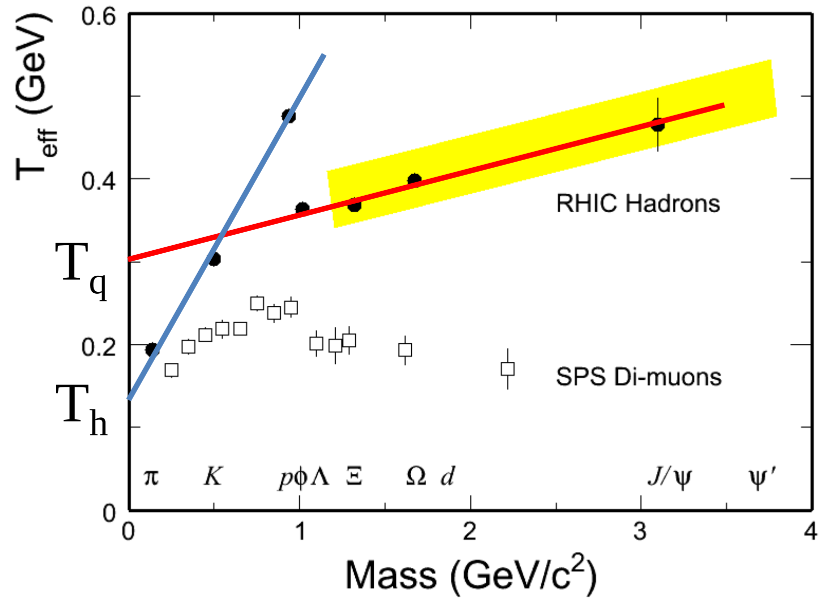
Vacuum ρ unable to describe data.

Rule out Dropping-Mass Scenario (Brown-Rho).

Good agreement with broadening of ρ spectral function (Rapp-Wambach).

Introduction: hadronic vs partonic





RHIC 200 GeV, NPA 757 (2005) 102

$$T_{\text{eff}} = T_0 + M v_T^2$$

LMR: inversed slopes show mass dependence

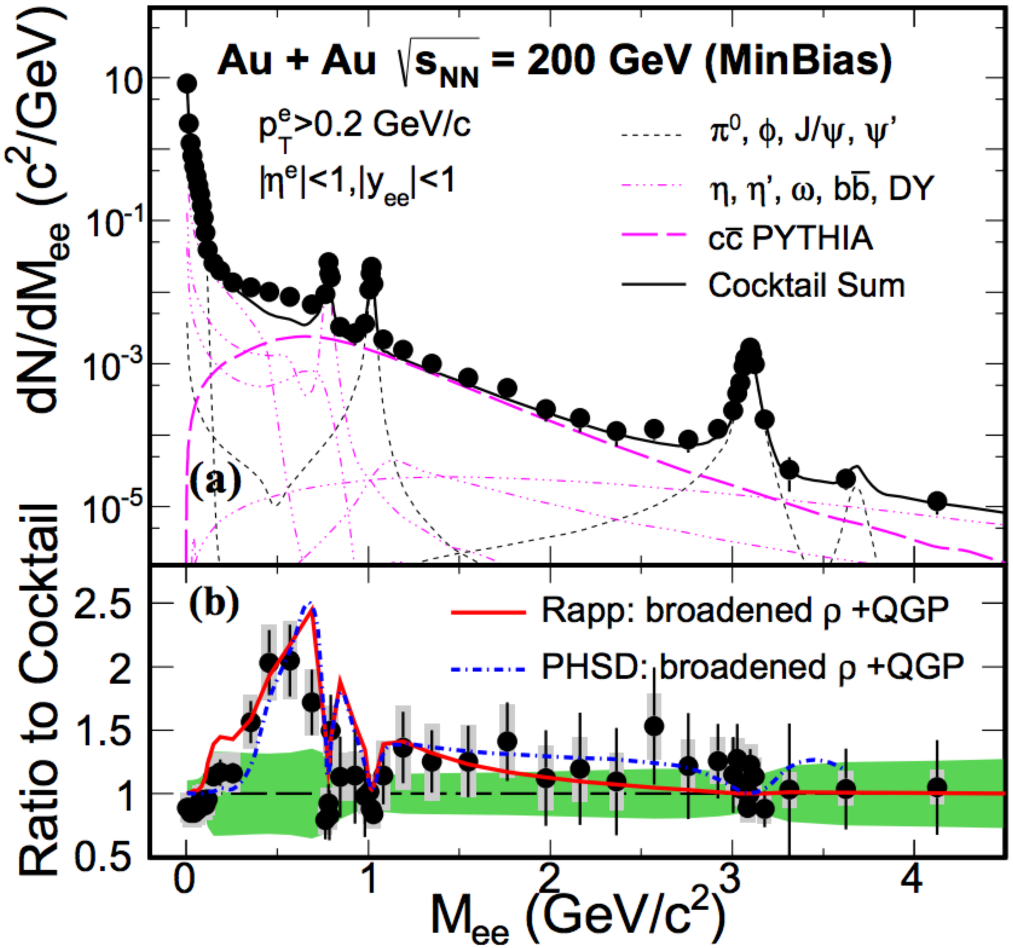
-- hadronic process dominate, radial flow

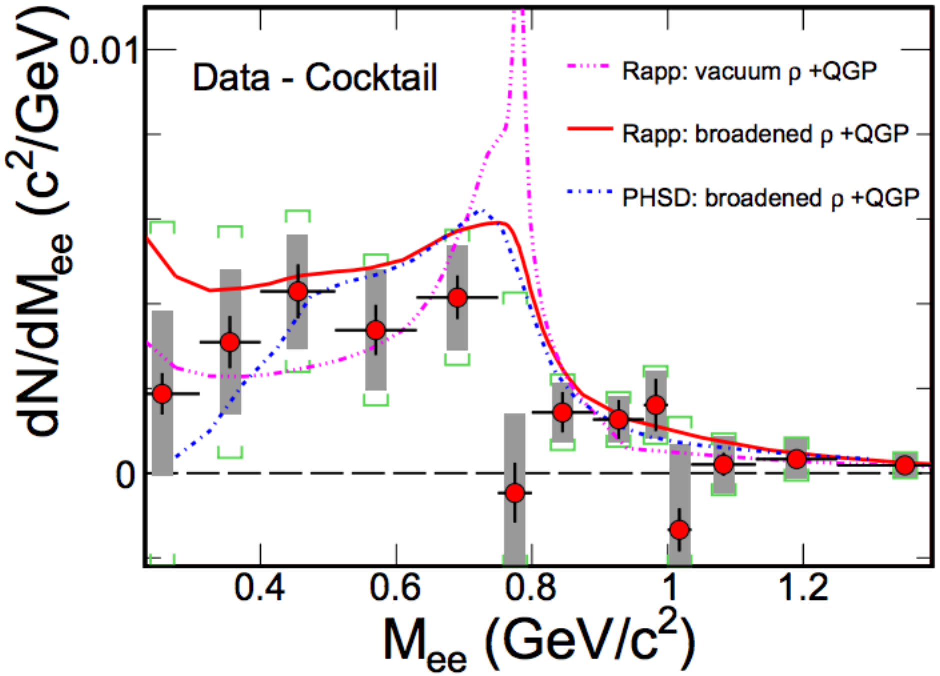
IMR: no indication of mass dependence

-- thermal radiation from partonic phase

Energy dependence of the slopes could be sensitive to the medium dynamics.

Dielectron production in Au+Au 200 GeV

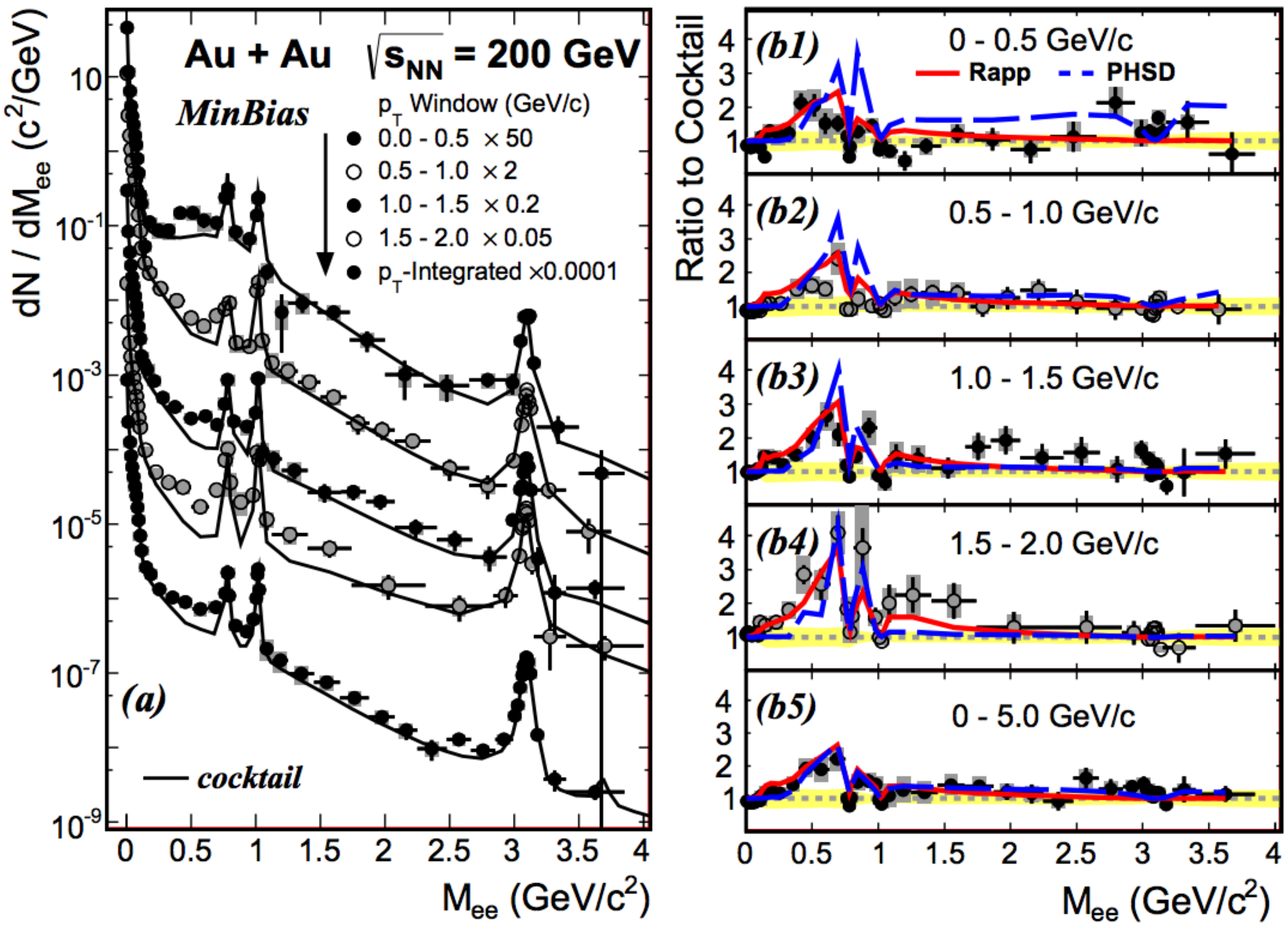




Data: STAR PRL 113 (2014) 022301
Rapp: PoS CPOD2013
PHSD: O. Linnyk et al., PRC 85 (2012) 024910

- ✧ LMR enhancement compared with cocktail w/o ρ. In-medium ρ plays important role, good agreement with data.
- ✧ IMR consistent with cocktail within errors, difficult to disentangle correlated charm and QGP radiation.

Dielectron production in Au+Au 200 GeV



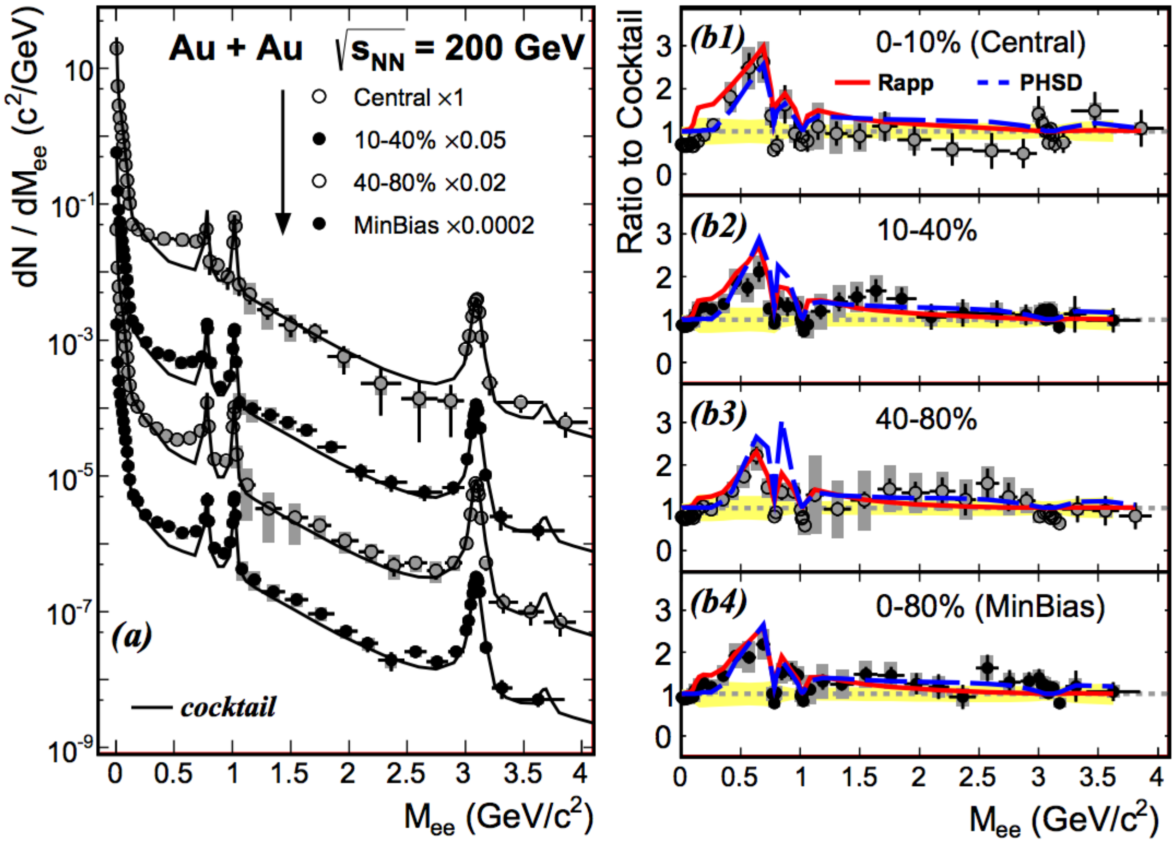
STAR PRC92 (2015) 024912.

Rapp: PoS CPOD2013
PHSD: O. Linnyk et al., PRC 85 (2012) 024910

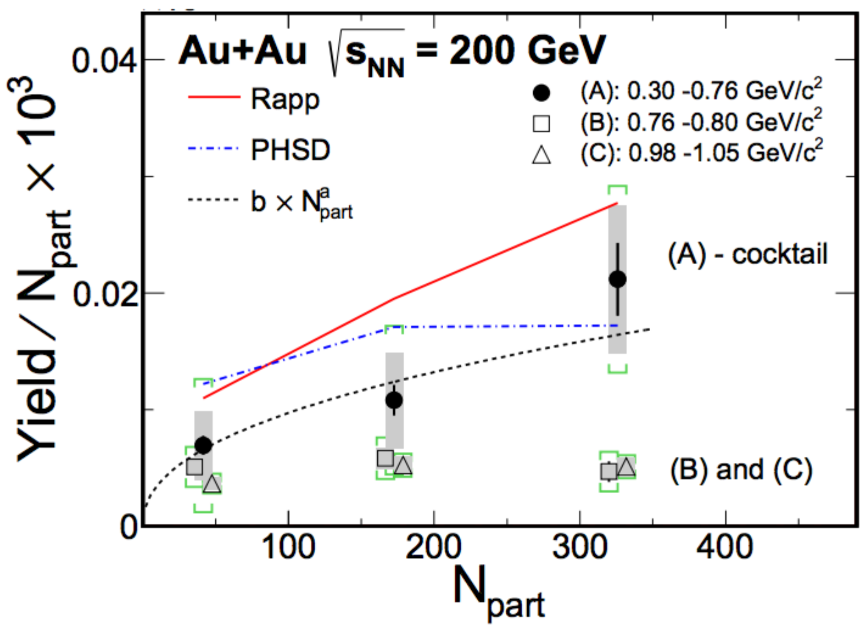
Good agreement with models with broadening ρ.

The enhancement factors show no significant p_T dependence .

Dielectron production in Au+Au 200 GeV



STAR PRC92 (2015) 024912.



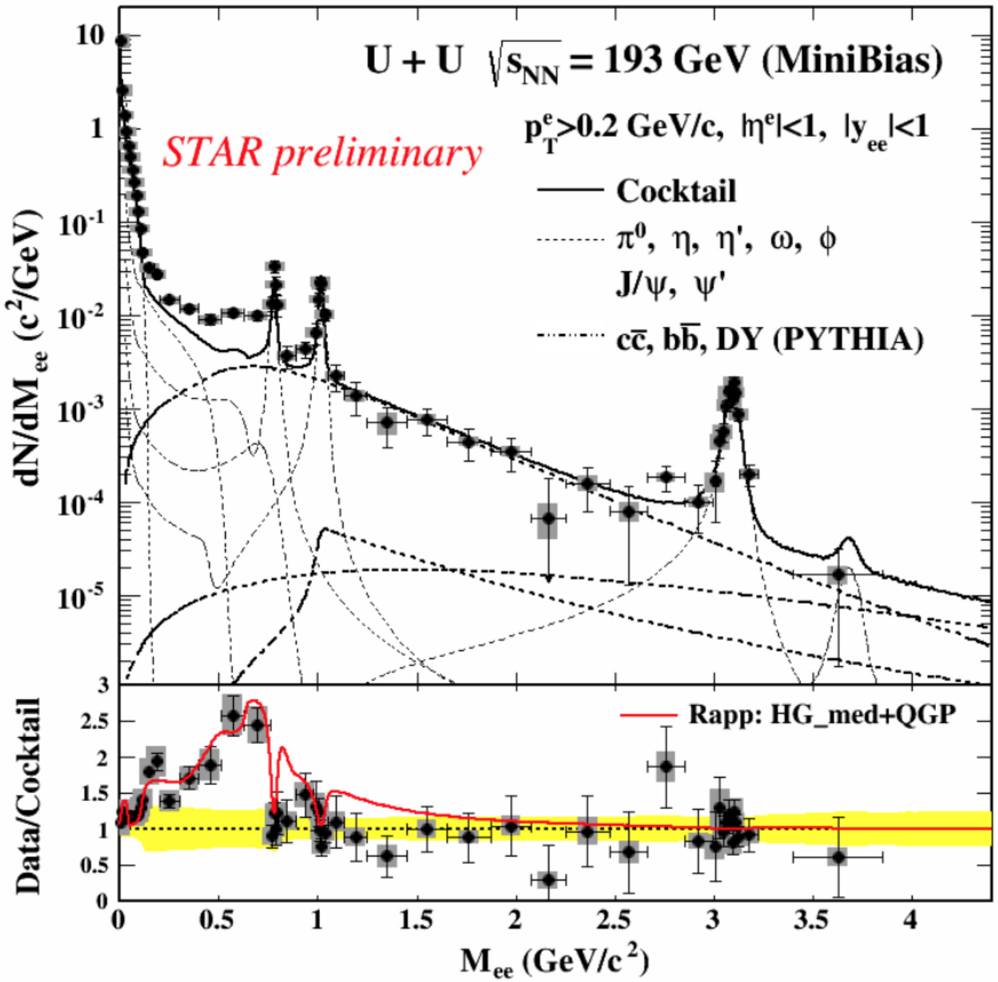
Rapp: PoS CPOD2013
PHSD: PRC 85 (2012) 024910

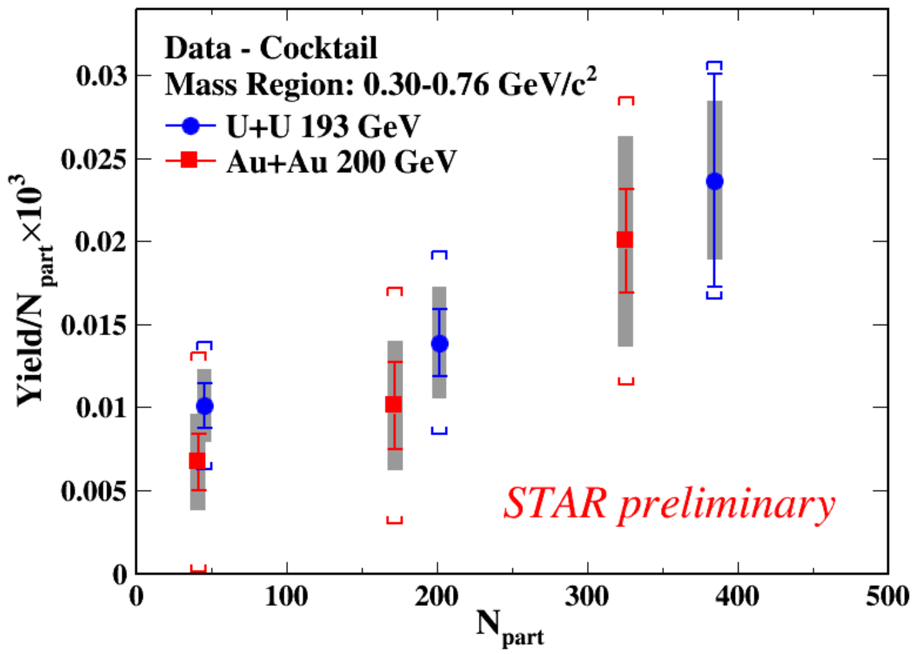
Good agreement with models with broadening ρ.

ω-like and ⟩-like mass regions show an N_{part} scaling.

The ρ-like yield excess increases faster than N_{part} scaling -> indicating a sensitivity to the QCD medium dynamics.

Dielectron production in U+U 193 GeV





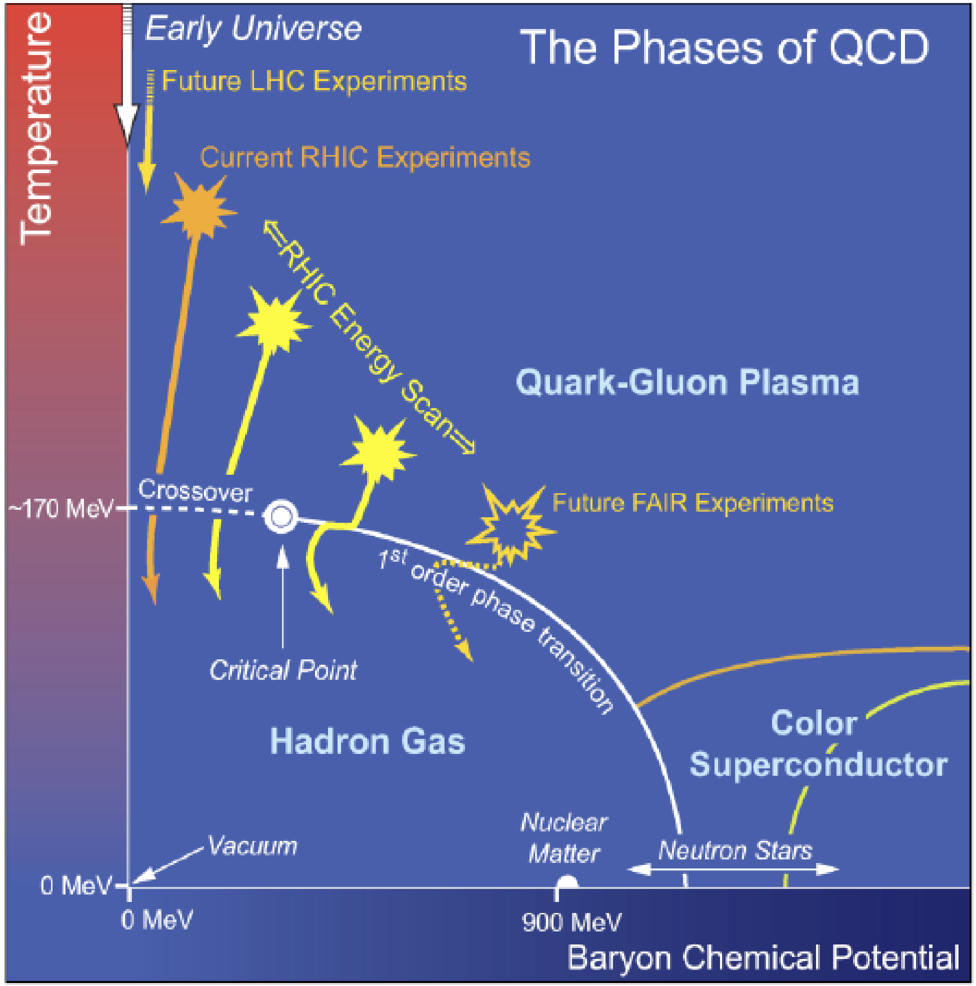
Au+Au: *STAR, PRL 113 (2014) 022301*

✧ Significant enhancement at LMR.

✧ Model with a broadened ρ spectra function shows good agreement with data.

✧ Extend the Au+Au trend vs centrality. Excess yield increases faster than N_{part} scaling, possible link to medium dynamics.

RHIC BES program



RHIC Beam Energy Scan Program:

- Mapping QCD phase boundary.
- Search for QCD critical point.

Observables: fluctuations, flow, correlations …

What about "dilepton"?

- Mass spectra, m_T slope, v_2 …

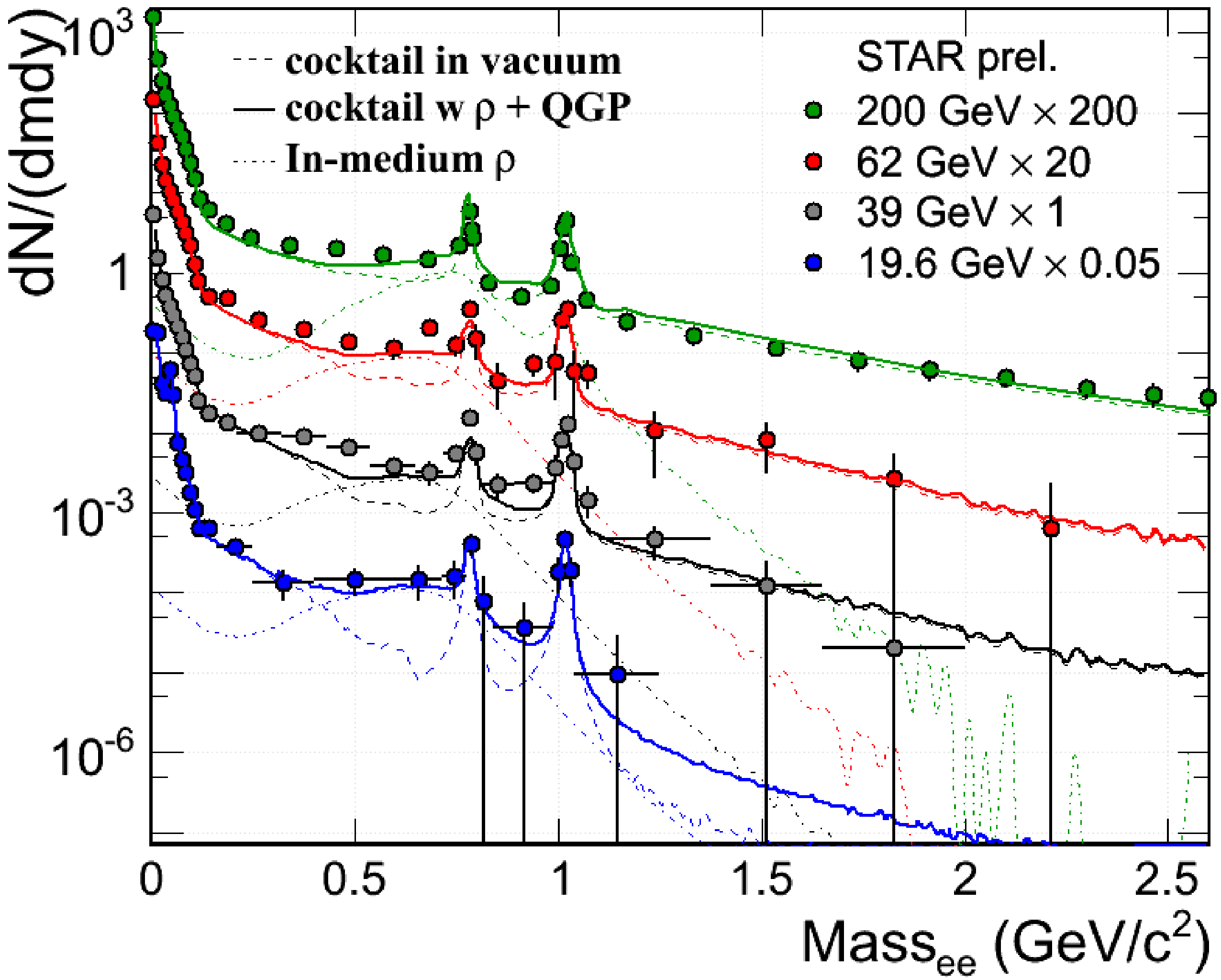
How about the energy dependence?

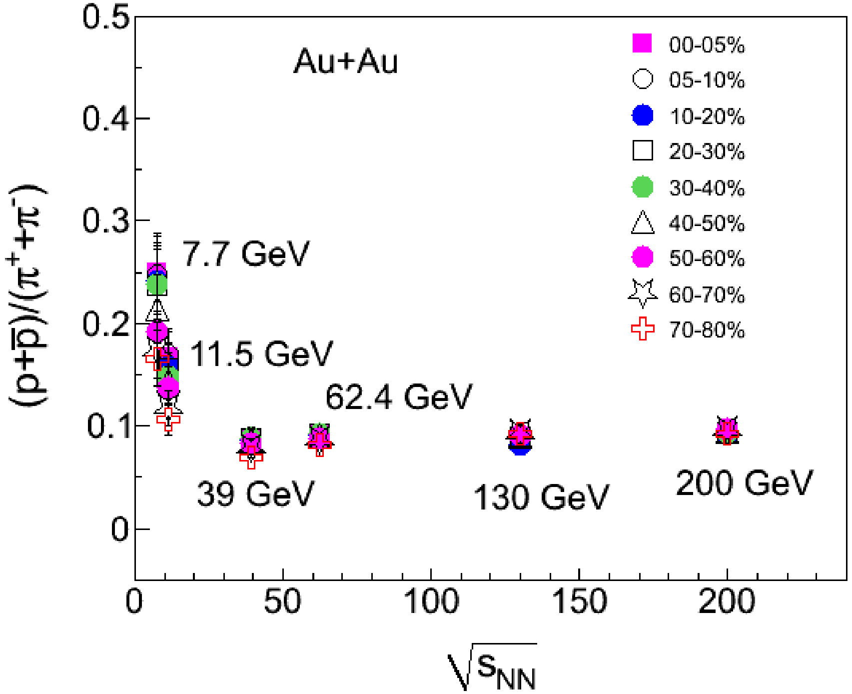
- In-medium modifications
- Chiral symmetry restoration
- Charm correlation
- QGP emissions

Phase-I 2010-2011

Energy	19.6 GeV	27 GeV	39 GeV	62.4 GeV	200 GeV
MB events	35.8M	(70M)	99.4M	54.6M	240M

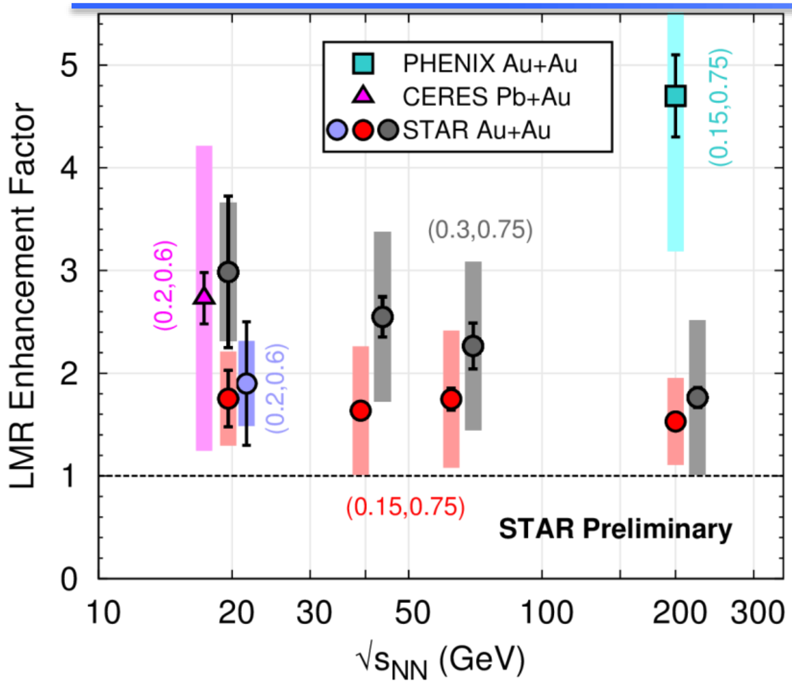
Dielectron production from RHIC BES-I





- RHIC BES-I Program: explore LMR down to SPS energy.
- Observed In-medium modifications in all energies.
- In-medium ρ w/ finite baryon density (nearly constant) describe LMR enhancement well.

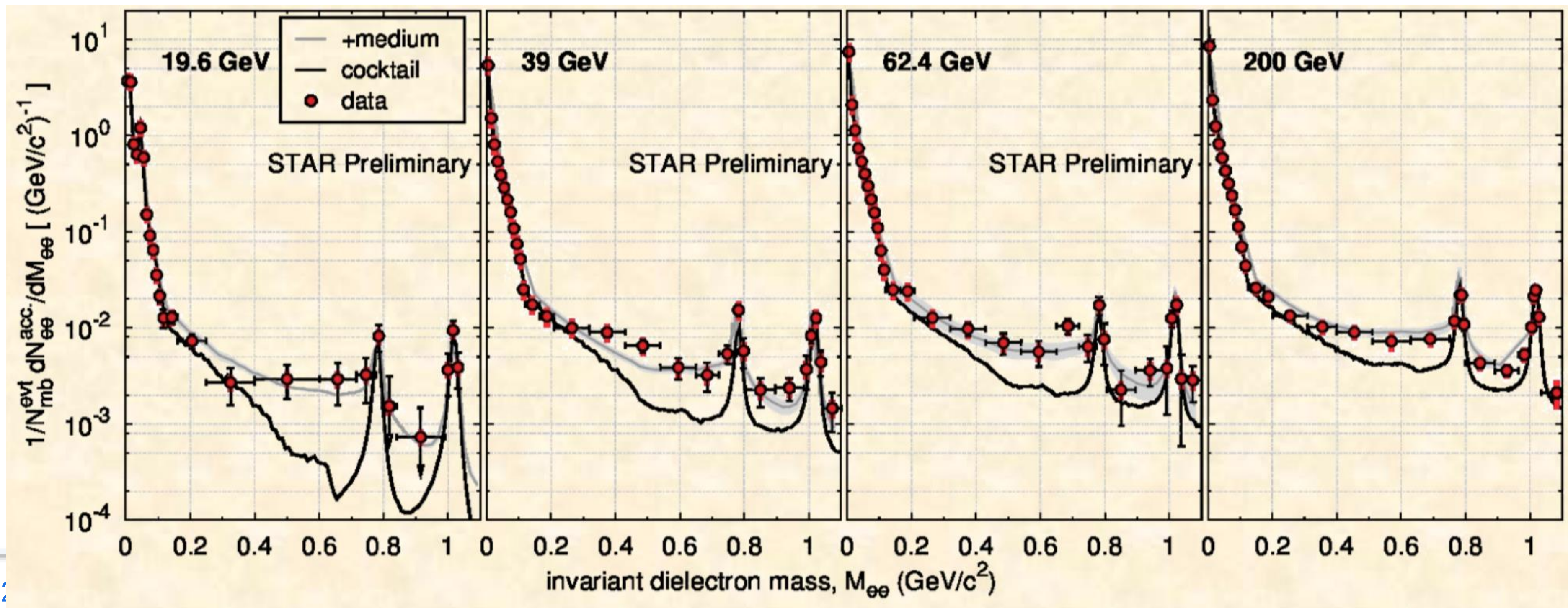
LMR enhancement vs. collision energies



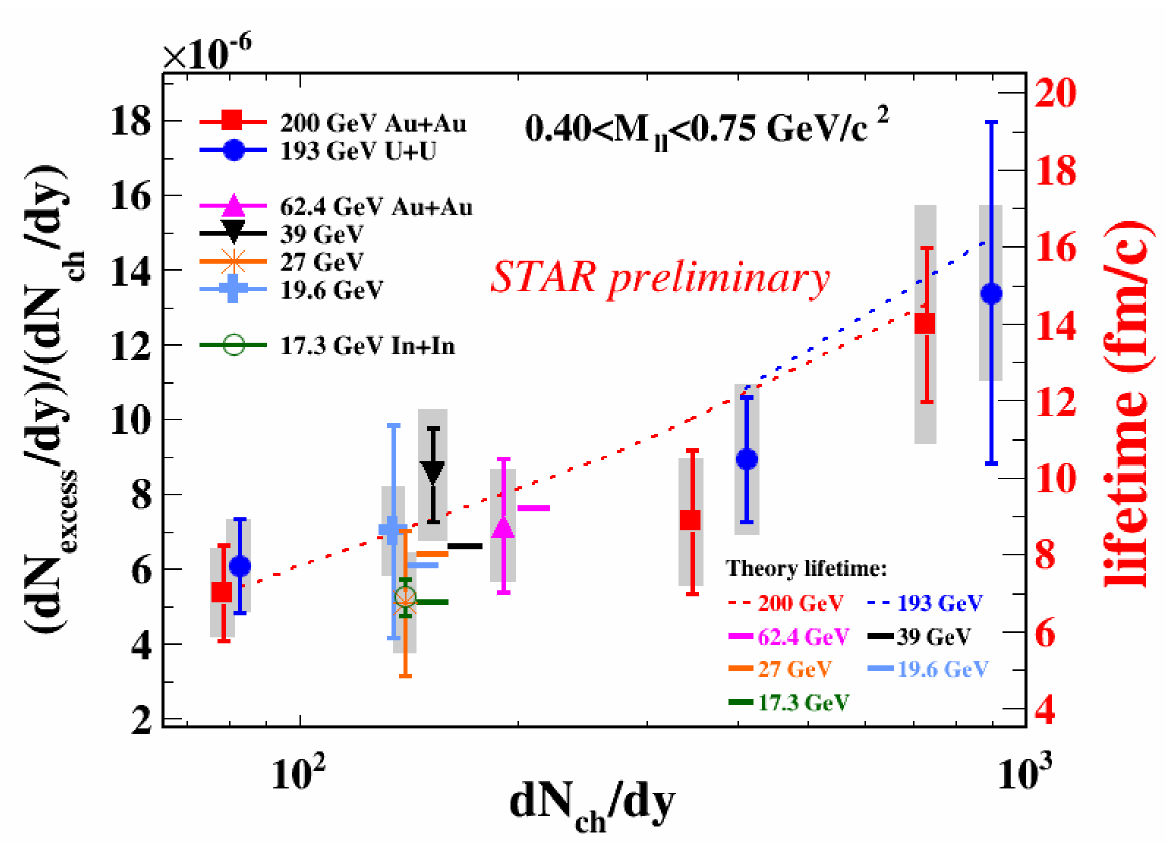
- LMR enhancement factor shows no significant energy dependence from 19.6 to 200 GeV.

- Theoretical calculations of in-medium ρ broadening with total baryon density from 19.6-200 GeV reproduce LMR excesses.

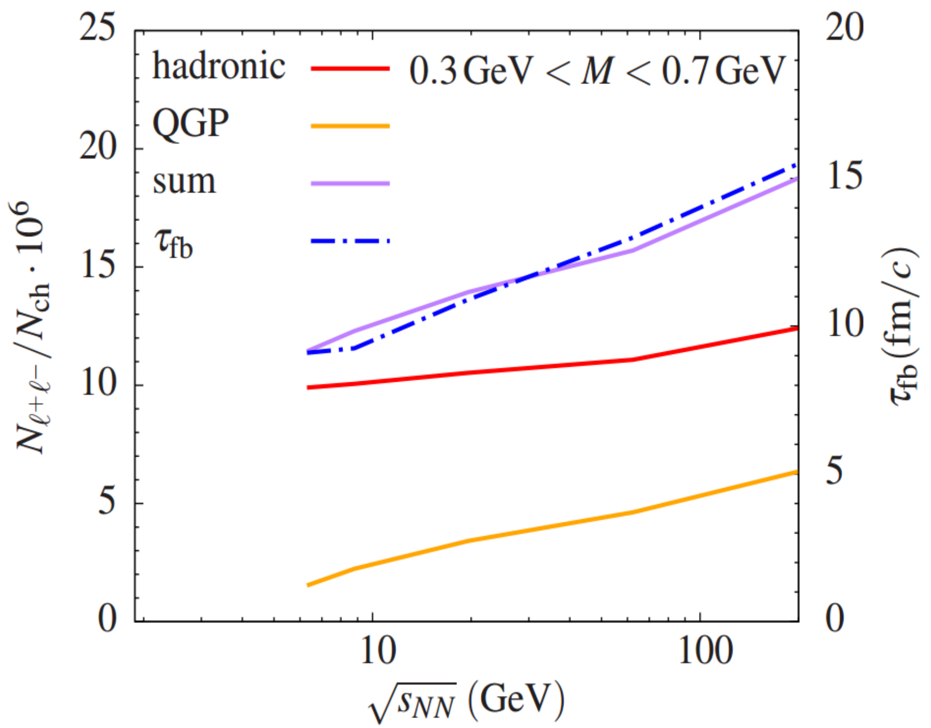
In-medium ρ: Rapp, Adv. Nucl.Phys. 25, 1 (2000)



Excess yield and medium life time



AuAu@200 GeV, 19.6 GeV: *STAR, PLB 750 (2015) 64*
InIn@17.3 GeV: *NA60, Eur. Phys. J. C 59 (2009) 607*
Rapp, van Hees,PLB 753 (2016) 586, arXiv:1411.4612

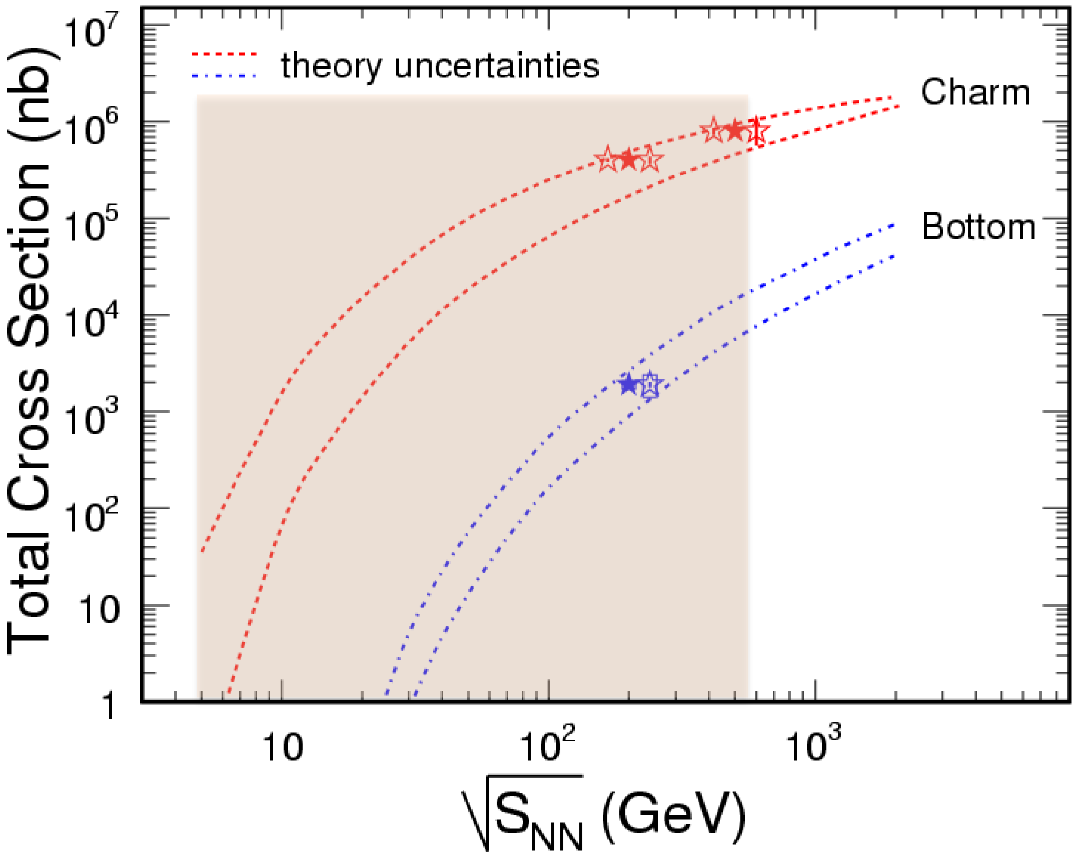


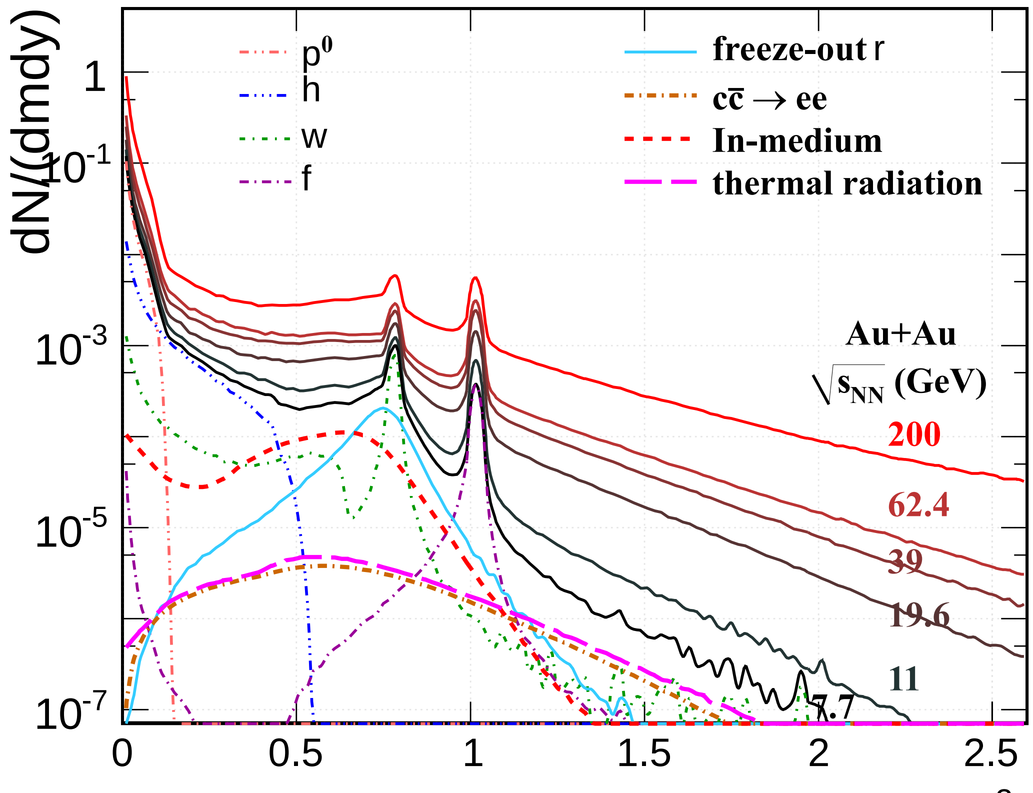
Data agree with model calculations.

The normalized excess yield is proportional to the medium life time (HG+QGP) from 17.3 to 200 GeV.

Nearly constant total baryon density.

Charm production in BES program

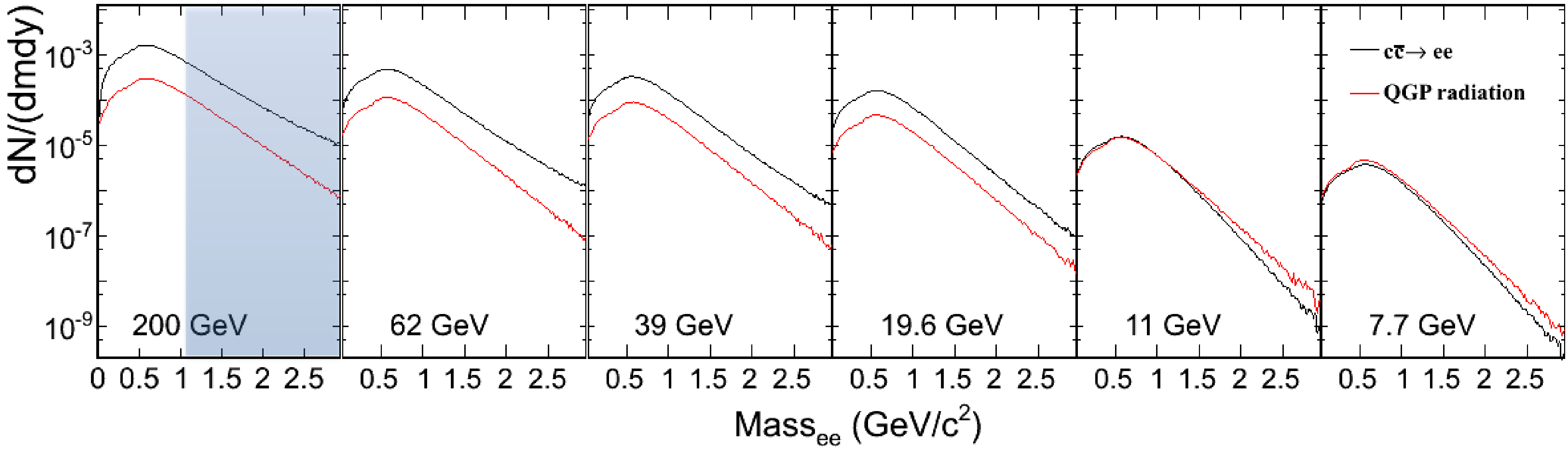


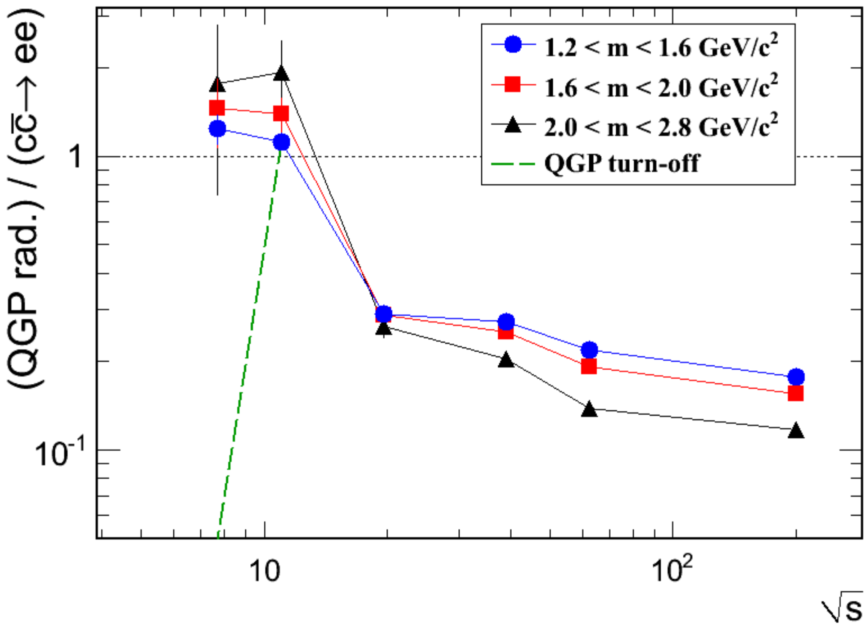


Y. Zhang, CPOD 11

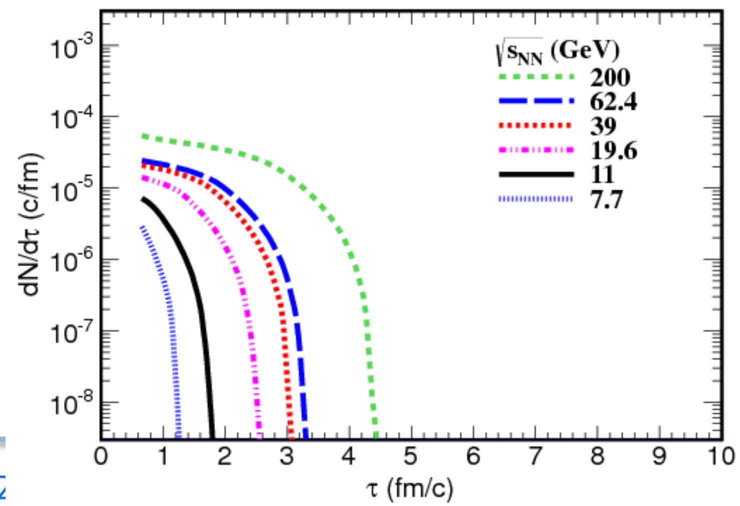
- Precisely measure charm production at top energy.
- Measure charm production in RHIC BES phase-II program.
- Measure charm in-medium modification.
- Not only direct QGP radiation, but also charm correlation itself: expect a different slope evolution of the dilepton at IMR.

IMR signal / background





- ✧ Signal / b.g. ratio is ~ a few percent in higher energies.
- ✧ Signal enhanced in lower energy, relative large emission rate even for a short-lived QGP system.
- ✧ Test possible phase transition.

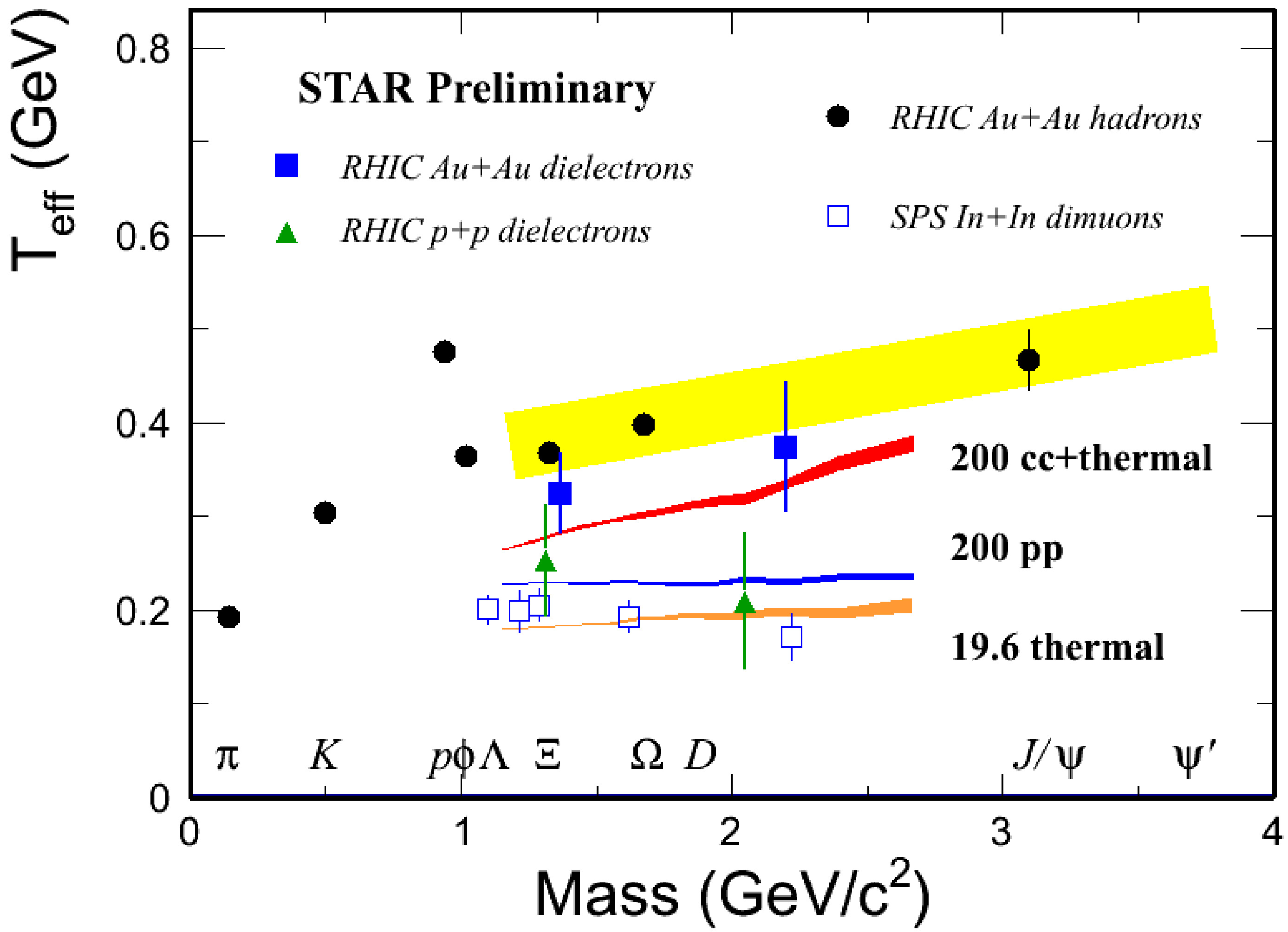


2+1D hydro:

B. Schenke, *et. al.*, PRC82, 014903 (2010)

H. Xu, *et al.*, PRC 85 024906 (2012)

m_T slope of in the IMR



Y. Zhang CEJP 10(6), 2012

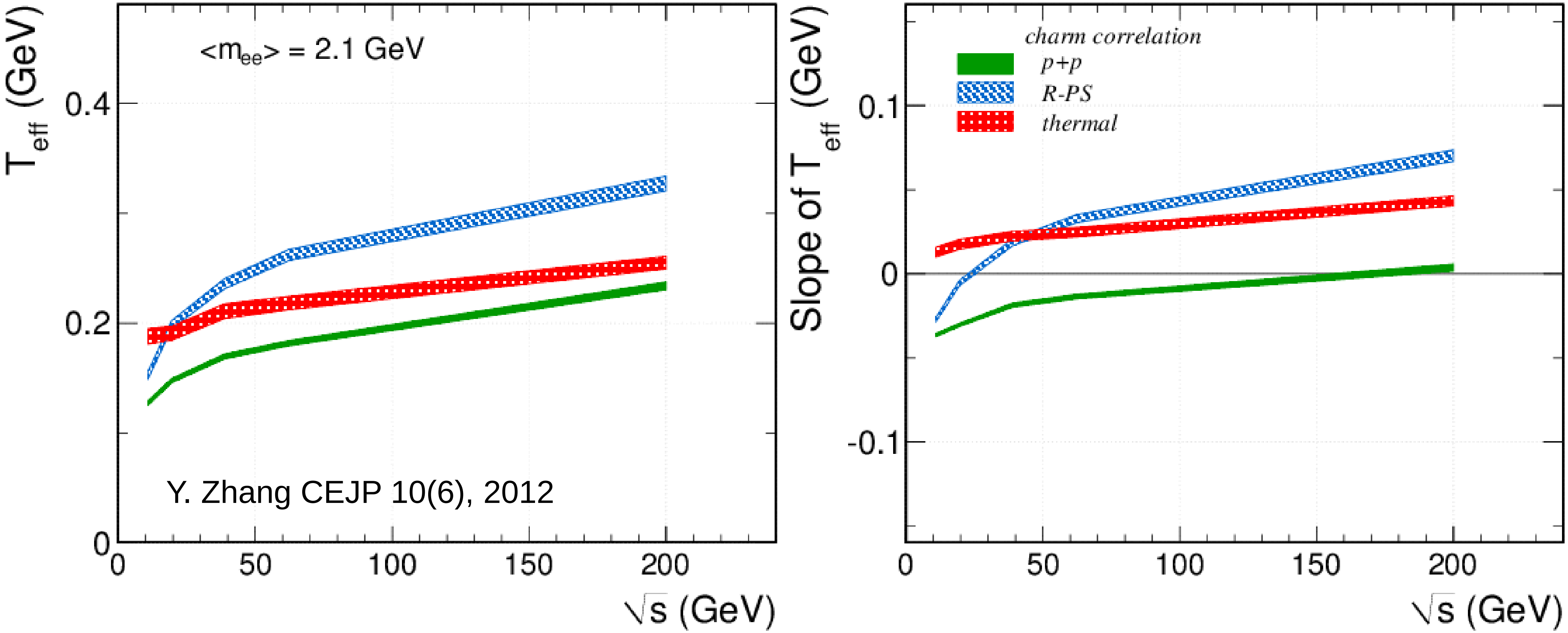
Au+Au: ccbar random phase modification + thermal

p+p: PYTHIA

thermal: 2+1D hydro

Within errors 19.6 GeV agrees with NA60 (~17 GeV), but seems different trend.
Charm correlation in p+p is consistent with STAR p+p data (QM11).
Charm correlation modified by medium. Thermal + charm reproduce STAR Au+Au data well.

Possible observation at phase transition?

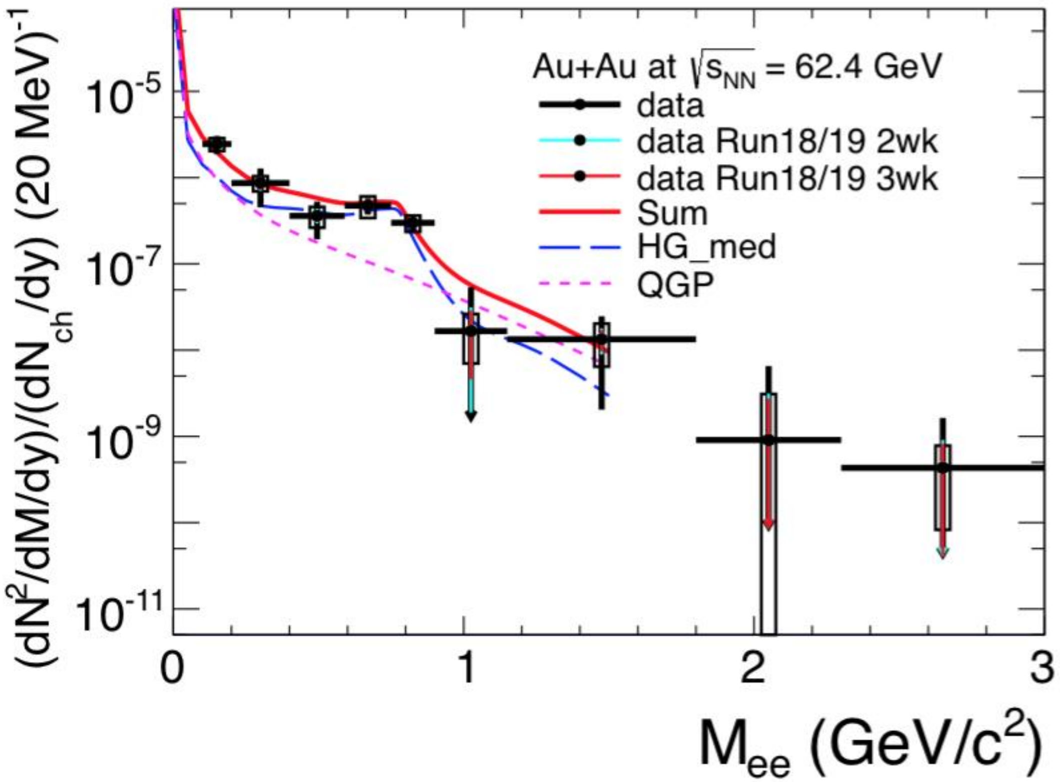


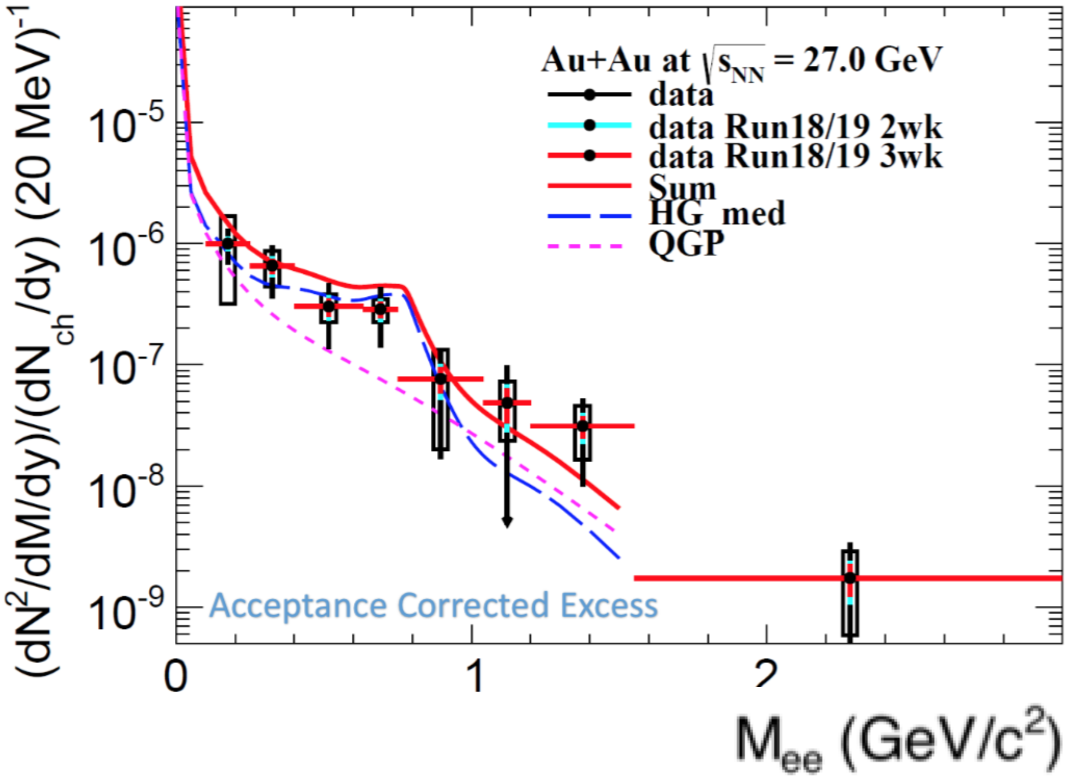
High energy dominant by charm correlation, lower energy charm and thermal contributions are comparable.

Both T_{eff} and its slope in medium are significant higher than the system w/o medium.

Phase transition could happen if the T_{eff} increases dramatically or the sign of its slope changes from negative to positive.

Projection of Run 18&19





- With 2-3 weeks data taken, the low mass statistics will be significantly improved.
- Possible access for QGP radiation component at IMR.

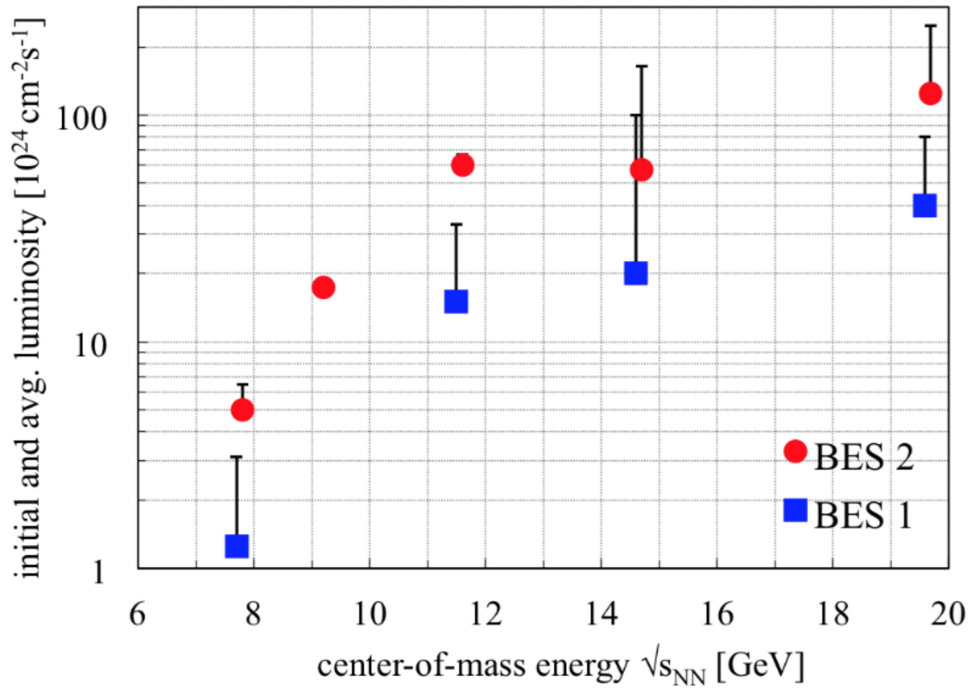
BES Phase II

✧ Electron cooling will provide increased luminosity.

✧ iTPC + HFT + MTD upgrades

✧ Enables increased statistics for the BES energies

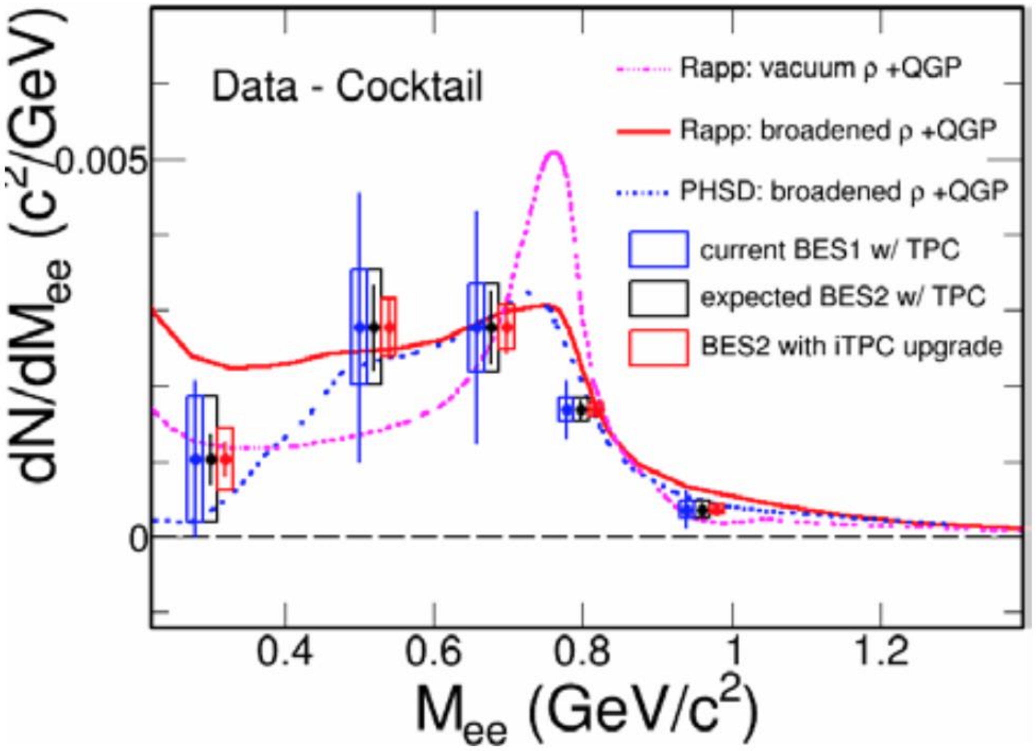
✧ Statistics enriched data for rare probes, especially for dilepton measurements.

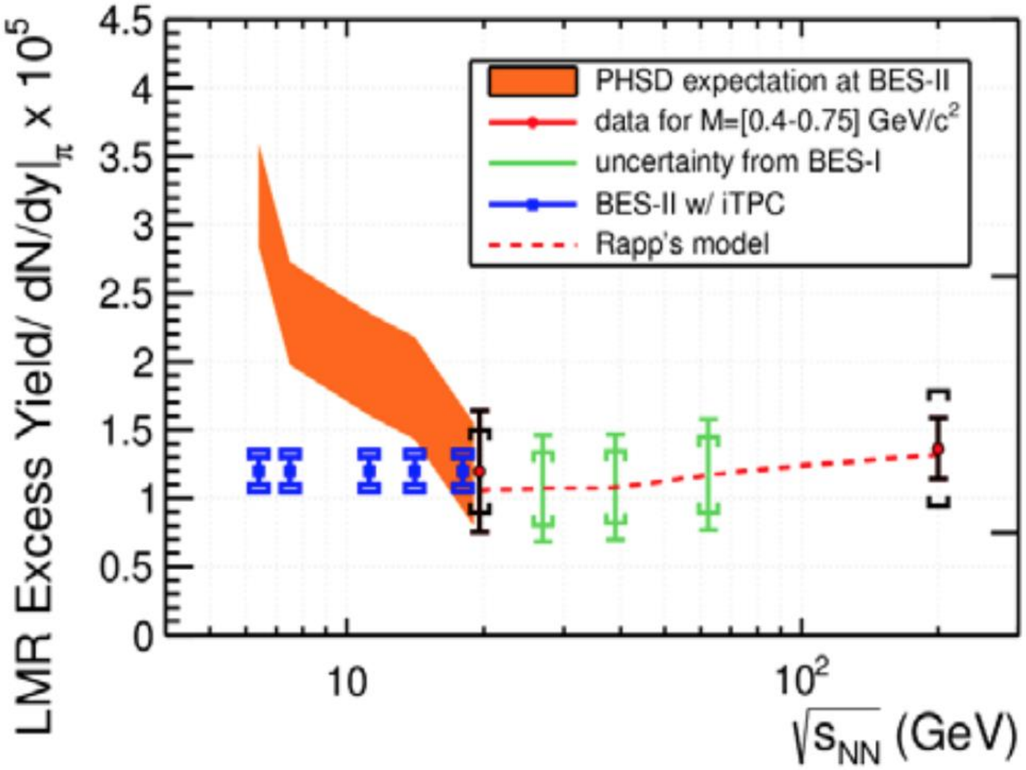


Proposed energies for BES-II (Years 2019-2020):

$\sqrt{s_{NN}}$ (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV)	420	370	315	250	205
BES II (MEvts)	100	160	230	300	400

Projection with iTPC for BES-II





- Systematically study dielectron continuum from 7.7 – 19.6 GeV.
- Inner Time Projection Chamber (iTPC) upgrade: reduce uncertainties.
- Quantify different models.
- Study total baryon density effect at lower energies from BES-II.

Summary

✧ Dielectron mass spectra in 19.6 - 200 GeV Au+Au collisions and 193 GeV U+U collisions were measured by RHIC-STAR.

✧ Low mass enhancement was observed and can be well described by model calculations with broadening ρ mass spectra function for all collision energies and systems at RHIC and SPS.

✧ The normalized excess yield is proportional to the medium life time from 17.3 to 200 GeV Au+Au collisions and 193 GeV U+U collisions.

✧ STAR future Runs and upgrades enable further exploration of the dilepton continuum.

-- QGP thermal radiation

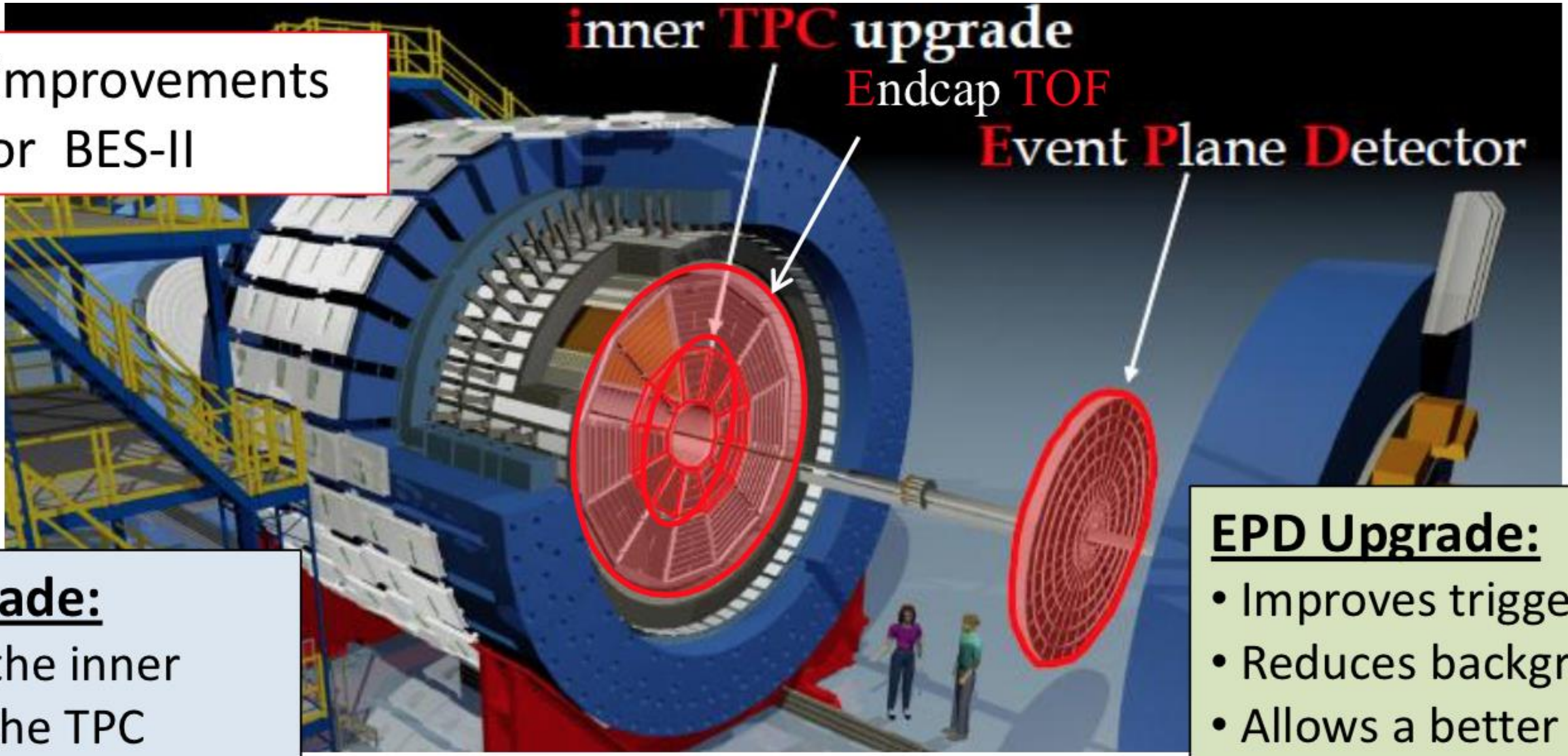
-- Correlated charm modifications

Thank you!

Backup Slides

STAR upgrades for BES-II

Major improvements for BES-II

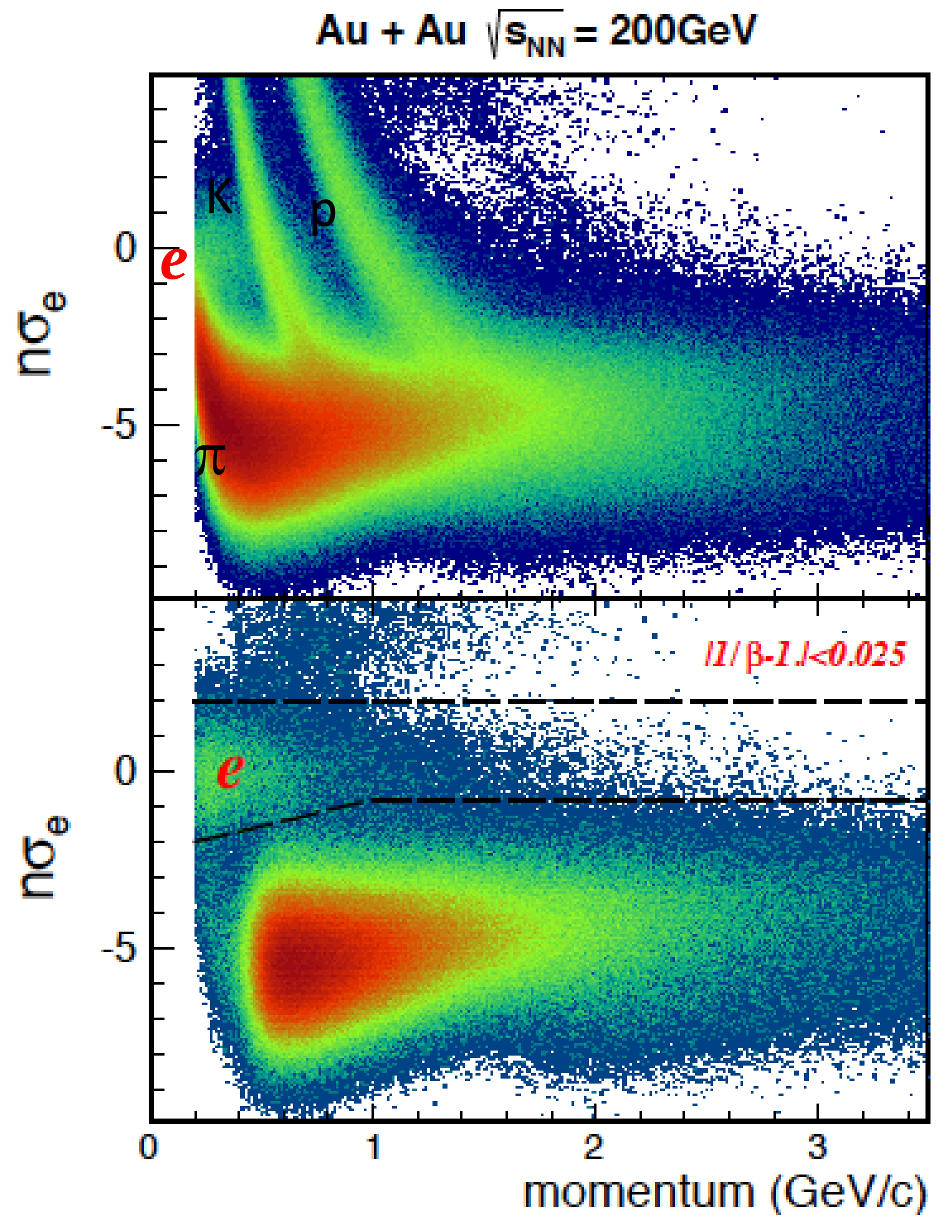


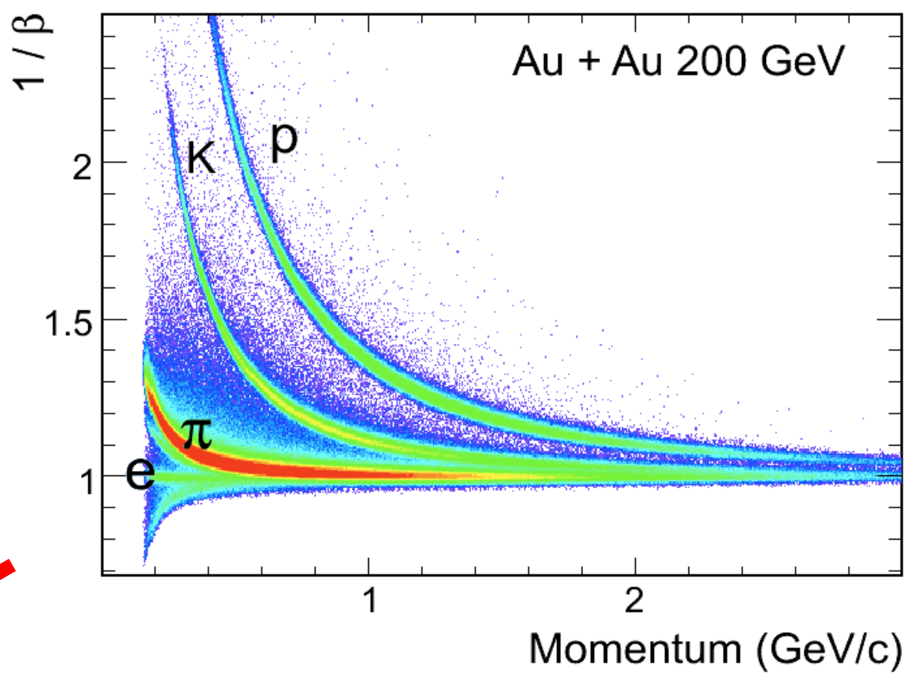
iTPC Upgrade:
- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut-in from 125 MeV/c to 60 MeV/c

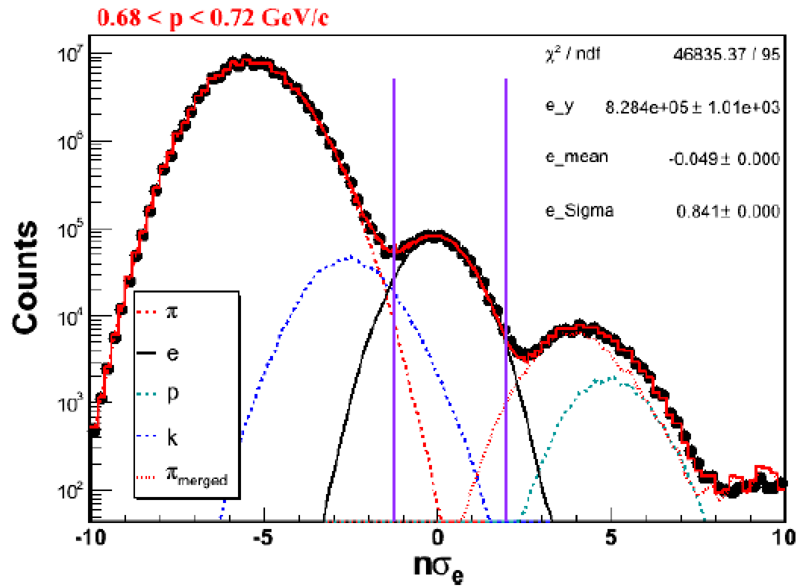
EndCap TOF Upgrade:
- Rapidity coverage is critical
- PID at forward rapidity
- Improves the fixed target program

EPD Upgrade:
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics

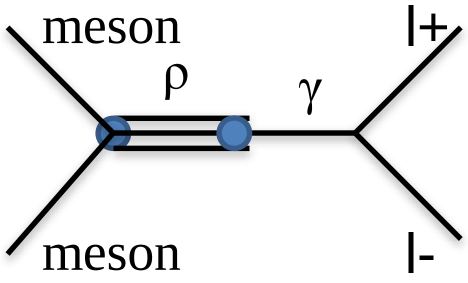
Electron Identification







ρ broadening



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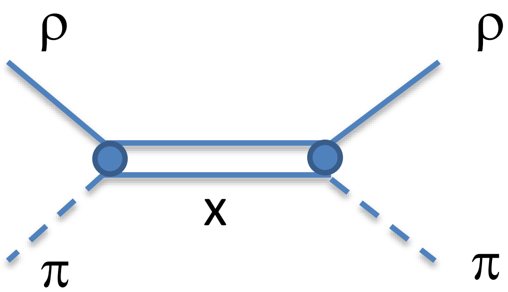

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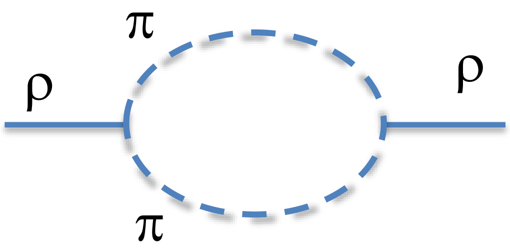

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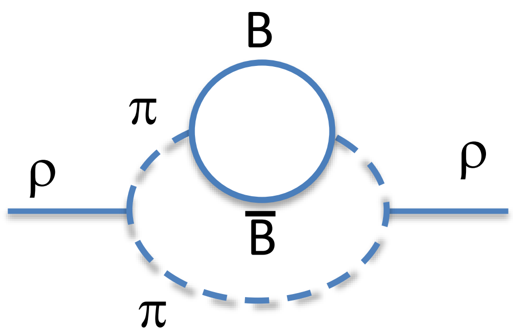


ρ self-energy changes due to interactions with medium.

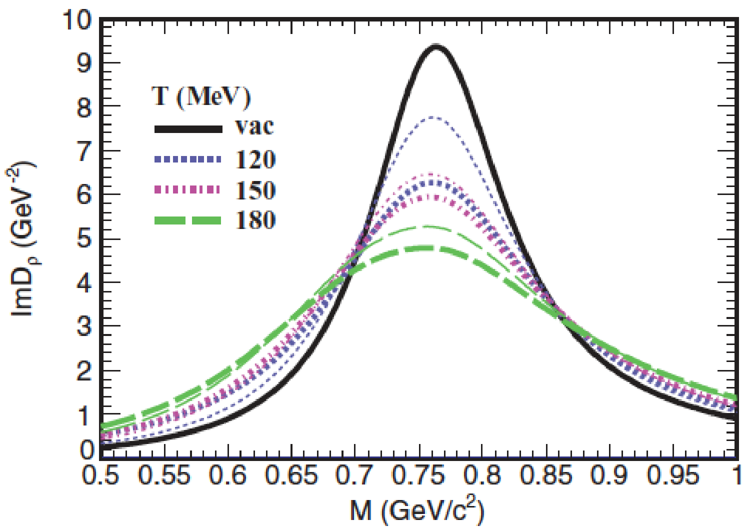
ρ interaction with meson gas.

ρ pionic decays.

pion-baryon scatterings.

Emission rate:
$$\frac{dN_{ll}}{d^4x d^4p} = -\frac{\alpha}{4\pi^4}\frac{1}{M^2}n_B(p\cdot u)\left(1+\frac{2m_l^2}{M^2}\right) \times\sqrt{1-\frac{4m_l^2}{M^2}}\,\mathrm{Im}\Pi^R(p,T).$$

V-m propagator:
$$\mathrm{Im}D_V^R = \frac{\mathrm{Im}\Pi_V^R}{\left(p^2-m_V^2+\mathrm{Re}\Pi_V^R\right)^2+\left(\mathrm{Im}\Pi_V^R\right)^2},$$

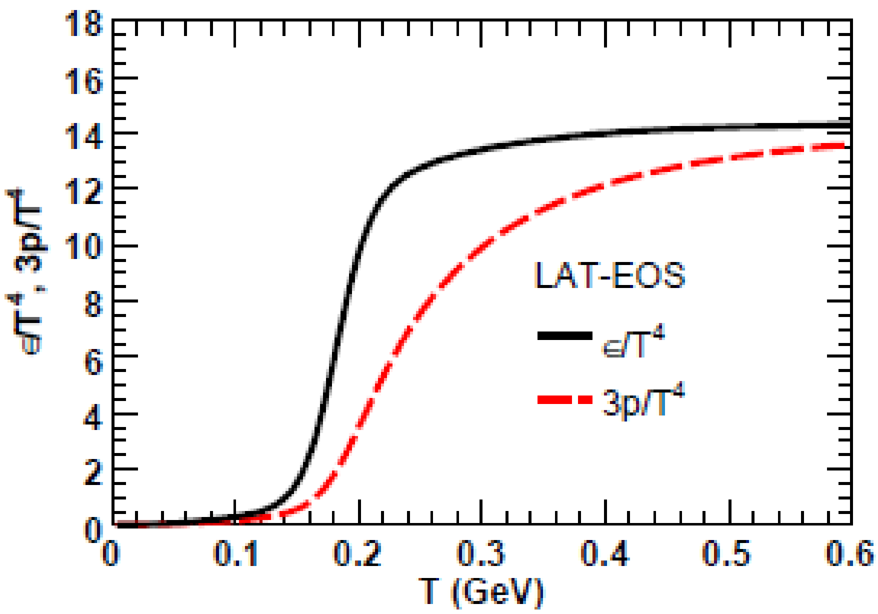


H. Xu, *et al.*, Phys. Rev. C 85 024906 (2012)

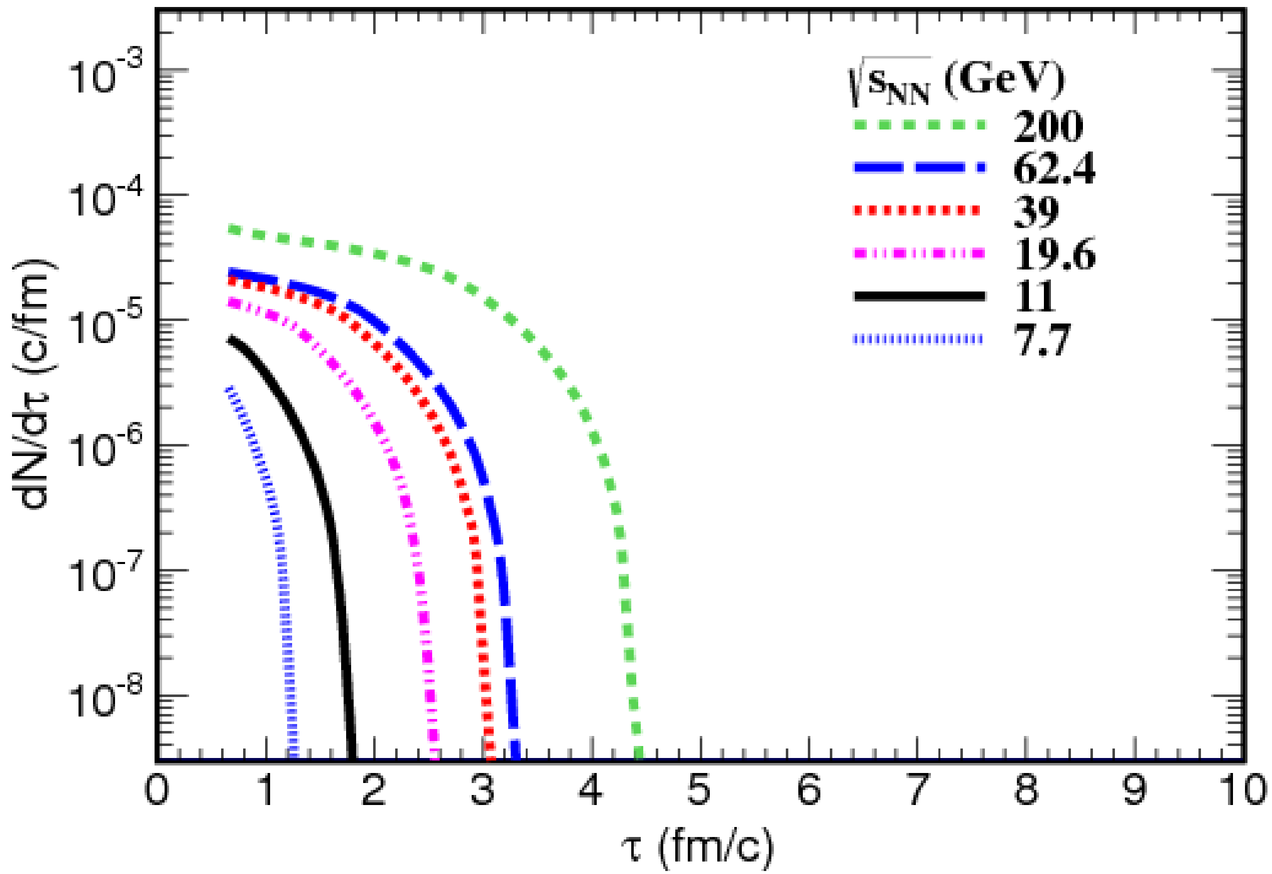
Space-time evolution

B. Schenke, et. al., PRC82, 014903 (2010)

(2+1)D ideal hydrodynamics
Lattice EOS
Parameters: S95P-PCE

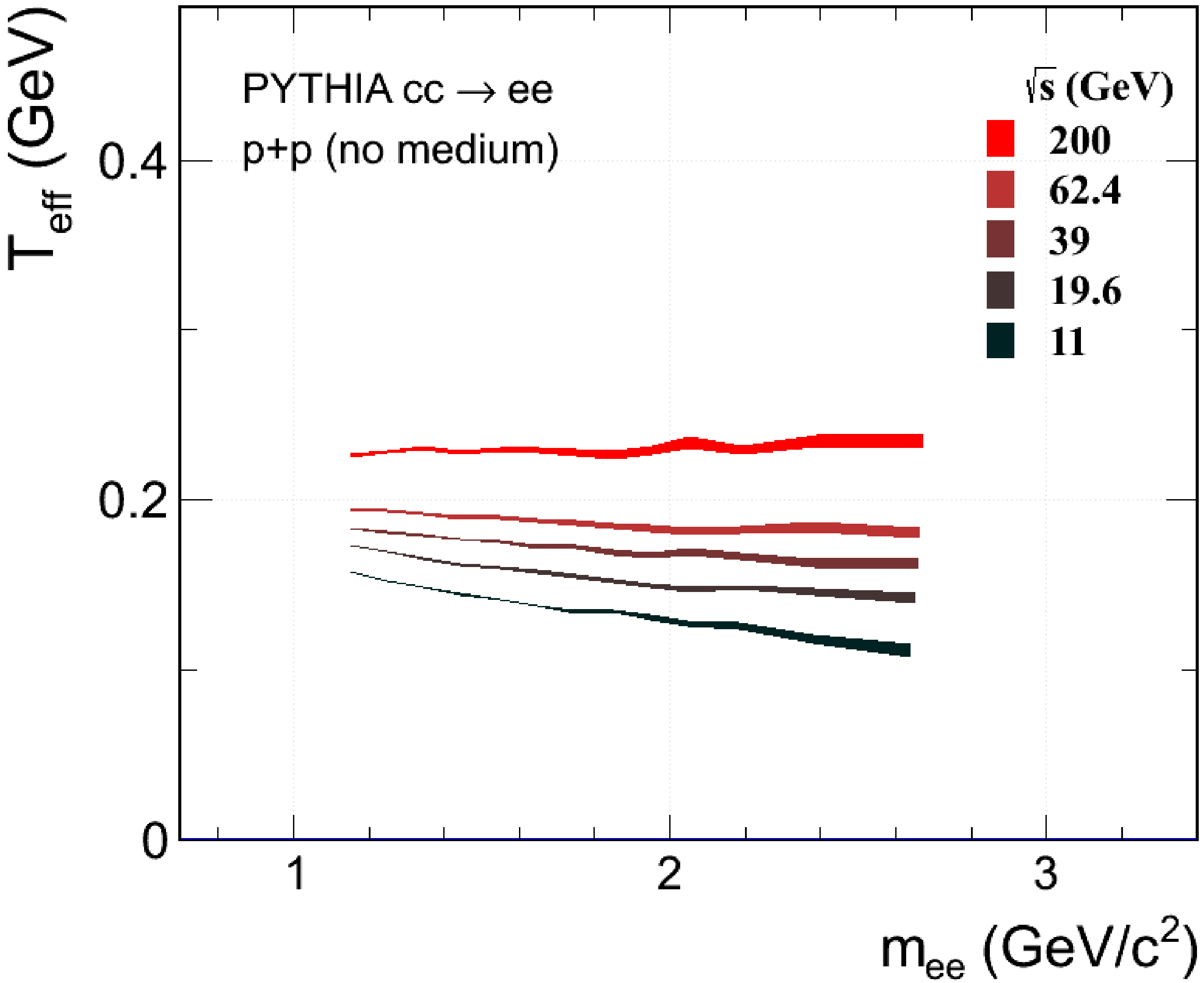


P. Huovinen and P. Petreczky, NPA837 (2010) 26.



Higher energy =>
larger initial temperature
longer evolution time.

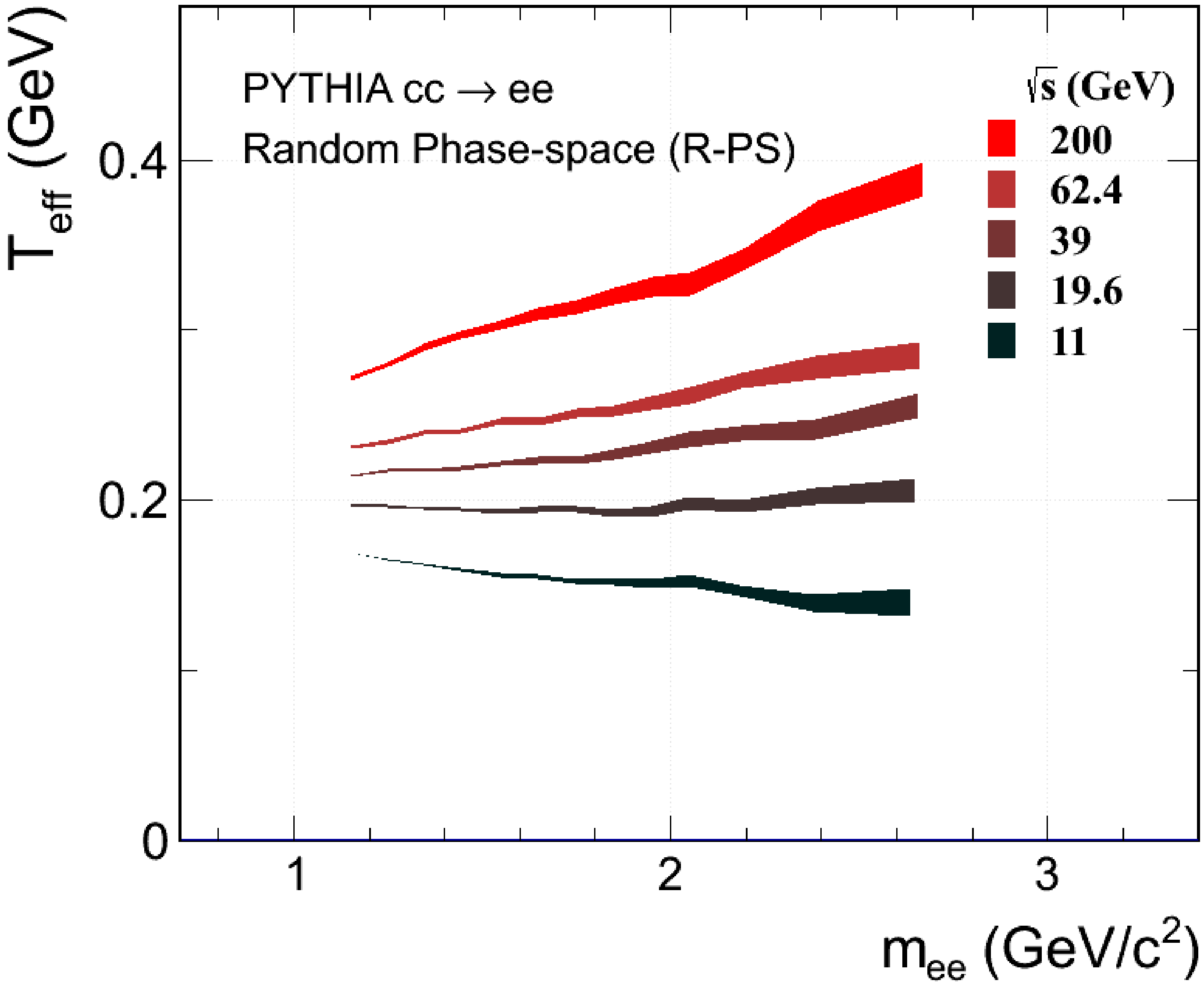
m_T slope of in the IMR



Y. Zhang CPOD2011

p+p from PYTHIA always shows decreasing vs. mass.

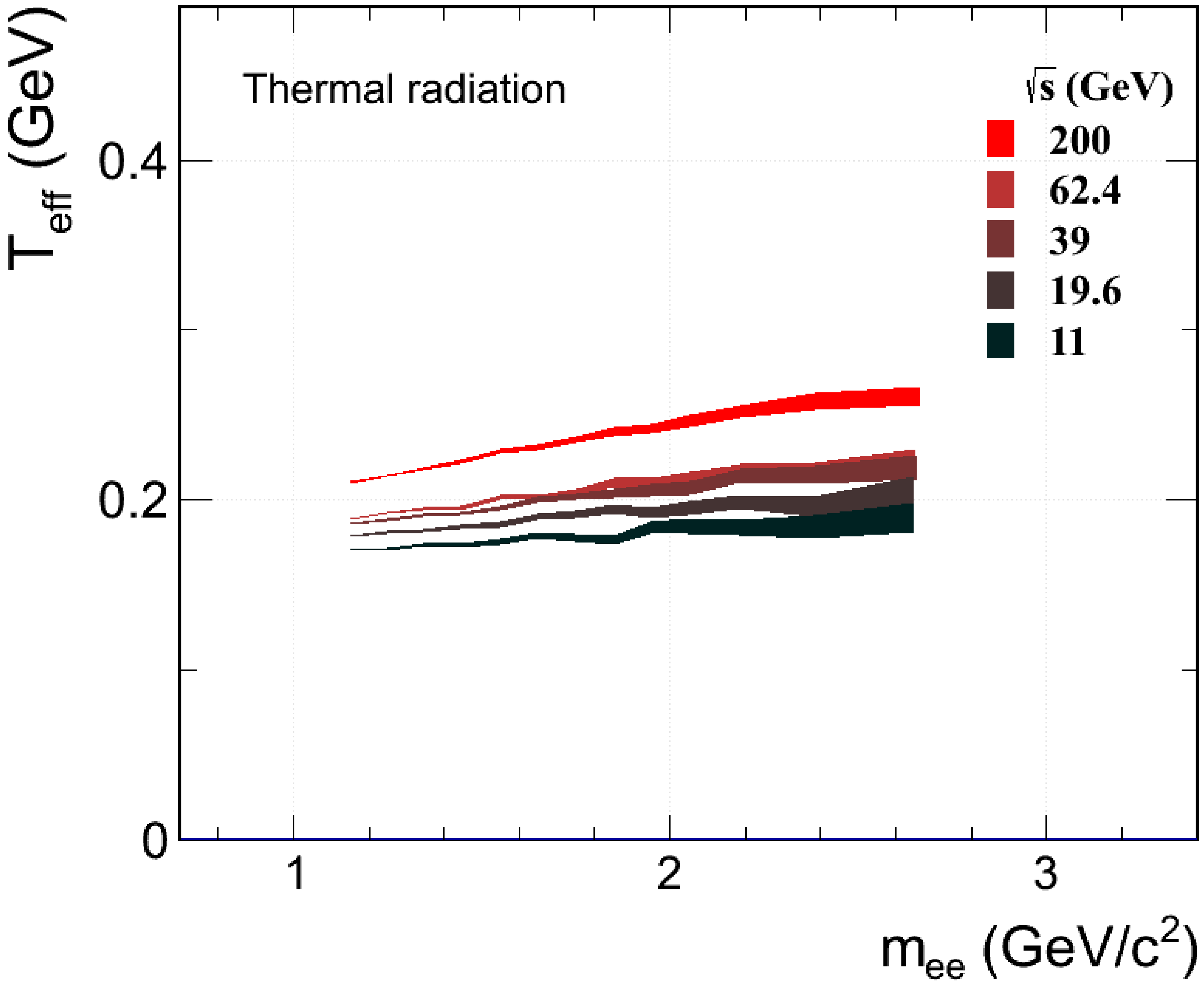
m_T slope of in the IMR



Y. Zhang CPOD2011

Assuming the angular correlation of the decay products is totally washed out in the medium, it gives much larger temperature and stronger energy dependence.

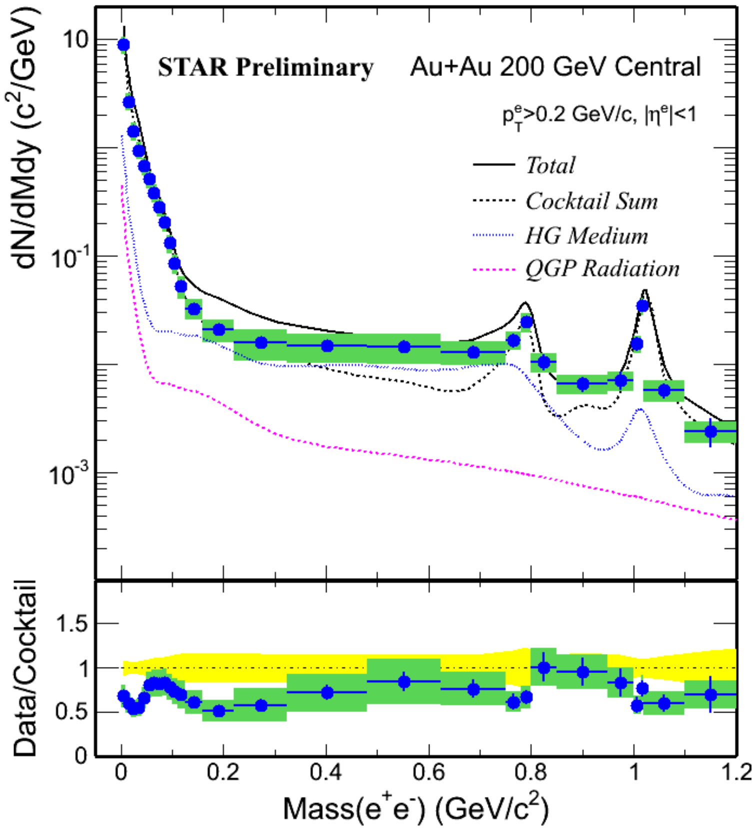
m_T slope of in the IMR



Y. Zhang CPOD2011

2+1D hydrodynamics gives weaker energy dependence, but always increases vs. mass.

Model calculations (I)



Ralf Rapp (priv. comm.)

R. Rapp, Phys.Rev. C 63 (2001) 054907

R. Rapp & J. Wambach, EPJ A 6 (1999) 415

Complete evolution:

Cocktail (in vacuum) + HG + QGP =>

- ρ "melts" when extrapolated close to phase transition boundary.

- agreement w/in uncertainties.

H. Xu, Q. Wang (priv. comm.)

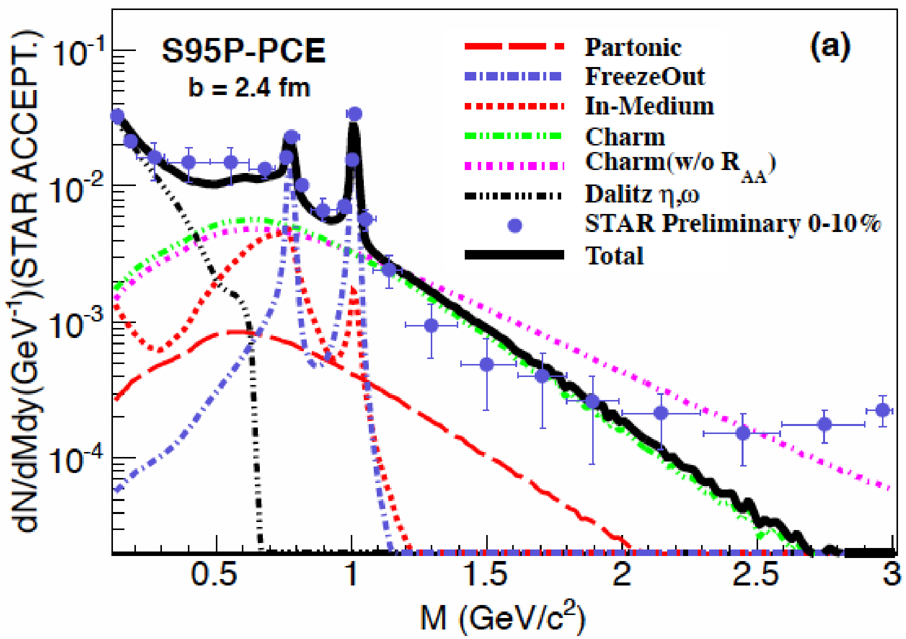
H. Xu, *et al.*, Phys. Rev. C 85 024906 (2012).

In-medium ρ: Multi-body effective theory

Partonic (QGP): 2+1D ideal hydro

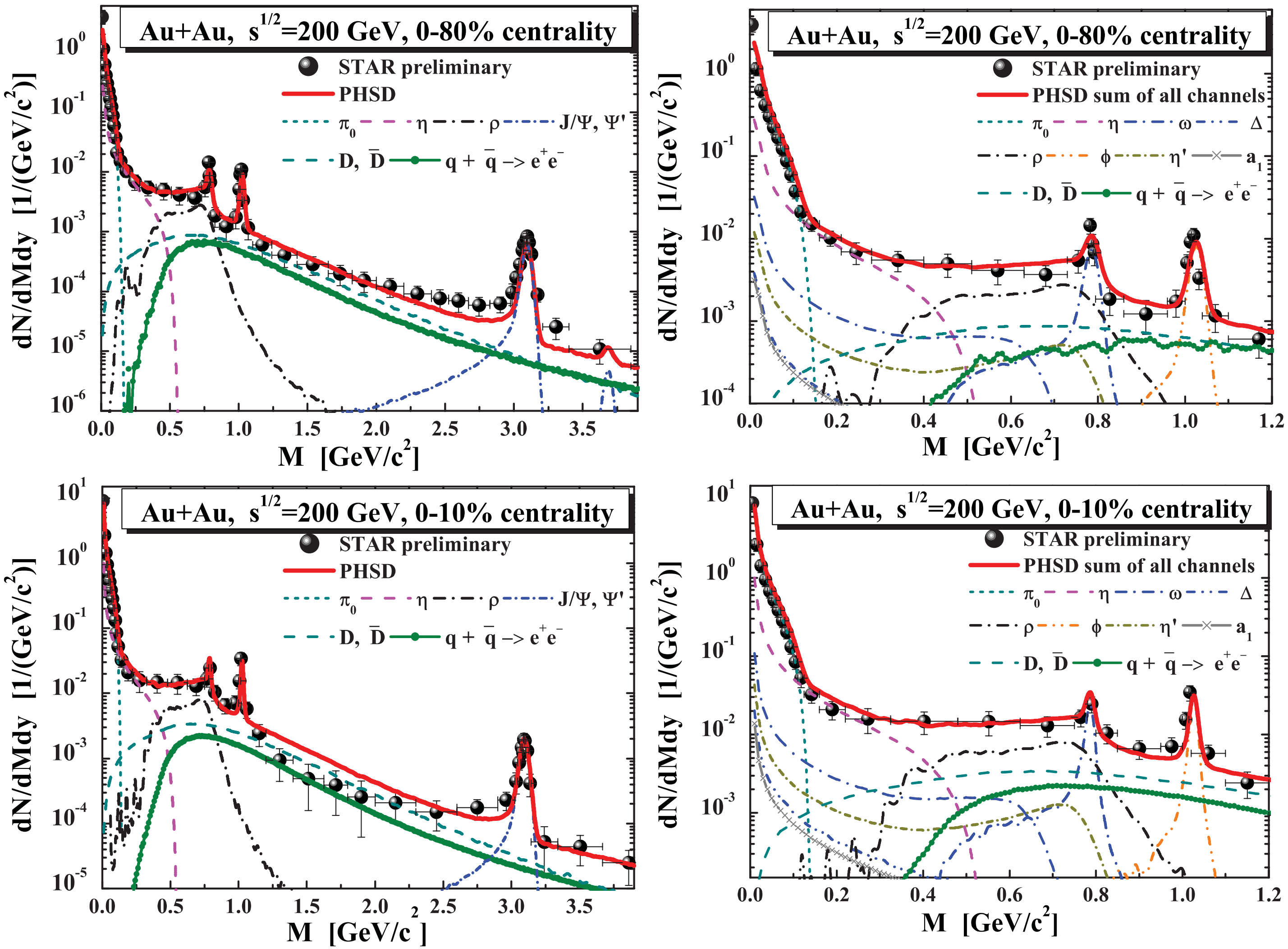
FreezeOut + IM + QGP =>

- agree w/in uncertainties.



O. Linnyk et al., Phys. Rev. C 85 024910 (2012)

Parton-Hadron String-Dynamics



1. Collisional broadening of vector mesons
2. Radiation from QGP

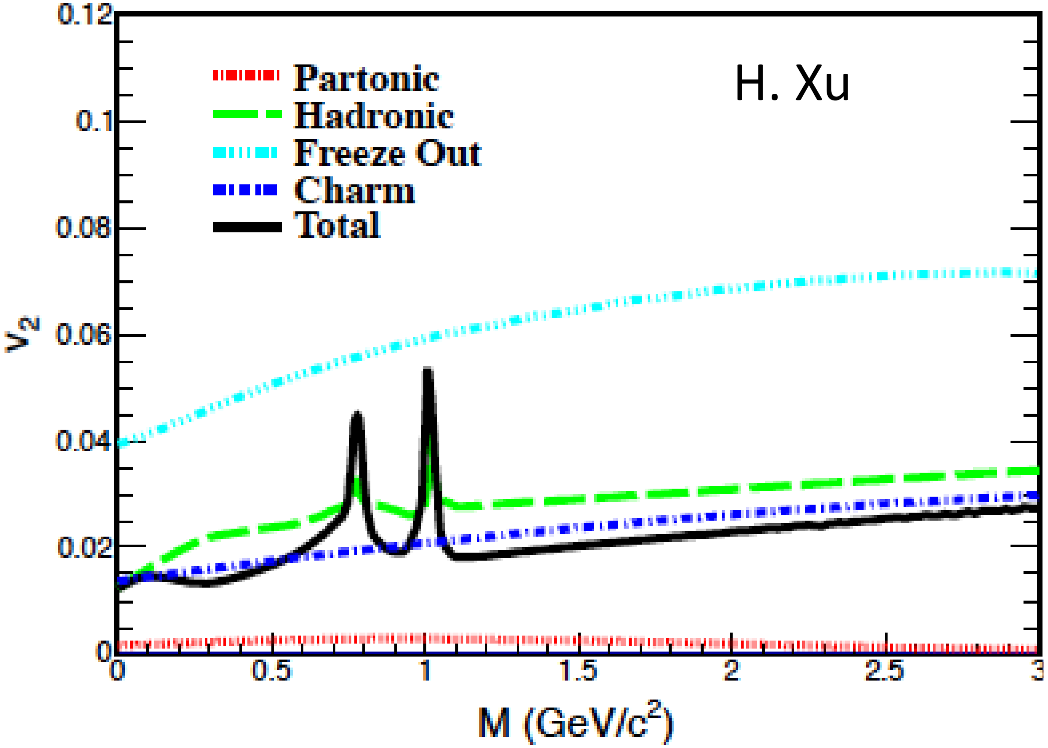
Minimum bias collisions (0-80%):

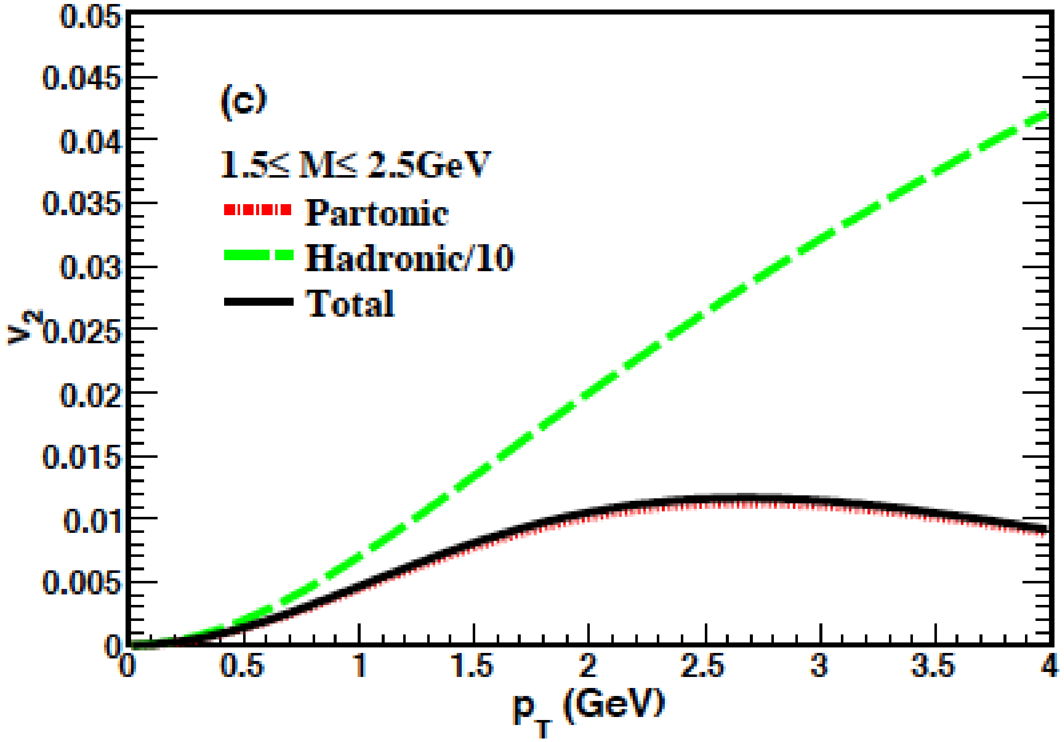
- Generally good agreement

Central collisions (0-10%):

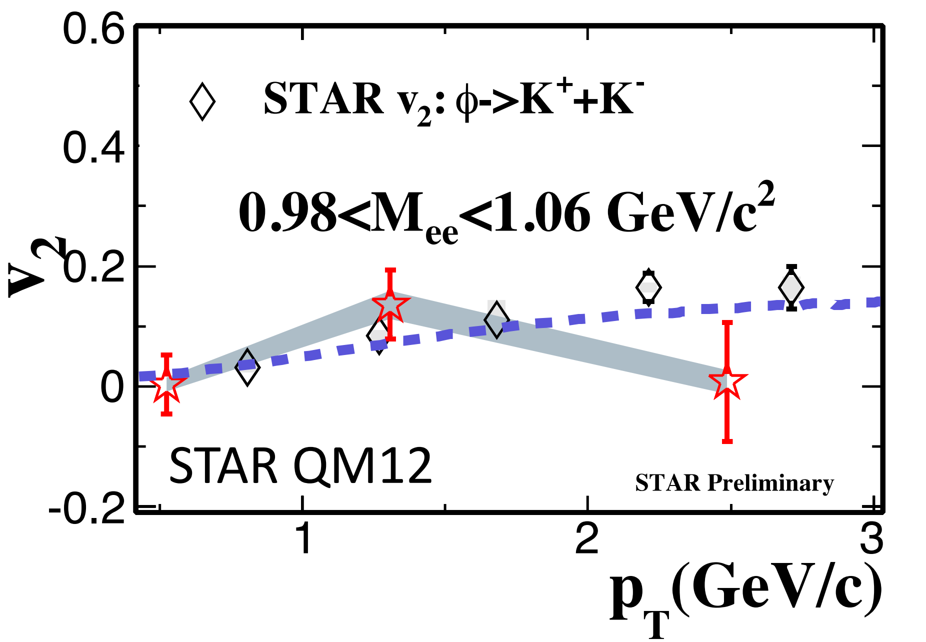
- PHSD roughly in line with LMR region
- Similar as STAR cocktail, overshot IMR.

Di-electron v_2



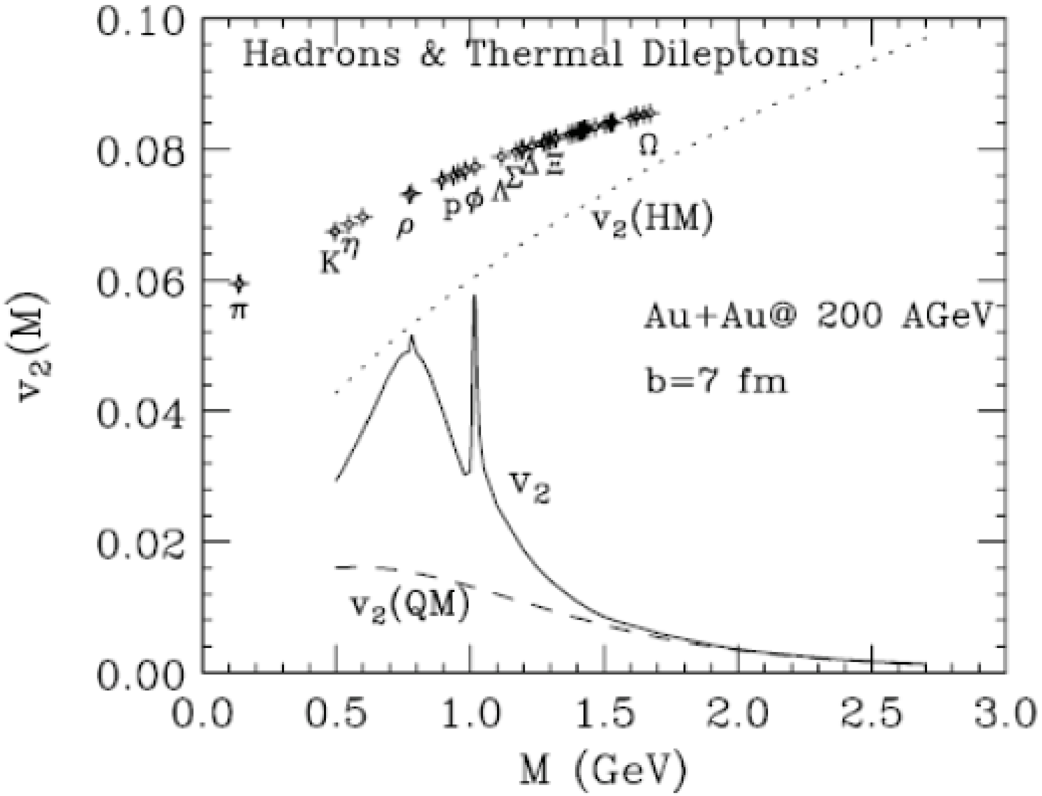


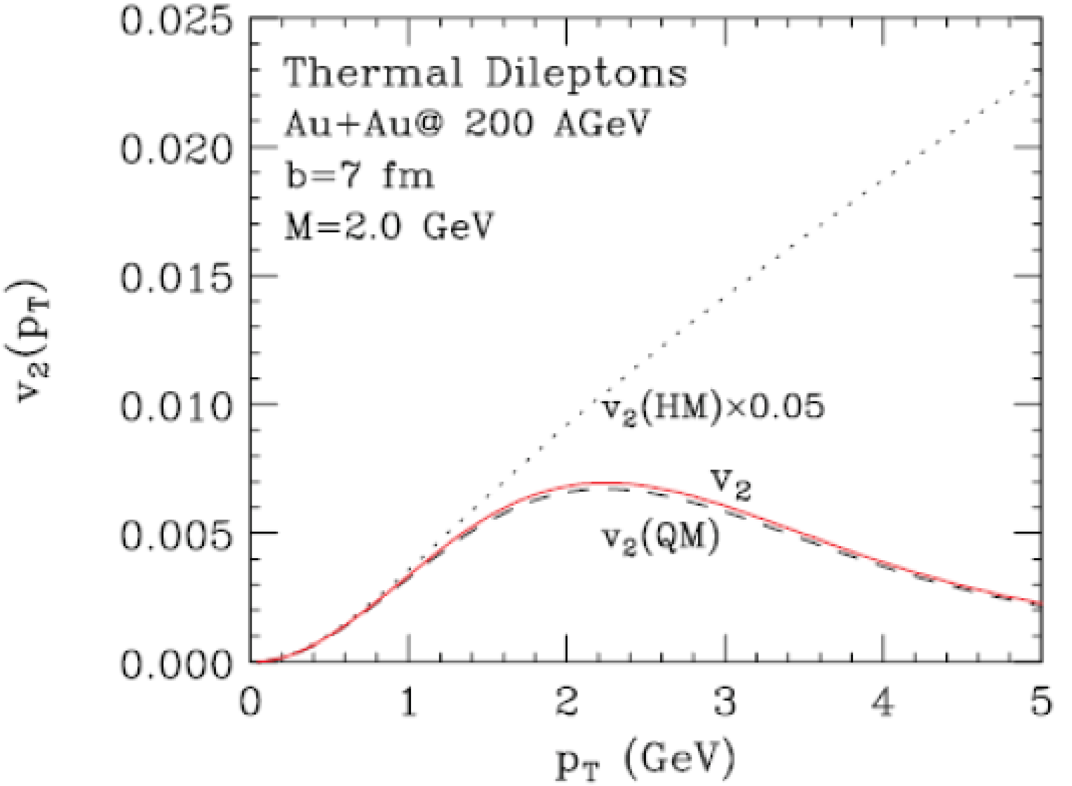
- Sensitivity to separate hadronic/partonic.
- Experimental data M_{ee} < ~ 1 GeV/c, expecting more statistics + upgrade for IMR and high p_T.



Introduction: hadronic vs partonic

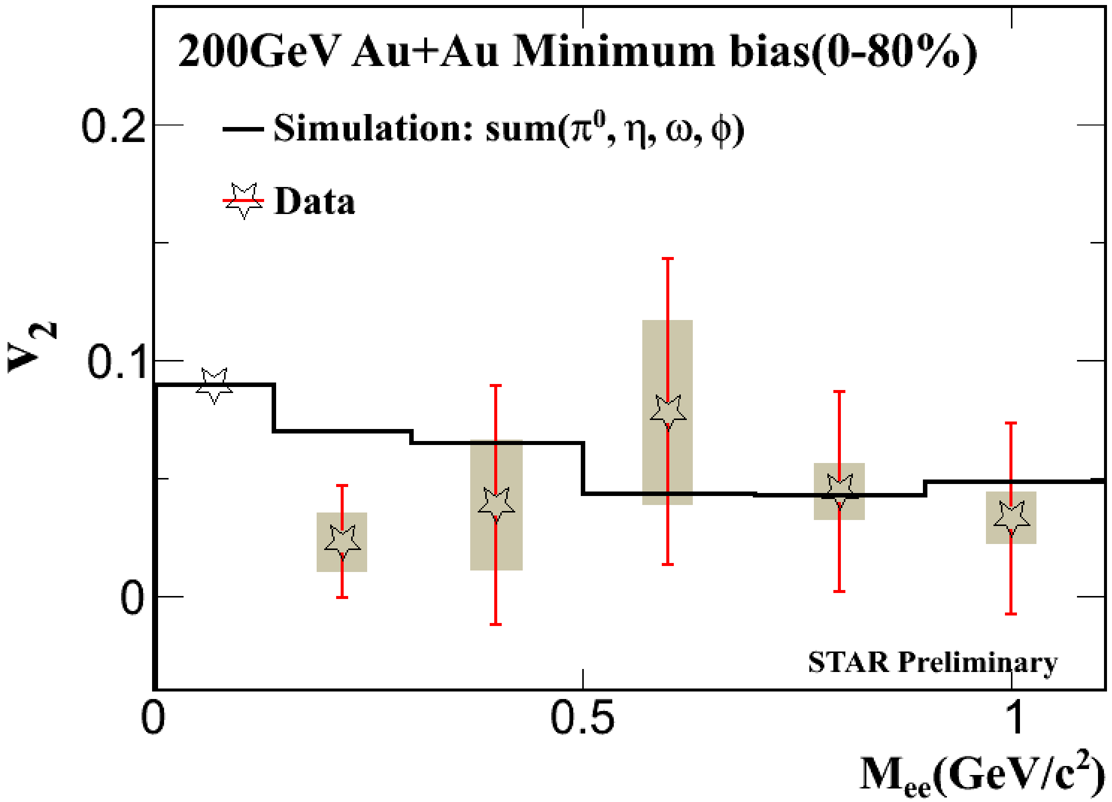
Rupa Chatterjee , et al., *Phys Rev C 75, 054909 (2007)*





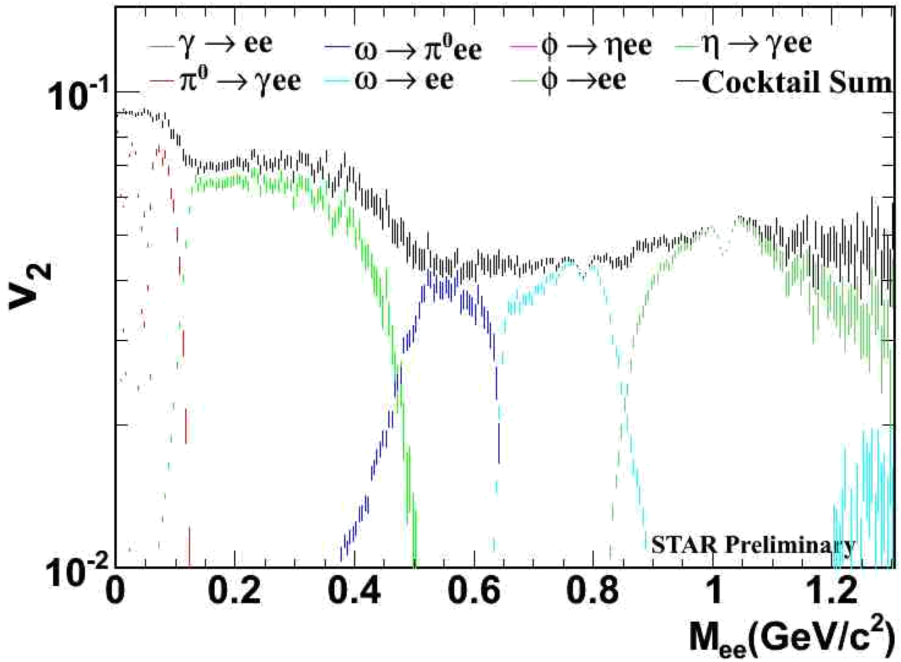
- ✧ Di-lepton produced in every stage of the time-space evolution, its v_2 contains integrated information of the fireball expansion.
- ✧ Its differential v_2 in (mass, p_T) dimension could help us distinguish partonic and hadronic radiation sources.

Di-electron v_2 in Au+Au 200 GeV

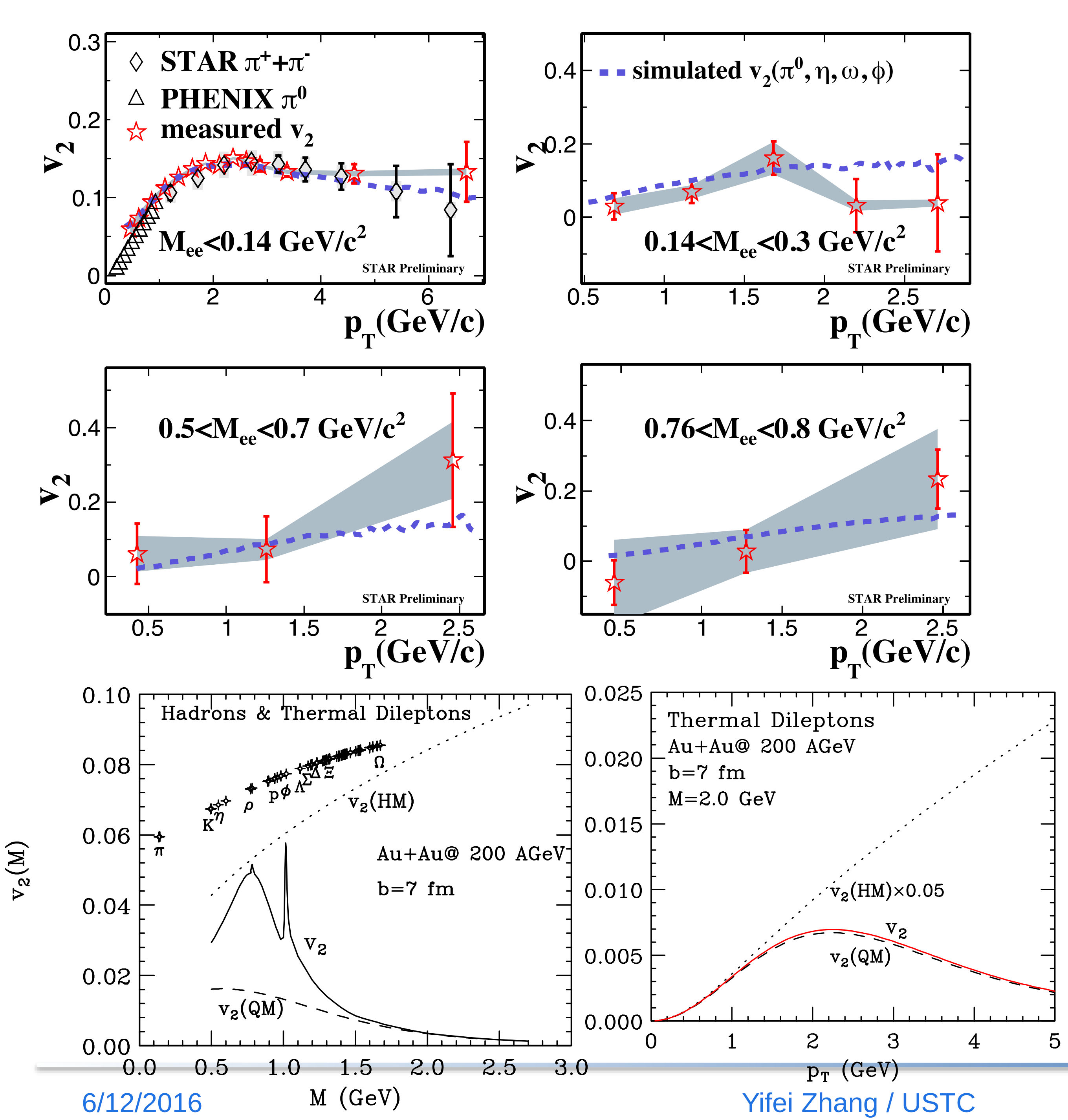


- First measurement from STAR.
- TPC event-plane method.
- Consistent with cocktail simulation with mesons decay in vacuum.

Current precision does not allow to study medium modification.



Di-electron v_2 p_T dependence

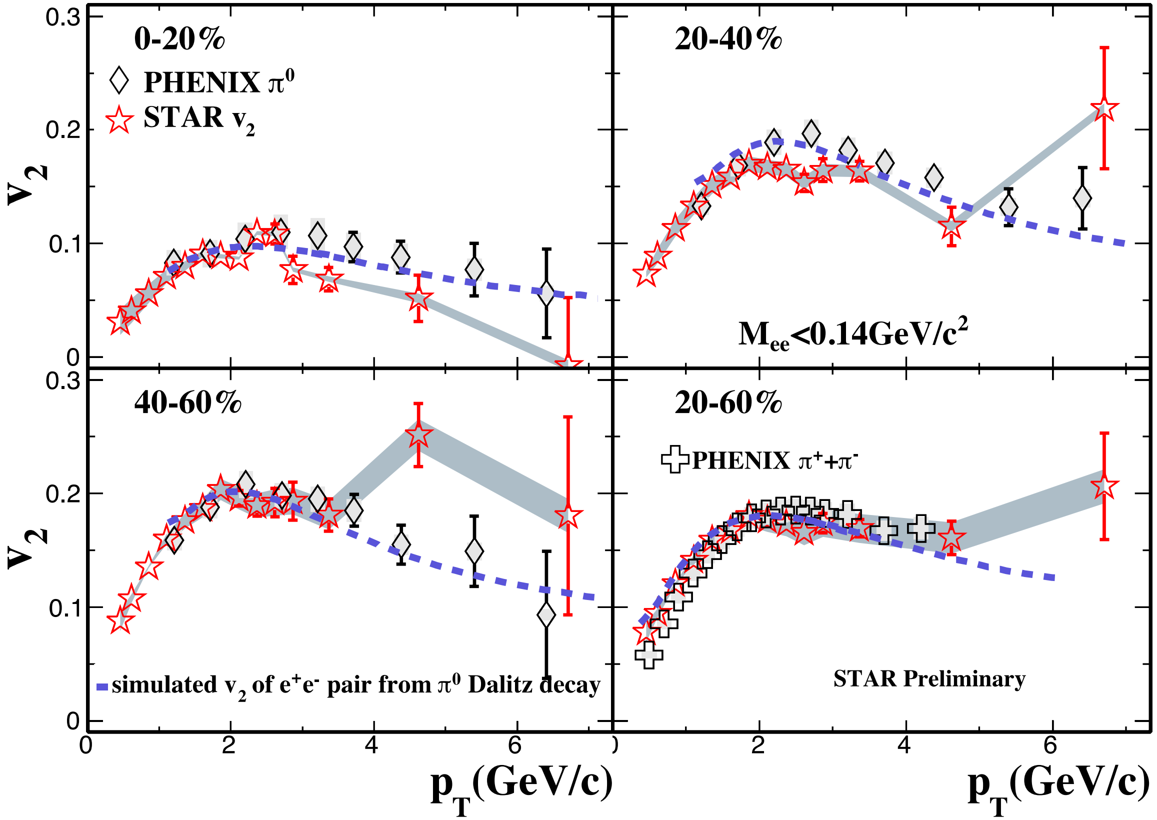


M < 0.14 GeV/c²
Consistent with measured $\pi^{\pm}$ (STAR) and π^0 (PHENIX) at high p_T.
Good tool to measure high p_T π^0

M ~ ρ (0.14 – 0.8 GeV/c²)
Need more data to study medium modification.

M ~ ϕ (0.98 – 1.06 GeV/c²)
Consistent with hadronic decay channel.
ϕ seems not dominant by KK->ϕ, need more data to confirm

Di-electron v_2 centrality dependence



LMR: hadronic process dominant
To distinguish hadronic/partonic contributions need extend this measurement to IMR.

Need detector upgrades:
- HFT => Reject long life-time decays, determine correlated charm
- MTD => e+μ correlation, IMR di-μ measurement.

Centrality dependence $v_2(p_T)$

M_{ee}<0.14 GeV/c^2 (π^0)

- consistent with simulations
- consistent with measurements