Hadron resonances in heavy ion collisions at RHIC and LHC: What do we know?

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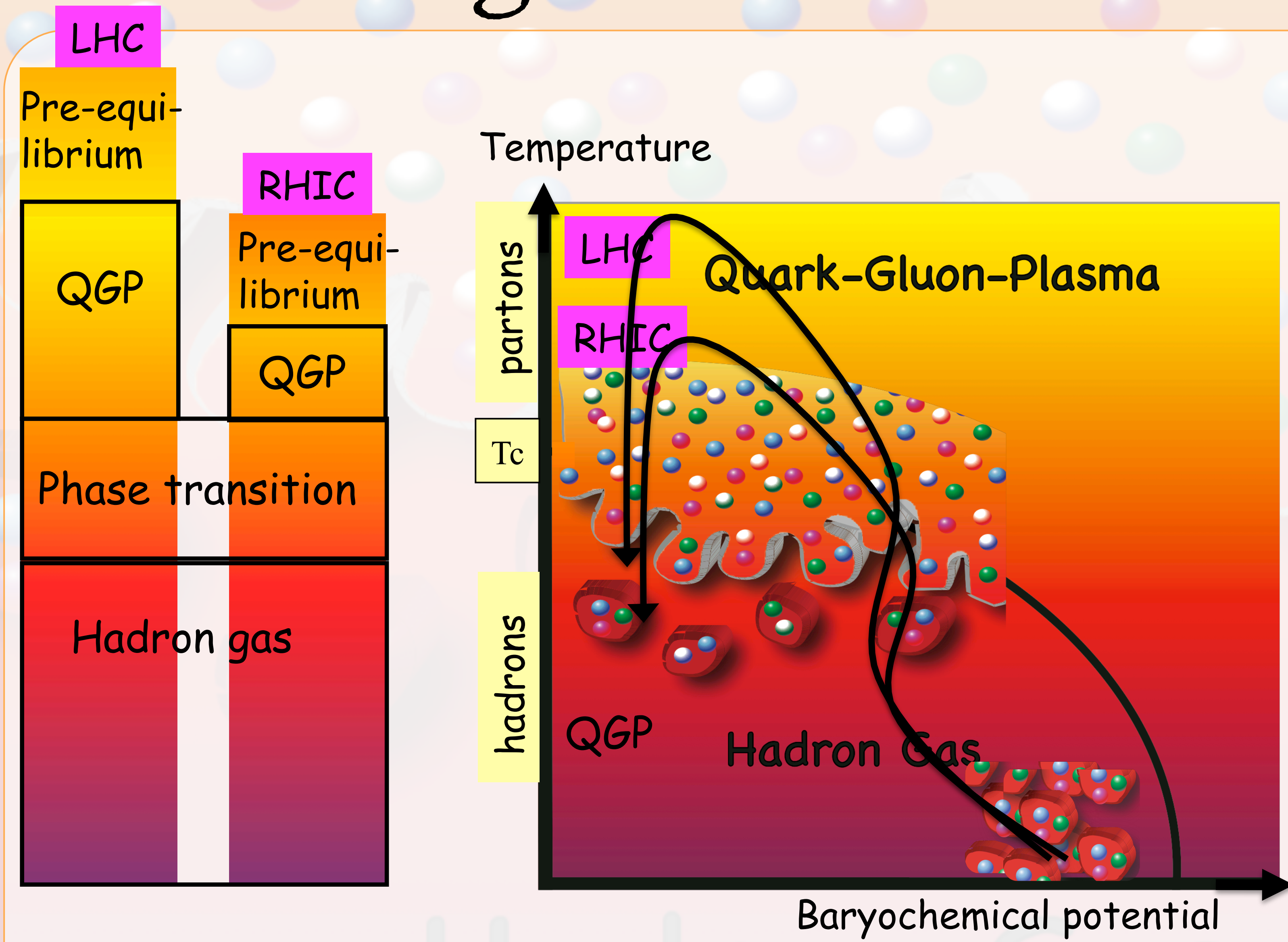
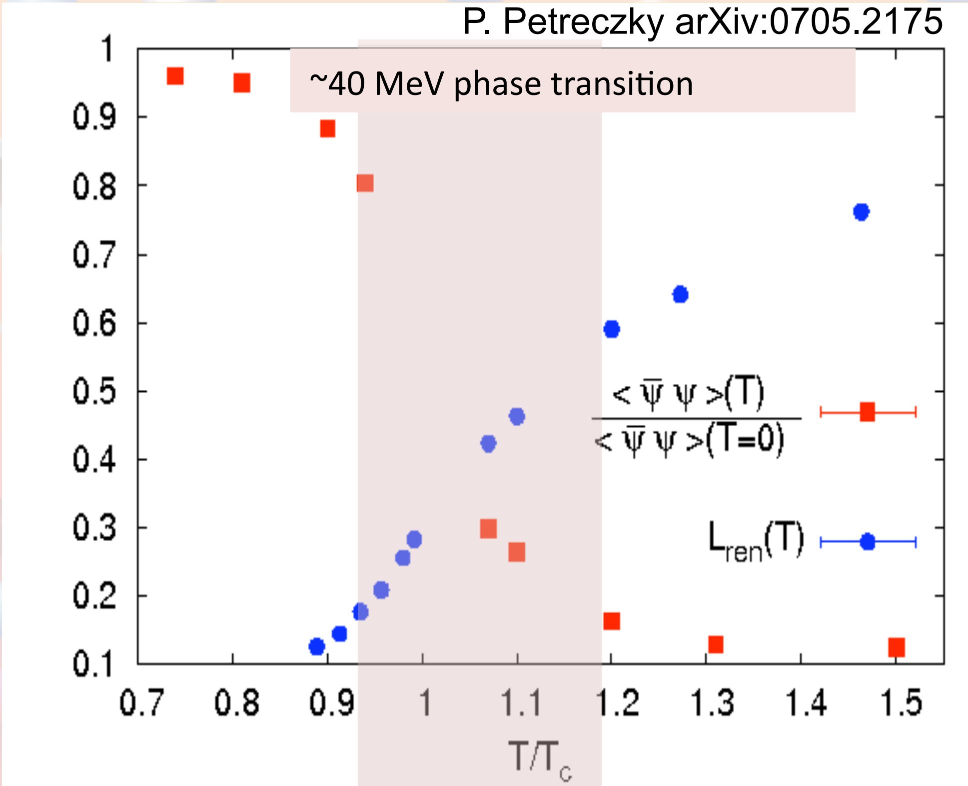
- Introduction
- Resonances in Medium
- Resonances at RHIC and LHC
- Conclusion (Future)

Phase diagram of nuclear matter

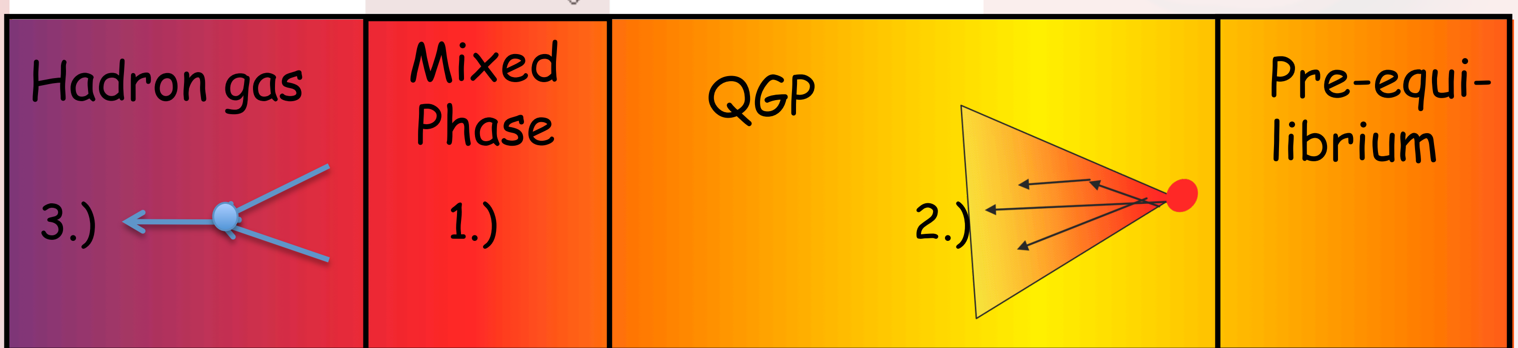


Resonance production



Features of QCD phase transition
(lattice QCD calculations):
deconfinement: Polyakov loop rises
chiral restoration: quark condensate drops hadron masses drop

1.) Medium: resonances are formed when partonic matter transitions into hadronic matter
2.) Hard-scattering: resonances created from a jet within the QGP phase
3.) Regenerated resonances

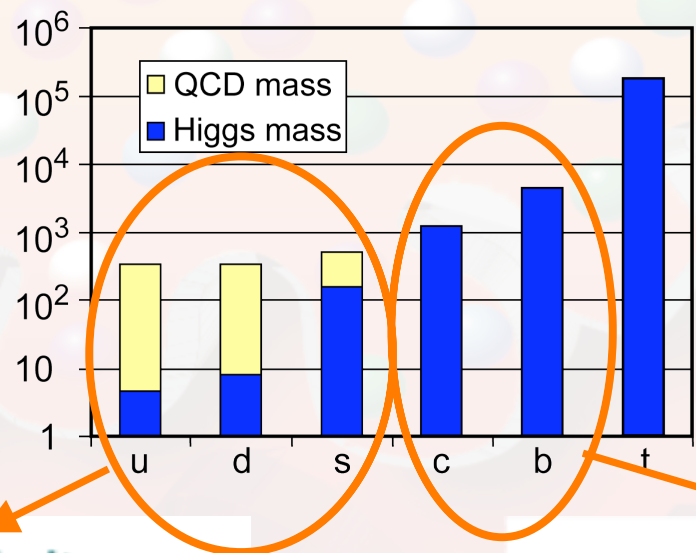


low p_T < 2 GeV/c ← high p_T

Probe for QCD phase transition(s)

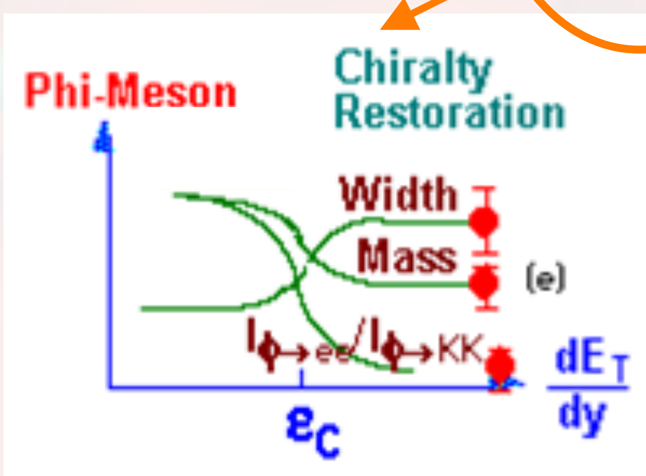
Mass shifts width broadening of resonance signal

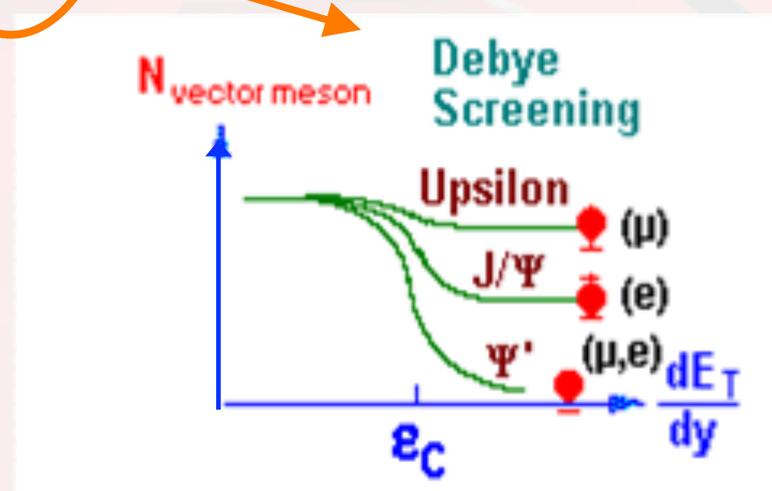
Light flavor probes



Suppression of resonance yields

Heavy flavor probes





Because of short lifetime and strong interactions with the medium, light vector mesons are the only probe of
chiral symmetry restoration

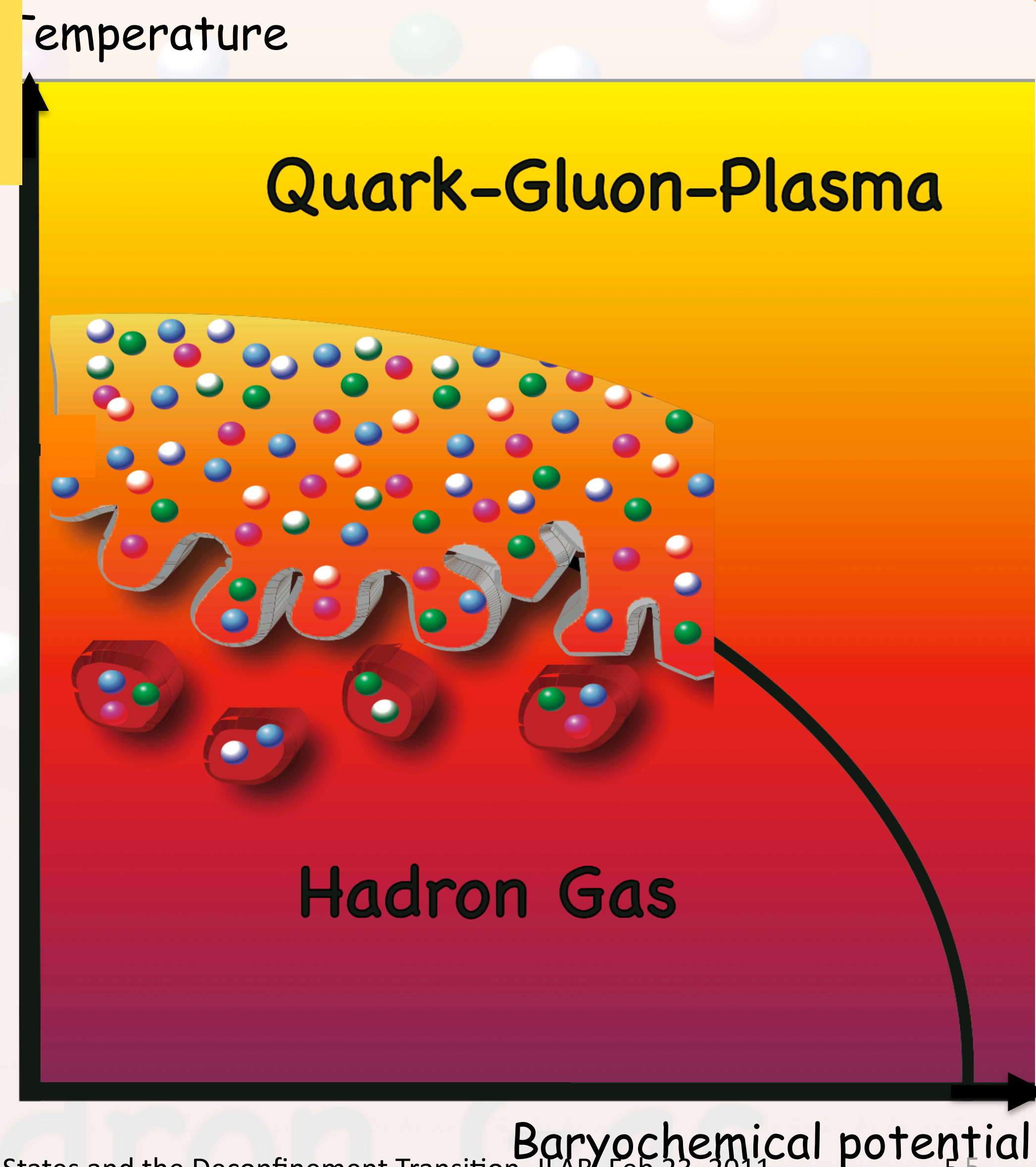
Because of color screening in the medium, heavy vector mesons are the most sensitive probe of
deconfinement conditions

Phase diagram of nuclear matter

Vitev Phys.Lett. B649:139-146,2007 survival of c/b-quark states

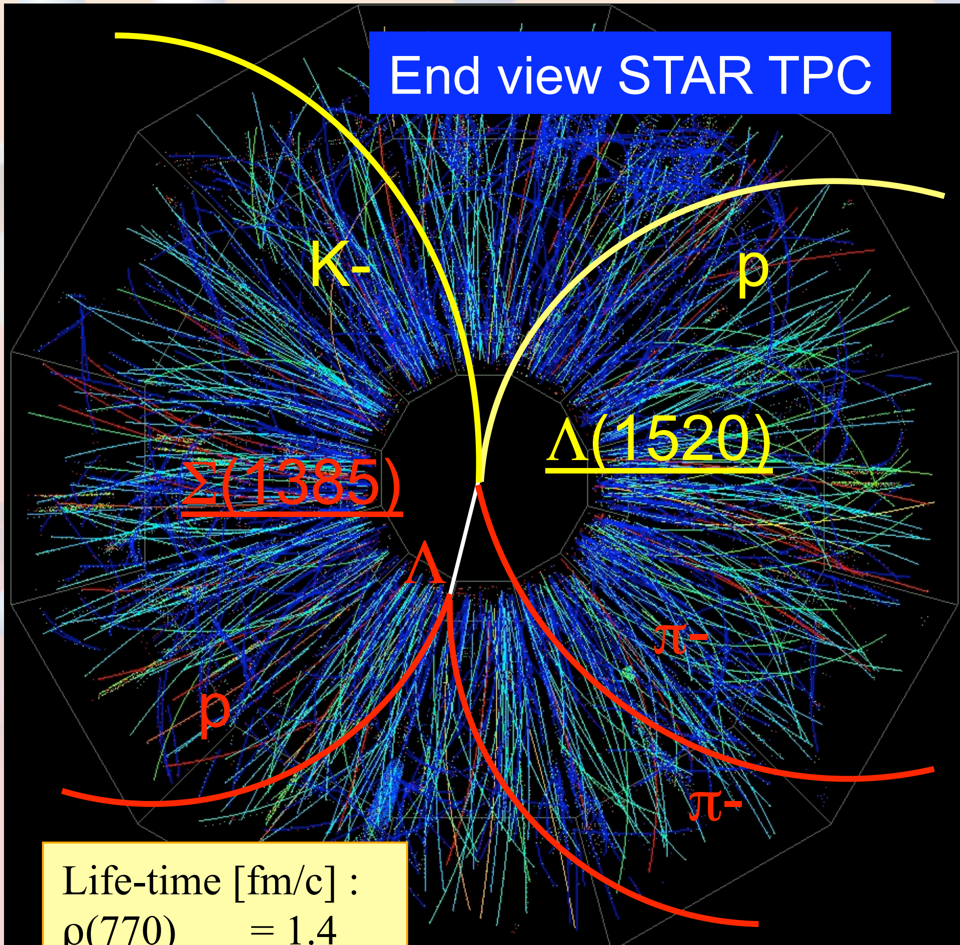
Survival of s-quark states ?

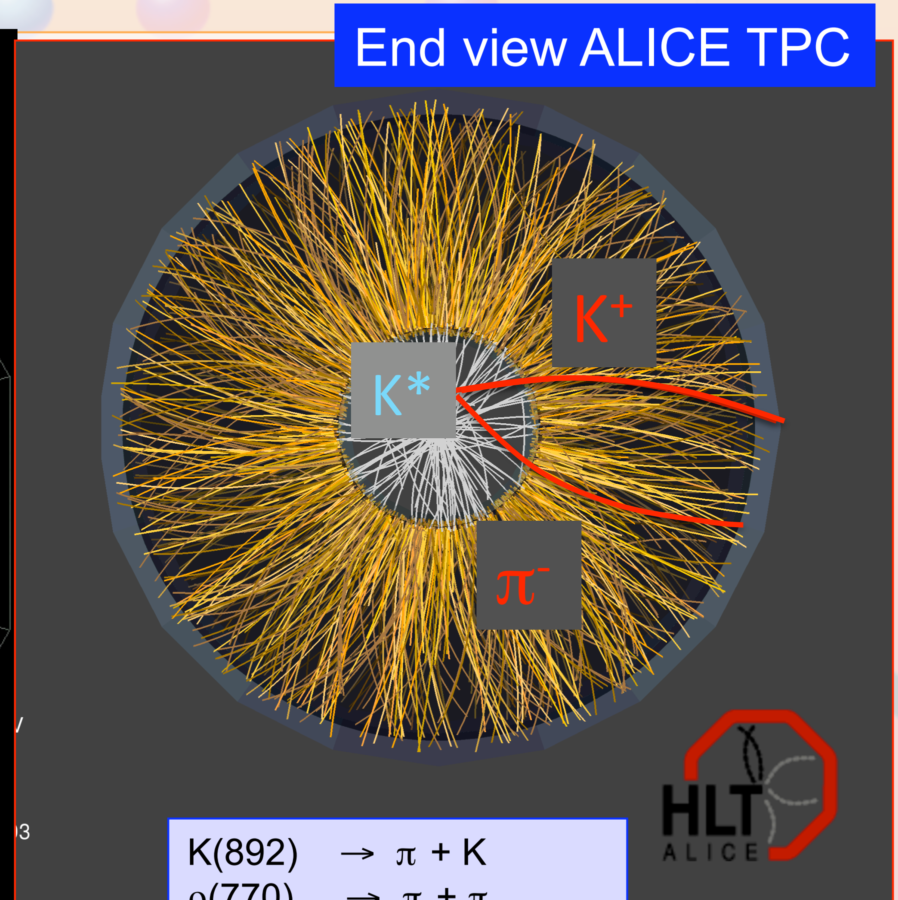
Mixed phase s-quarks Hadrons (Lattice)



Mocsy & P. Petreczky, Phys. Rev. Lett. 99 (2007)

Resonance reconstruction with TPC



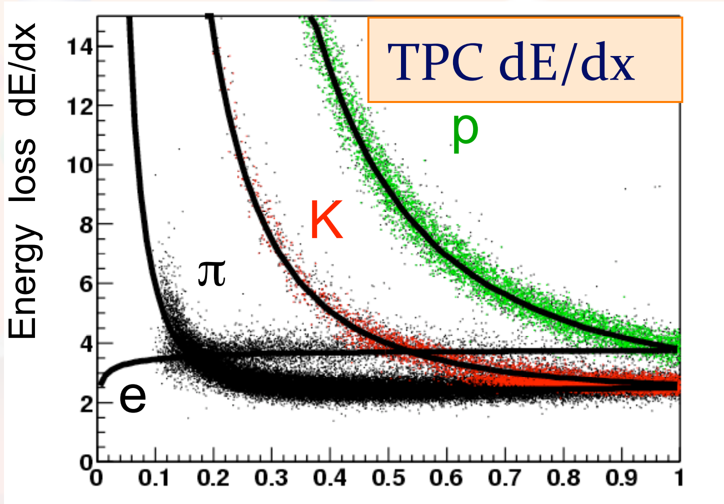


Life-time [fm/c] :

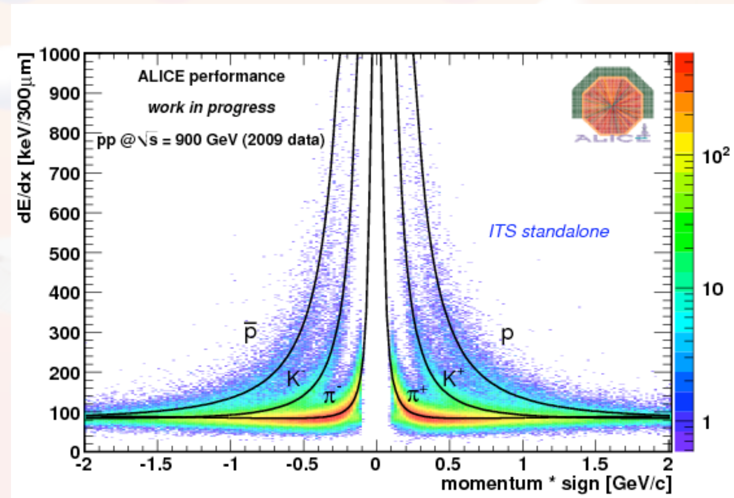
ρ(770)	= 1.4
Δ(1232)	= 1.6
K(892)	= 4.0
Σ(1385)	= 5.7
Λ(1520)	= 13
ϕ (1020)	= 45

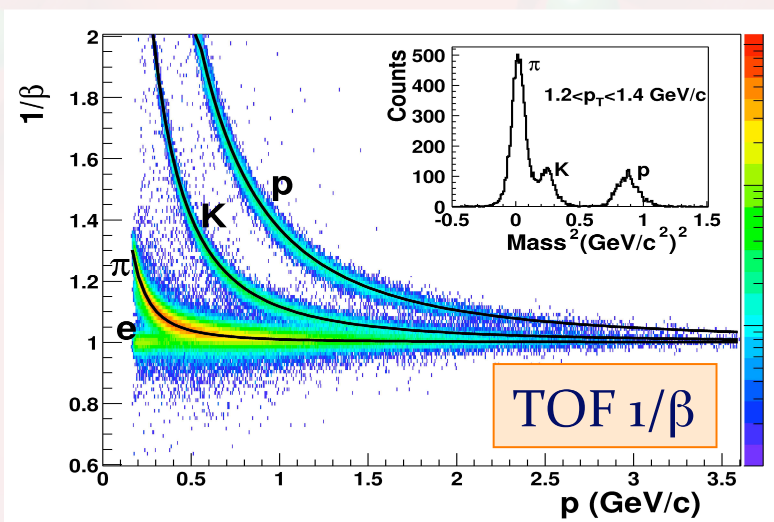
K(892)	→ π + K
ρ(770)	→ π + π
ϕ(1020)	→ K + K, $e^+ + e^-$
Δ(1232)	→ p + π
Σ(1385)	→ Λ + π
Λ(1520)	→ p + K
Ξ(1530)	→ Ξ + π

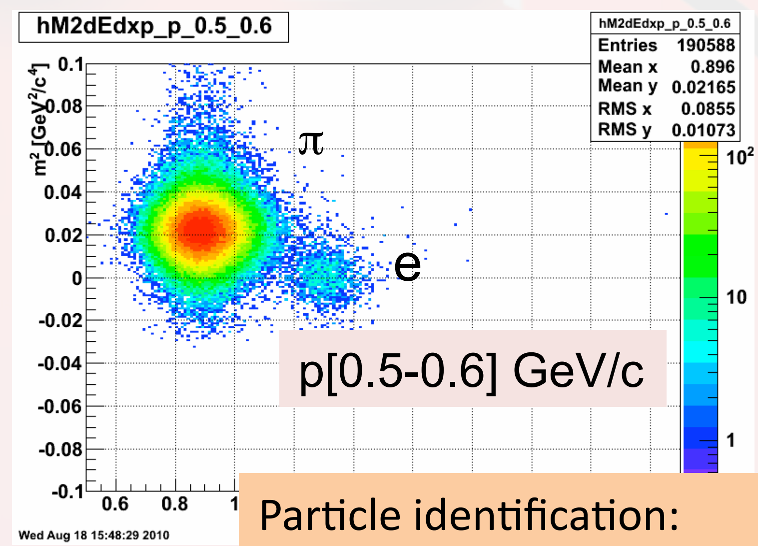
Particle identification



momentum [GeV/c]





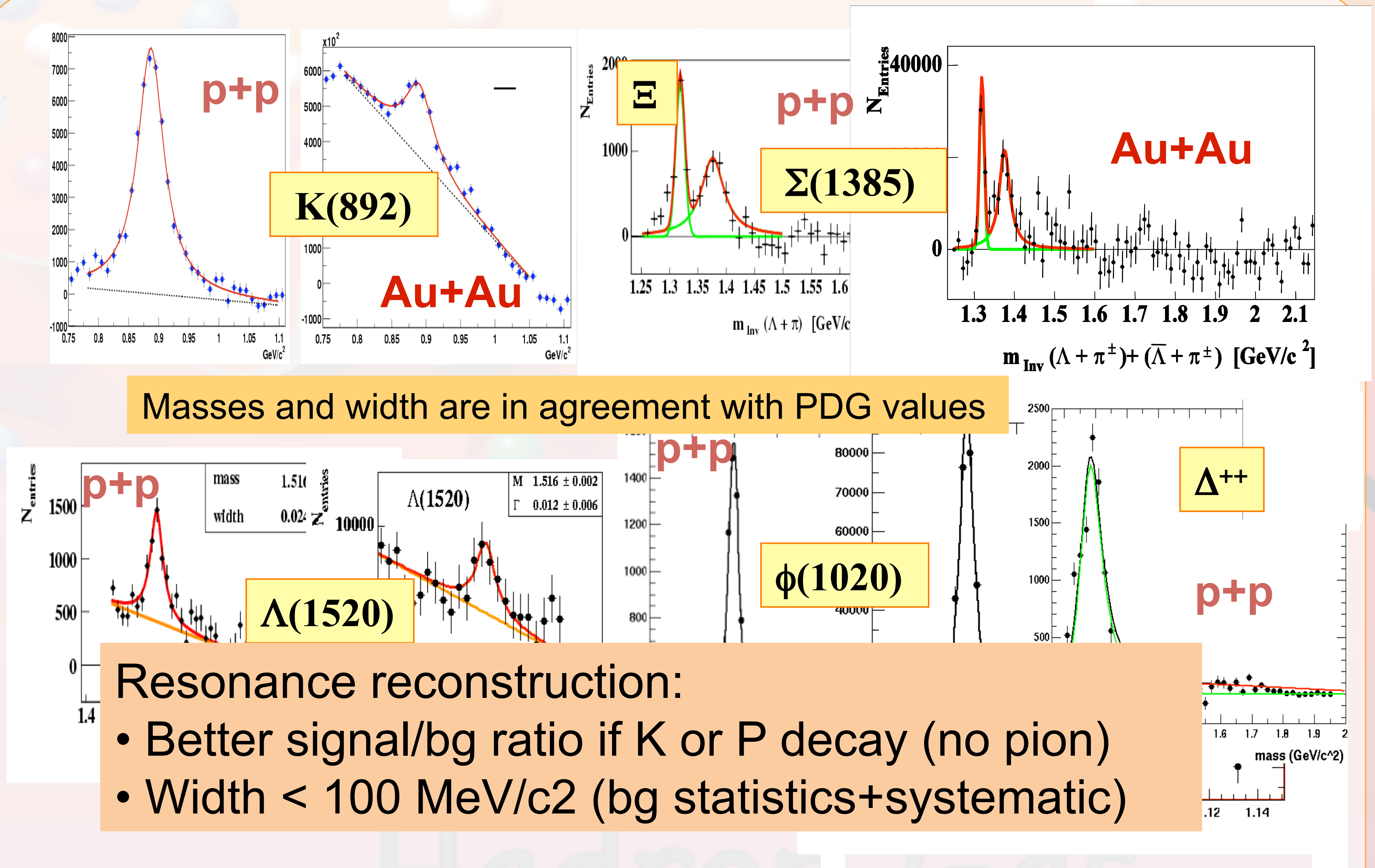


Particle identification:

TPC resolution = 7-9%

TOF resolution = 100 ps (<1%)

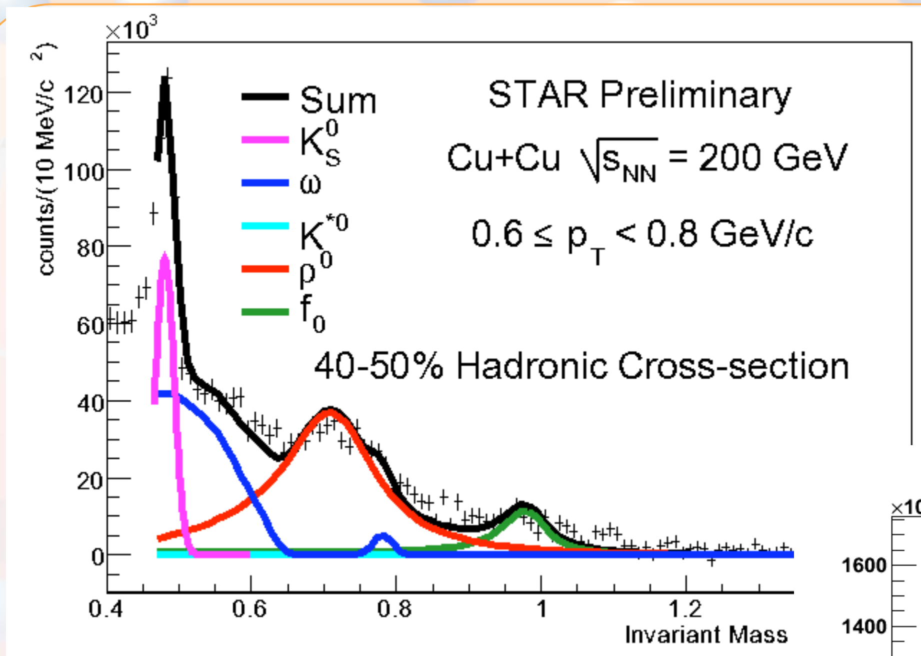
Resonances in p+p and Au+Au at 200 GeV



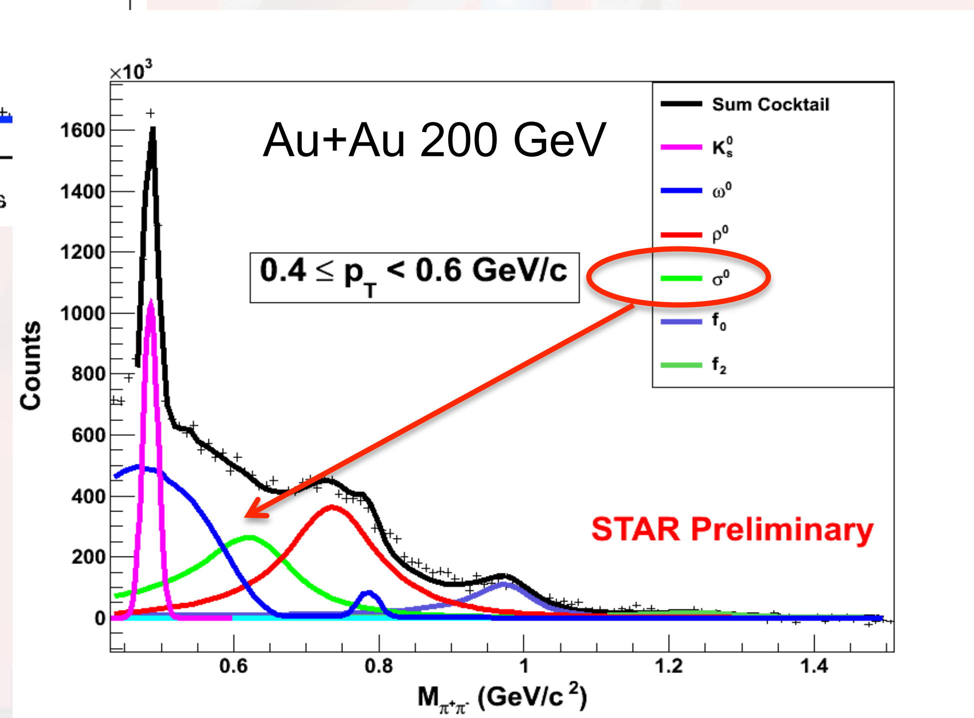
Masses and width are in agreement with PDG values

Resonance reconstruction:
- Better signal/bg ratio if K or P decay (no pion)
- Width < 100 MeV/c2 (bg statistics+systematic)

$\pi^{+} + \pi^{-}$ invariant mass distribution



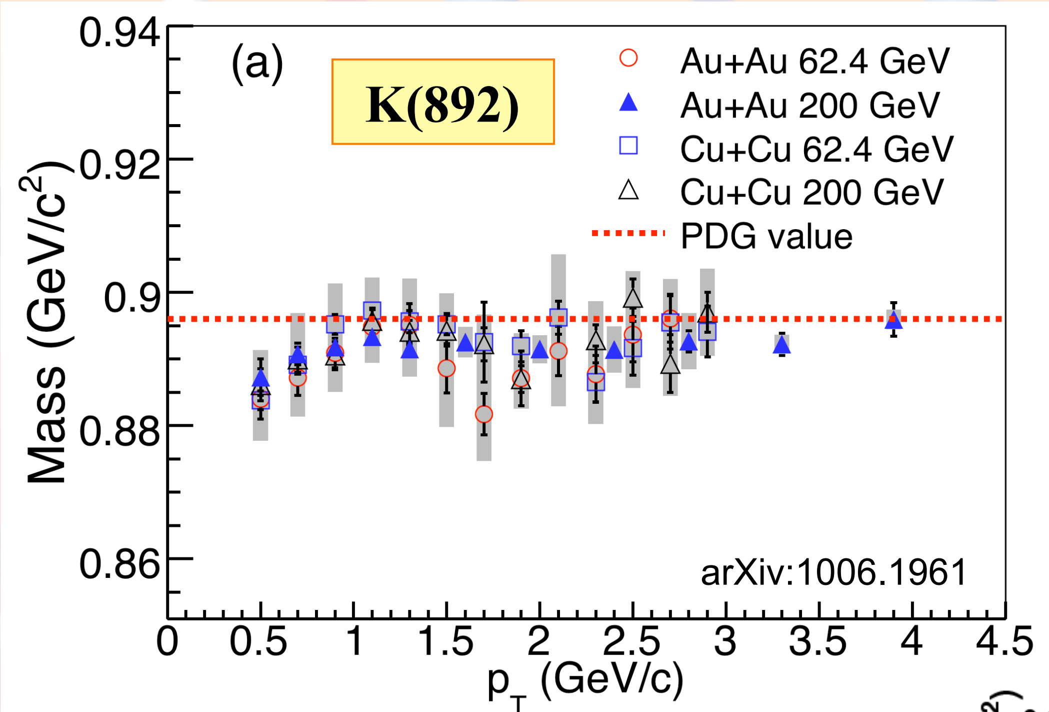
Nucl.Phys.A830:837C-840C,2009



The mass and width of σ^0 is fixed at 630 MeV/c² and 160 MeV/c²

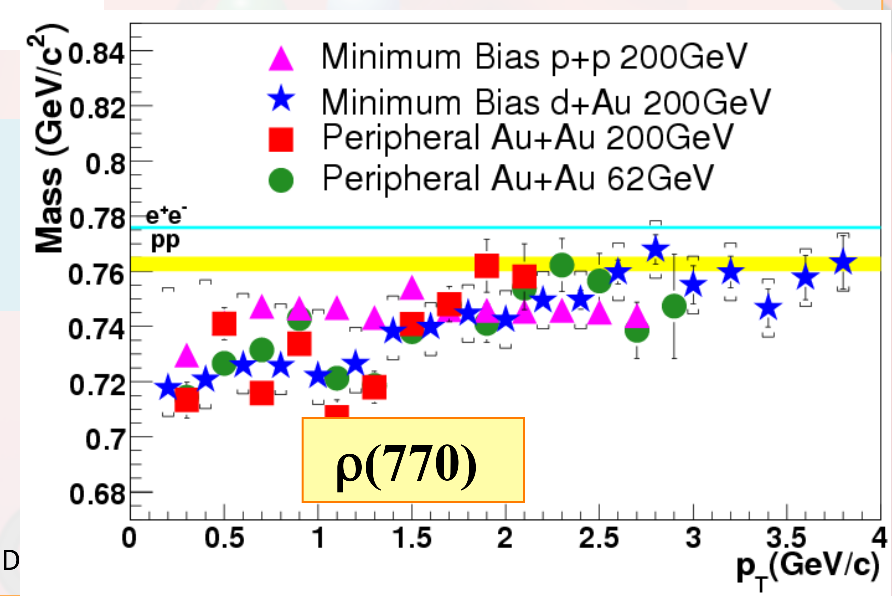
Prabhat Pujahari ICPAQGP2010

Mass shifts



Waiting for ρ mass including σ^0 resonance

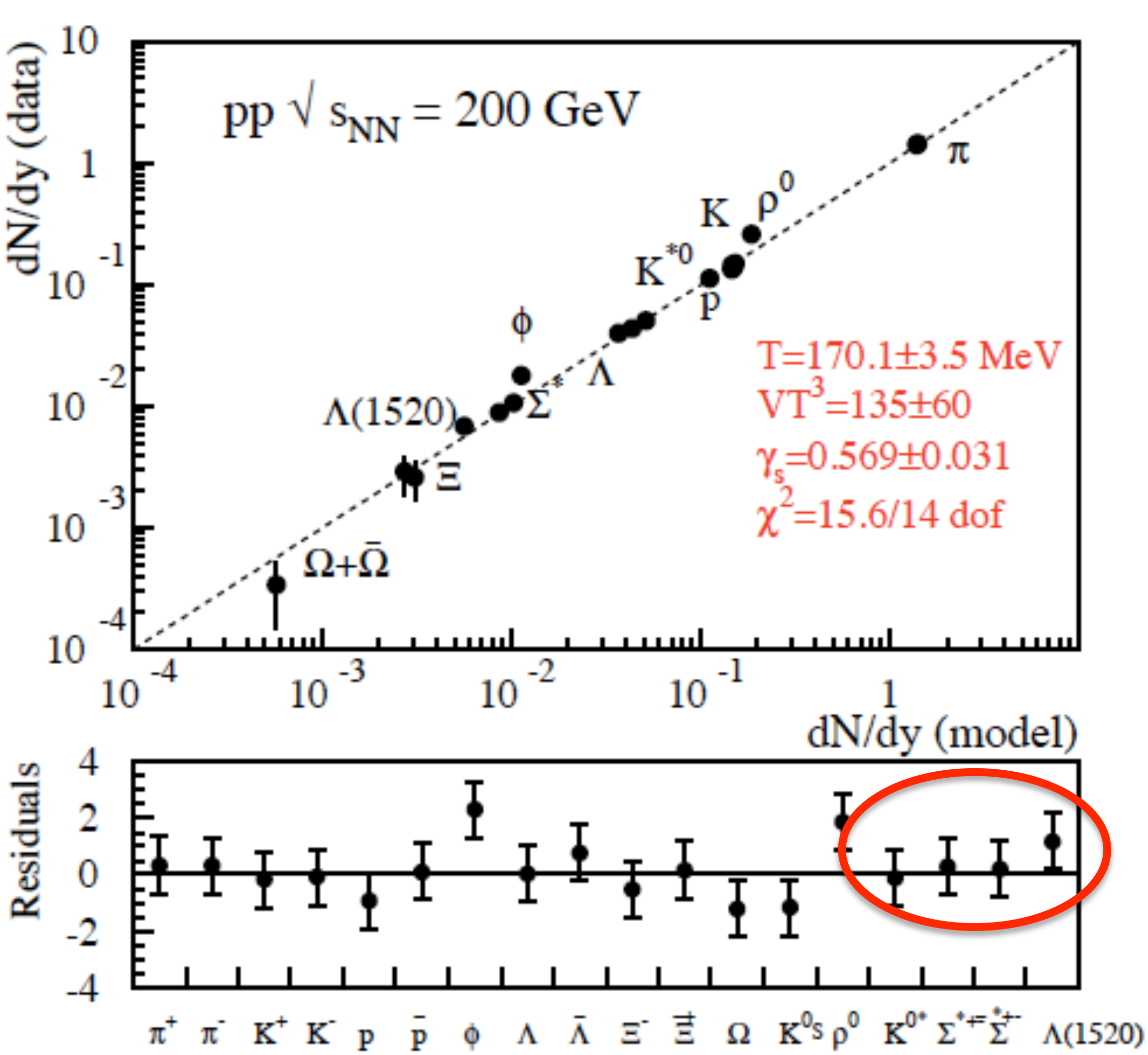
- No mass shift for K(892) visible within statistical and systematical errors.
- ρ same mass shift in all system sizes



Phys.Rev.Lett.92:092301,2004

Resonances in p+p at 200 GeV

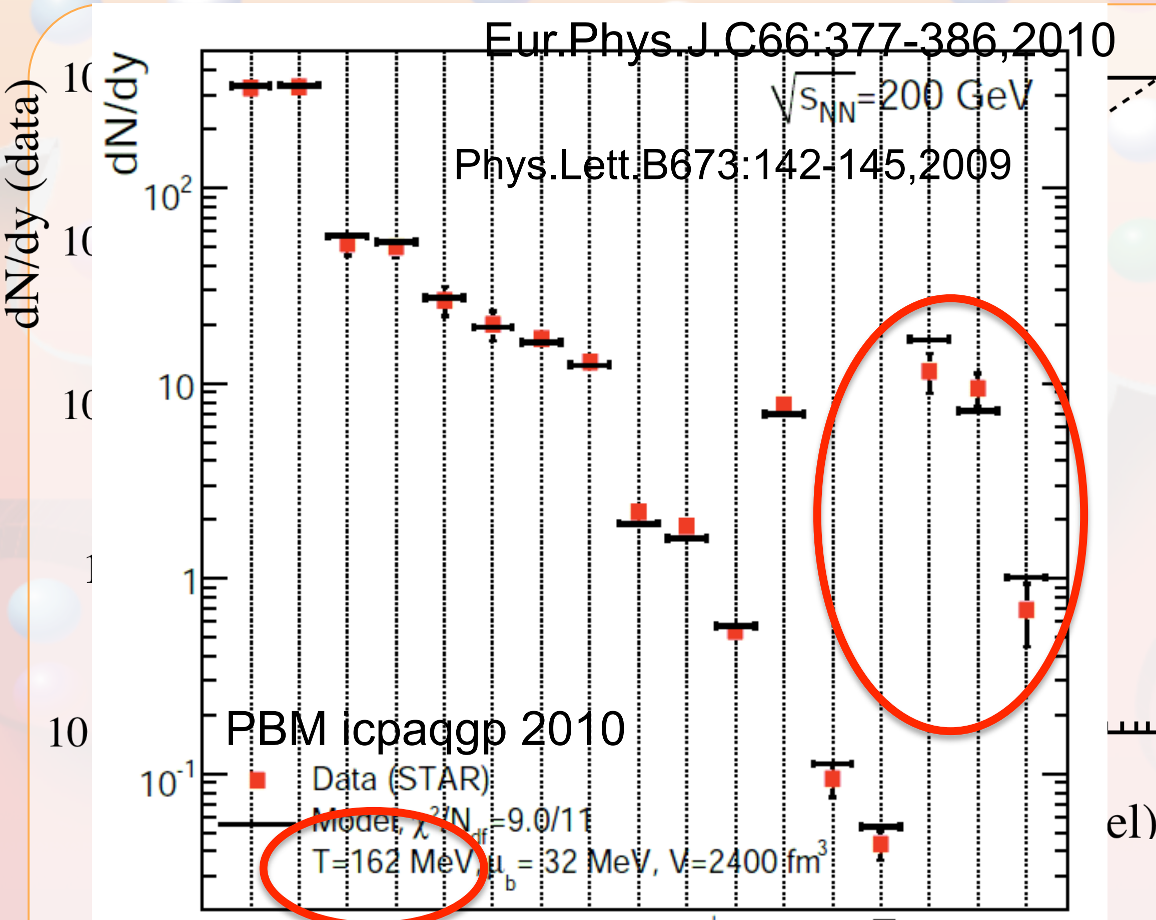
Eur.Phys.J.C66:377-386,2010



K(892),Σ(1385),Λ(1520) are in agreement with statistical model description

ρ,ϕ are too low by 2σ

Resonances in Au+Au at 200 GeV



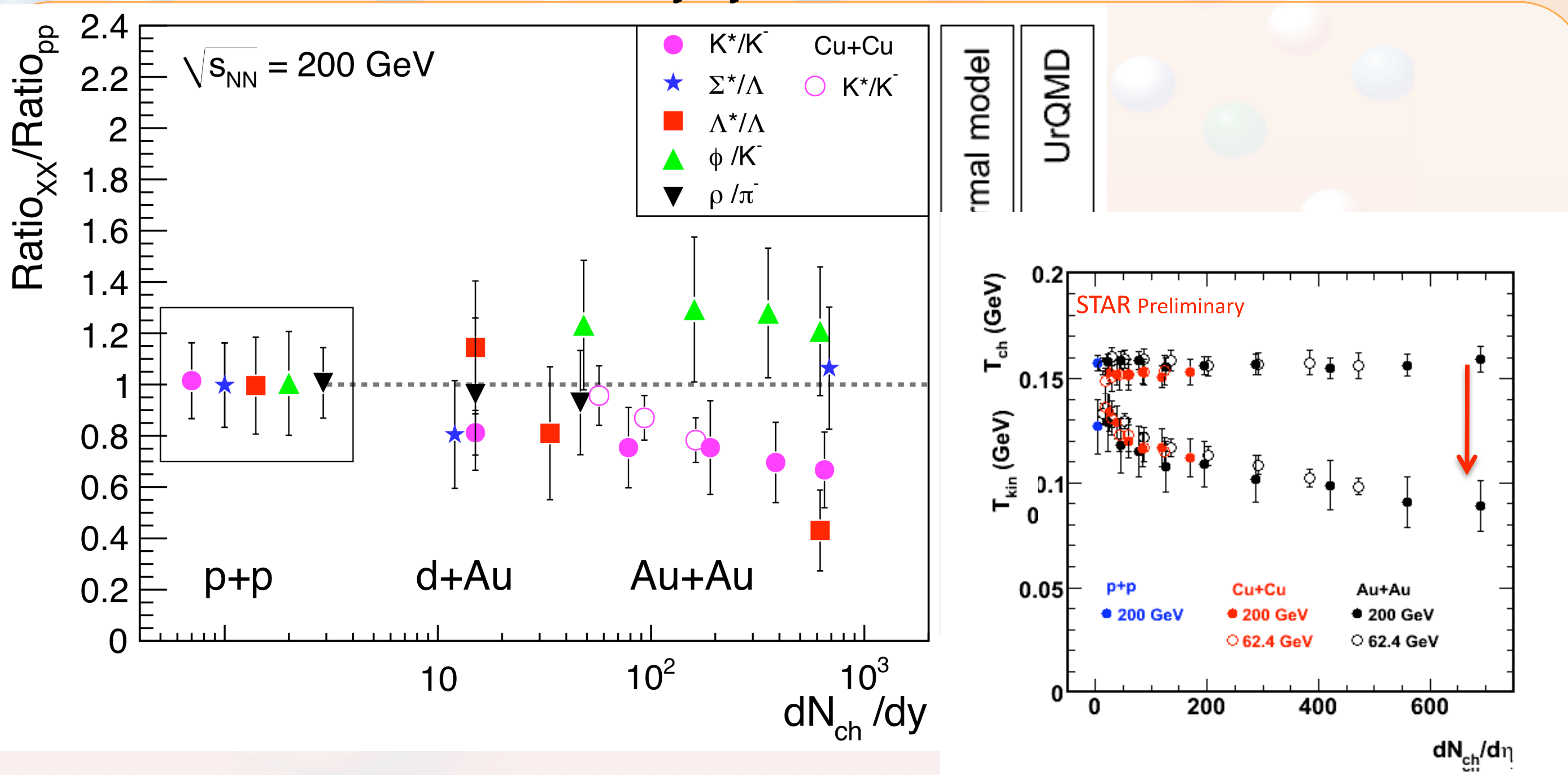
K(892), Λ(1520)
Not described by statistical model
→re-scattering of decay daughters

T = 168 +- 4 MeV
γs =0.932 +- 0.040

Including resonances can alter the fit results !!
Resonance suppression lowers freeze-out temperature in fit.

chemical freeze-out
(RHIC and SPS (LHC?)

Resonance suppression at RHIC

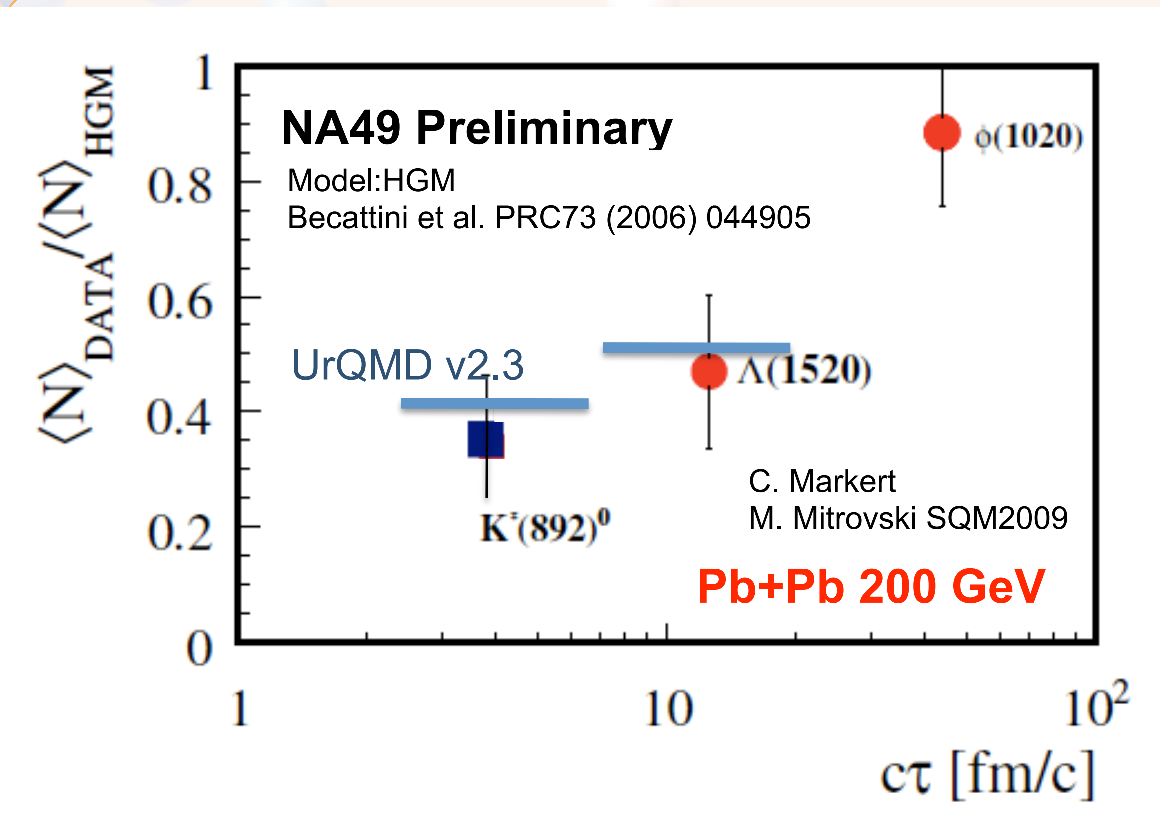


Hadronic lifetime > 4-5 fm/c (in central collisions)
Fireball lifetime ~ 10 fm/c
→partonic lifetime ~ 5 fm/c

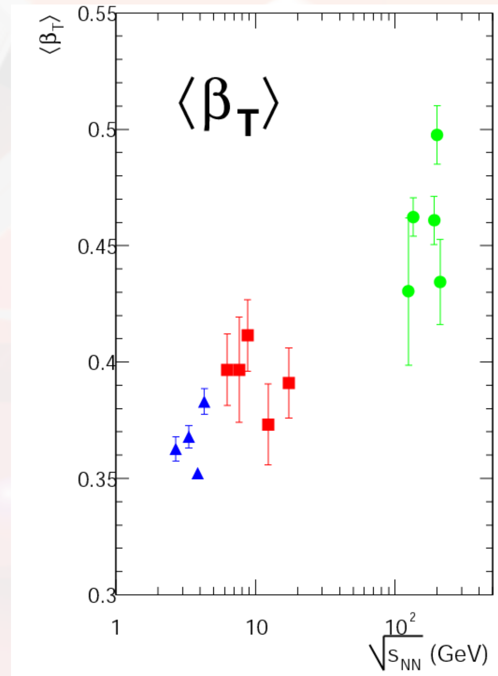
CM, G. Torrieri and J. Rafelski, hep-ph/0206260

Phys. Rev. Lett. 97 (2006) 132301
Phys. Rev. C 78 (2008) 44906
e-Print Archives (1006.1961)

Resonances at lower energies (SPS)



Tch and Tkin are similar at SPS and RHIC



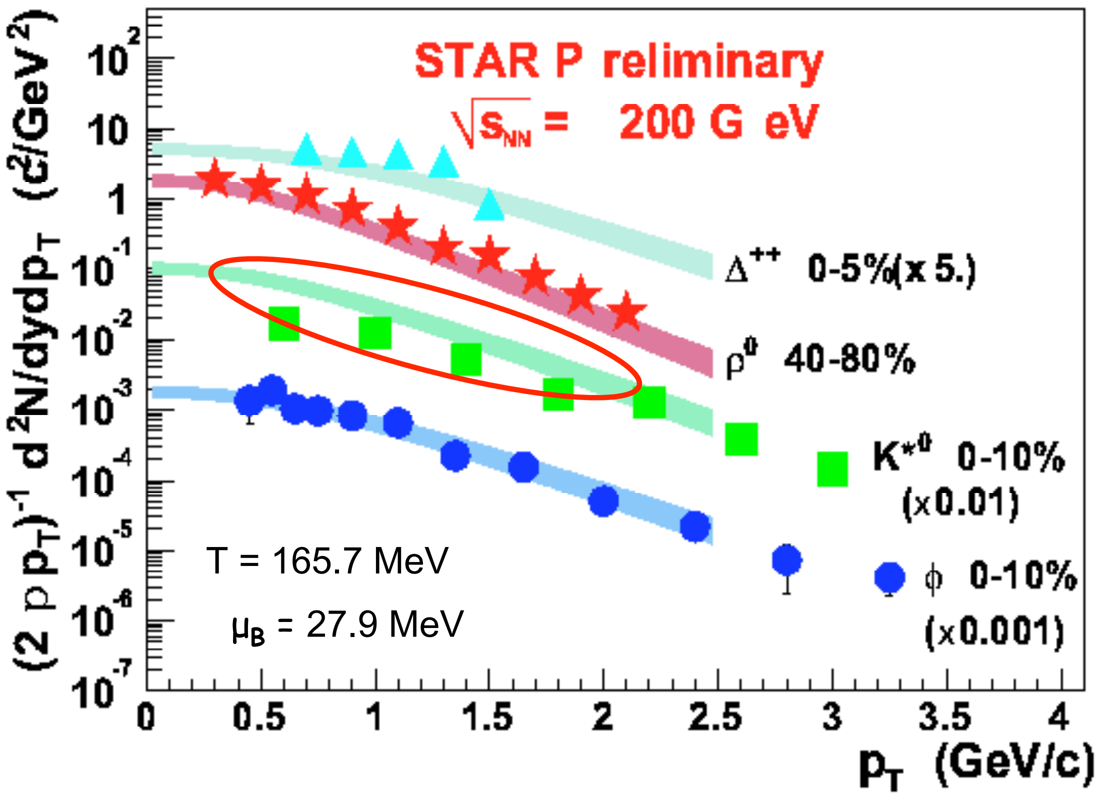
Larger resonance suppression at SPS than at RHIC:

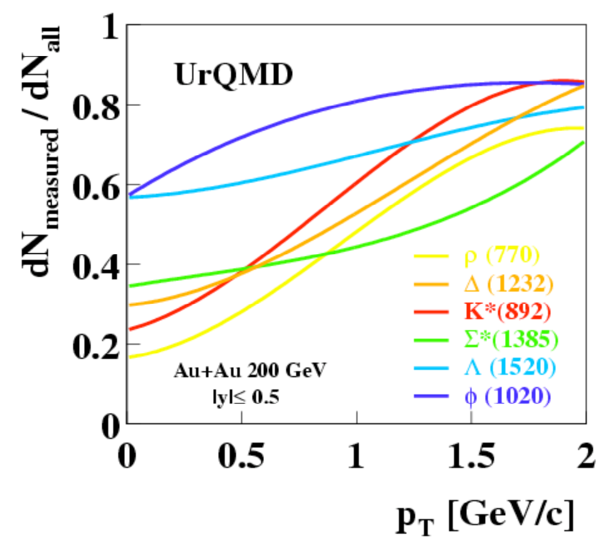
→ More re-scattering than regeneration

→ Suggest longer lifetime of hadronic phase

Particle spectra from thermal model

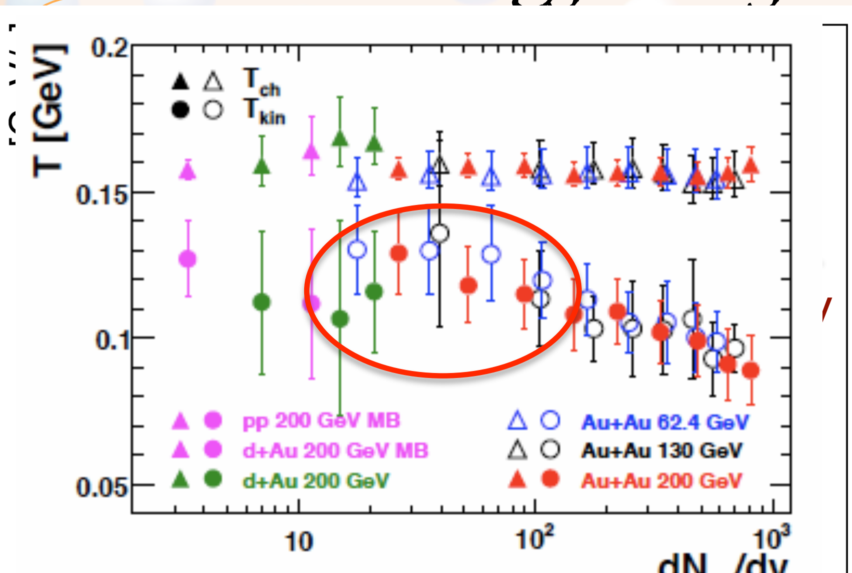
W. Florkowski, SQM2004



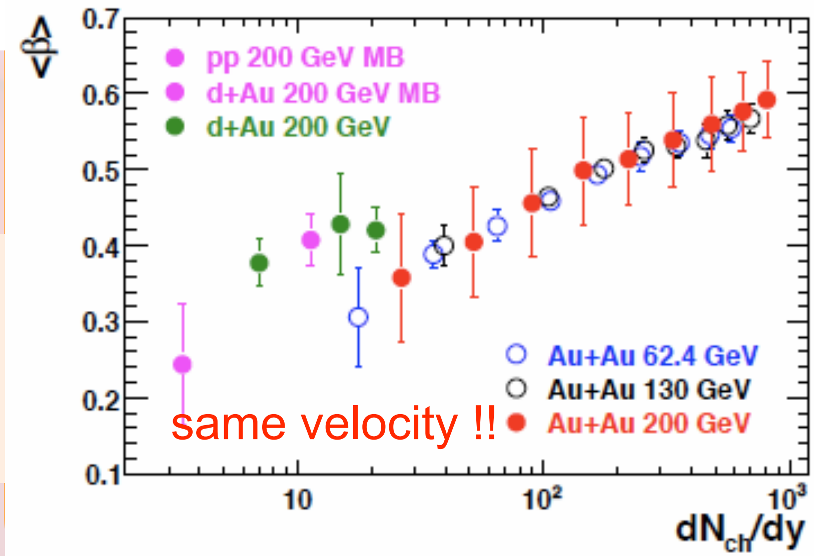


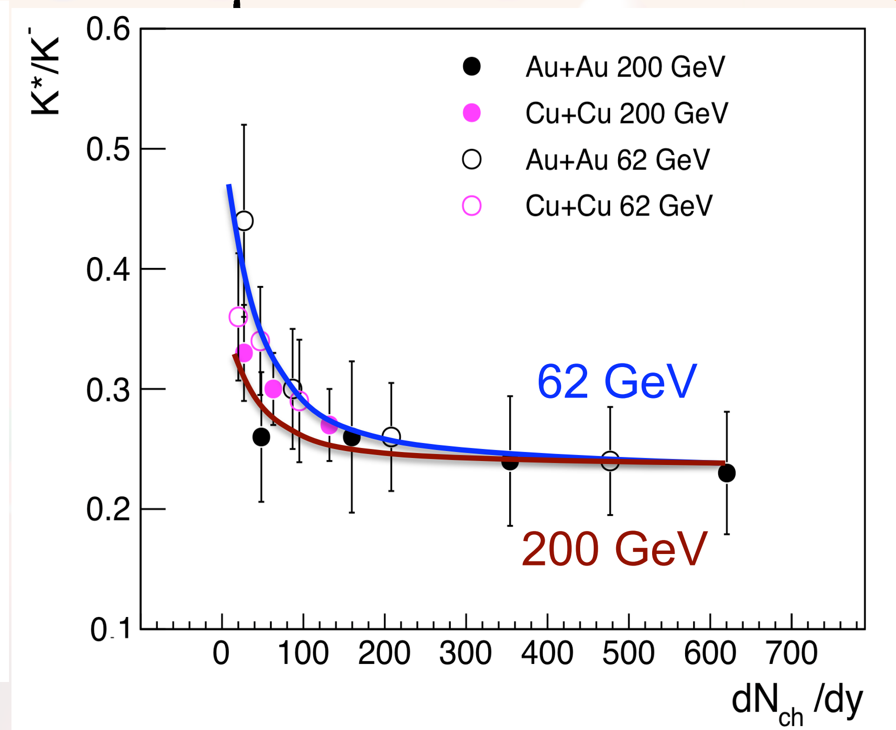
Signal loss for K* in low momentum region due to re-scattering in hadronic phase

Resonance suppression
(Energy and system size dependence)



Phys. Rev. C 79 (2009) 34909

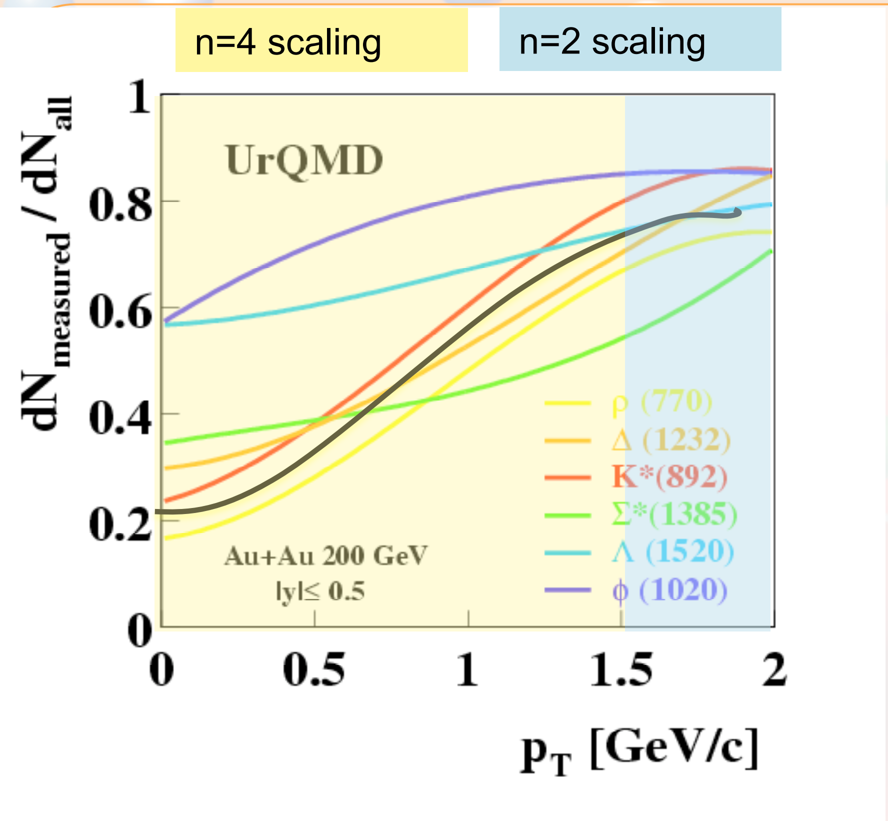


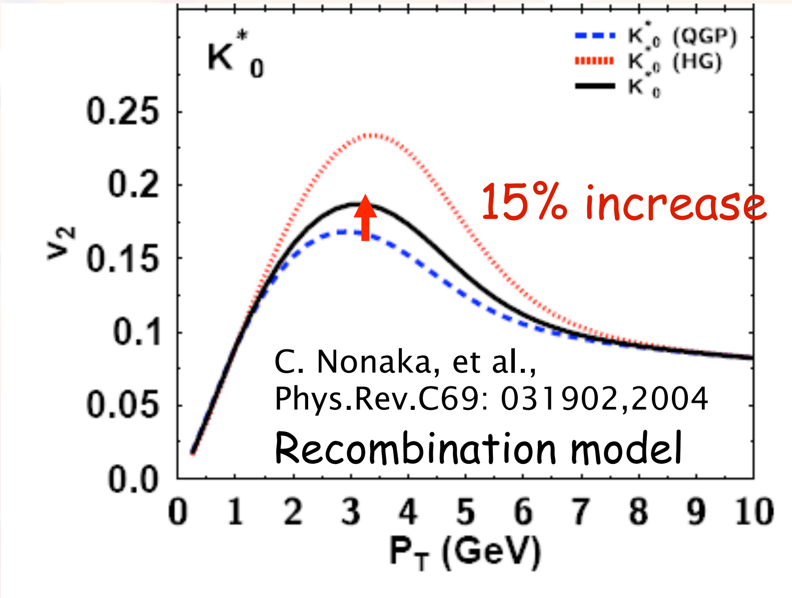


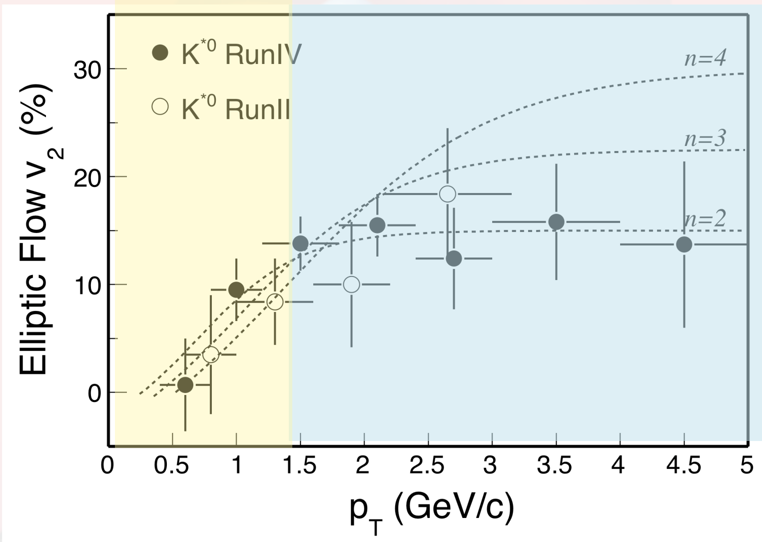
e-Print Archives (1006.1961)

g in low p_T region)

Resonances v_2 and NCQ scaling test



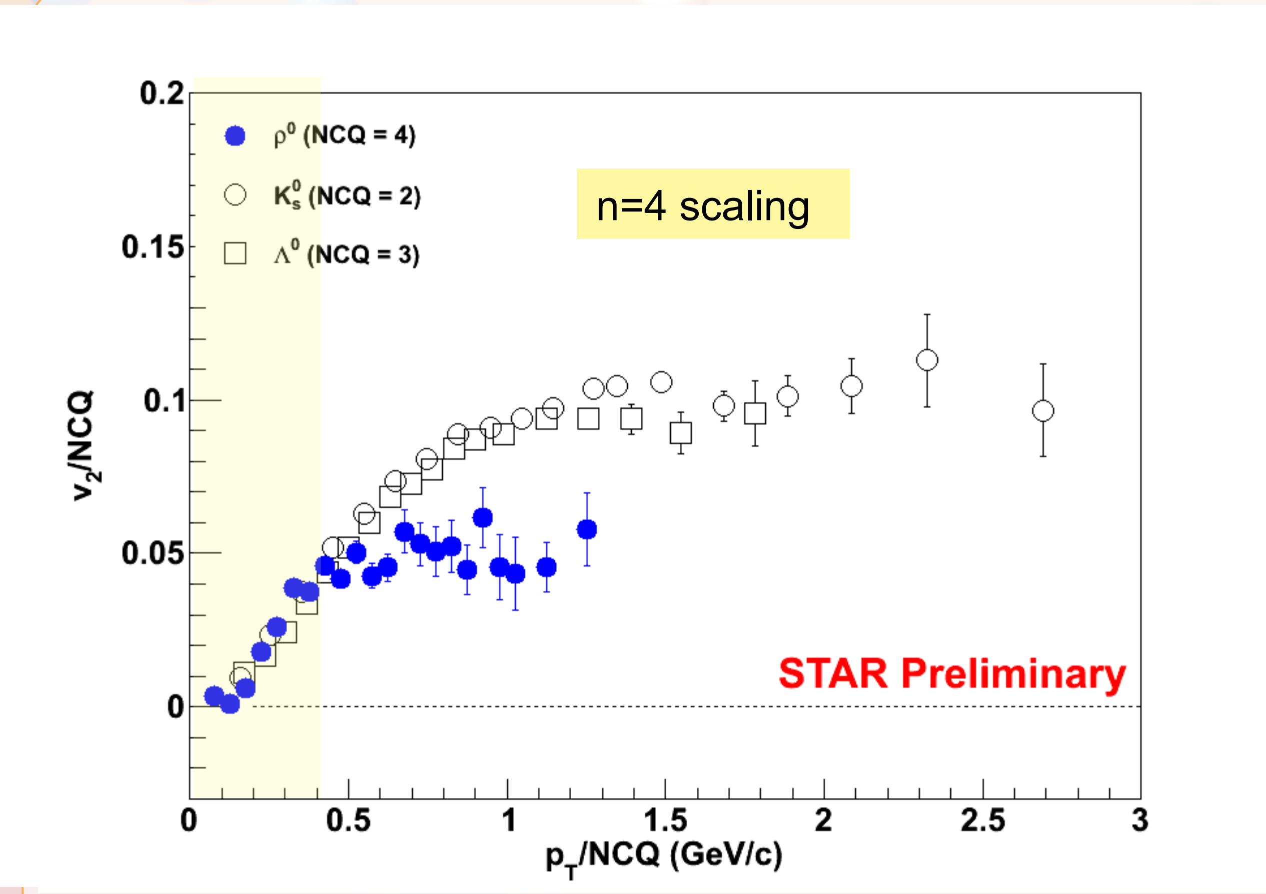




K* = 2 quarks

π +K → K* = 4 quarks

Elliptic flow of ρ resonance



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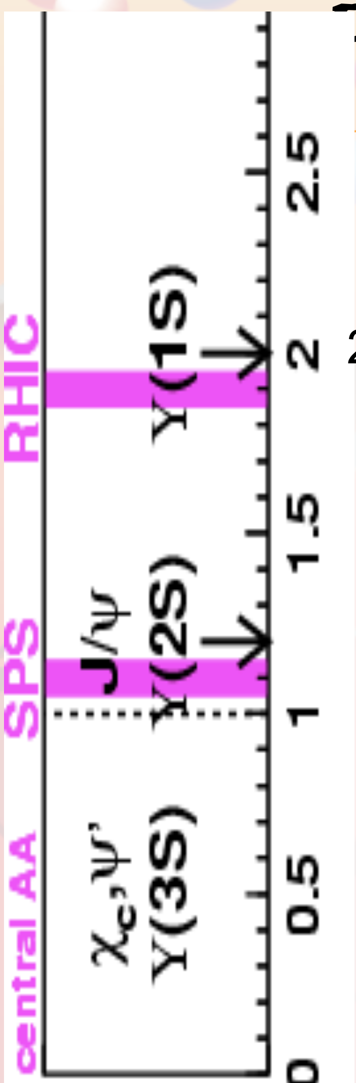
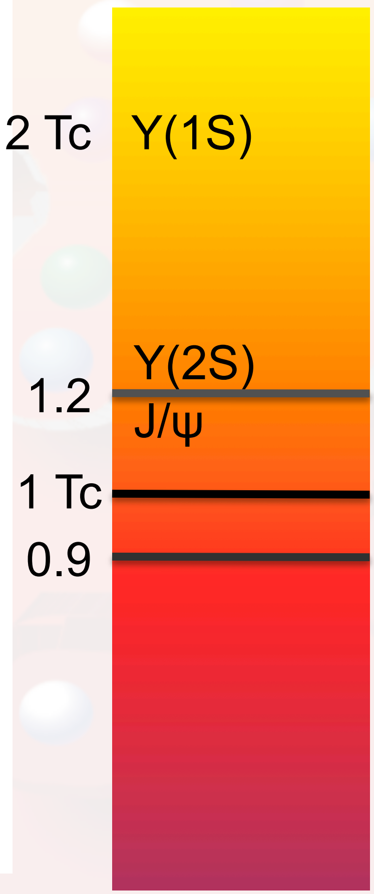
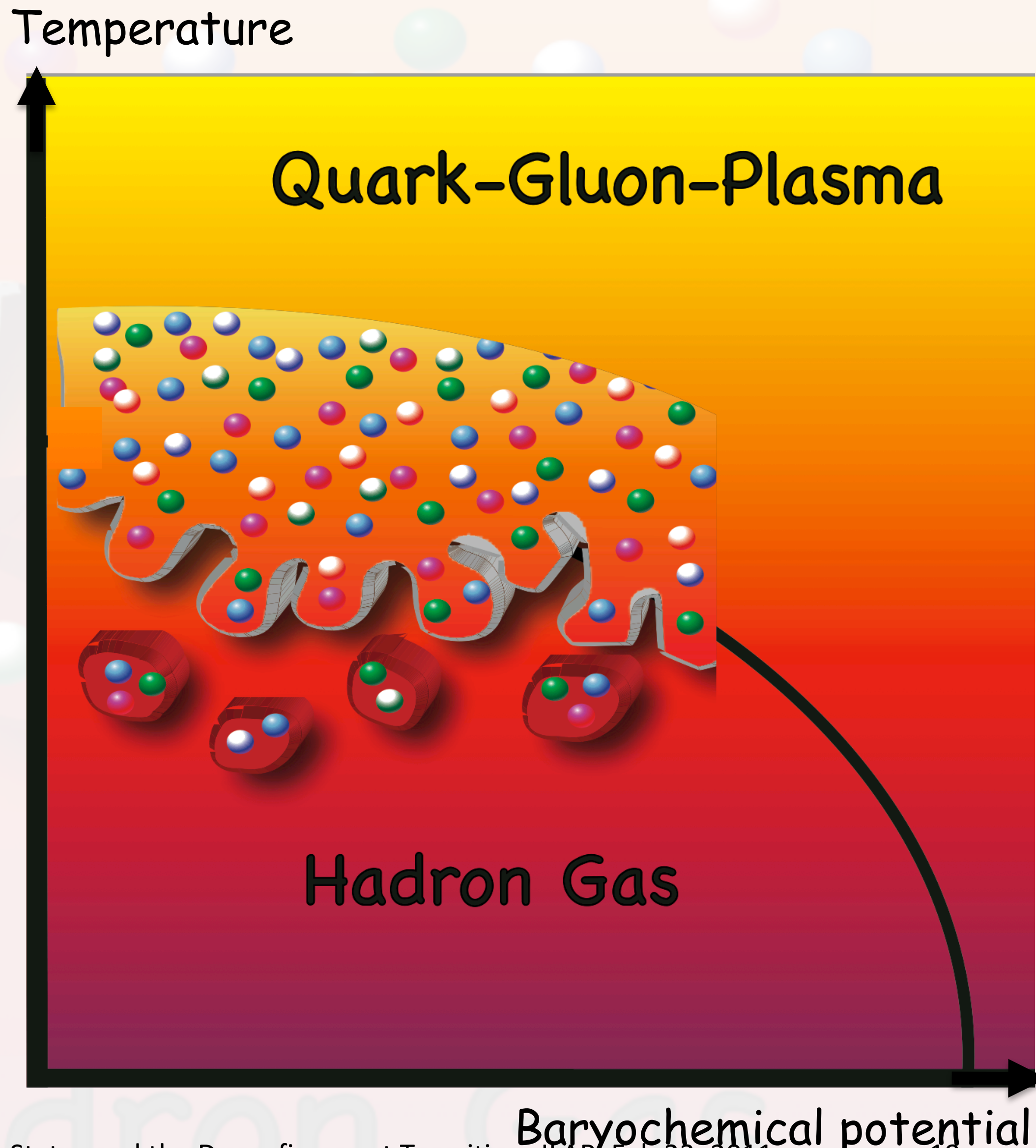
In agreement with low p_T n=4 scaling and high p_T n=2 scaling

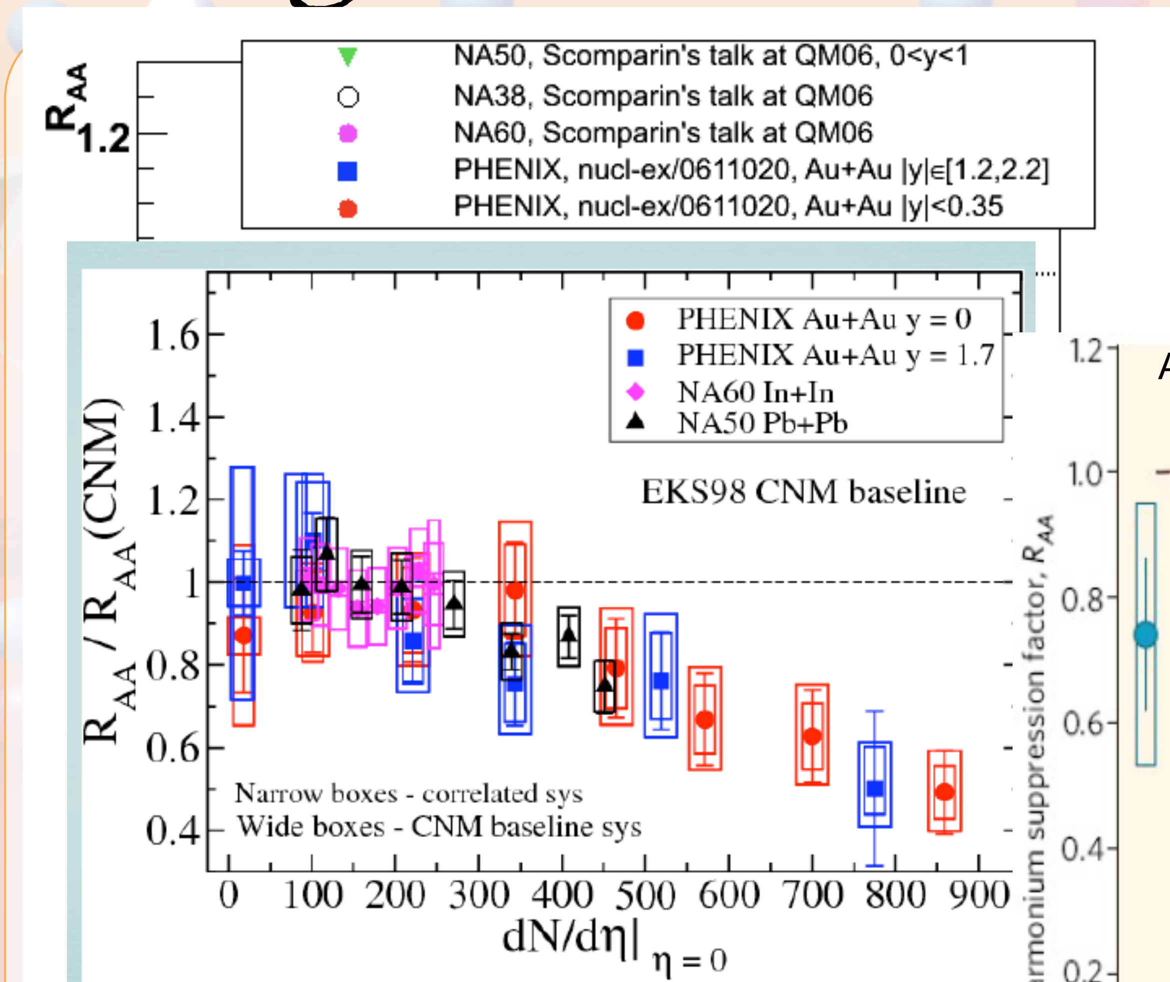
Phase diagram of nuclear matter

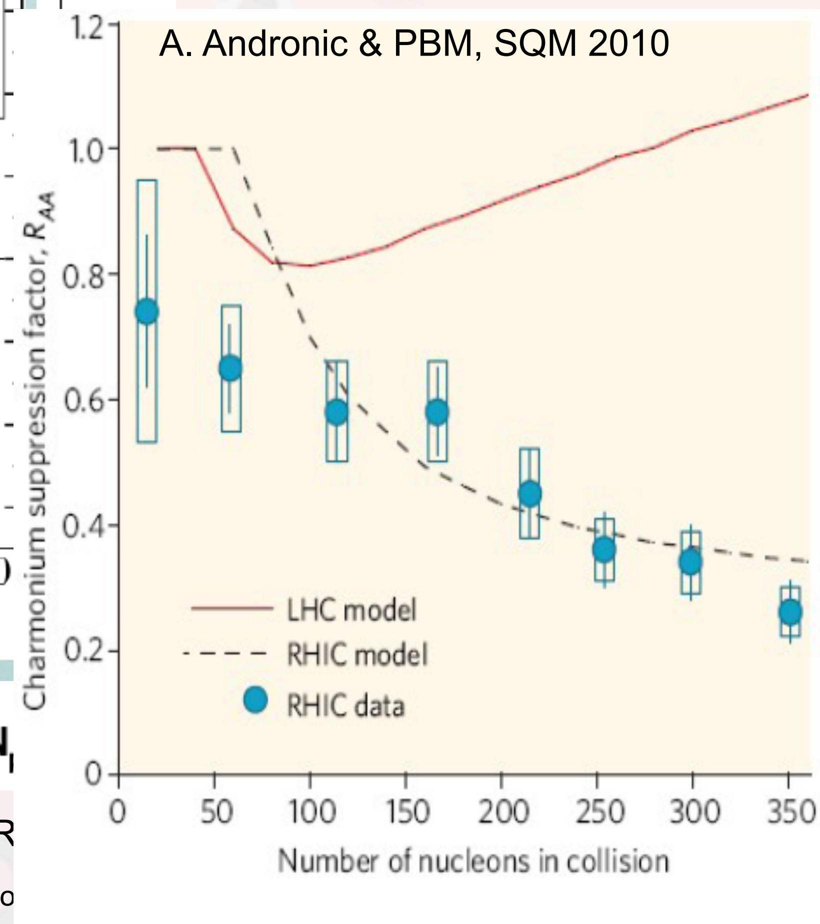






Regeneration of J/ψ at RHIC ?





After CNM effect subtraction SPS and RHIC data are consistent with each other and with statistical hadronization

Measure chiral symmetry restoration

1. via leptonic decay of resonances
   → do not interact with hadronic medium

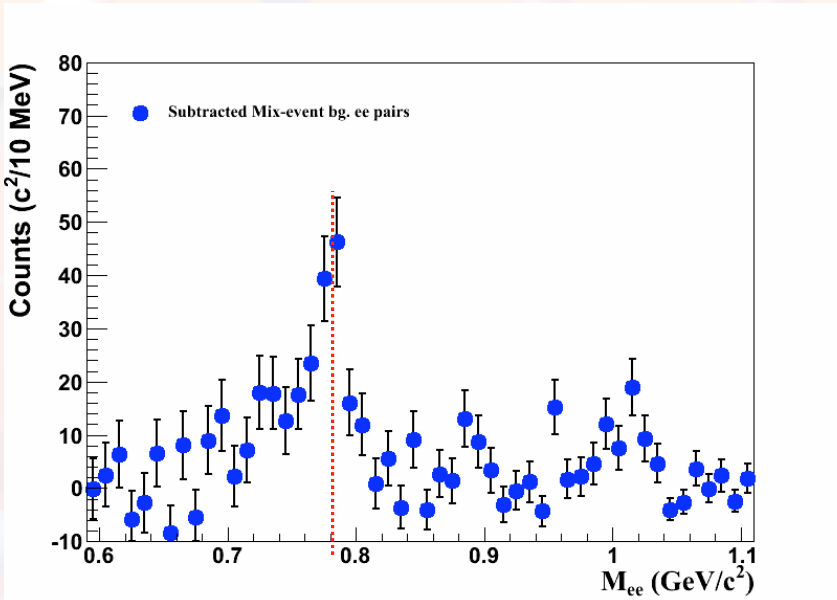
However leptonic decays from regenerated resonances possible

2. Use momentum dependence to avoid hadronic phase.

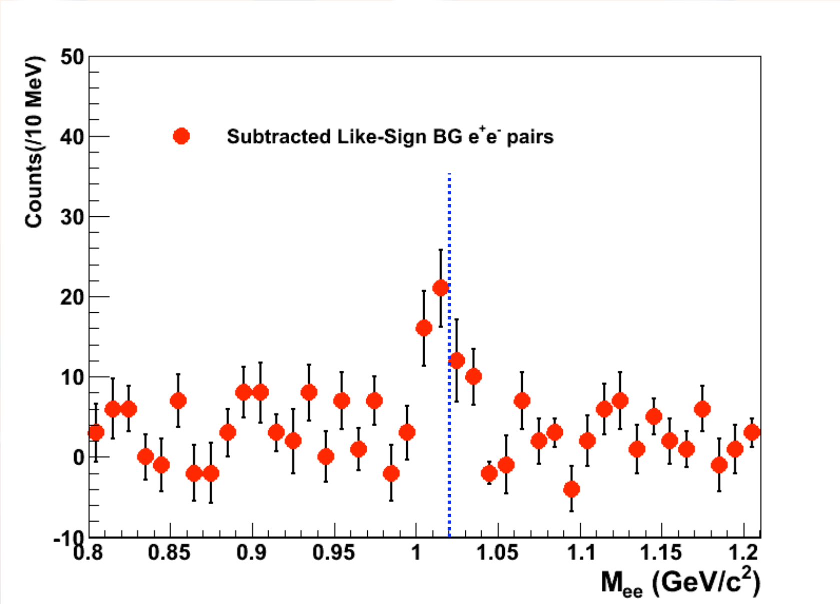
via resonances from jets
   → filter resonances from early medium

Di-electron measurement p+p (STAR)

$\omega(782)$ BR = 7.18 x 10^{-5}



$\phi(1020)$ BR = 2.97 x 10^{-4}



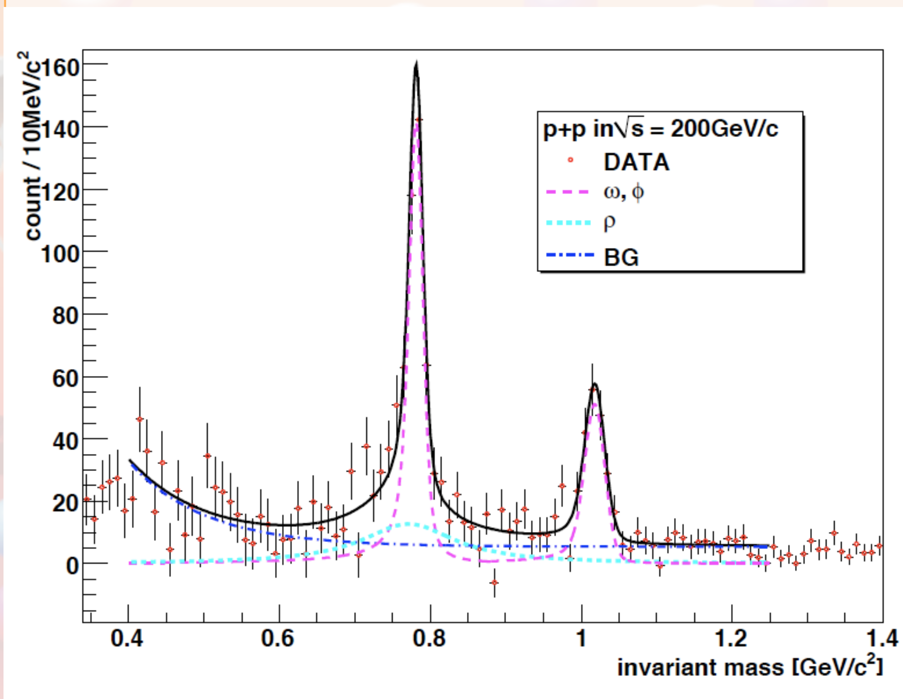
Markert WISH2010

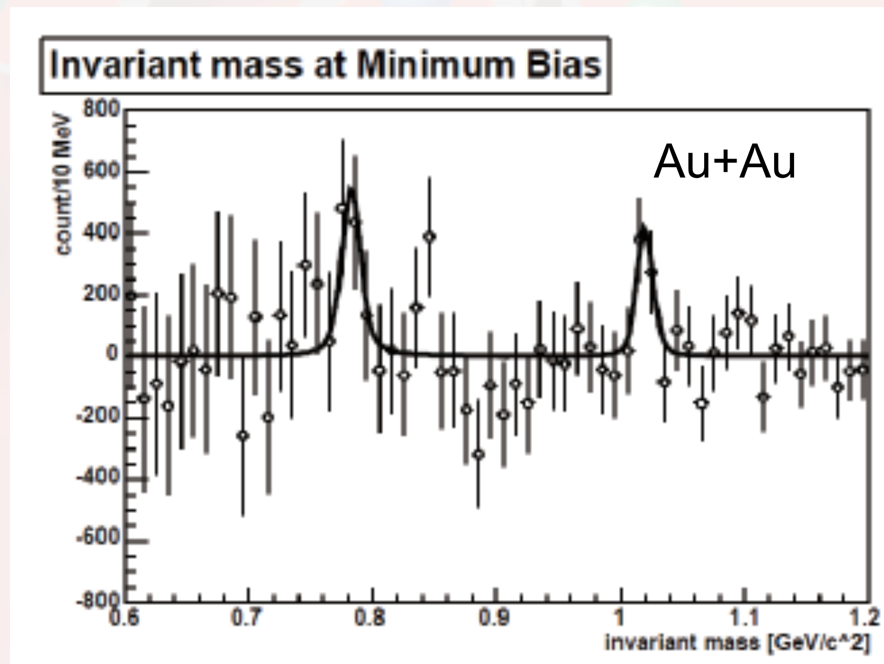
First look - more details from STAR to follow…

Masses appear in agreement with PDG
ω and φ signals significant

Di-electron measurement (PHENIX)

Misaki Ouchida, J.Phys.Conf.Ser.230:012022,2010



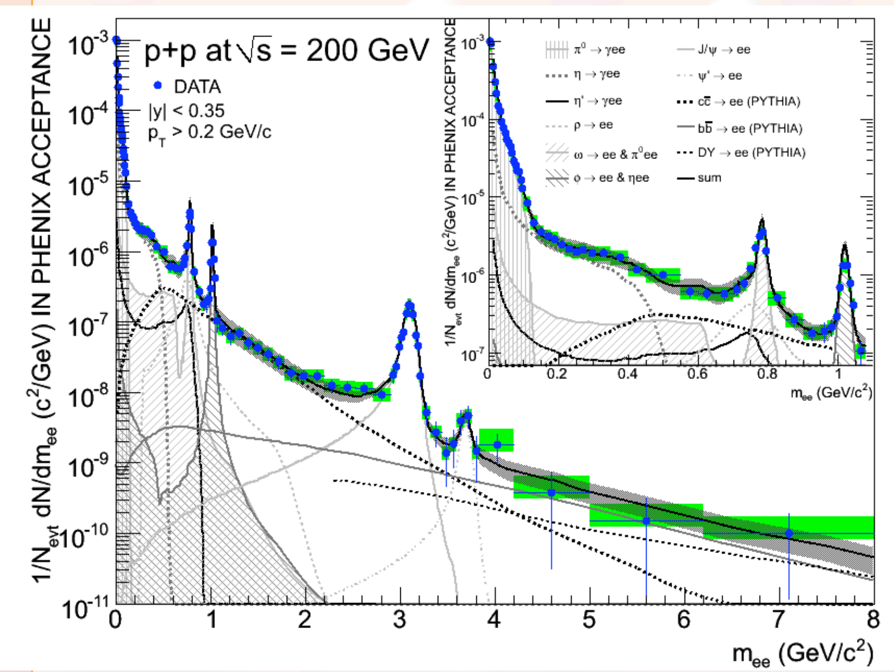


Breit-Wigner fit parameter
mass and width
taken from PDG

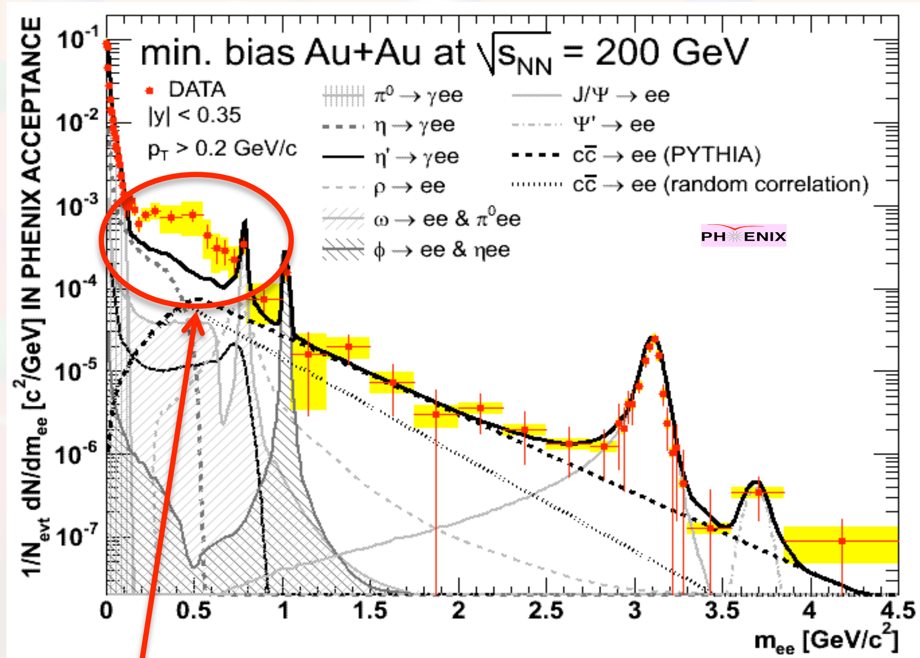
Di-electron measurement (PHENIX) II

p+p

Au+Au minimum bias



Phys.Lett.B670:313-320



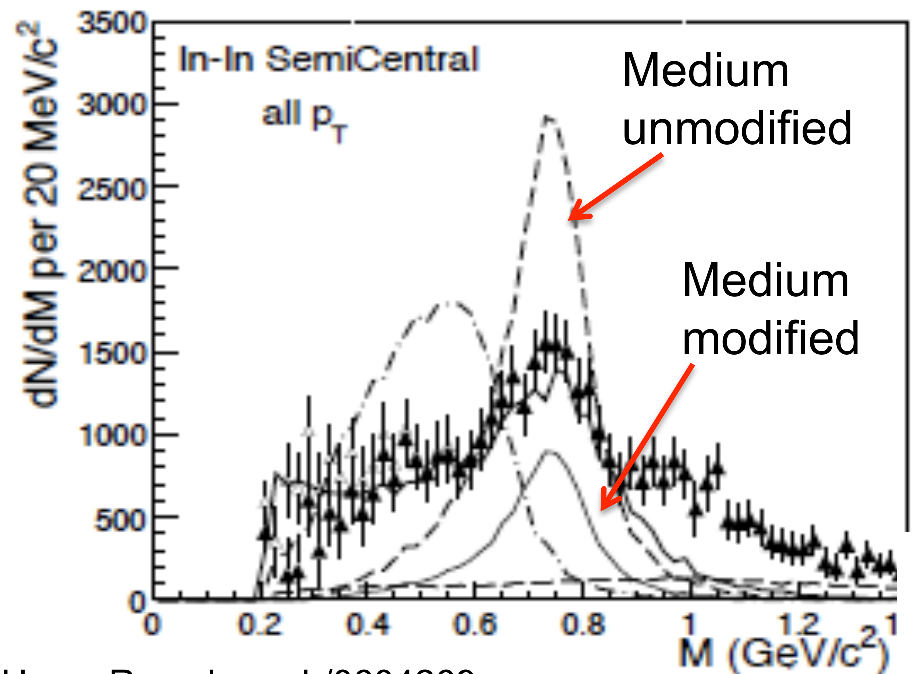
arXiv:0706.3034

A significant excess is observed at low mass in Au+Au minimum bias

Alberica Toia QM2008

Low-Mass Continuum:
enhancement 150 < m_{ee} < 750 MeV:
3.4 ± 0.2(stat.) ± 1.3(syst.) ± 0.7(model)

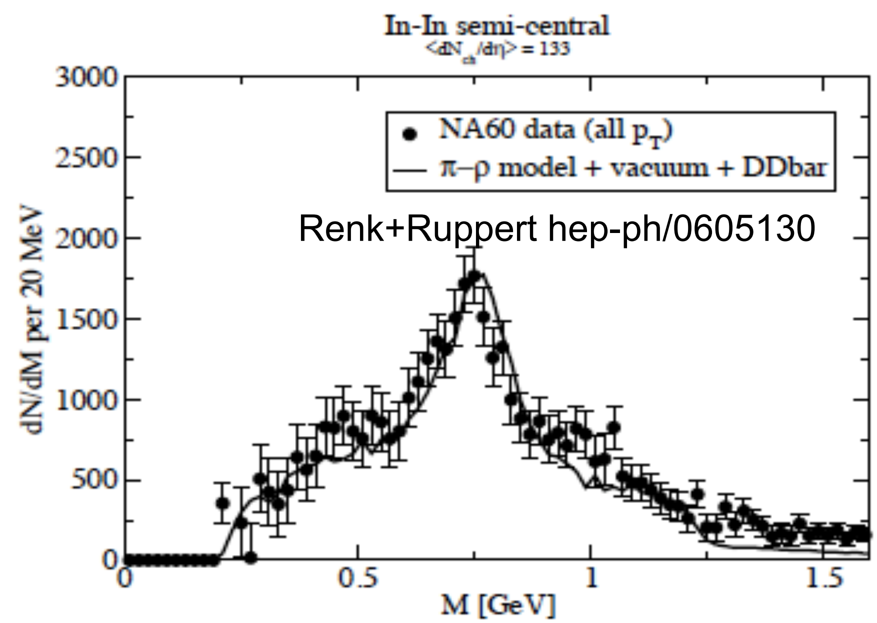
Di-muon measurement (NA60)



Hees+Rapp hep-ph/0604269

Width broadening of
rho meson
in di-muon spectrum
due to chiral medium ?

Contribution of hadronic medium ?
Need to measure ϕ and ω.

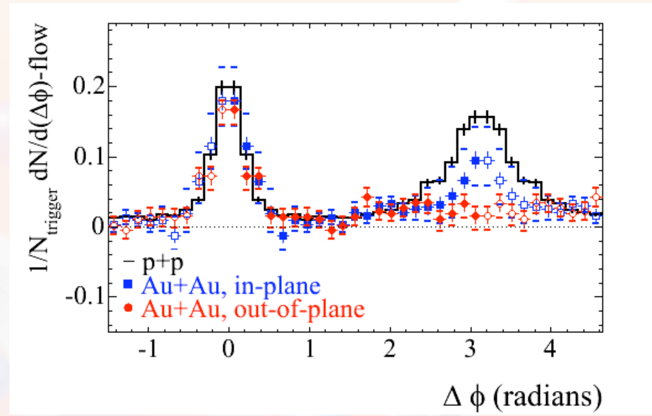


Renk+Ruppert hep-ph/0605130

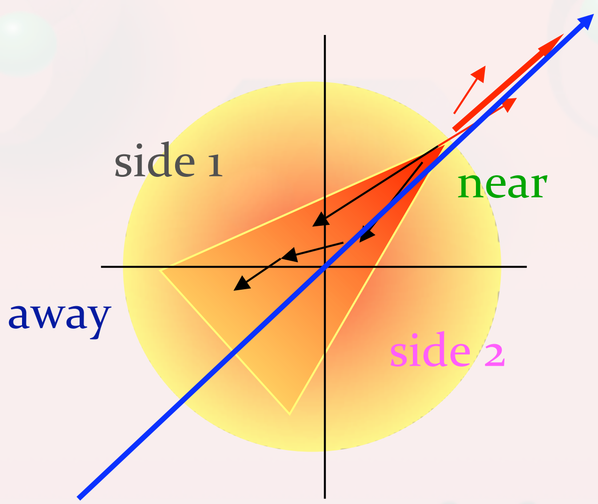
Resonances from jets to probe chirality

We want early produced resonances and decay in chirally restored medium
→ resonances from jets

CM, R. Bellwied, I.Vitev, Phys.Lett.B669:92-97,2008



Resonance with respect to jet



side	Low p_T	High p_T
near	no medium	no medium
away	hadronic medium → Resonance suppression	Partonic or early hadronic medium →Mass shift and/or width broadening →Chiral medium

Formation of Hadronic Resonances (from jets)

light cone variables:

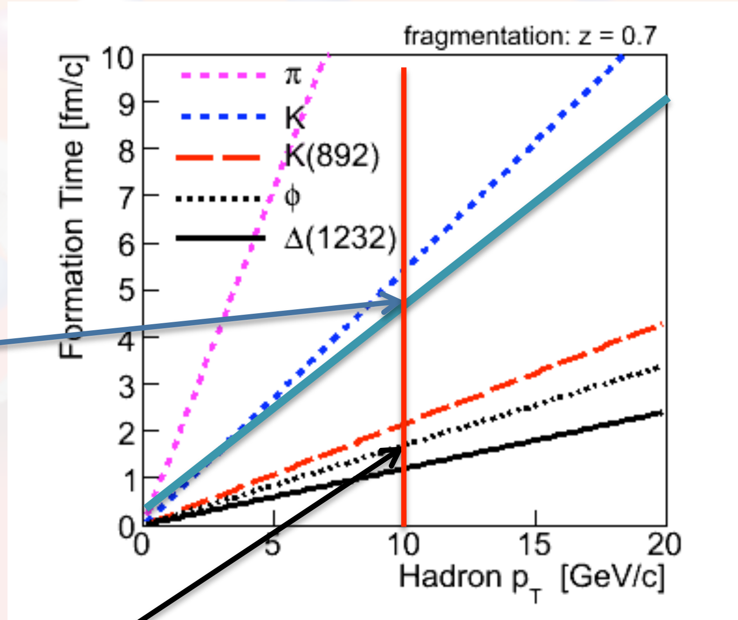
large z (=p_h / p_q)
= Resonance is leading particle in jet
→shortens formation time
→color neutral pre-hadron (resonance)

$$\tau_{\text{form}} = \tau_0 \frac{E}{m}$$

τ_o ~ 1 fm/c :

τ ~ 4.5 fm/c

10 GeV/c $\phi(1020)$



$$\Delta y^+ \simeq \frac{1}{\Delta p^-}$$
$$= \frac{zp^+}{m_h} \times 2 \left[m_h + \frac{\mathbf{k}^2}{(1-z)m_h} - \frac{zm_q^2}{m_h} \right]^{-1} . \quad (3)$$

The formation time then reads:

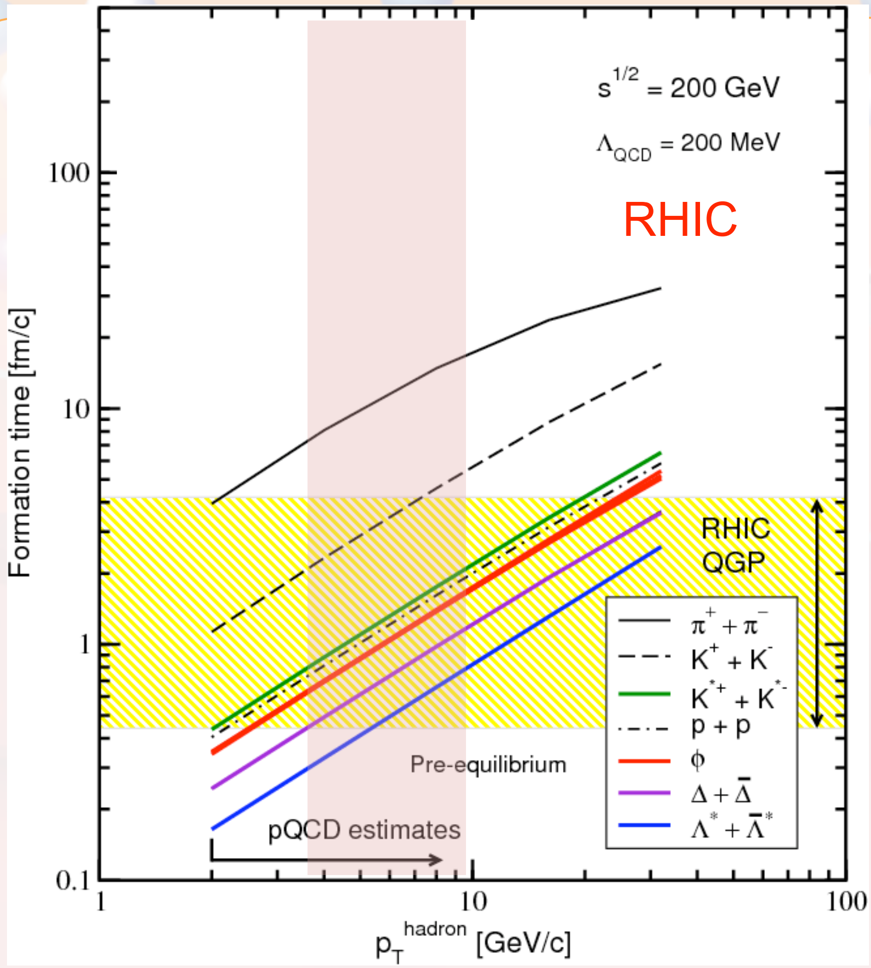
$$\tau_{\text{form}} = \frac{\Delta y^+}{1+\beta_q} , \quad \beta_q = \frac{p_q}{E_q} .$$

τ ~ 1.5 fm/c

CM, R. Bellwied, I.Vitev, Phys.Lett.B669:92-97,2008

Heavier particles of same momentum formed earlier
High momentum particles formed later

Formation Time of Resonances



At LHC the momentum range of reso
is extended to higher momentum d

ϕ(1020): RHIC p_T= [3-10] GeV

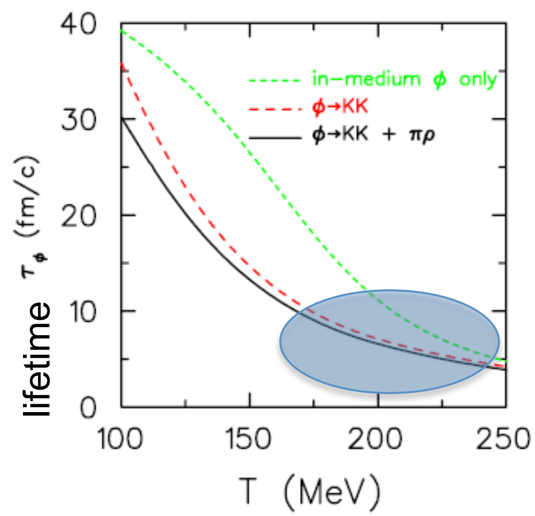
Resonance needs to decay in the partonic or the dense hadronic medium:

→ short lived resonances reconstruction difficult (broad states):

Resonances are medium modified

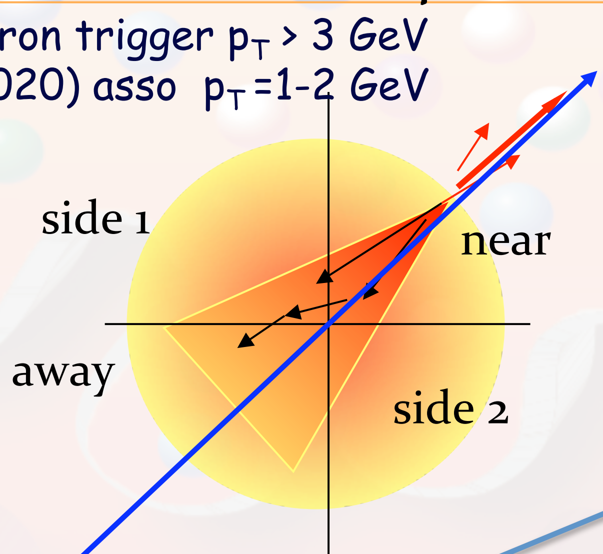
→short lifetime

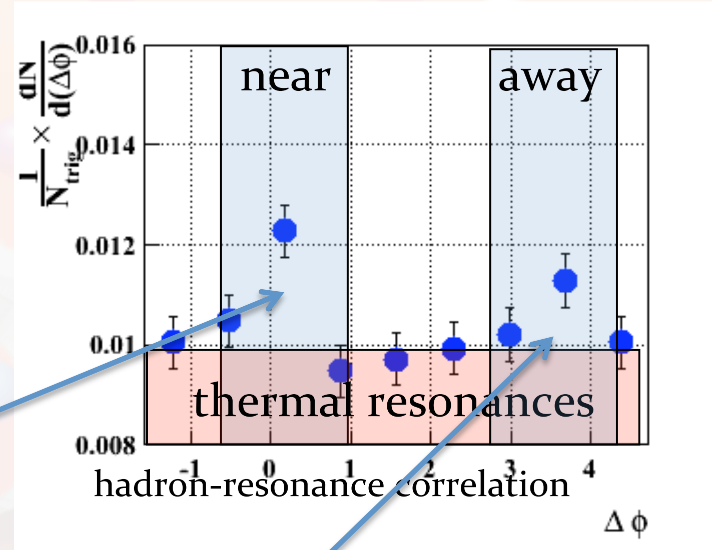
→modified K*, Λ*, Σ*, ϕ are good candidates

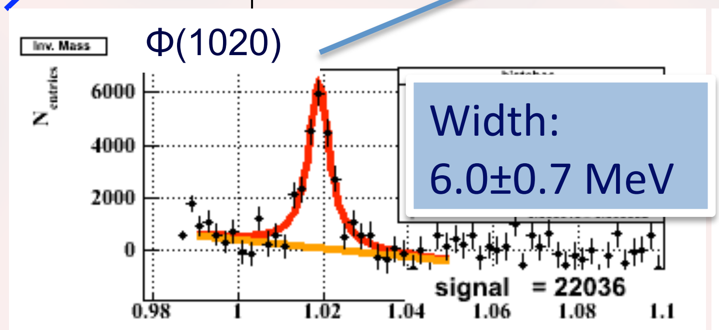


Holt & Haglin, J. Phys. G31 (2005)

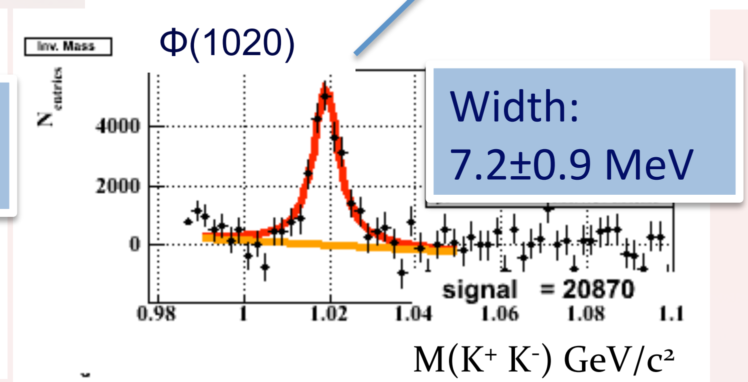
Triggered Resonance (STAR) Cu+Cu
(quadrant correlation analysis)







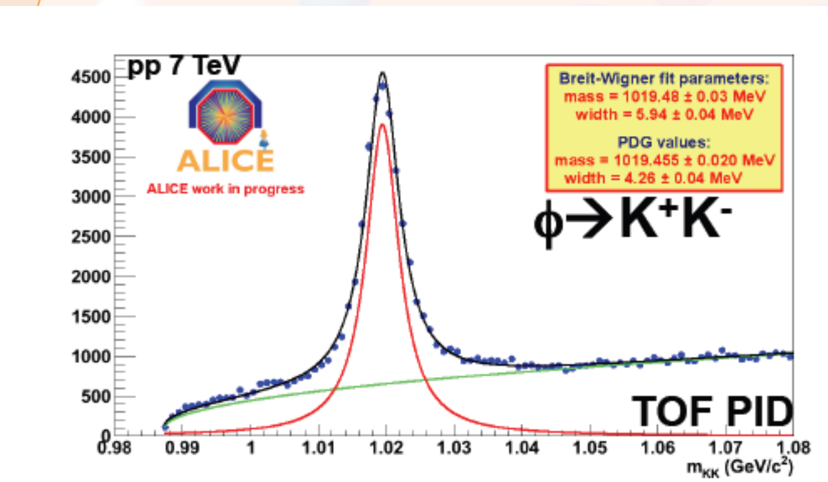
HQ2008



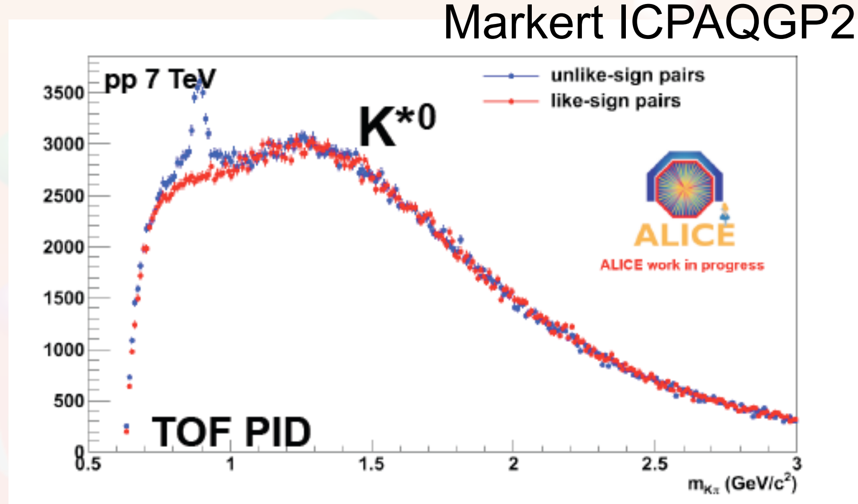
No evidence for mass shifts and
width broadenings on the away-side
Most ϕ(1020) are from thermal medium (90%)
→Need higher p_T resonances → lot of events needed

Resonances in p+p collisions ALICE

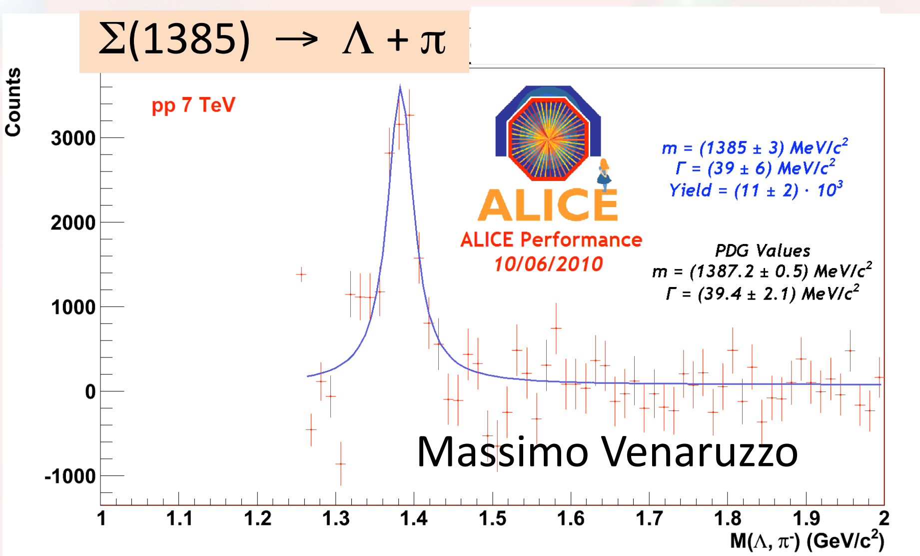
Markert ICPAQGP2010

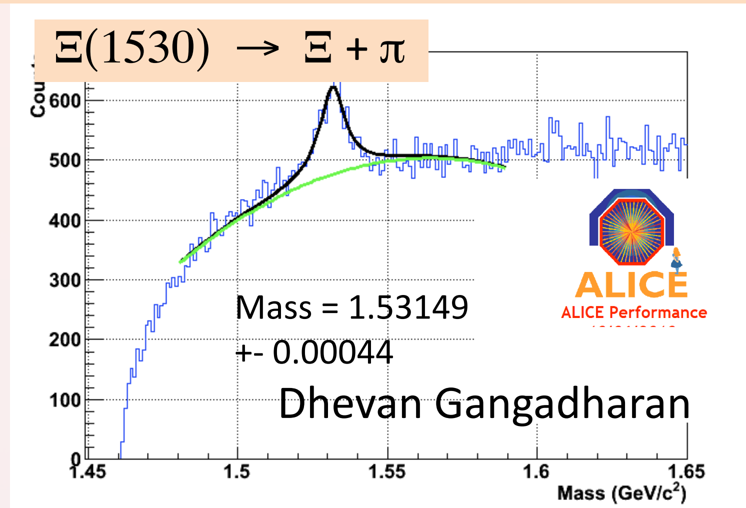


Alberto Pulvirenti



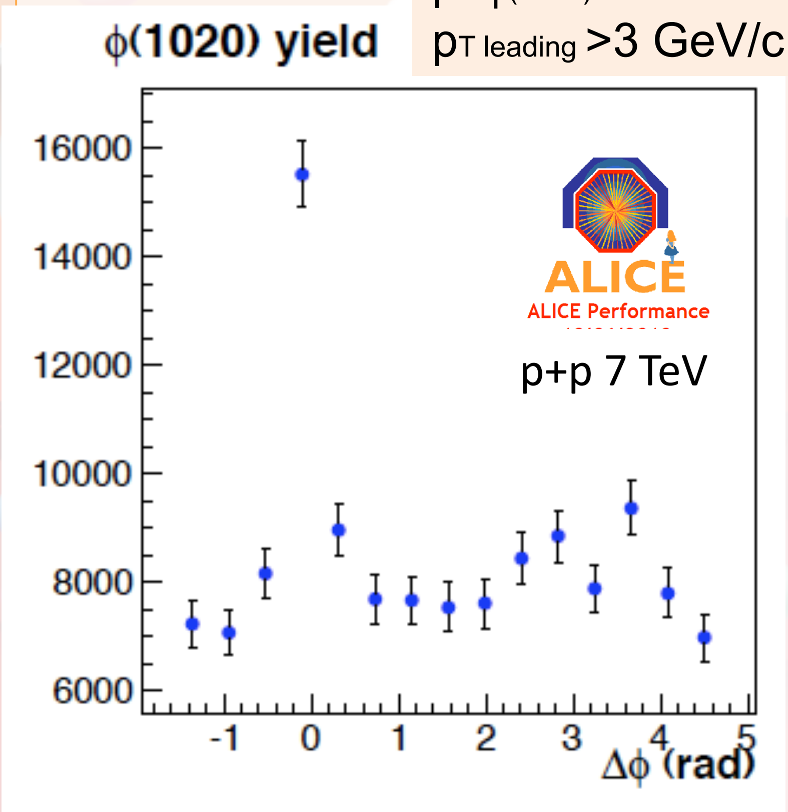
Masses are in agreement with PDG values





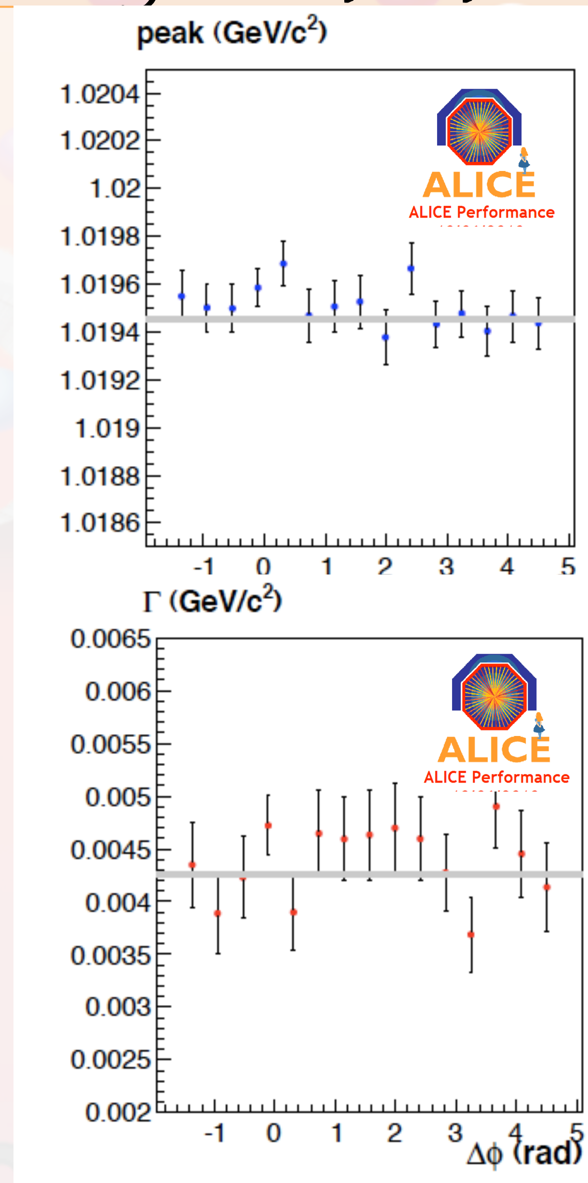
ϕ(1020) resonance from jets p+p 7 GeV

p_T ϕ(1020) >1.5 GeV/c,
$p_{T\ leading}$ >3 GeV/c



Francesco Blanco

Markert ICPAQGP2010



PDG value

PDG value

K(892) Resonance from Jets p+p 7 GeV

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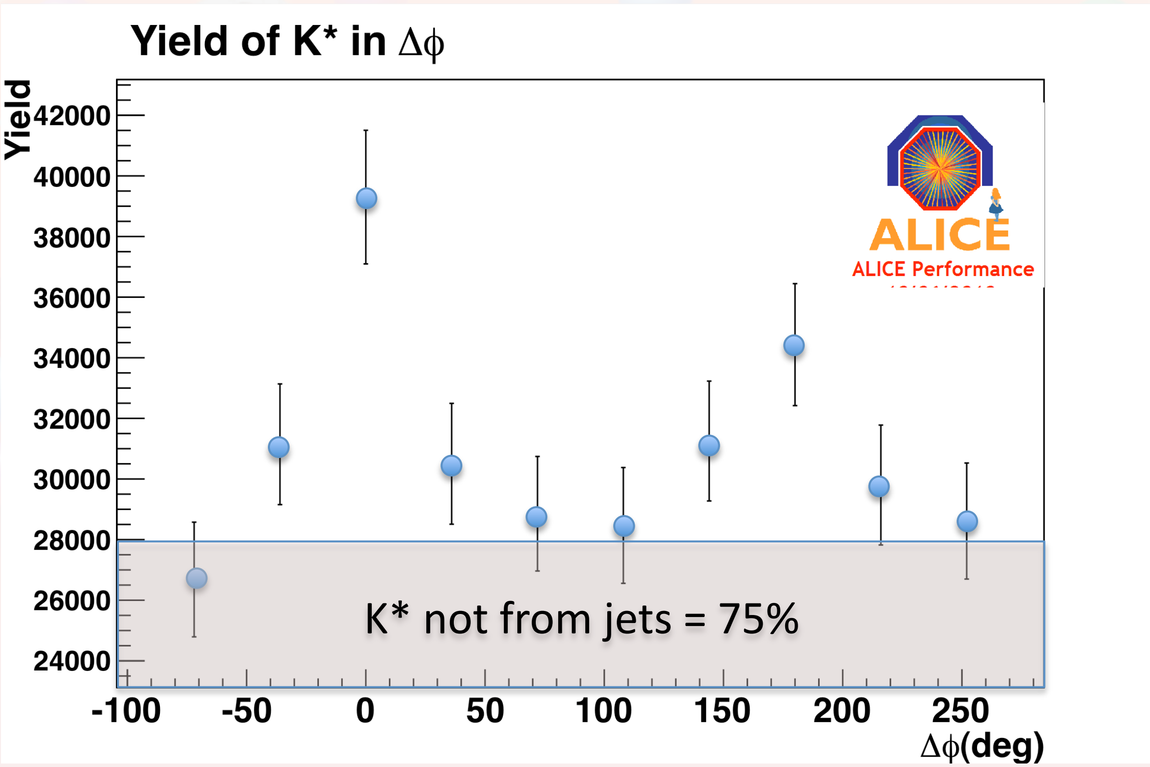
No cut on K(892)
$p_{T\ leading}$ >2 GeV/c



Dilan Don

Hadronization in deconfined matter

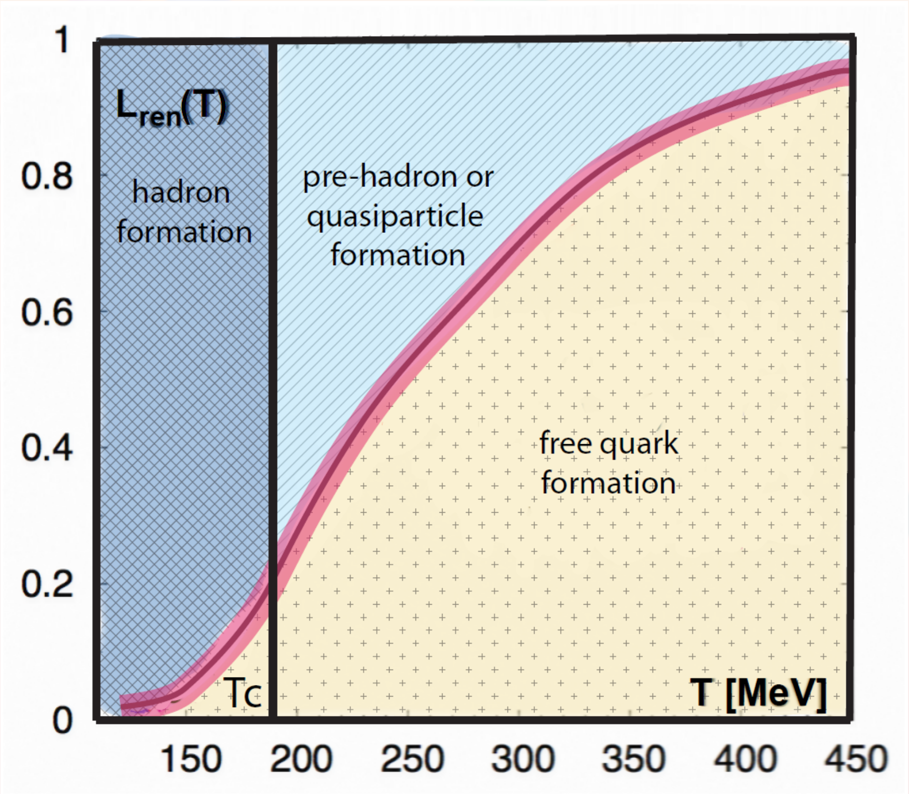
(R.Bellwied CM, PLB691, 208 (2010))

General idea:

1. Color neutral pre-hadrons in the deconfined matter above T_c form a mixed phase of degrees of freedom

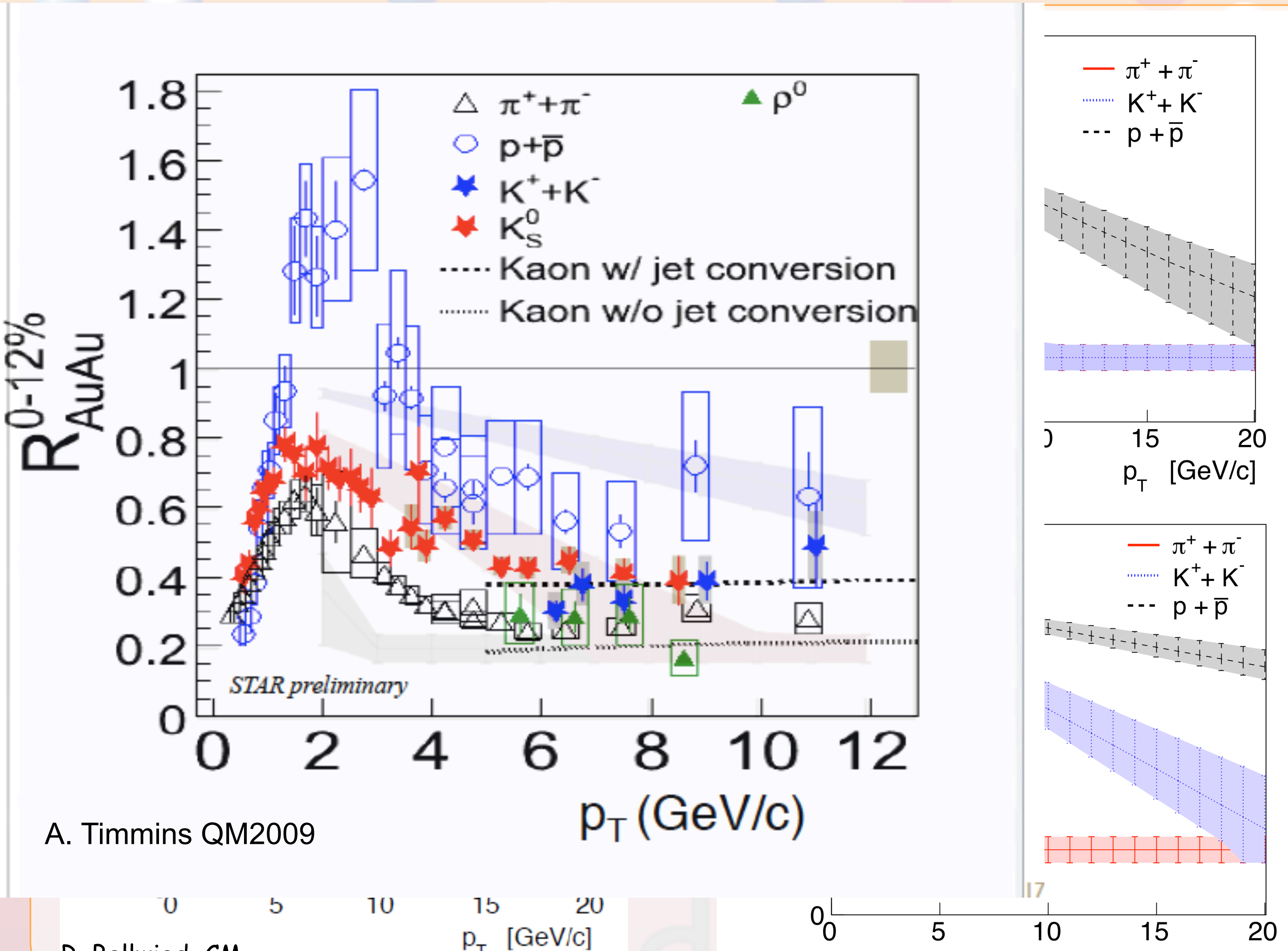
2. Color-neutral objects will exhibit a reduced interaction probability with the colored medium due to color transparency (P. Jain , Phys.Rep.271 (1996))

→ Enhanced survival probability and reduced quenching for early formed (pre-)hadrons



Red curve: polyakov loop calculation of level of deconfinement (Bazavov, Petreczky, arXiv:1005.1131)

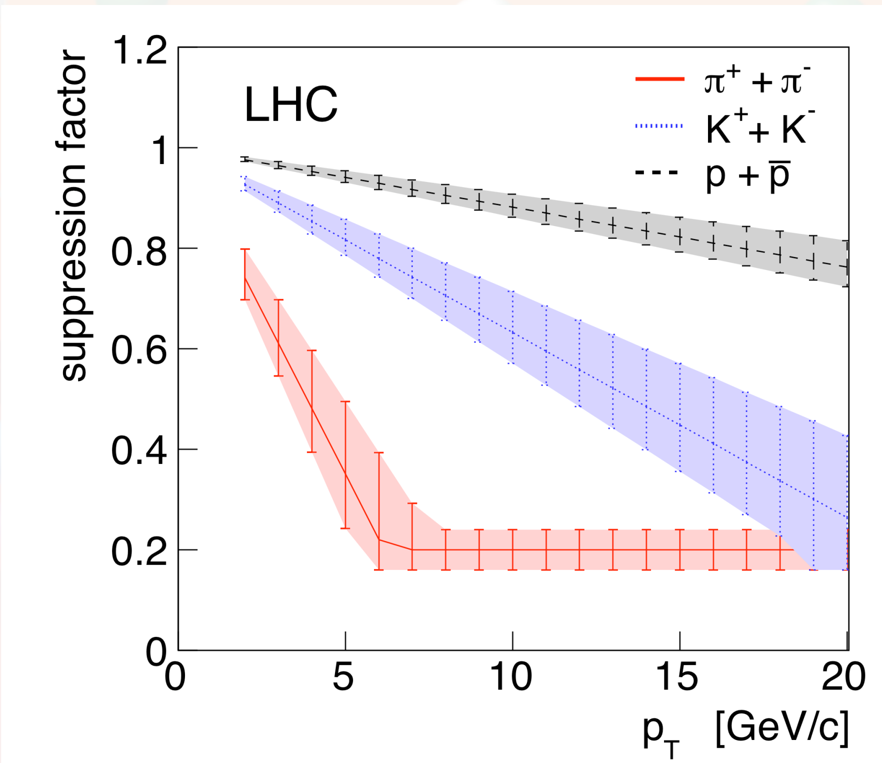
Hight p_T suppression for identified hadrons

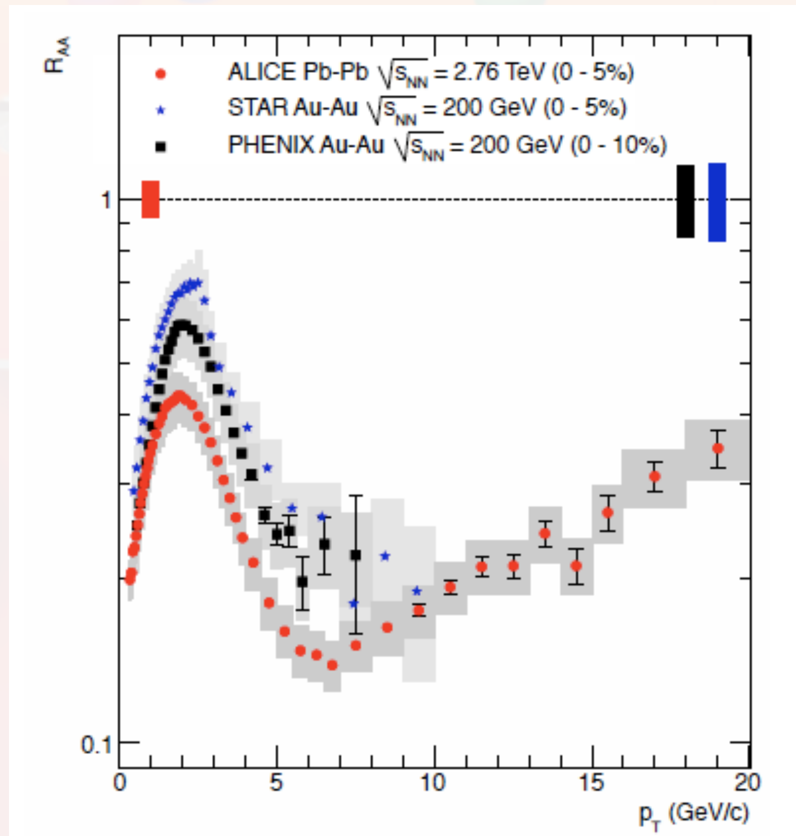


A. Timmins QM2009

R. Bellwied, CM,
Phys.Lett.B691, 208 (2010)

Hight p_T suppression at LHC energies





Phys.Rev.Lett.99:112301,2007.

Conclusion

Hadronic resonances are measured at different energies and system sizes. Can be used to extract hadronic lifetime.

New detector upgrades at RHIC and LHC experiments will help to study higher p_T resonance and leptonic decays.

Resonances from jets will be used to study chiral symmetry restoration. → Theory needed to find right momentum range.

New resonance measurement: $a_1 \rightarrow$ pion+ gamma, …

Most recent LHC results from ALICE. Unexpected rise of R_{AA} at high pT

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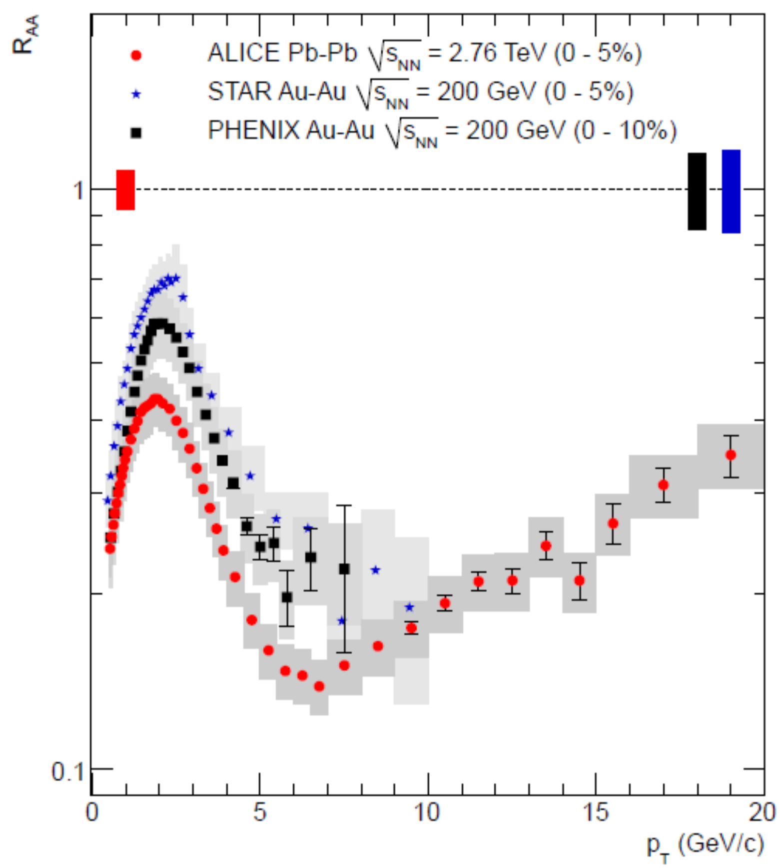
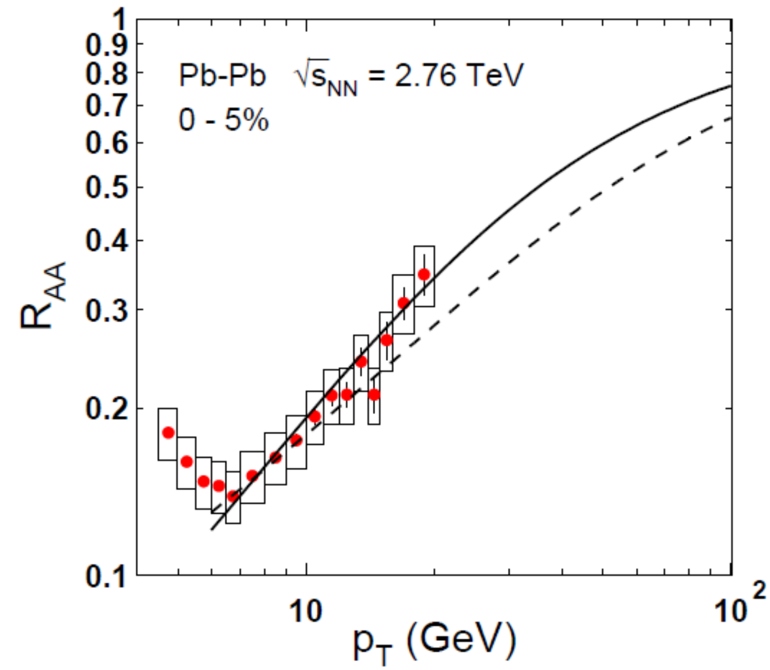
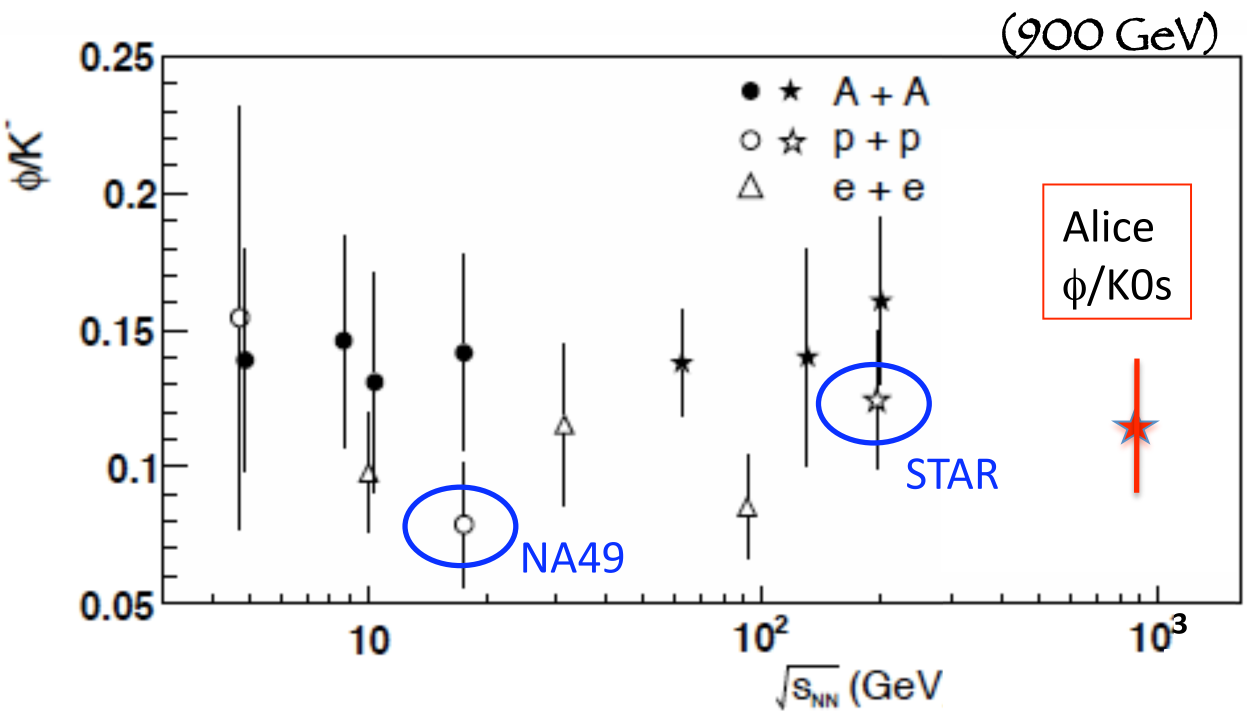


Kopeliovich et al.,arXiv:1012.2854v1
Color transparency – rise at high p_T
~ survival of color dipole in medium.
Similar idea to CM & RB



Comparison to other p+p data

Markert ICPAQGP2010



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ϕ = 0.021 ± 0.004 ± 0.003

K0s = 0.184 +- 0.002 +- 0.006