Experimental overview on hadronic resonance production in high-energy nuclear collisions

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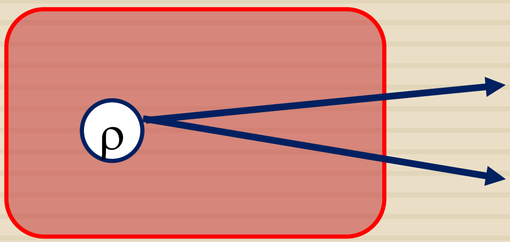
Outline

- Hadronic resonances
  - **Low mass vector mesons**
- Dilepton decays
- Hadronic decays
- Summary

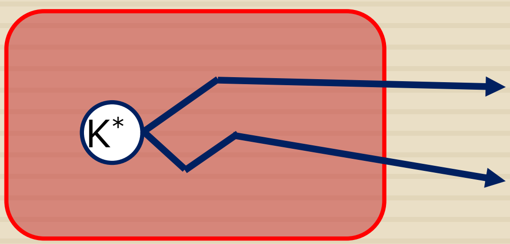
Physics motivations

	ρ	ω	ϕ	**K*(892)**
Mass (MeV/c^2)	775	783	1019	896
Lifetime (fm/c)	1.3	23	46	4.2
Decay modes	l^+l^-, $\pi^+\pi^-$	l^+l^-	l^+l^-, K^+K^-	$K^+\pi^-$



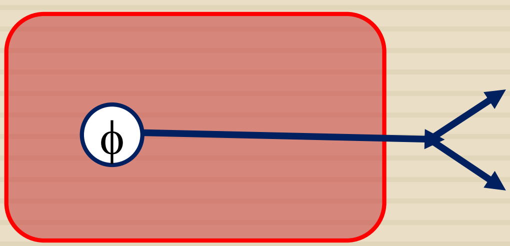
In-medium properties of hadrons

- Partial restoration of chiral symmetry
- Suitable for dilepton decays



Evolution dynamics of hot hadron gas

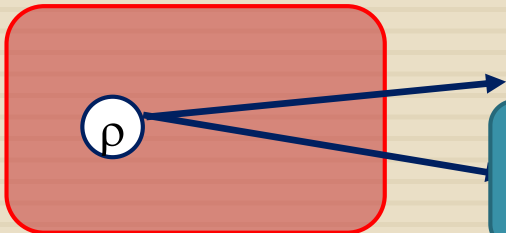
- Rescattering and regeneration of resonances
- Suitable for hadronic decays



Information from the partonic stage

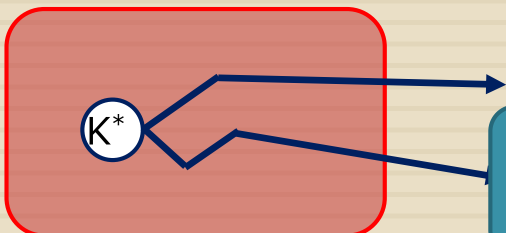
- ϕ has a long lifetime
- Small hadronic interaction cross sections of ϕ

Physics motivations



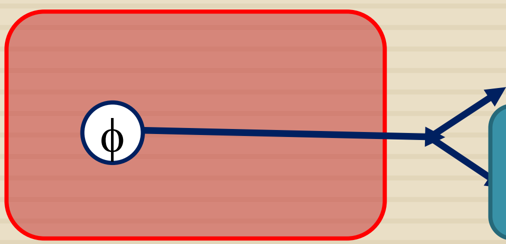
In-medium properties of hadrons

Dielectron spectra in Au-Au (HADES)
Dielectron spectra in Pb-Pb (ALICE)



Evolution dynamics of hot hadron gas

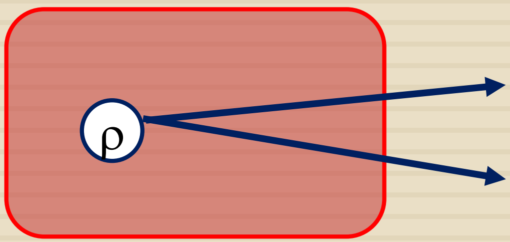
K* vs multiplicity in pp, p-Pb, Pb-Pb (ALICE)
$\rho \rightarrow \pi\pi$ in Pb-Pb (ALICE)



Information from the partonic stage

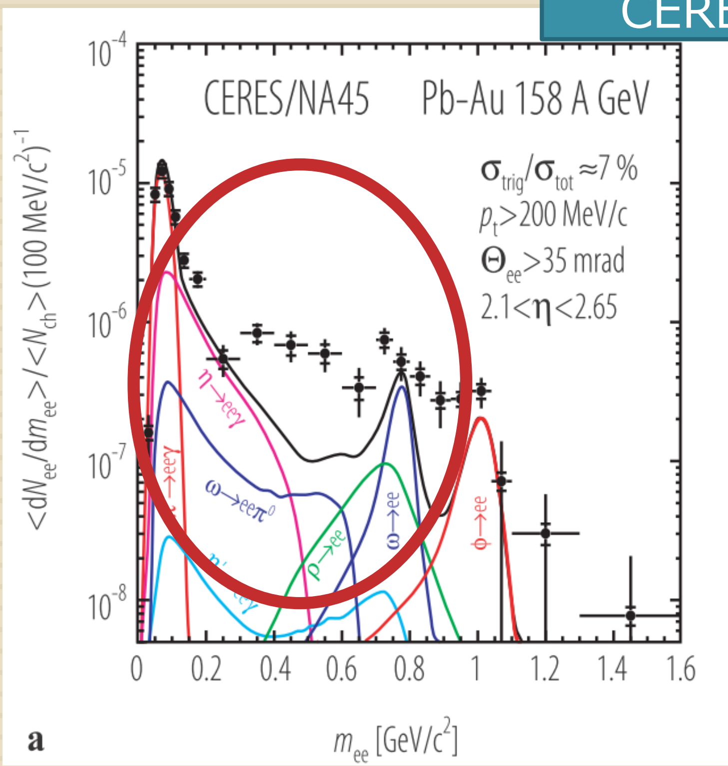
ϕ meson's v_2 in Au-Au (STAR)

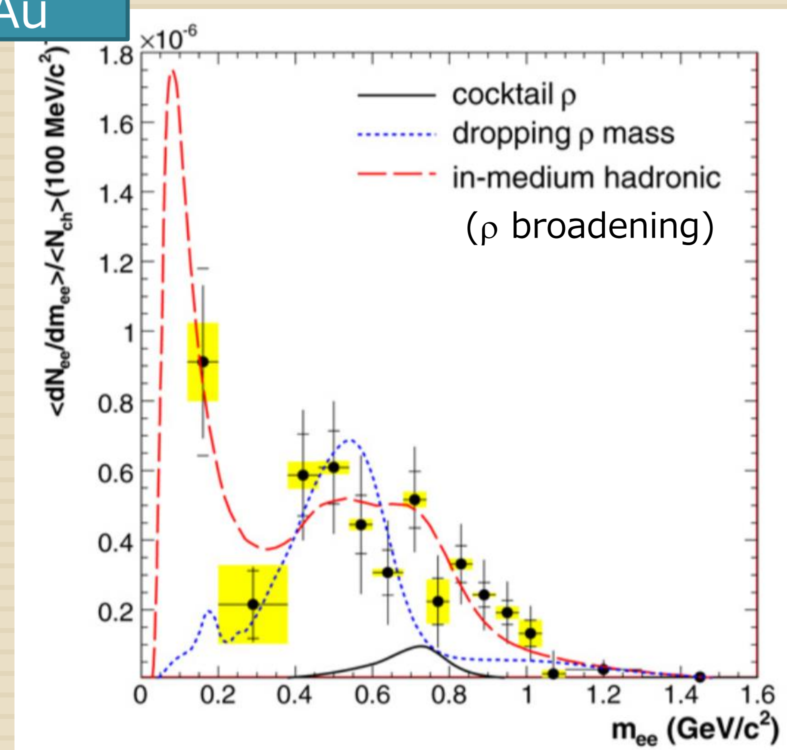
Dilepton decays



CERN-SPS

CERES Pb-Au





PLB 666 (2008) 425

- Expected hadronic decay contributions: “cocktail”
- Excess at m_{ee} ~ 500 MeV/c^2: $\pi\pi \rightarrow \rho \rightarrow ee$
- Excess spectra are consistent with ρ broadening model
  - Confirmed by NA60 with very high statics data (EPJC 61 (2009) 711)

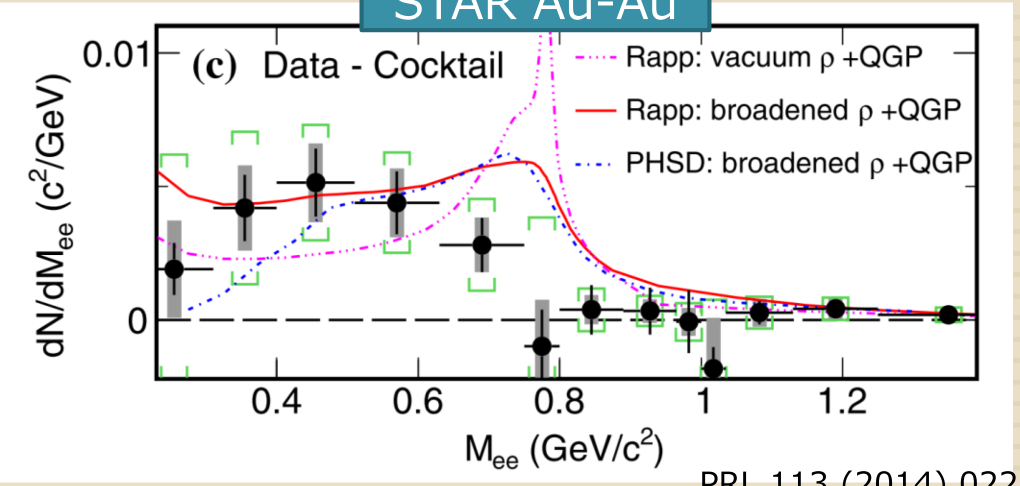
In-medium ρ spectra at RHIC

- There were discrepancies between PHENIX and STAR for $\sqrt{s_{NN}}$ = 200 GeV
- New PHENIX results were presented in QM2015
  - Hadron Blind Detector upgrade
  - Analysis improvements in eID and background subtraction
  - Phys. Rev. C 93 (2016) 014904
- PHENIX and STAR are now consistent
- Spectra from both experiments are consistent with ρ broadening

Data/cocktail ($0.3 < m_{ee} < 0.76$ GeV/c^2)

	value±stat ±syst ±model
PHENIX (New)	$2.3 \pm 0.4 \pm 0.4 \pm 0.2$
STAR	$1.76 \pm 0.06 \pm 0.26 \pm 0.29$

STAR Au-Au

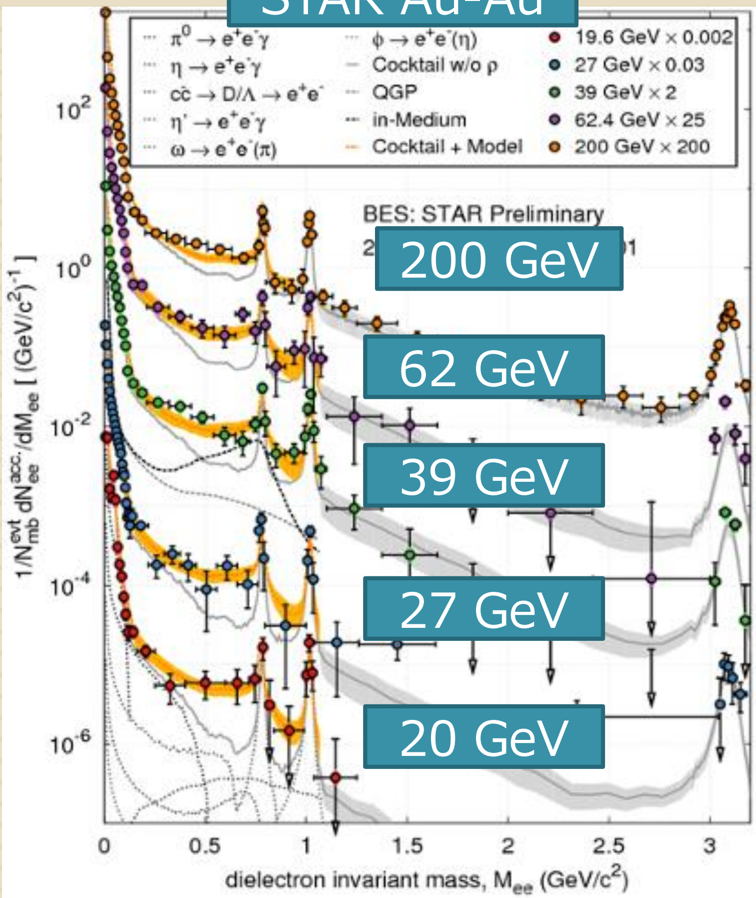


PRL 113 (2014) 022301

Energy, p_T, centrality dependence

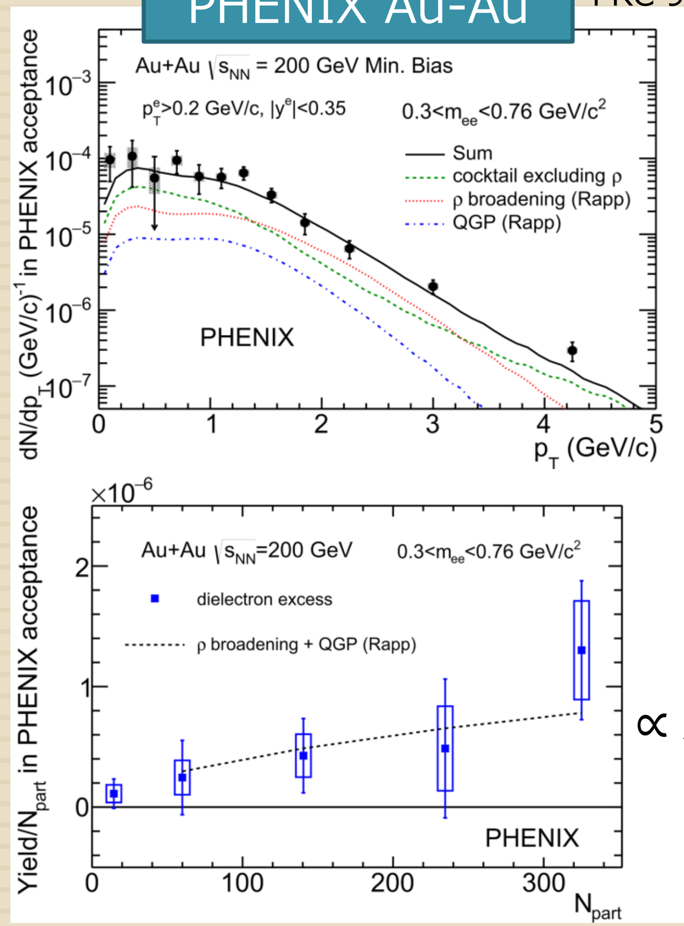
Broadening of ρ meson explains the LMR excess in the energy region $\sqrt{s_{NN}}$ =20-200 GeV including p_T and centrality dependence

STAR Au-Au



PHENIX Au-Au

PRC 93 (2016) 014904

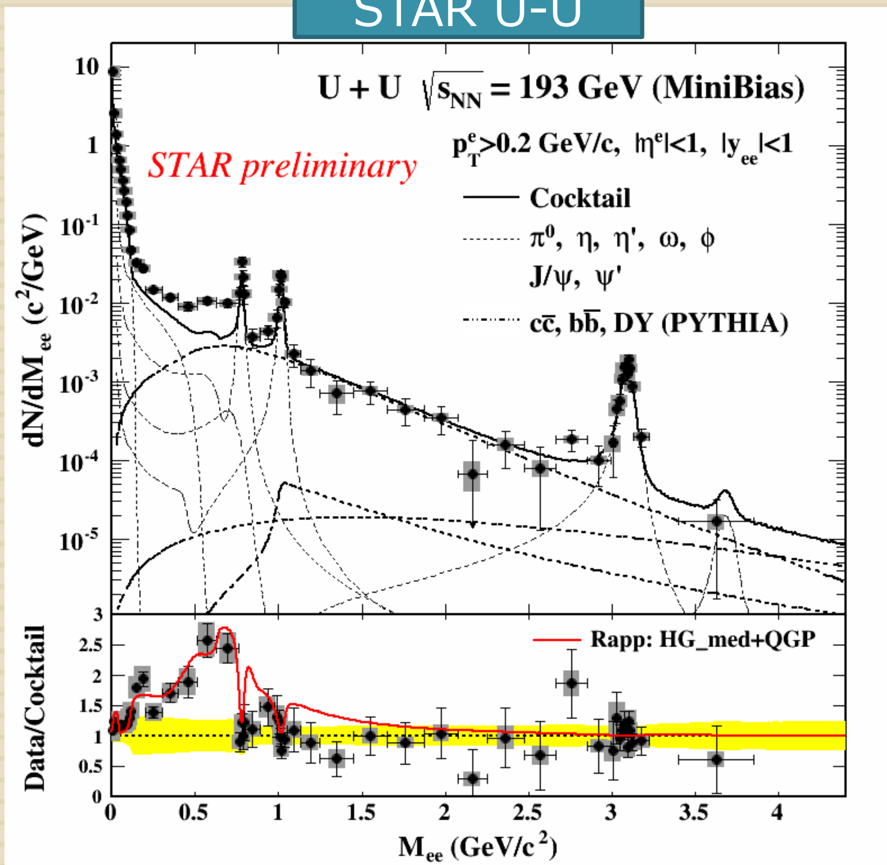


$\propto N_{part}^{1.45}$

System size dependence

- ρ broadening describes the excess also in U-U collisions

STAR U-U

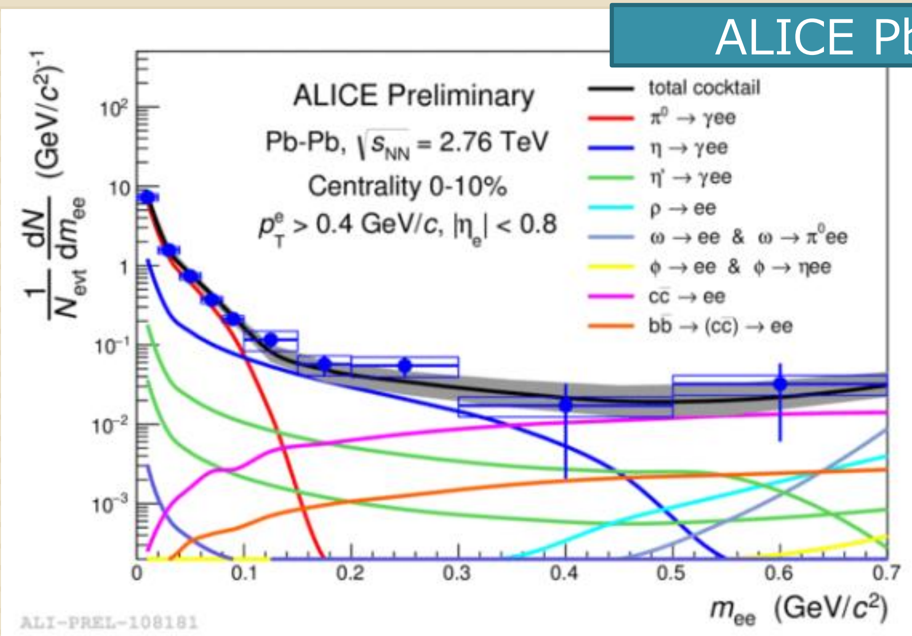


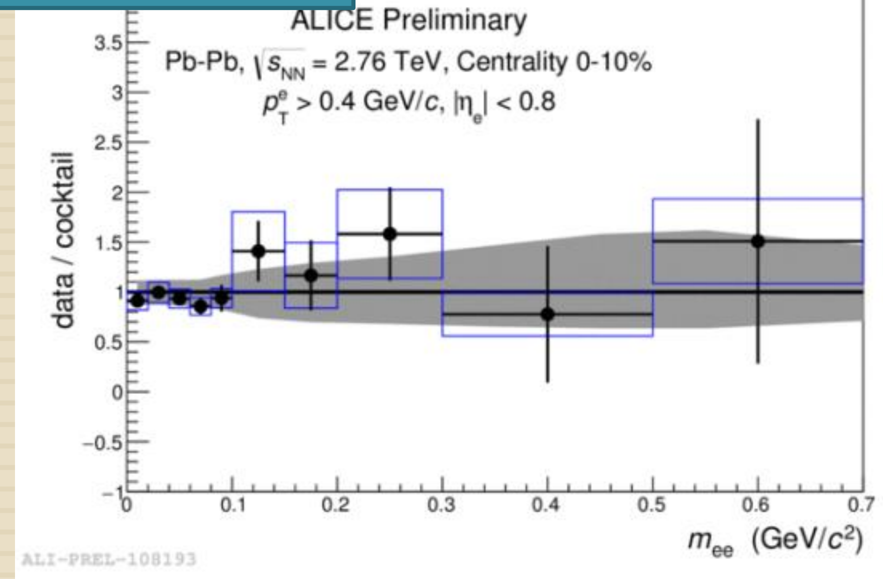
QM2015 talk by S. Yang

LHC-ALICE

- Dielectron spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV are presented
  - ALICE p_T^e>0.4 GeV/c, PHENIX/STAR: p_T^e > 0.2 GeV/c
- Consistent with no enhancement
  - Extracted limits compatible with ALICE real photon measurements and previous results from PHENIX and STAR
  - Large charm cross sections at LHC energies

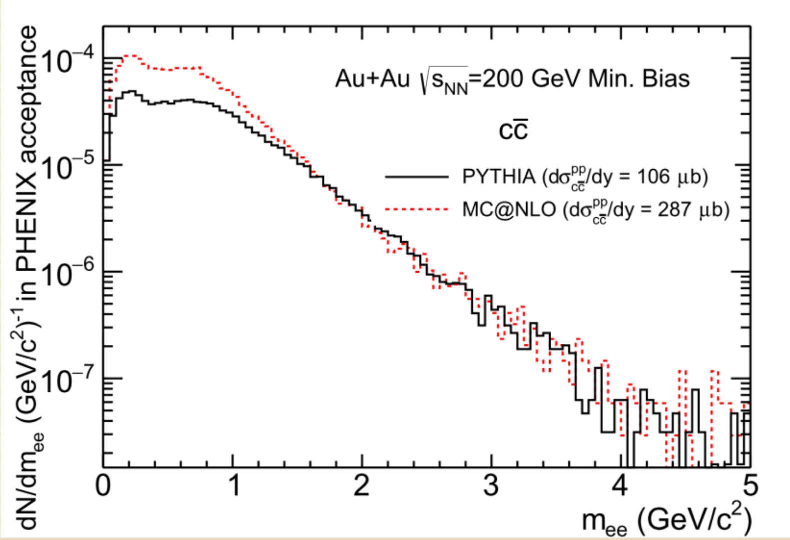
ALICE Pb-Pb 0-10%





$c\bar{c}$ in cocktail

- Understanding of the charm contributions in cocktail is crucial to study in-medium ρ spectra
- New PHENIX result: PYTHIA and MC@NLO
  - 40% difference in data/cocktail ($0.3 < m_{ee} < 0.76$ GeV/c^2)
    - PYTHIA: 2.3 ±0.4±0.4±0.2, MC@NLO: 1.7 ±0.3±0.3±0.2
  - Cross sections are derived using IMR of d-Au collisions
  - Uncertainty in extrapolation to m~0
    - Lack of understanding in $c\bar{c}$ cross section and correlation
- Vertex detectors (PHENIX, STAR, ALICE) and MTD (STAR)

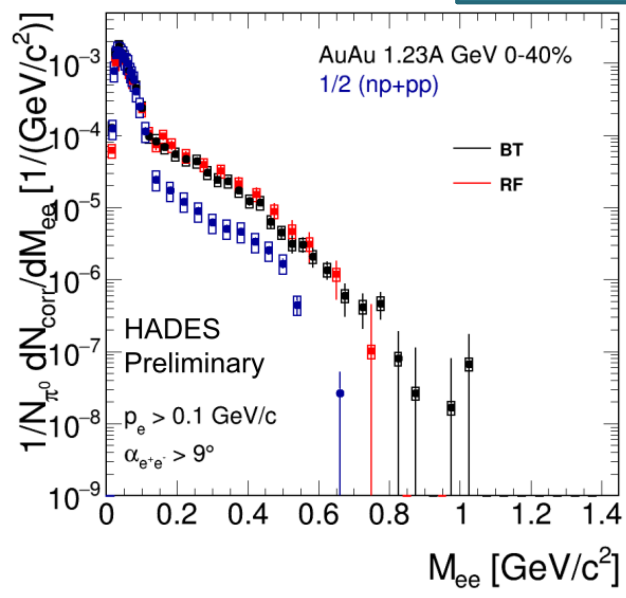


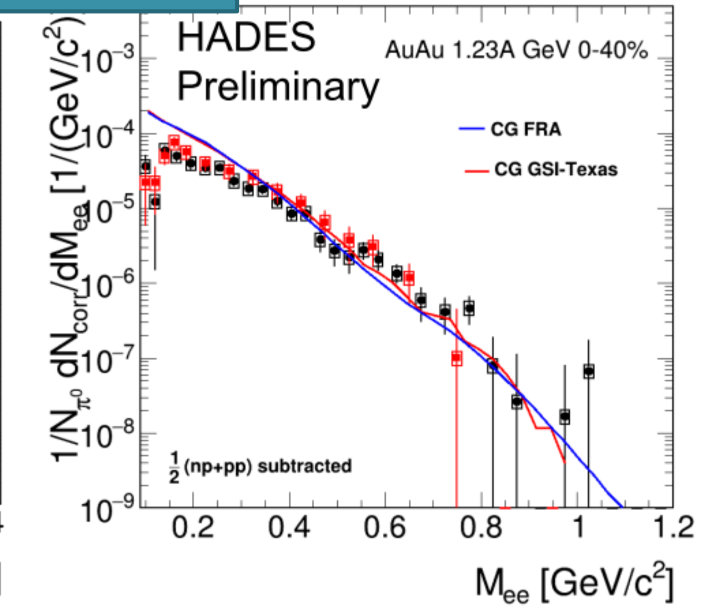
	$d\sigma^{pp}_{c\bar{c}}/dy$ (μb)
PYTHIA	$106 \pm 9^{stat} \pm 33^{syst}$
MC@NLO	$287 \pm 29^{stat} \pm 100^{syst}$
STAR (D meson) PRL 113(2014)022301	171 ± 26

PRC 93 (2016) 014904

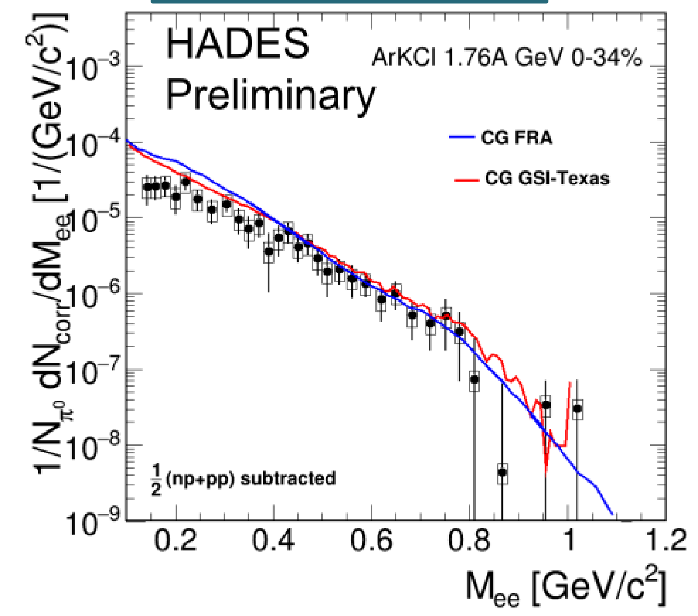
HADES

HADES Au-Au





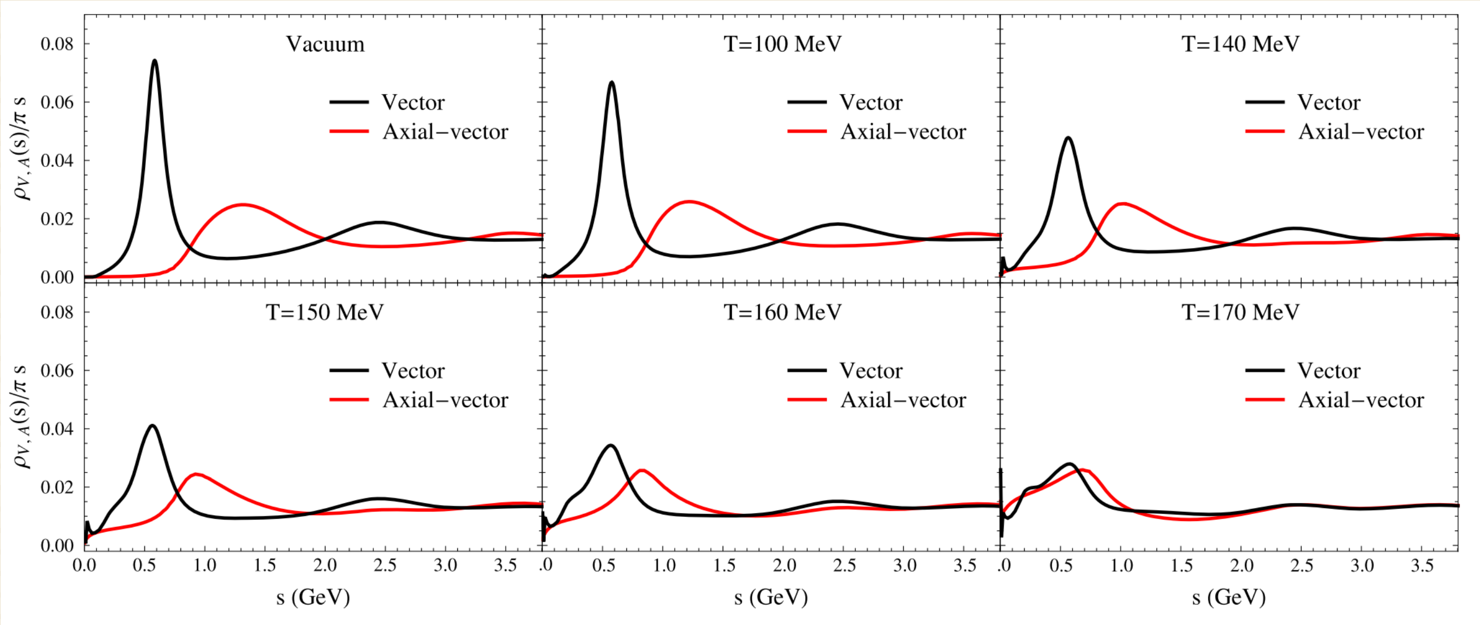
HADES Ar-KCl



- Baryon dominated matter
- Excess from the elementary collisions in Au-Au collisions
  - Excess is well described by models with ρ broadening + system evolution described by UrQMD
- System size dependence is also studied, such as p-Nb, C-C, Ar-KCl
  - Gradual increase of the enhancement factor as going to the heavier system
  - The same model also works in Ar-KCl collisions

Link to chiral symmetry restoration

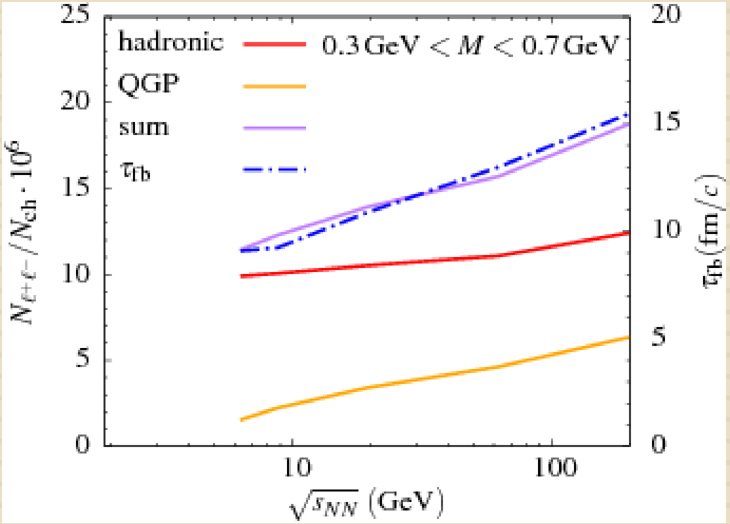
- In-medium ρ spectra are well described by the models with "ρ broadening"
- Measurement of the a_1 meson is experimentally difficult
- According to PLB 731 (2014) 103, the medium-modified ρ and a_1 meson degenerate with each other at high T



R. Rapp, PLB 731 (2014) 103

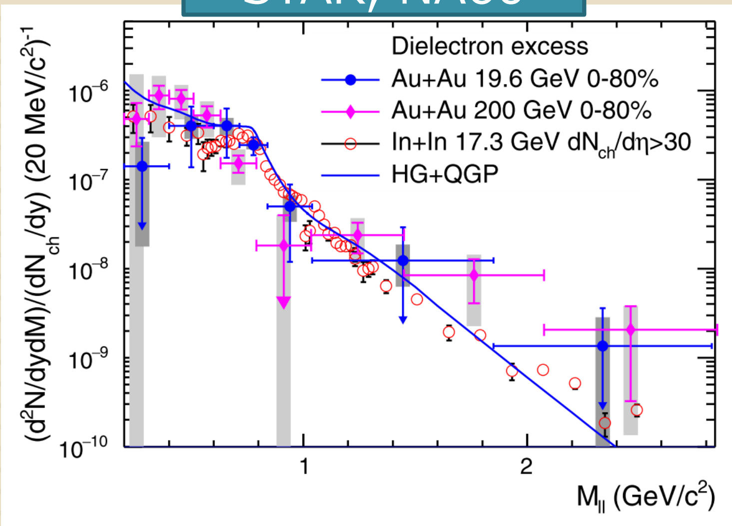
Acceptance correction

- Acceptance correction is needed to learn more things from experimental data
  - Dielectron excess $\propto \tau_{fireball}$ (R. Rapp PLB 753 (2016) 586)
  - Moments of the ρ spectra can be related to QCD condensates (T. Hatsuda http://www.ectstar.eu/sites/www.ectstar.eu/files/talks/ECT_SPF_12.1.2015_web_Hatsuda.pdf(2015), Y.Kwon et al PRC 78 (2008) 055203)
- Acceptance-corrected excess in STAR is consistent with that in NA60 within experimental uncertainties



R. Rapp PLB 753 (2016) 586

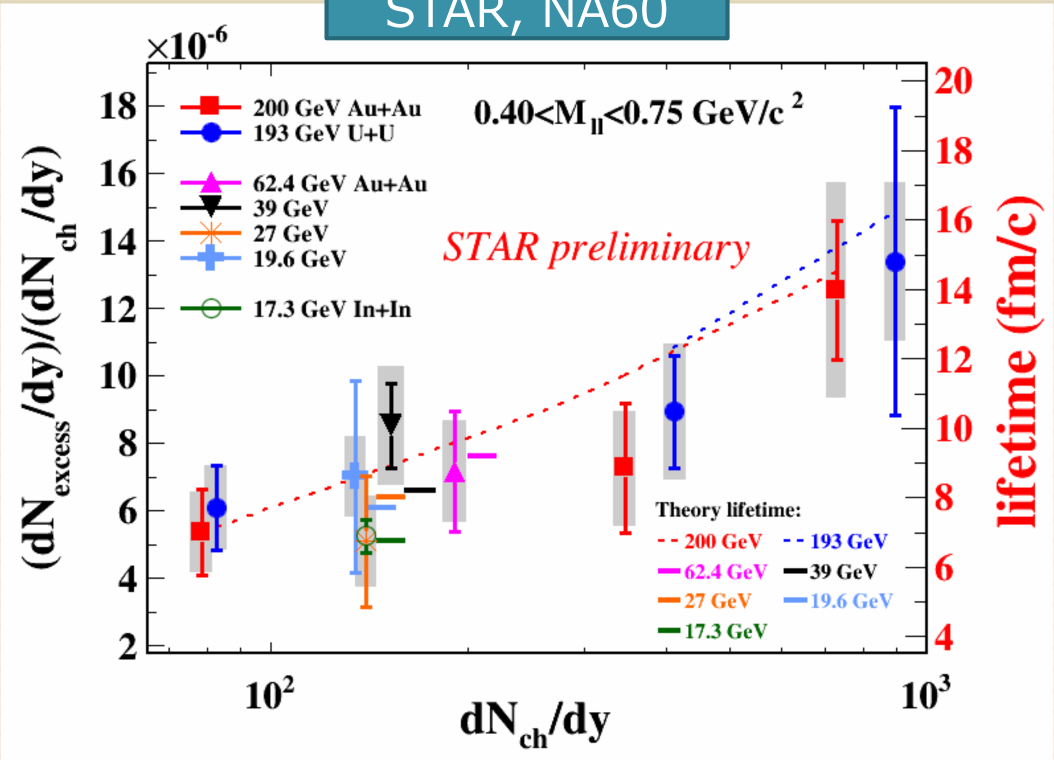
STAR, NA60



PLB 750 (2015) 64

Excess yield and fireball lifetime

STAR, NA60

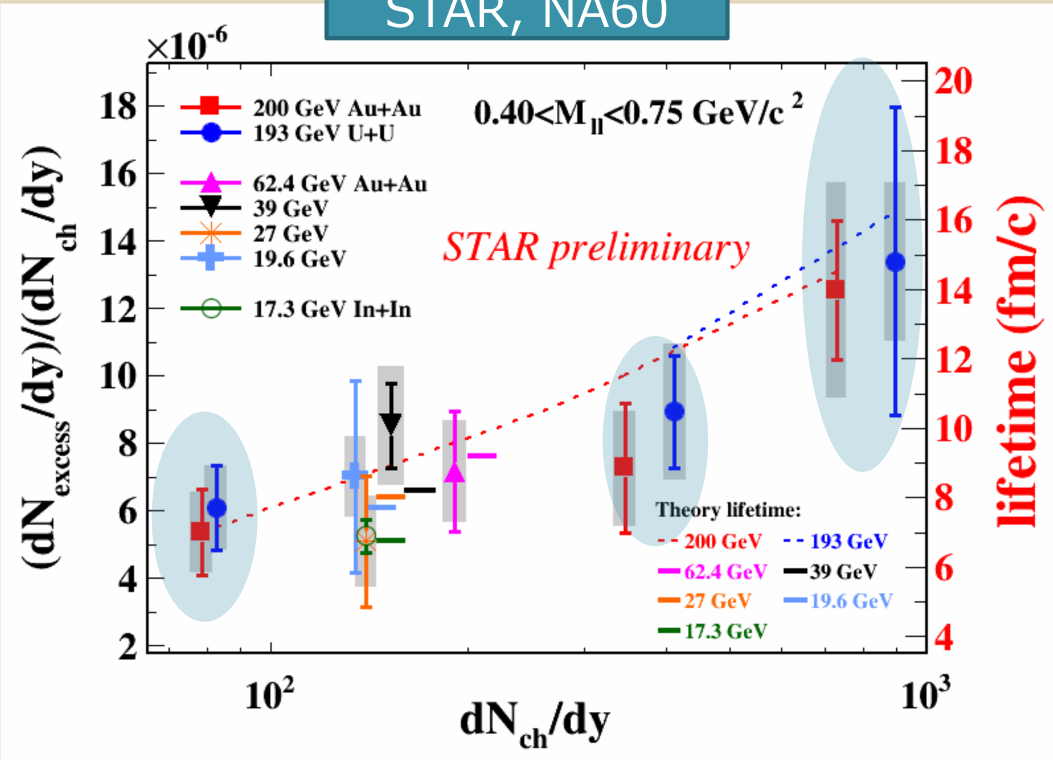


QM2015 talk by S. Yang

- Fireball lifetime is longer in central collisions than in peripheral collisions
- Fireball lifetime is longer in central 200 GeV than in low energies

Excess yield and fireball lifetime

STAR, NA60



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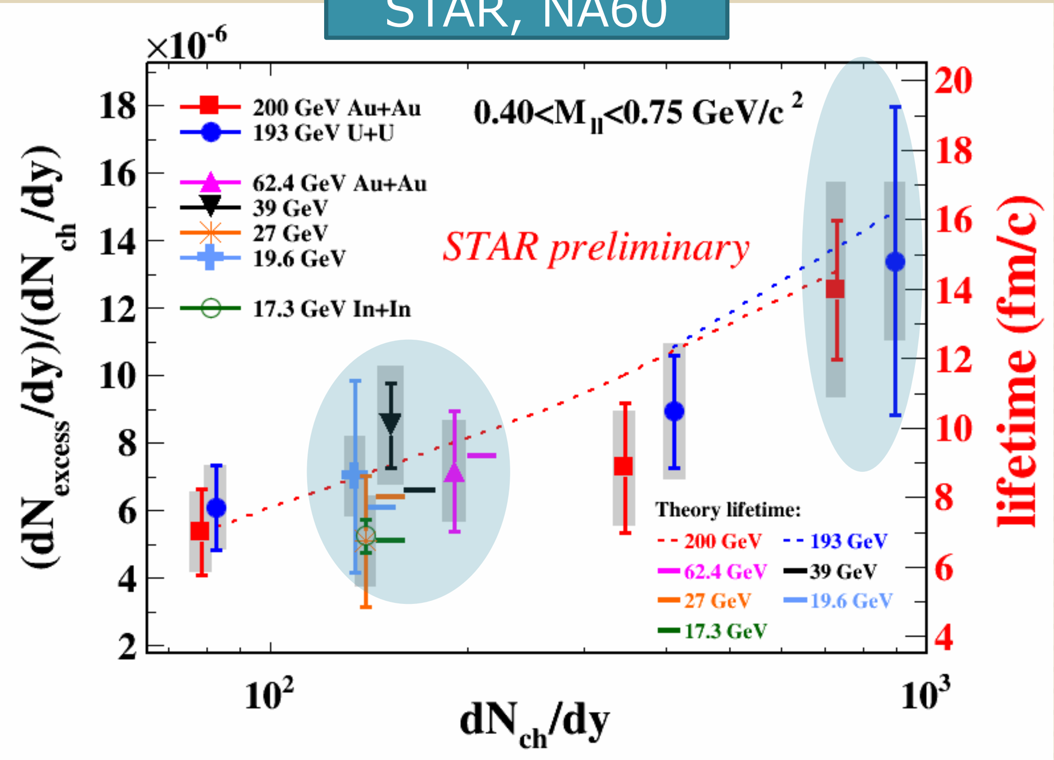
Excess yield and fireball lifetime

STAR, NA60

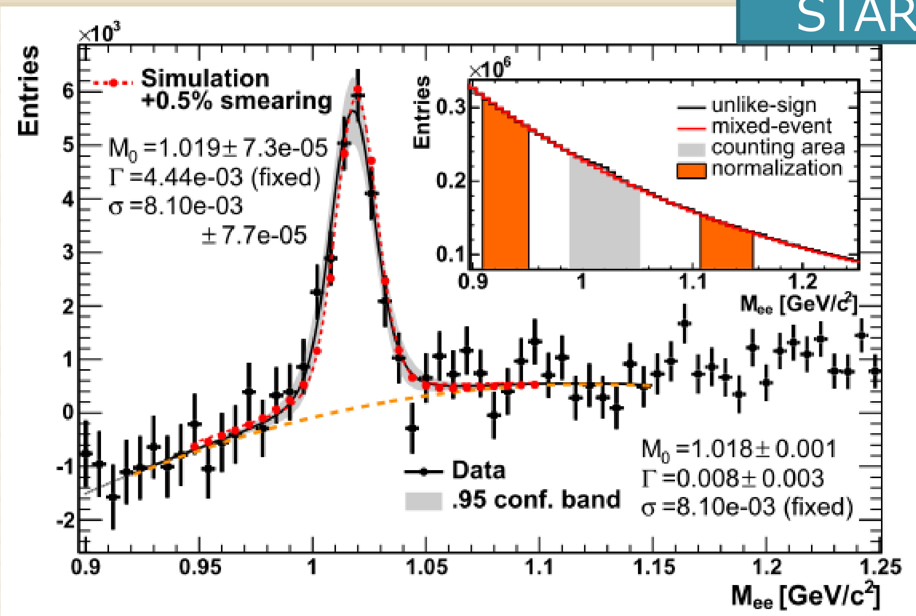


QM2015 talk by S. Yang

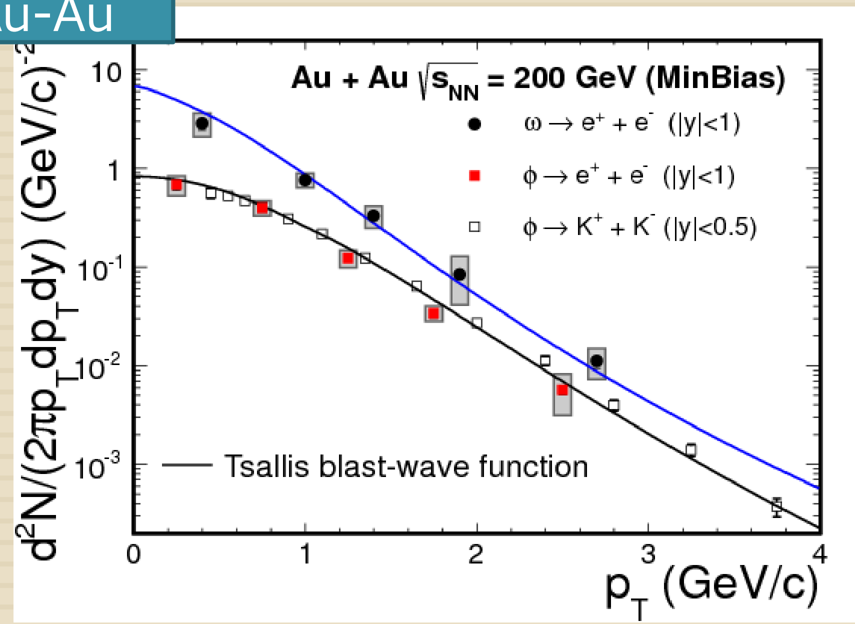
- Fireball lifetime is longer in central collisions than in peripheral collisions
- Fireball lifetime is longer in central 200 GeV than in low energies

ω and ϕ at RHIC

STAR Au-Au



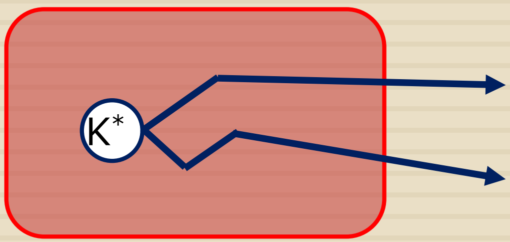
arXiv: 1503.04217



PRC 92 (2015) 024912

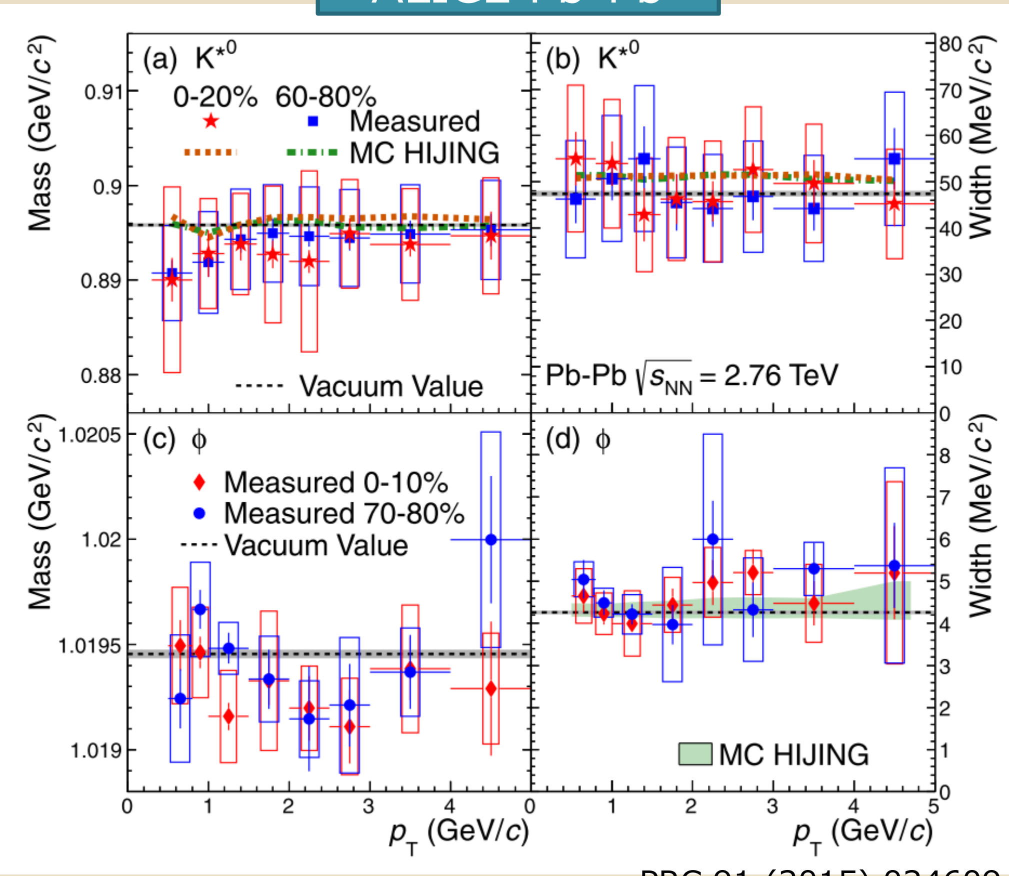
- Detailed analysis of ϕ spectral shape is performed by STAR
  - No significant difference (<2σ) from vacuum mass and width
- Yields are well described by Tsallis blast-wave function within experimental uncertainties
- ϕ→ee and ϕ→KK give consistent results

Hadronic decays

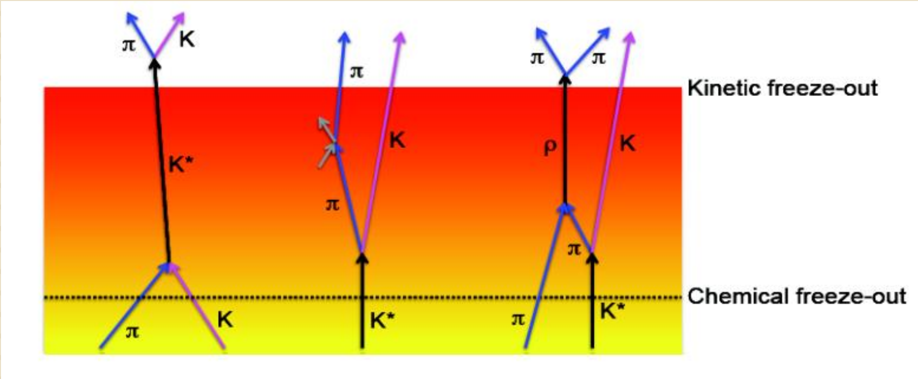


K* and ϕ mass and width

ALICE Pb-Pb



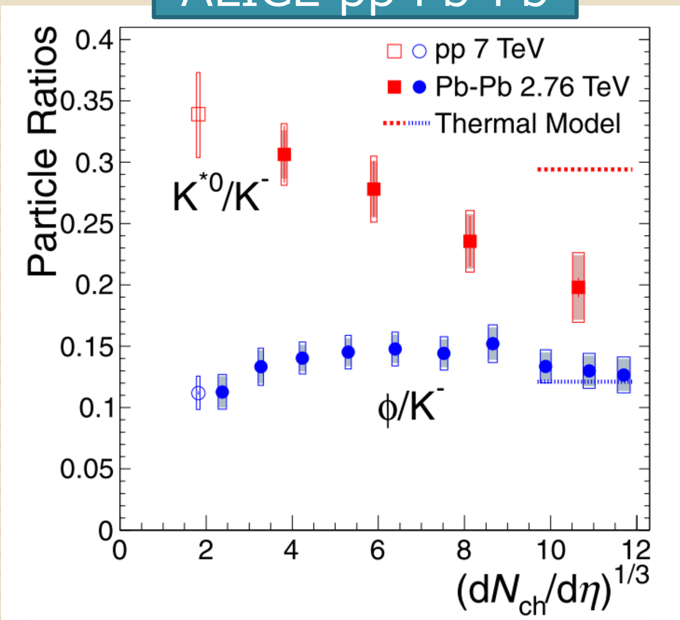
PRC 91 (2015) 024609



- Mass and width reconstructed with hadronic decays are affected by:
  - Chiral symmetry restoration
  - Final state interactions (rescattering/regeneration)
- Mass and width are consistent with vacuum values
  - No centrality nor p_T dependence

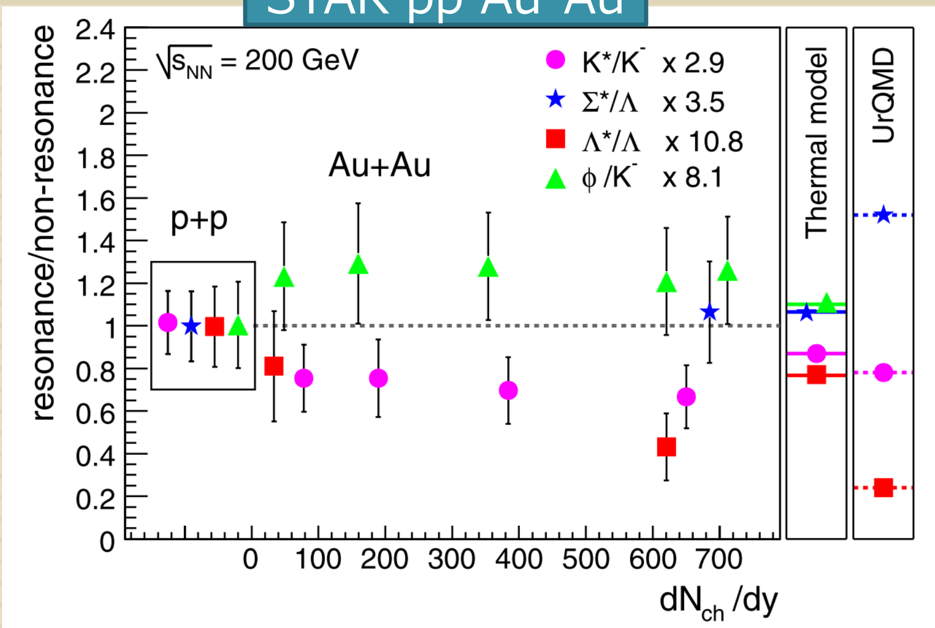
ϕ/K and K*/K

ALICE pp Pb-Pb



PRC 91 (2015) 024609

STAR pp Au-Au

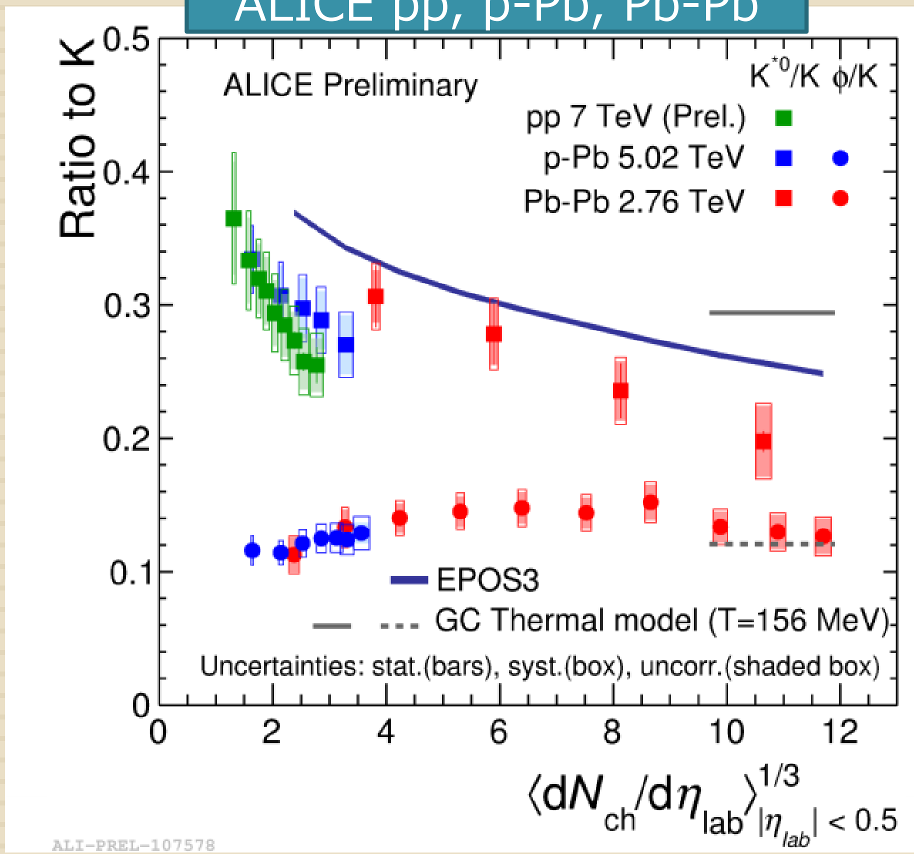


PRL 97 (2006) 132301

- K*/K decreases with increasing multiplicity
  - Rescattering > Regeneration
  - Lower limit for the hadronic phase lifetime: ~ 2 fm
- Comparison with other strange baryons ($c\tau$ K*: 4 fm, Λ*: 13 fm, Σ*: 5 fm)
  - Λ*(1520)/Λ ~ K*/K, No suppression for Σ*/Λ
  - Need to consider other effects, e.g. regeneration, etc

K*/K in small systems

ALICE pp, p-Pb, Pb-Pb

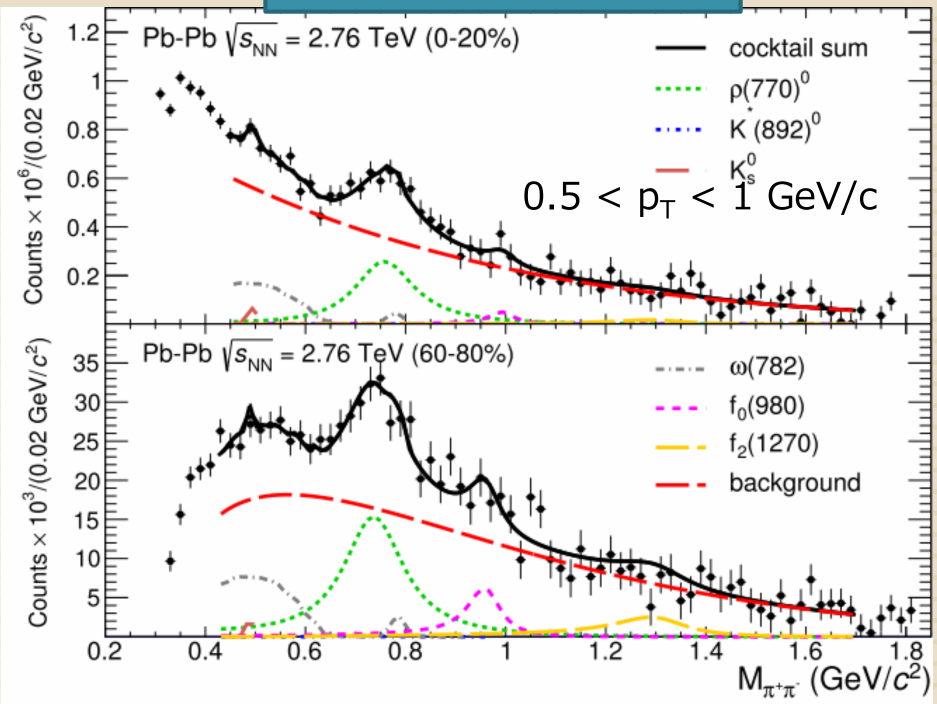


Talk by A. Knospe and F. Bellini

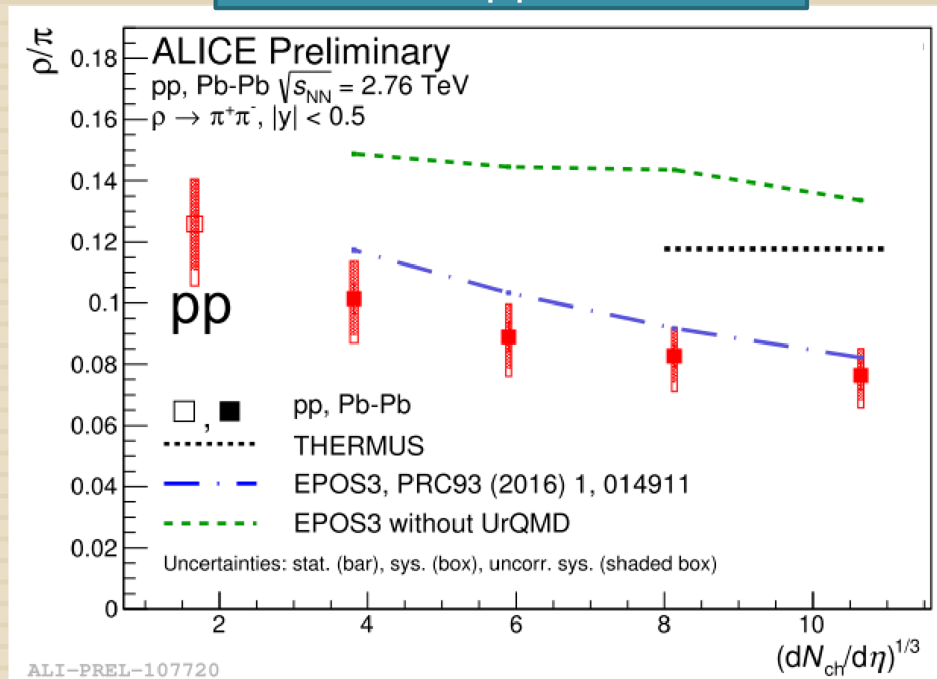
- K*/K decreases as going to the higher multiplicity bin
  - Qualitatively similar trend as Pb-Pb
  - Rescattering also in small systems?

$\rho \rightarrow \pi^+\pi^-$

ALICE Pb-Pb

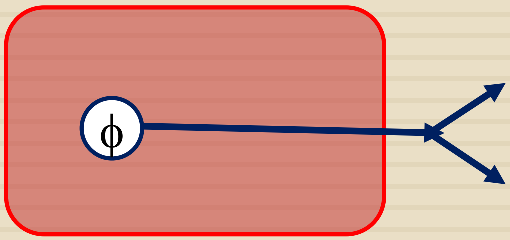


ALICE pp Pb-Pb



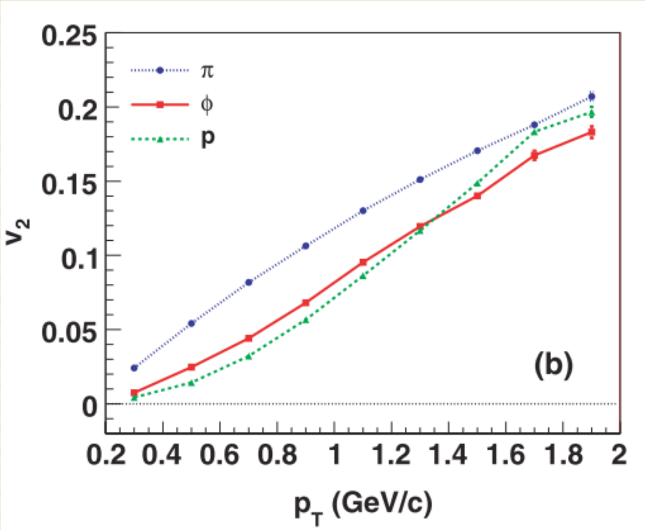
- Clear peak also in the most central bin
  - Peripheral bins are previously studied by STAR (PRL 92 (2004) 092301)
- ρ/π ratio is suppressed from pp to central Pb-Pb
  - Well described with EPOS3 with UrQMD

Hadronic decays



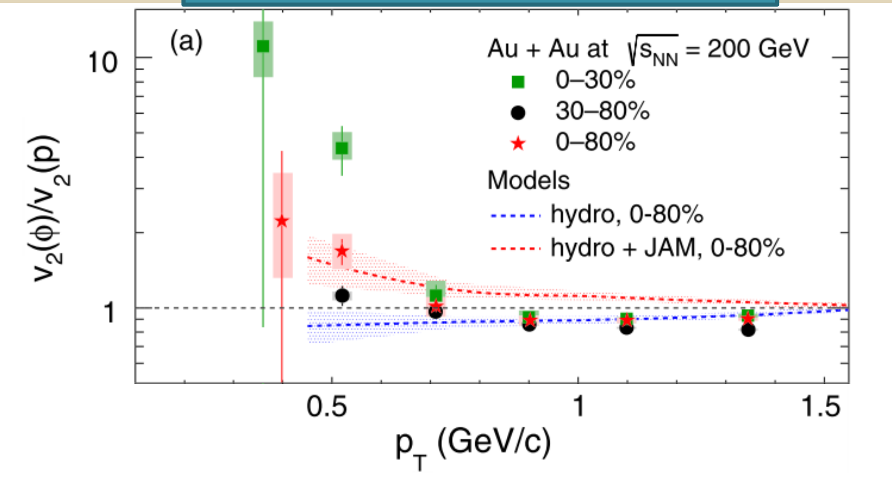
Violation of mass ordering for ϕ

- Hydrodynamic models predict mass ordering of elliptic flow (v_2)
- The mass ordering is broken between ϕ and p
  - Late stage hadronic scattering effects on proton
  - Small hadronic cross section for ϕ
- ϕ (and other multi-strange hadrons) is a penetrating probes carrying the information from the partonic stage



T. Hirano et al, PRC 77 (2008) 044909

STAR Au-Au



PRL 116 (2016) 062301

Summary

- Recent results related to low mass vector mesons are presented
- Dilepton decays
  - Dielectron excess up to RHIC energies are described by "ρ broadening"
    - Preliminary dielectron spectra from ALICE and HADES are presented
  - Understanding of $c\bar{c}$ contribution is crucial for high energies
  - Acceptance corrected excess is studied as a function of system size and collision energy
- Hadronic decays
  - K* production is suppressed in the most central collisions
    - Similar trend for $\rho \rightarrow \pi\pi$
  - K* production is also suppressed in high multiplicity pp and p-A collisions
  - The elliptic flow of the ϕ meson violates "mass ordering"

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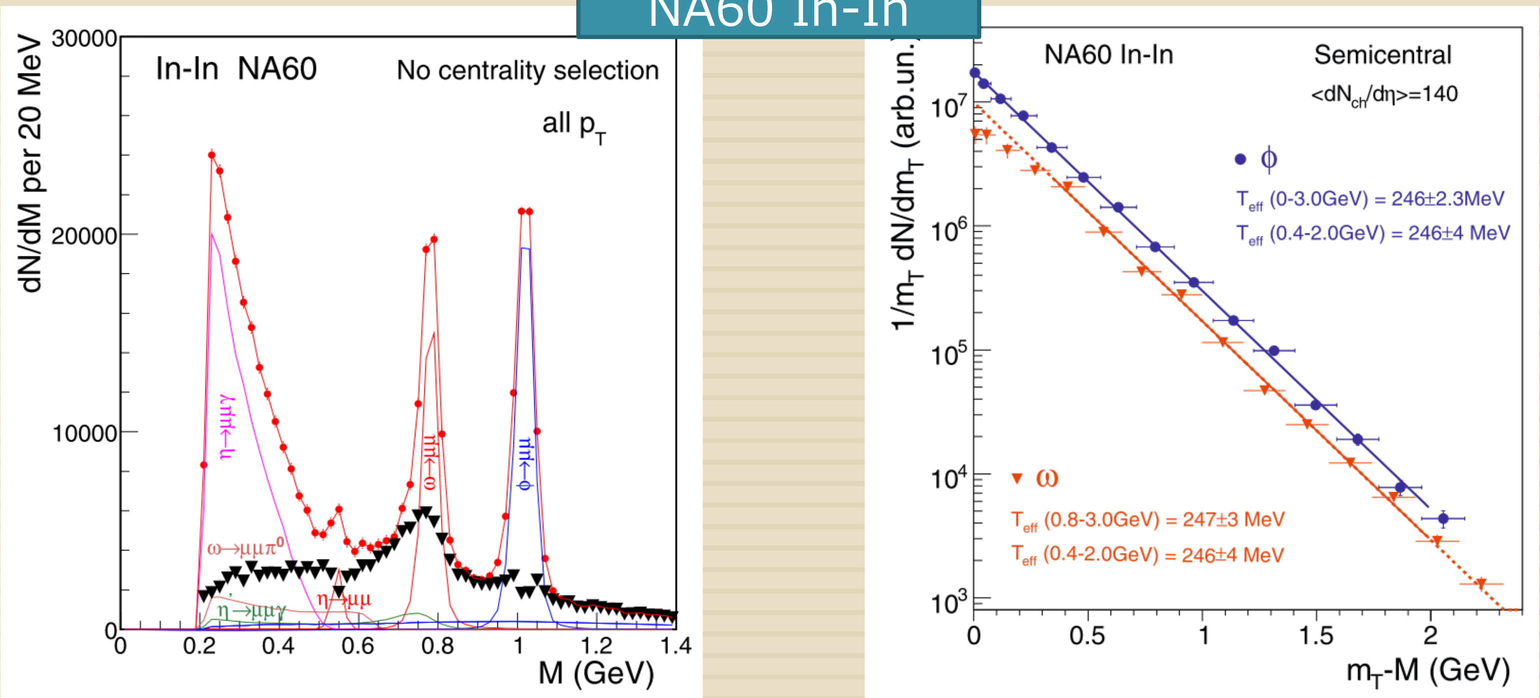
Backup

ω and ϕ at SPS

NA60 In-In



EPJC 61 (2009) 711

- Clear peaks are visible
- Suppression of ω at low p_T was observed
  - Suppression is larger in the most central collisions