A summary of


SQM 09
INTERNATIONAL CONFERENCE
ON STRANGENESS IN QUARK MATTER
SEP. 27 – OCT. 2, 2009
Búzios – Rio de Janeiro – Brazil

Topics of SQM09

Physics topics of this conference

The conference will focus on the recent theoretical and experimental progress in understanding the production and properties of strange and heavy flavor (charm, beauty) quarks in high-energy nuclear collisions and in astrophysical phenomena, as well as in elementary processes. Properties of the strongly interacting quark-gluon plasma, recent advances in heavy-ion collisions at lower energies, the future heavy-ion program at CERN/LHC, and astrophysical objects in view of strangeness and heavy flavors are also topics of the conference. In the tradition of the SQM series, the conference aims to stimulate discussions with a lively, informal and friendly atmosphere with ample discussion time. […]

- Strange and Heavy Quark Production in Nuclear Collisions
- Strange and Heavy Quark Production in Elementary Processes
- Bulk Matter Phenomena Associated with Strange and Heavy Quarks
- Strangeness in Astrophysics
- New Developments and New Facilities
- Open Questions

Decoding SQM09

- SQM09: Strangeness in Quark Matter
  - S is for STRANGENESS and that was obvious from the agenda
- SQM09: Sabores em Quark Matter
  - S is for Sabores, thus we can talk about charm and beauty
- SQM09: identified particleS Quark Matter
  - S is for … identified particleS, thus …

Outline

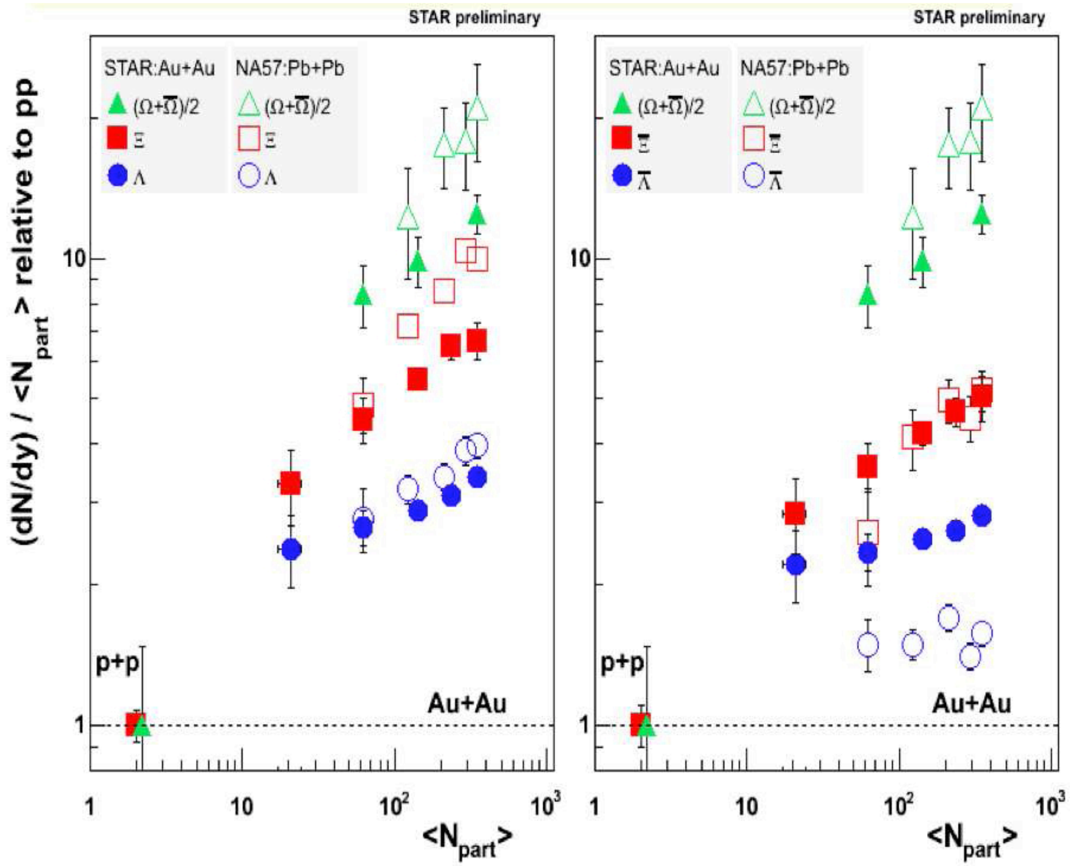
- Strangeness
- Heavy flavours
- The medium
- …

http://omnis.if.ufrj.br/~sqm09/sqm09_program.html

STRANGENESS

Strangeness Enhancement (still here)

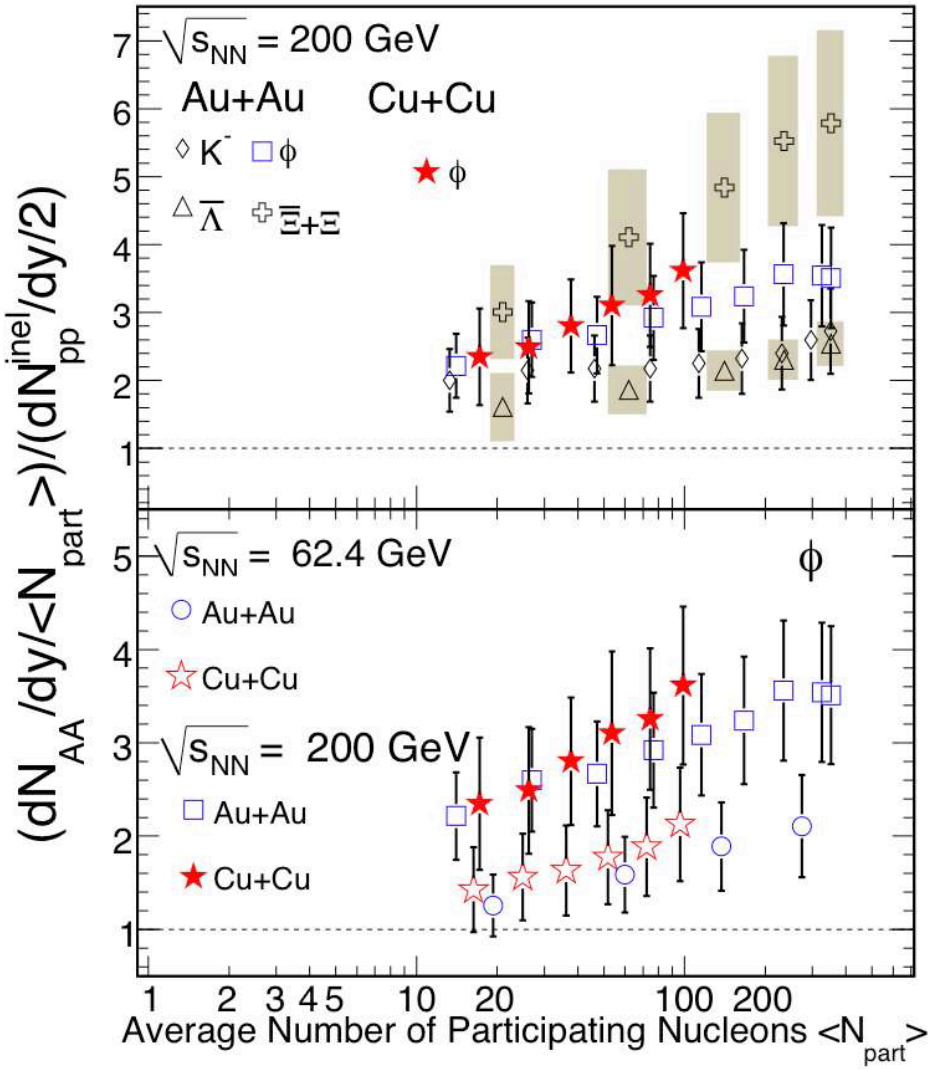
With us since 1982, Rafelski et al.



- Enhancement increases with
  - strangeness content
  - centrality
- Energy up, enhancement down
  - Elementary collision further away from equilibrium
  - Interplay with baryon density
- Strangeness enhancement in AA or suppression in pp (phase space)?
- Is centrality dependence understood

M. Munhoz
L. Šándor

Strangeness Enhancement or Suppression



- The ϕ meson production shows equivalent enhancement, although it is not subject to "canonical suppression"

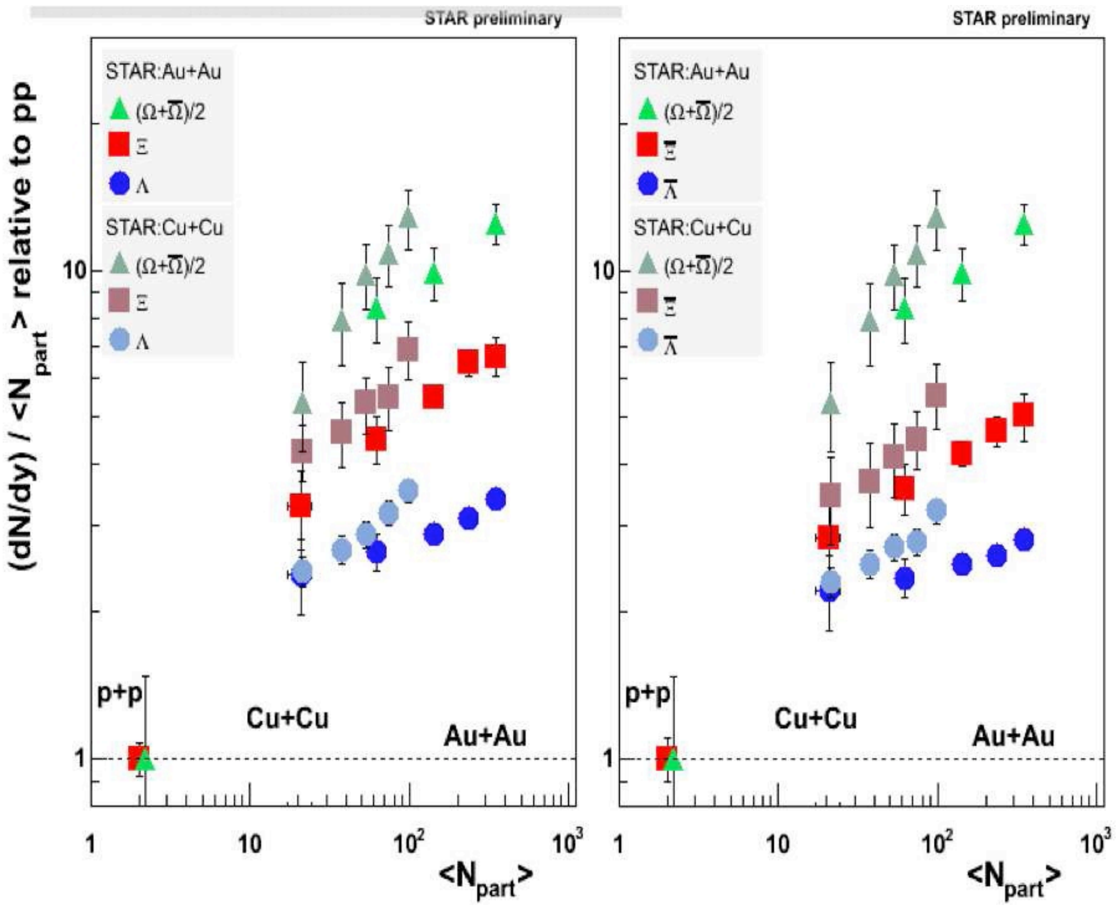
  ⇒ strangeness enhancement

STAR Collaboration
Phys. Lett. B673, p.183 -191, 2009.

M. Munhoz

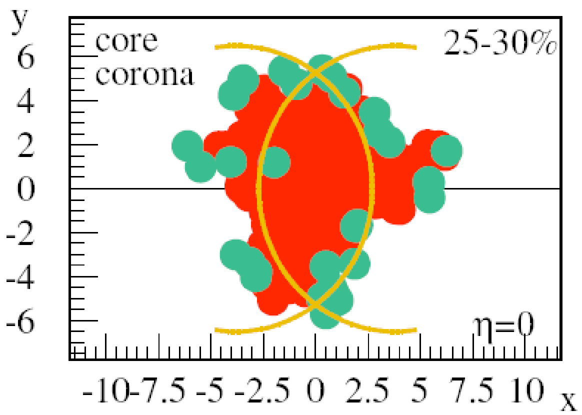
Strangeness Enhancement (again & again)

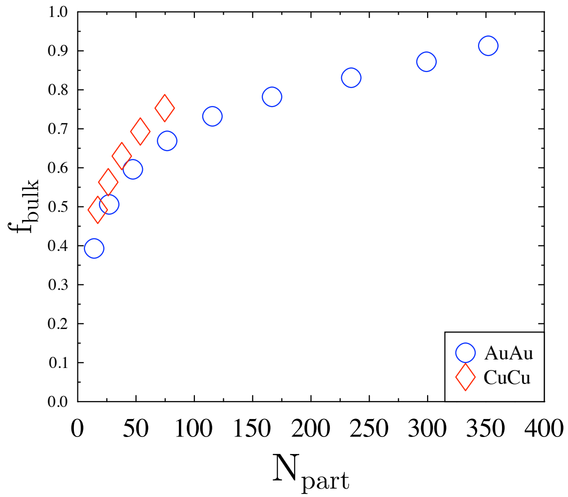
- Au+Au and Cu+Cu have different N_{part} dependence



M. Munhoz

Strangeness Enhancement (still)



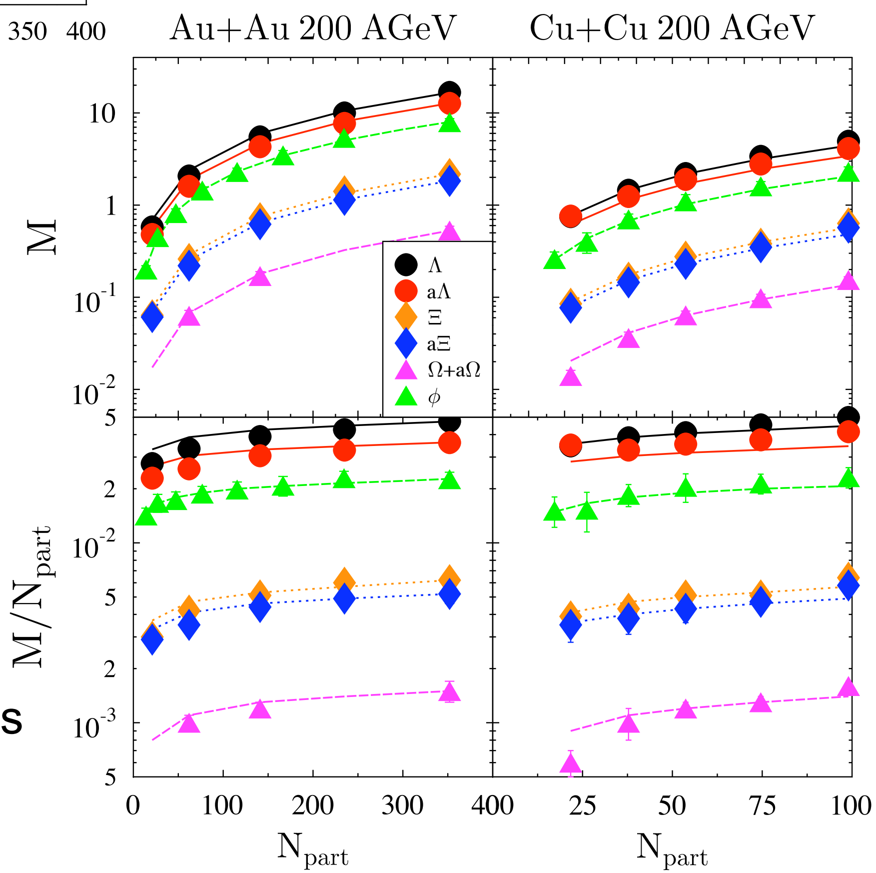


- Assumptions and inputs
  - 1 initial coll: corona
  - more: core
  - $M^i(N_{\rm part}) = N_{\rm part}\left[f(N_{\rm core})\cdot M^i_{\rm core} + (1 - f(N_{\rm core}))\cdot M^i_{\rm corona}\right]$

$$M^i_{\rm corona} = \frac{1}{2}\frac{dn^i}{dy}\Big|^{pp}_{y=0}$$

$$M^i_{\rm core} = \frac{1}{N_{\rm part}}\frac{dn^i}{dy}\Big|_{y=0} \text{ from stat. model or most central HI collision}$$

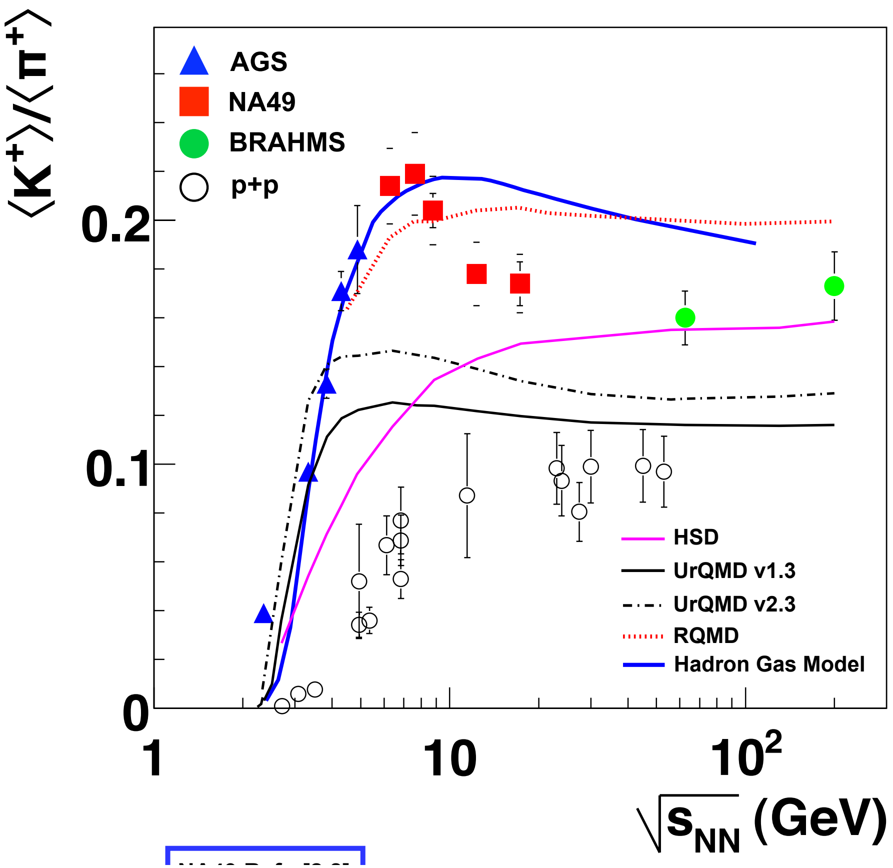
$1 - f(N_{\rm core})$ = fraction of nucleons which have scattered only once ($\rightarrow$ Glauber)



- Describes multiplicities
  - SPS, RHIC, AuAu, CuCu
- ϕ is also explained
- Strangeness enhancements in reality strangeness suppression in pp (core follows stat. model predictions)

J. Aichelin

The Horn: Onset of Deconfinement

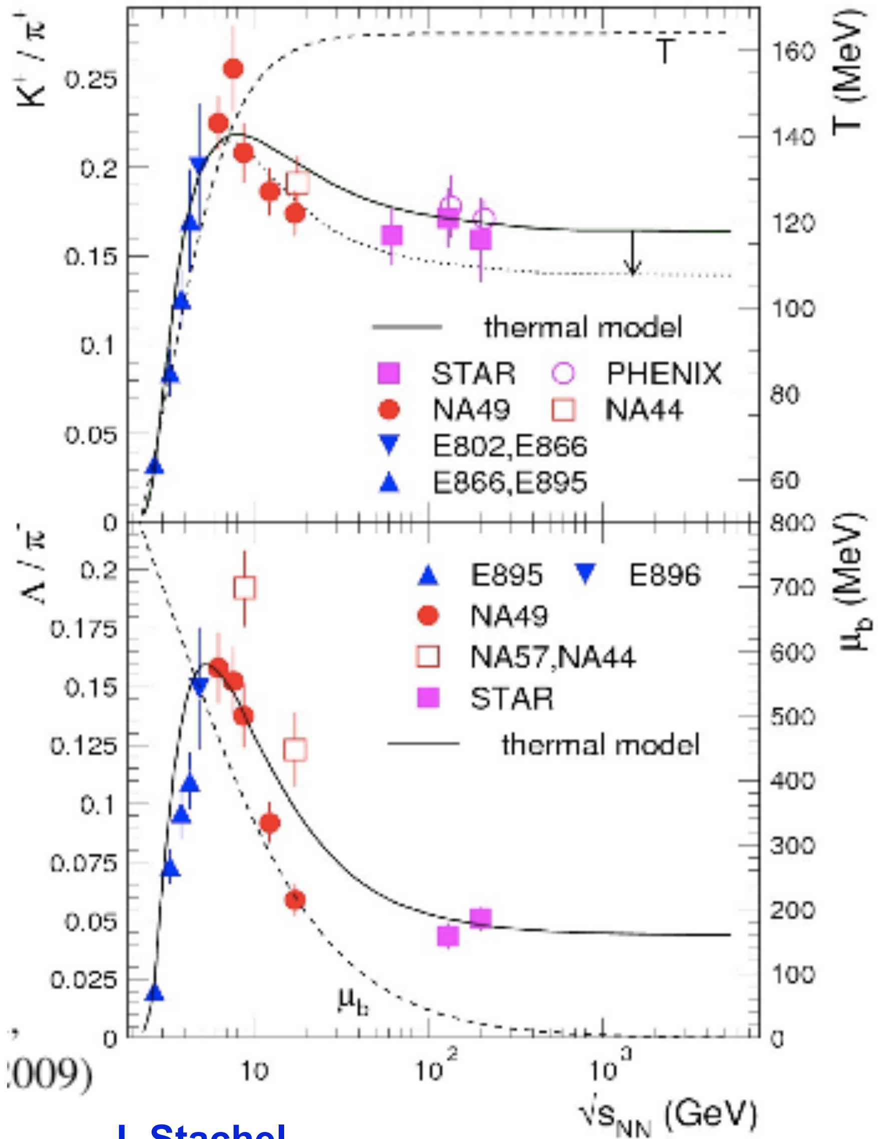


- Non-monotonic structure in A+A, not visible in p+p.
- Large deviation between various string-hadronic models.
- Hadron gas model with $\sqrt{s_{NN}}/\mu_B$ relation does fit sharp changes in energy dependence of $<K^+>/<\pi^+>$ ratio at low SPS energies.

⇒ Indication for the onset of deconfinement at low SPS energies

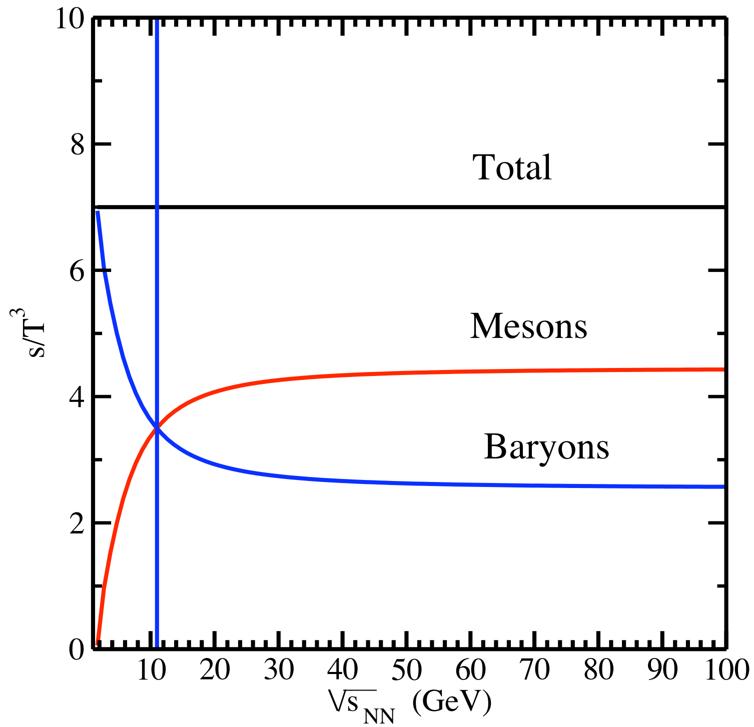
M. Mitrovski

The thermal model gets the Horn



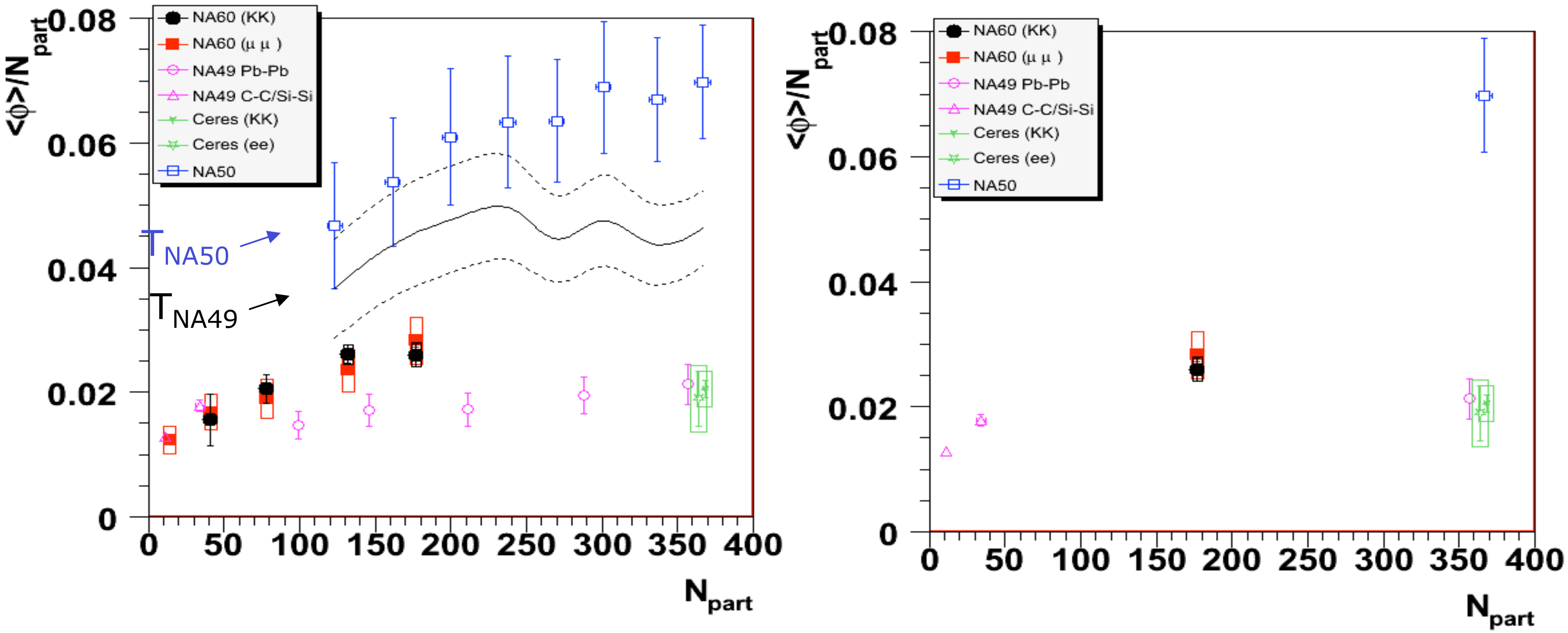
J. Stachel
J. Cleymans

- Expand the model to include
  - more resonances
  - … Hagedorn states
- and the horn is well understood via transition from baryon to meson dominated hadron gas



The φ puzzle

φ→KK and comparison with φ→μμ (⟨φ⟩)



Comparison between various systems for central collisions difficult

- $<\phi>/N_{part}$:
  - In-In much lower than NA50 (with various assumptions on T)
  - higher than NA49/CERES in kaon pairs and dielectrons
  - Still room for a physical effect in KK vs μμ in PbPb?

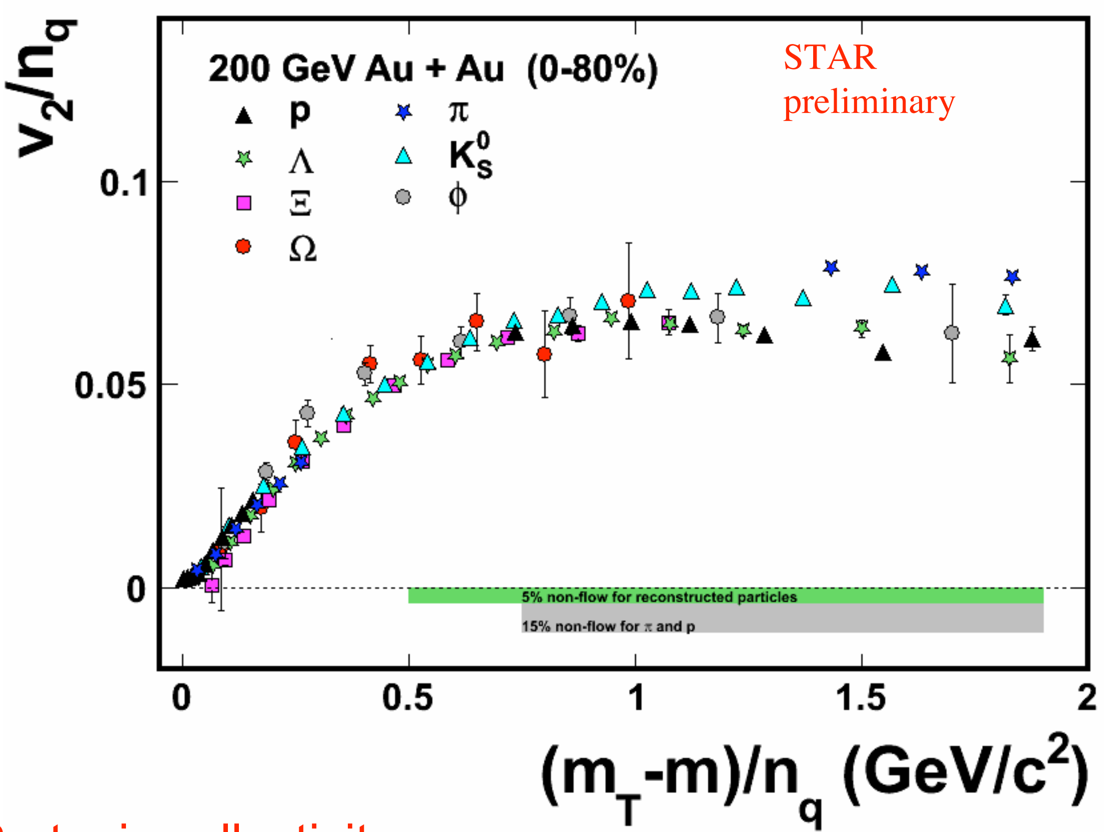
12

New measurement in Pb-Pb would be interesting

G. Usai

Elliptic flow of strange hadrons

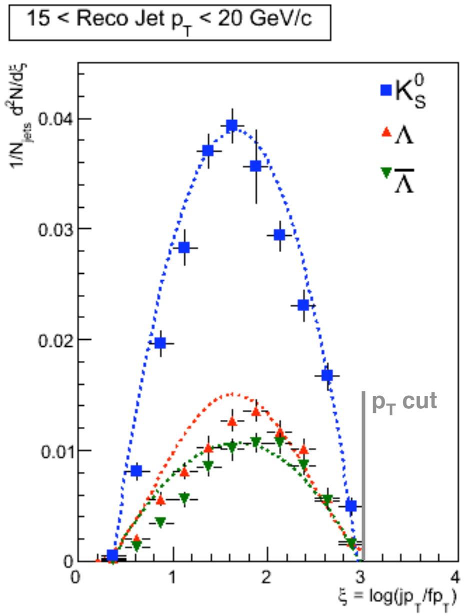
- At low p_T Hydro approach reproduces mass ordering
- v_2 of strange hadrons shows baryon-meson difference:
  - n_q scaling: hadronization of partons
- Indications of a different behavior for higher p_T

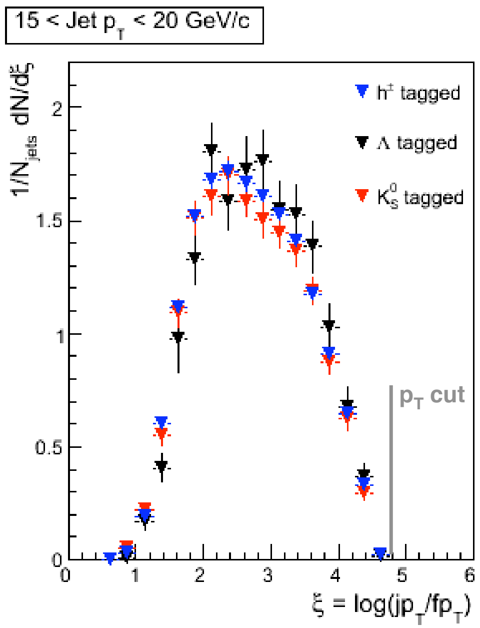


⇒ Partonic collectivity
⇒ deconfinement

M. Munhoz

Understanding pp





- *Strange particle Fragmentation Functions*
  - Measured data not corrected for tracking efficiency/jet energy uncertainties
    - Errors statistic + systematic (different jet finders)
    - V0 p_T> 1 GeV/c
  - Pythia 6.4 ran through STAR reconstruction chain
    - Describes K^0_S OK, some deviations for strange baryons

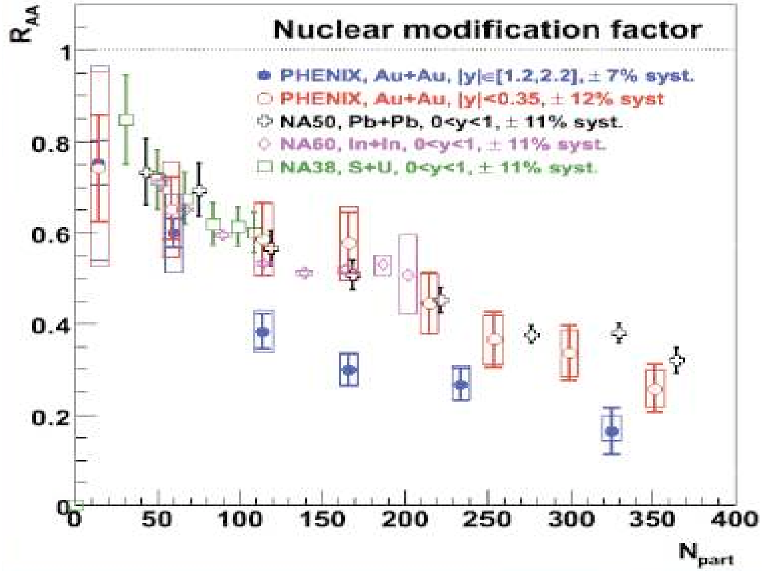
- *Jets with leading strange particles…*
  - Do strange particle tagging baryon/meson select on quark/gluon jets?
    - Quark jets -> $h^{\pm}$ FF suppressed at large ξ
    - Gluon jets -> $h^{\pm}$ FF enhanced at large ξ
  - Measurements show charged hadron FF invariant upon strange particle tagging…

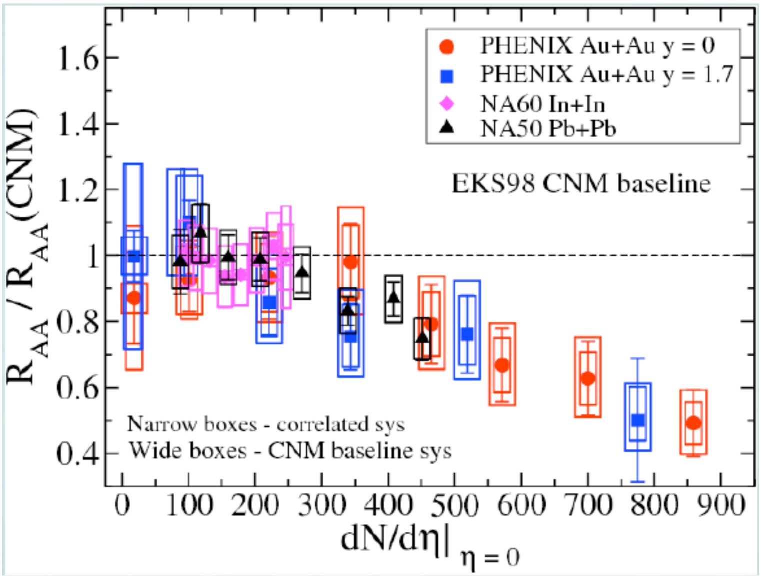
A. Timmins

HEAVY FLAVOURS

J/ψ suppression (still here too)

With us since 1986, Matsui & Satz

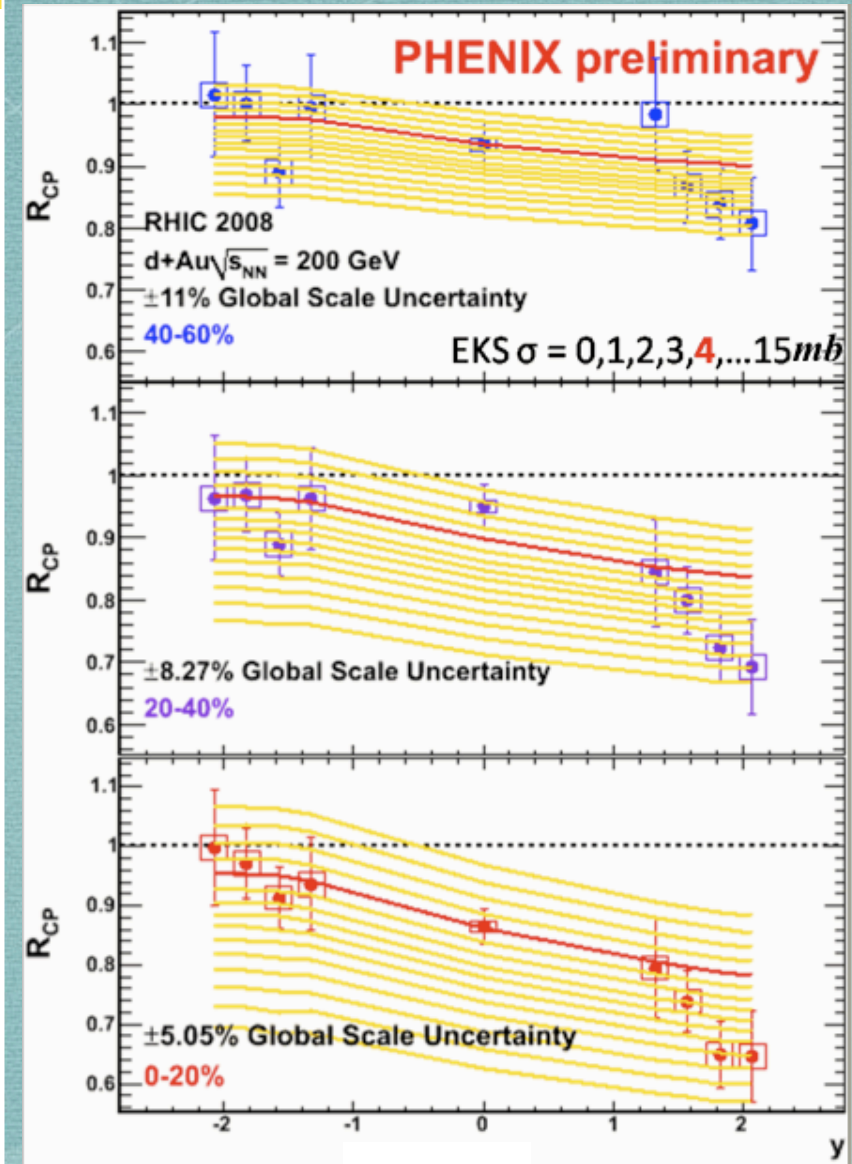




- We still have much to study and understand...
  - the challenge to isolate suppression of the J/ψ in the QGP from other mechanisms in HI collisions that affect J/ψ production remains
    - J/ψ more suppressed at forward rapidity
    - at mid-rapidity suppression similar to SPS.
  - cold nuclear matter effects might account for the difference in mid-rapidity and forward rapidity
  - regeneration (?)
  - statistical hadronization

M. Donadelli
G. Usai

J/ψ in dAu: R_{cp} but no R_{dA}



J/Ψ in d + Au

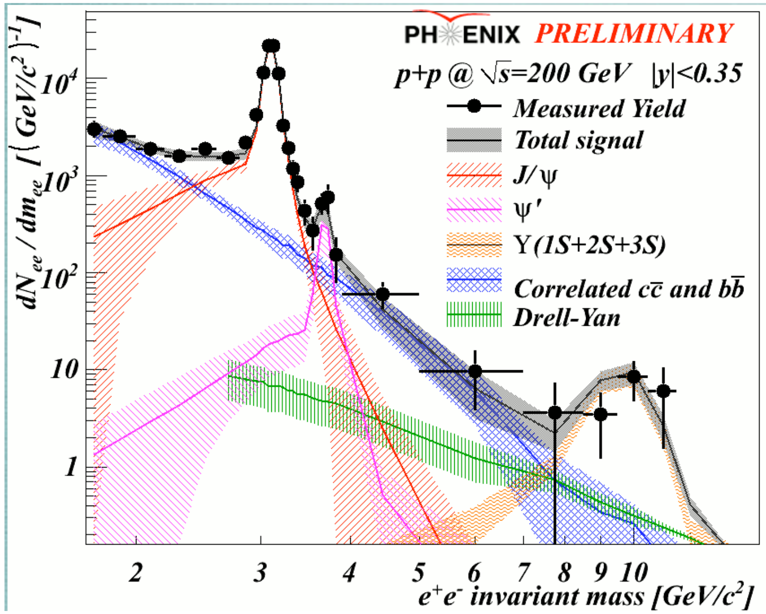
- ✓ d + Au Run 8 with 30 X more luminosity than Run 3 (*Phys. Rev. C.* **77**, 024912 (2008));
- ✓ first nuclear modification measurements in Run 8;
- ✓ reference yield : 60-80% centrality range.

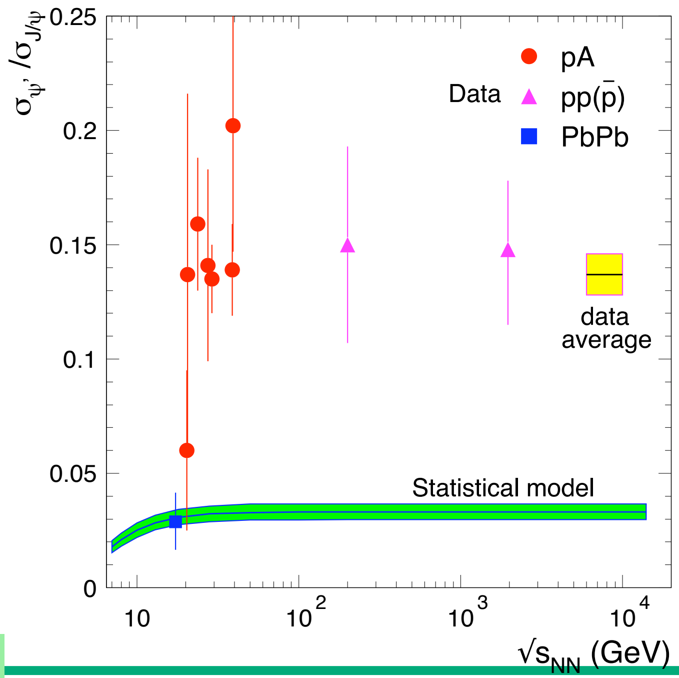
$$R_{cp} = \frac{\left(\frac{dN_{J/\psi}}{dy} / N_{coll}\right)}{\left(\frac{dN_{J/\psi}^{60-80\%}}{dy} / N_{coll}^{60-80\%}\right)}$$

- ✓ systematic uncertainties cancel out in R_{cp} measurements;
- ✓ y < 0 , large x (in the anti-shadowing region) of the gluon distribution: no nuclear effects within uncertainties;
- ✓ considerable suppression at y =0 and at y>0;
- ✓ not described by known nuclear modified gluon distributions (EKS98, EPS08 and NDSG) for any fixed breakup cross section;
- ✓ additional CNM effects?

M. Donadelli

Moving forward: ψ’



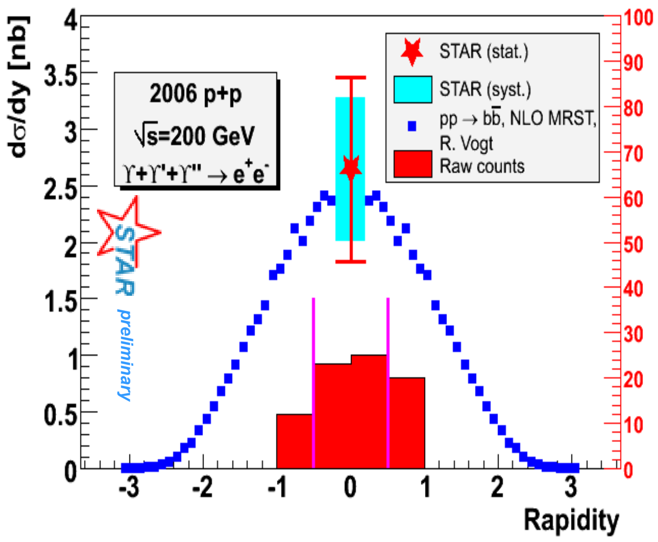


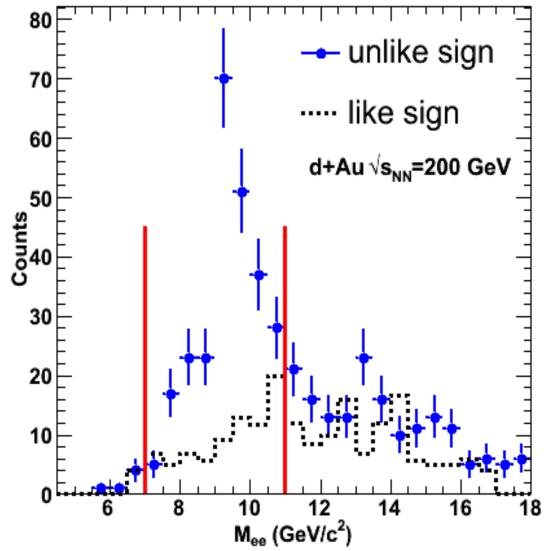
- Continuum spectrum estimated by simulation (JHEP 0605, 026 (2006)): correlated D and B mesons besides Drell-Yan contributions(1997))
- first ψ’ cross section at RHIC energies
- ψ’ / J/ψ ~ 2%, in agreement with HERA-B (Eur. Phys. J. C 49, 545 (2007) and CDF (Phys. Rev. Lett. 79, 572 (1997))
- Feed down for J/ψ at PHENIX in agreement with world average results (JHEP 10, 004 (2008)):
  - < 42 % (90 % CL) from χc
  - ≈ 1 to 4 % from B
  - = (8.6 ± 2.5) % from ψ’

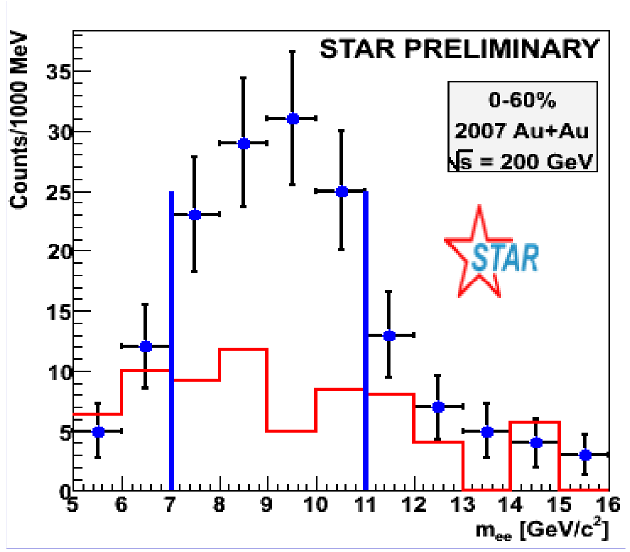
- ψ’ / J/ψ is far from thermalized (model is for AA)
- while a thermal value is reached in central PbPb (NA50, SPS)

M. Donadelli
A. Andronic

Υ in STAR







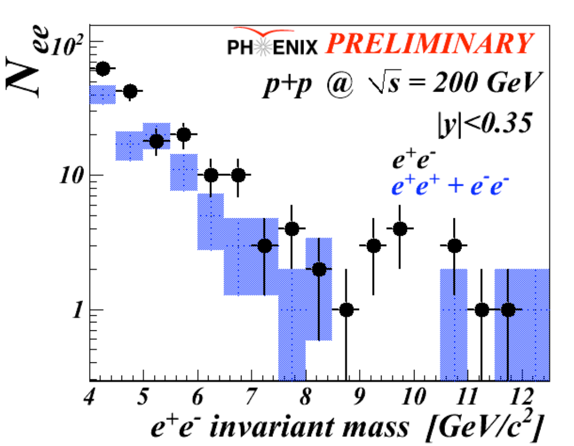
- p+p - 6σ Signal Significance
  - $B_{ee} \times (d\sigma/dy)_{y=0}$ = 91±28(stat)±22(sys) pb
- d+Au - 8σ Signal Significance
  - $B_{ee} \times (d\sigma/dy)_{y=0}$ = 35±4(stat)±5(sys) nb
  - R_{dAu} =0.98±0.32(stat)±0.28(sys) Follows Binary Scaling
- Au+Au(central 0-60%) – 4σ Signal significance
  - R_{AA}< 1.3 at 90% CL (should be 0.69 if 2s and 3s states melt and 1s is not affected)

R. Reed

Υ in PHENIX (!)

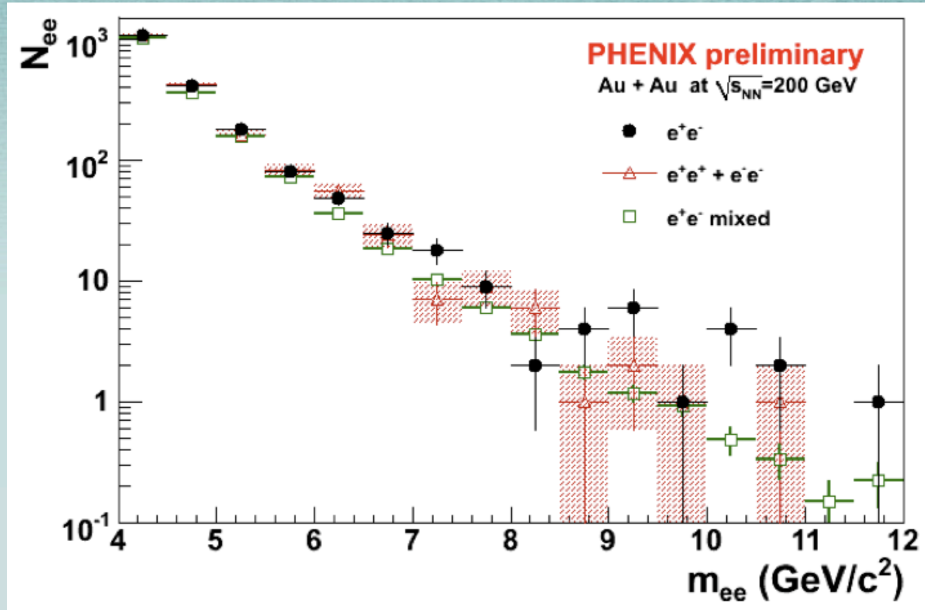
ϒ in Au + Au

Looking at *p+p*...



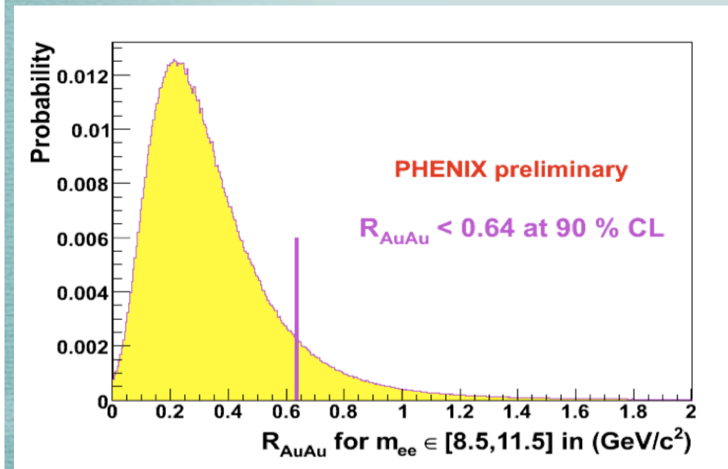
[8.5-11.5] GeV/c²:

n_{like}=12 & n_{unlike}=1



[8.5-11.5] GeV/c²:

n_{like}=17 & n_{unlike}=5



High mass unlike sign di-electrons are suppressed!

(background from DY and correlated open heavy flavor not subtracted)

After statistical analysis upper limit on R_{AA} was calculated

M. Donadelli

Feed-down from χ_b? Cold nuclear matter effects?

Thermal width of a QQ pair in AdS/CFT

- The imaginary part of the heavy quark potential induces a thermal width $\Gamma = \langle\psi|\mathrm{Im}\mathcal{V}_{Q\bar{Q}}|\psi\rangle$ for heavy quark bound states, such as the Υ.

- $\Gamma \neq 0$ at both weak and strong coupling in the temperature range below the dissociation temperature T_d. Since the width is zero below T_c, a measurement of $\Gamma \neq 0$ would clearly indicate that a deconfined medium was created.

- Perhaps the easiest way to measure Γ is via the R_{AA} for the process $\Upsilon \rightarrow l^+ l^-$.

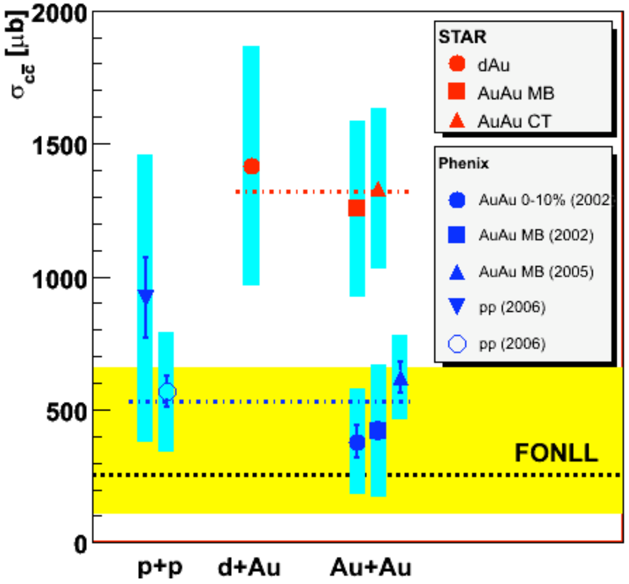
- Neglecting “regeneration" of bound states from $b\bar{b}$ pairs in the medium, the number of Υ's that **have not** decayed into unbounded b and $\bar{b}$ quarks can be estimated by

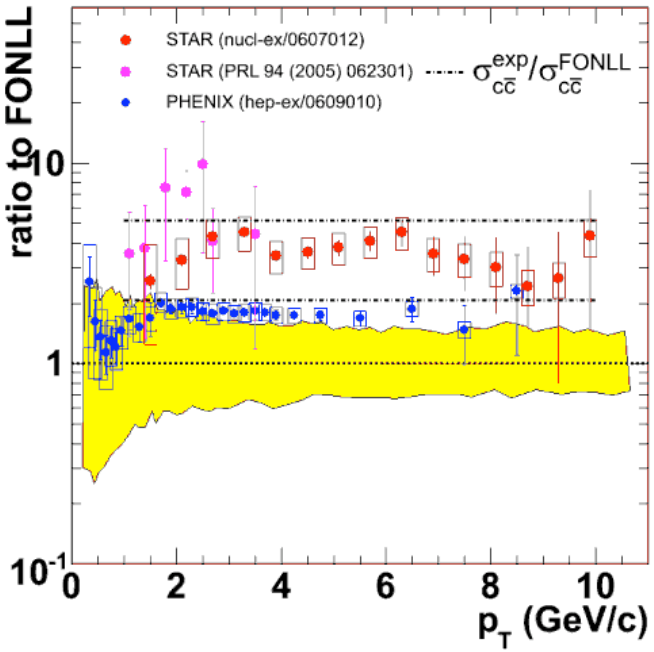
$$N_\Upsilon(t) = N_0 e^{-\int d\tau\, \Gamma(T(\tau))}$$

where $N_0 = N_{binary} N_\Upsilon^{pp}$. Thus, we predict that $R_{AA}(\Upsilon \rightarrow l^+ l^-) < 1$ in A+A collisions at RHIC.

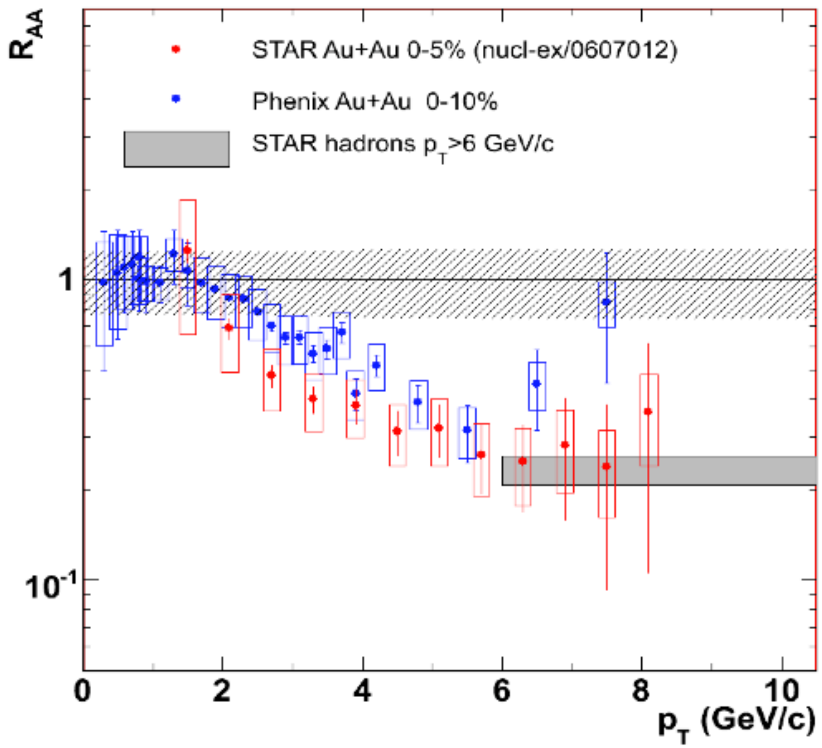
J. Noronha

Charm and Beauty production





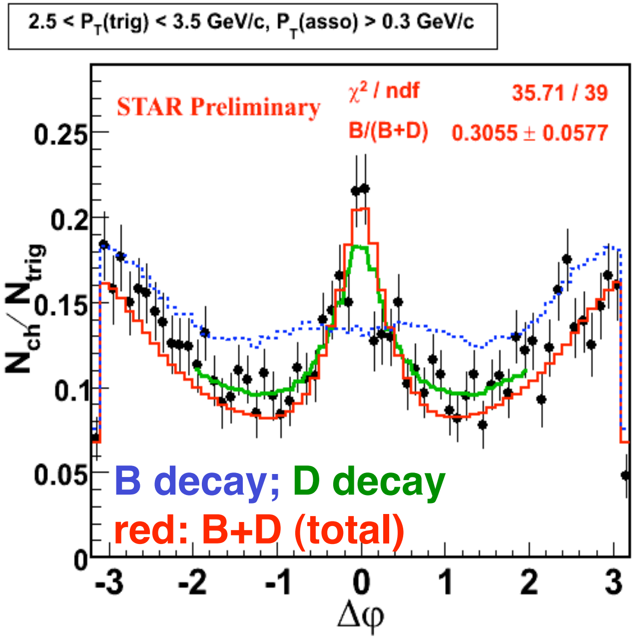
- ccbar discrepancy still with us!
- Never mind, lets do R_{AA}
  - Same high p_T suppression than light hadrons

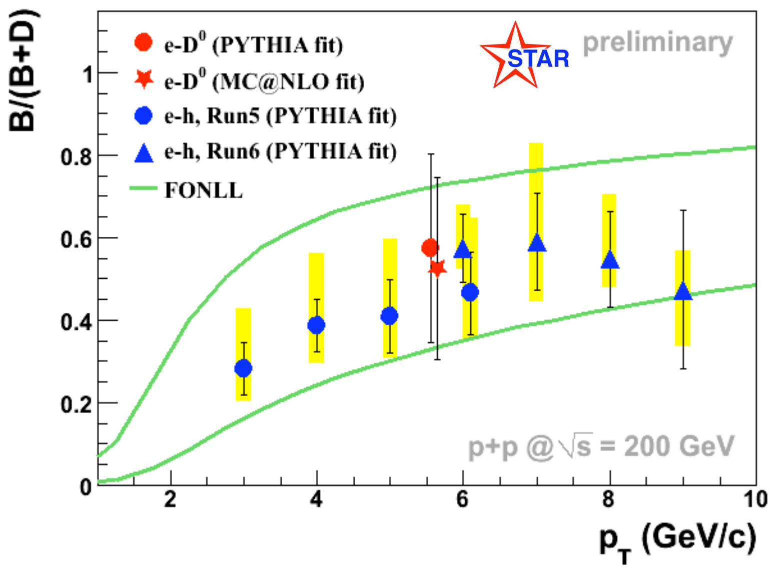


  - Is it c or b?

L. Ruan
M. Donadelli

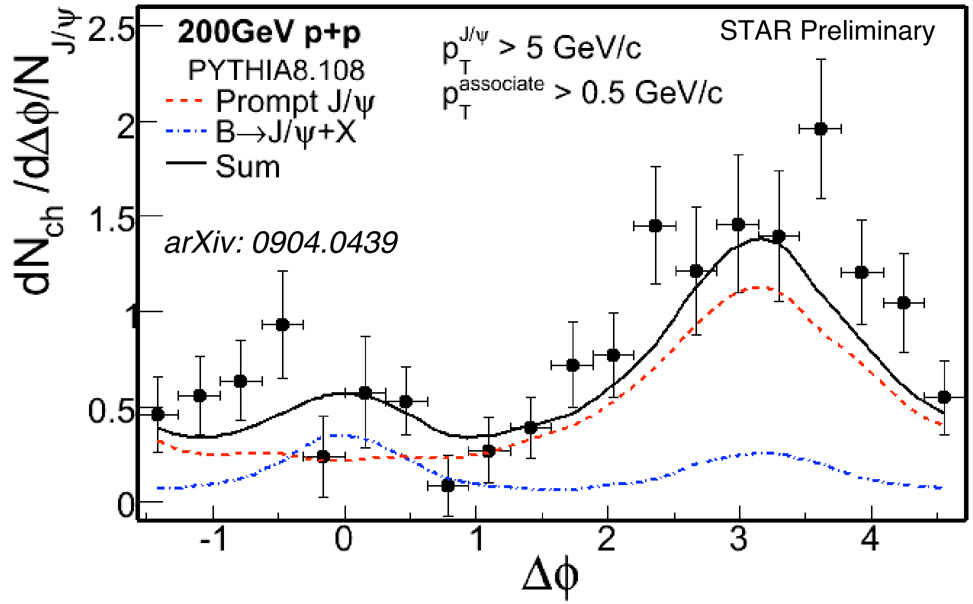
Measuring B in STAR





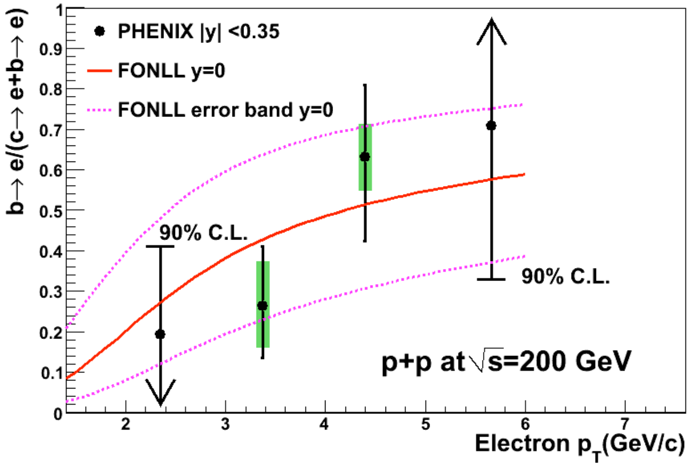
L. Ruan

- Extract bottom contribution from the data/simulation (PYTHIA) comparison
  - non-photonic electron spectra has a significant contribution from bottom

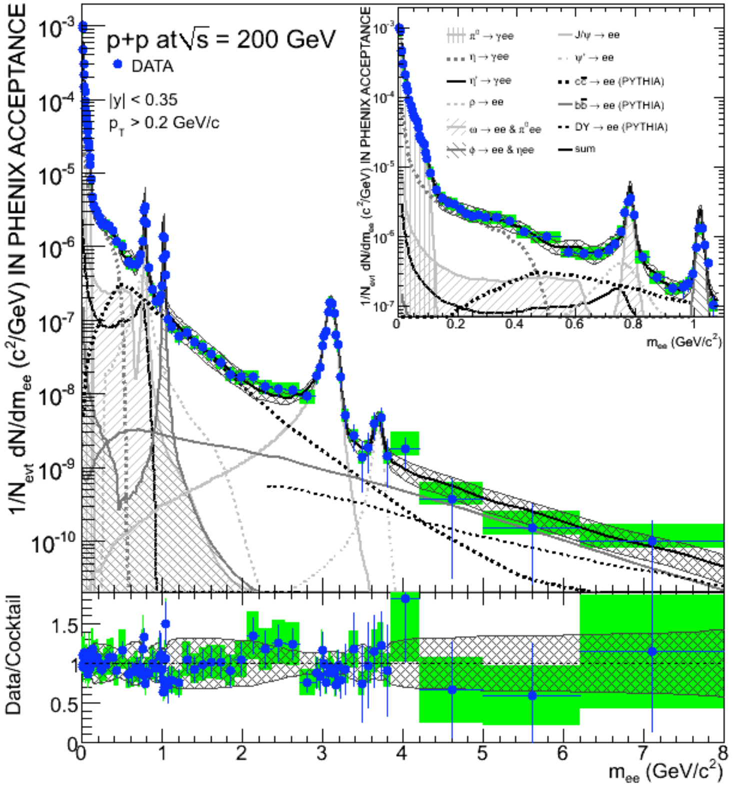


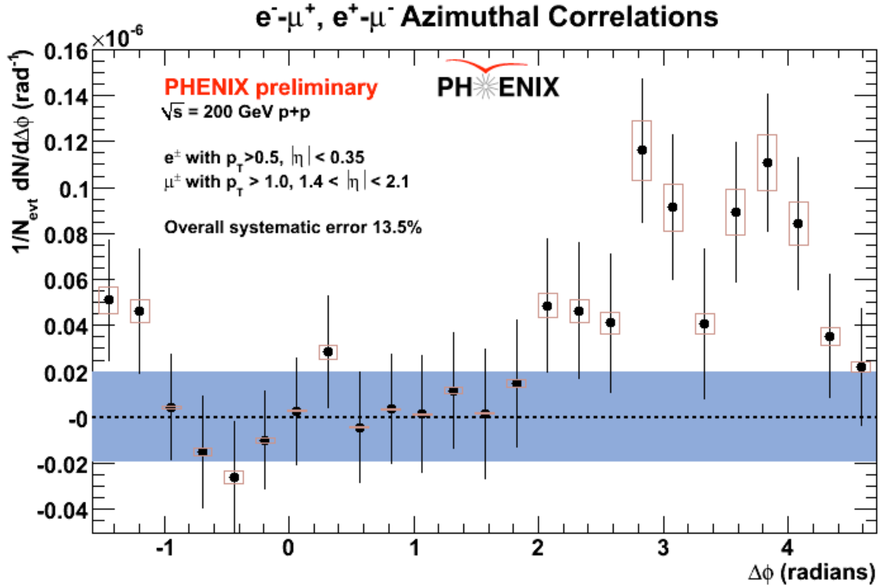
- Extract J/ψ from B using J/ψ-h correlations
  - low B contribution (13 ± 5) %
  - can used to further constrain B yields

Also in Phenix



- b/(c+b) from e-K correlations at mid-rapidity
  - $\sigma_{b\text{-}bbar} = 3.2\ ^{+1.2}_{-1.1}$ (stat) $^{+1.4}_{-1.3}$ (sys) μb
- separating c/b in a PYTHIA dependent way
- good agreement with single electron results:
  - $\sigma_{c\text{-}cbar}$ = 518 ± 47 (stat) ± 135 (sys) 190 (model) μb
  - $\sigma_{b\text{-}bbar}$ = 3.9 + 2.4 (stat) +3.0 -2.0 (sys) μb



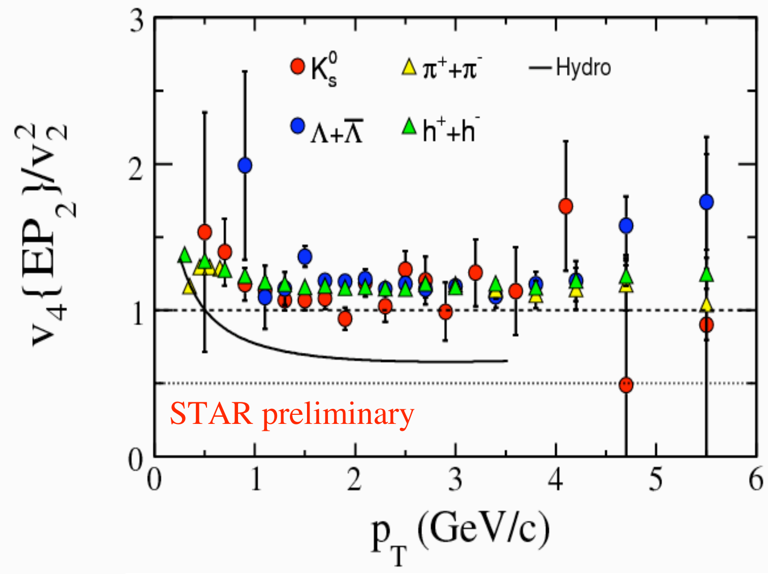


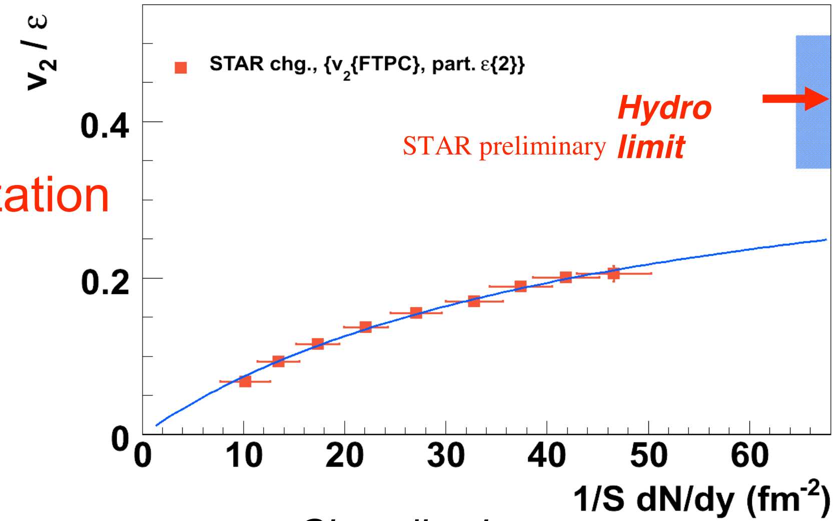
- e-μ: a new method for the c-cbar measurement!
  - Invariant Yield: $2.11\times10^{-07} \pm 3.4\times10^{-08}$(stat) ± 3.5×10^{-08}(sys)

M. Donadelli

THE MEDIUM

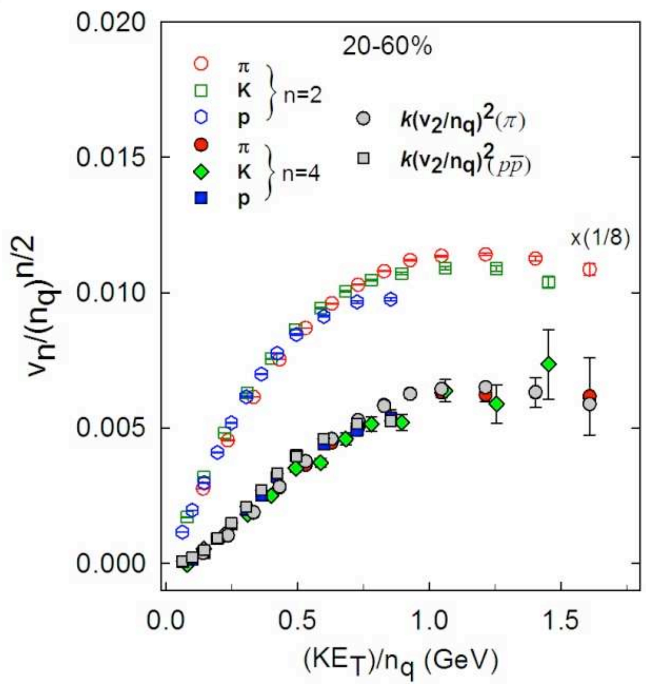
Thermalization, hydro



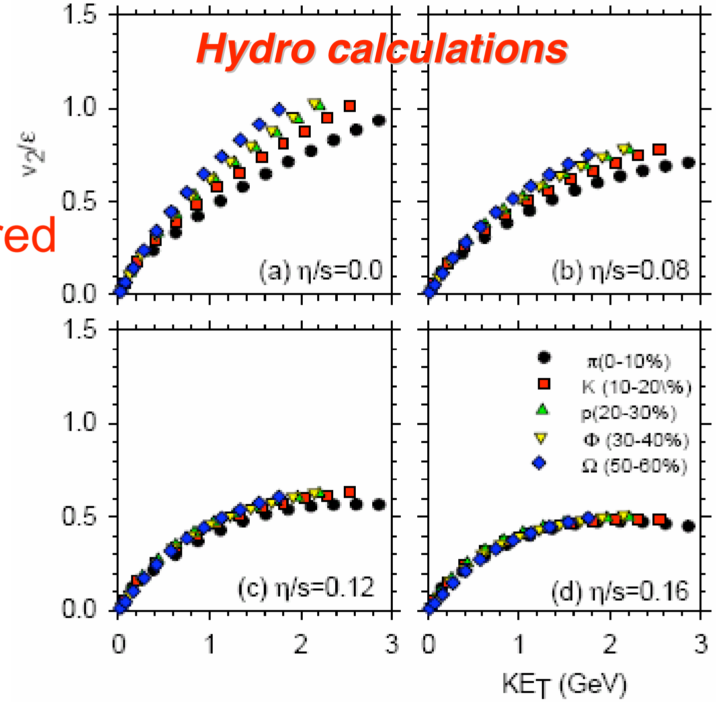


Partial thermalization
Non-ideal hydro
More by Clement

Chaudhuri



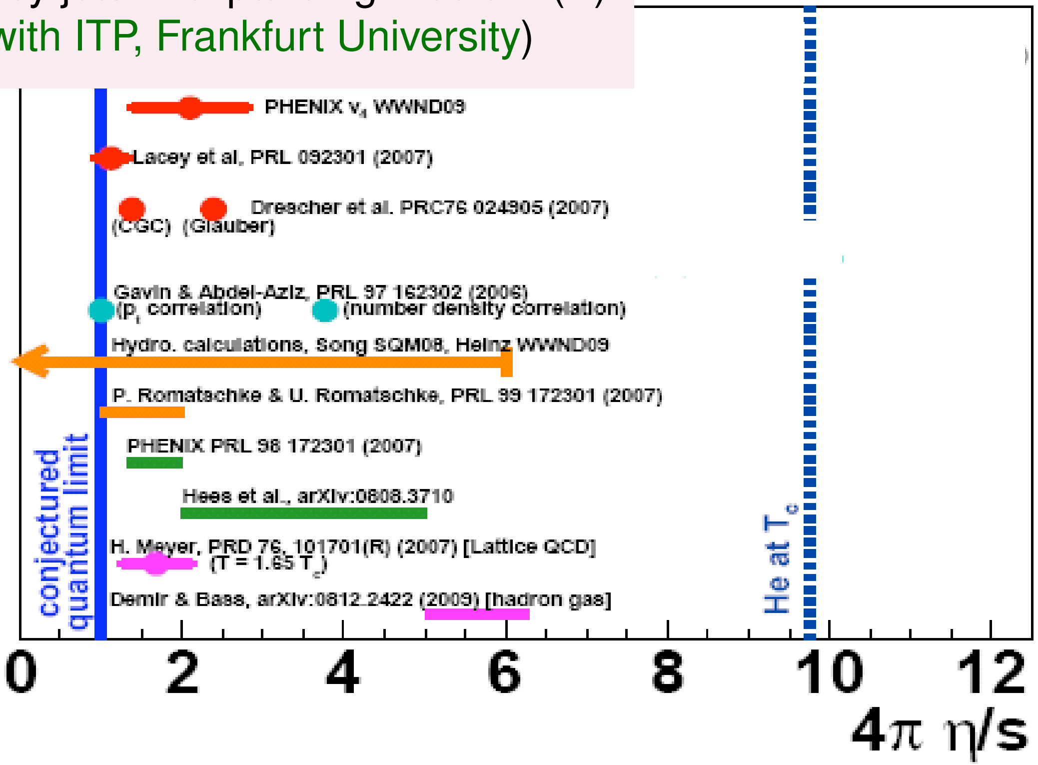
Viscosity required



M. Munhoz
R. Lacey

Viscosity, hydro …

- Hydrodynamics has evolved since the “perfect news” days
- We now have causal theories converging
- We now have different groups with viscous hydrodynamics numerical algorithms
- Comparison with cascade models helps to constrain the coefficients and dissipative fluxes
- Comparison with experiments helps to extract the coefficients (see Roy Lacey’s talk)
- There are efforts to to constrain transport coefficients from the studies of (i) Shock wave structure (ii) Energy-loss by jets in expanding medium (iii) Chemical equilibration (in collaboration with ITP, Frankfurt University)

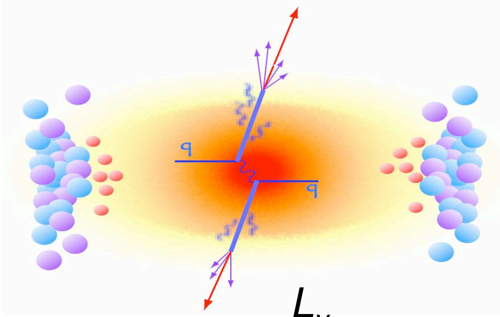


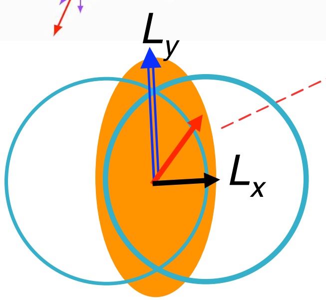
A. Muronga
R. Lacey

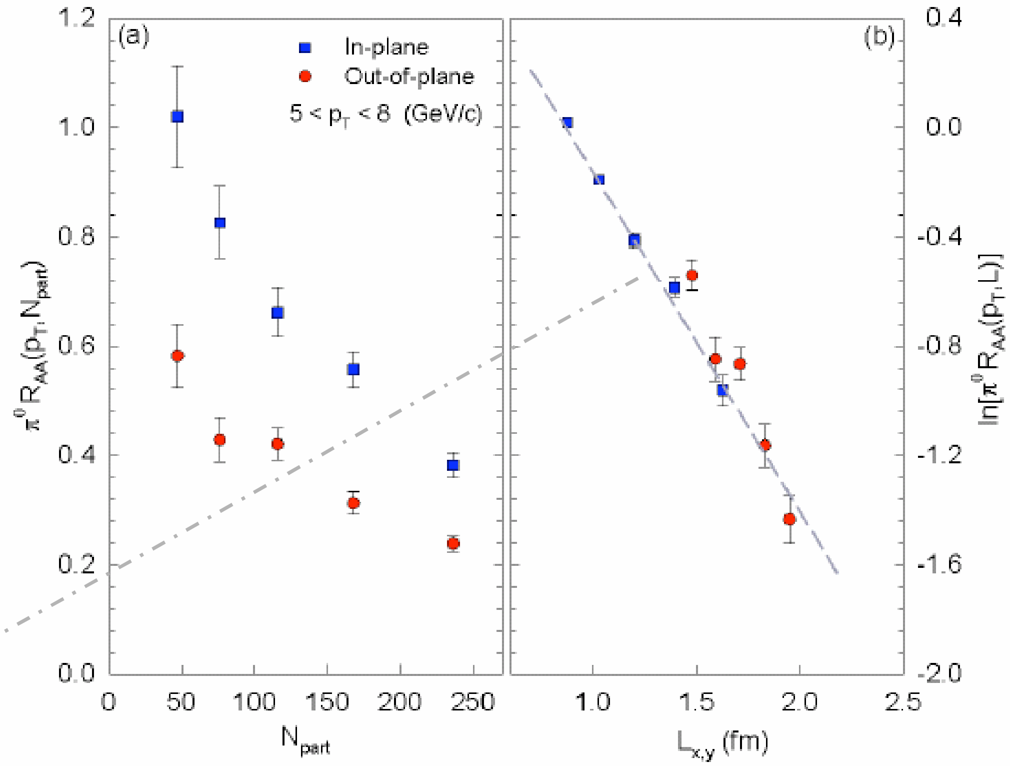
Characterizing the medium

Scaling of Jet Quenching
Reaction plane dependence

$$R^{l}_{\mathrm{AA}}(p_T, L) \simeq \exp\left[-\frac{2\alpha_s C_F}{\sqrt{\pi}} L \sqrt{\hat{q}\frac{\mathcal{L}_l}{p_T}}\right]$$







Transport Coefficient
→ light parton

$$\hat{q} \sim 1 \frac{GeV^2}{fm}$$

$$4\pi\frac{\eta}{s} \sim 4\pi\left(1.25\frac{T^3}{\hat{q}}\right) \sim 1.4$$

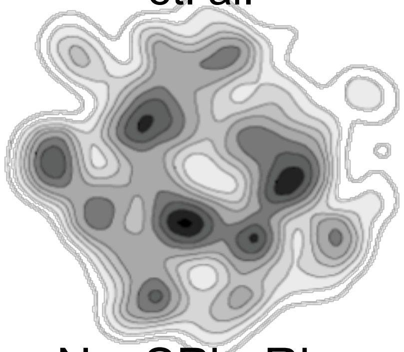
Further validation of path length scaling
→ high-p_T v_2 is path length driven

R. Lacey

The fluid which leads to large collective flow is also responsible for strong jet quenching

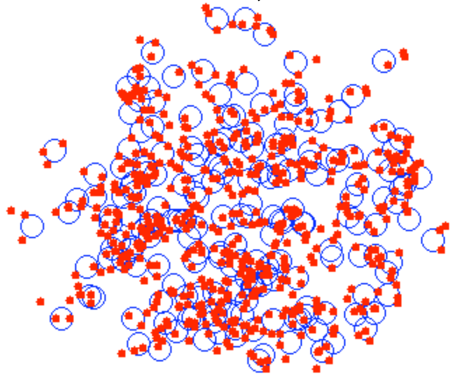
Initial conditions and fluctuations

Hama, Grasi, Kodama, et. al.



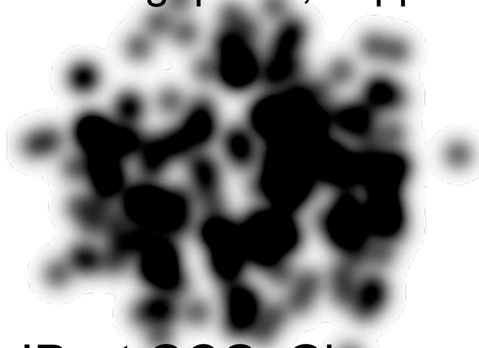
NexSPheRio

Kumar Pruthi, Sorensen

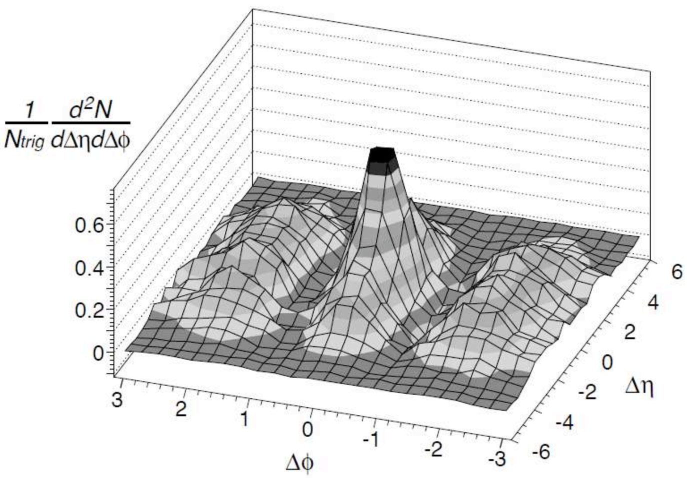


Additive Quark Model

Dumitru, Gelis, McLerran, Venugopalan, Lappi

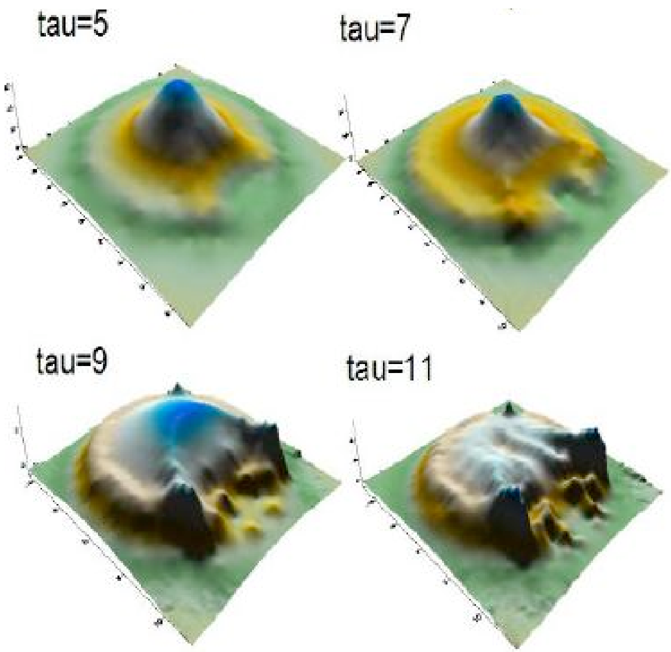


IPsat GCG, Glasma



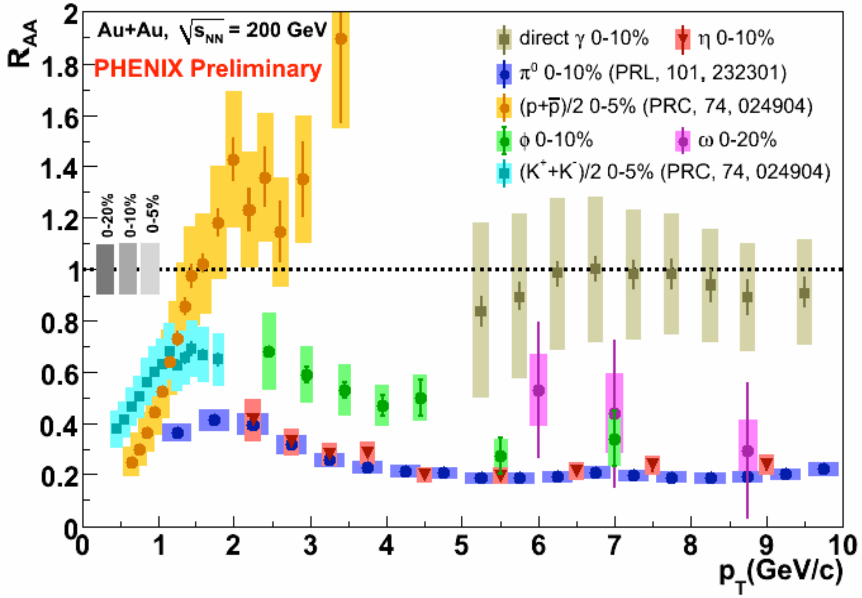
P. Sorensen
S. Gavin
W-L. Qian

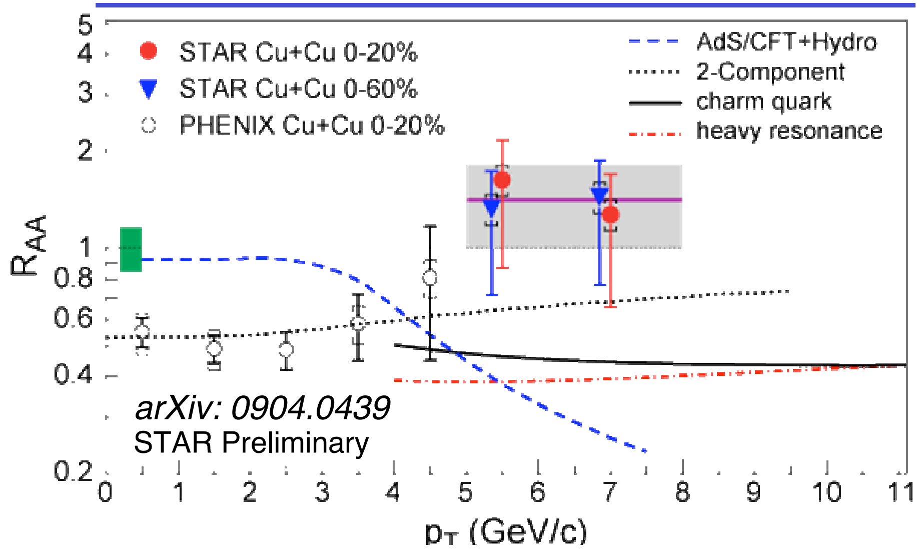
Ridge, cones, peaks, v_n (you name it) can be explained by non-uniform initial conditions, fluctuations and expansion!

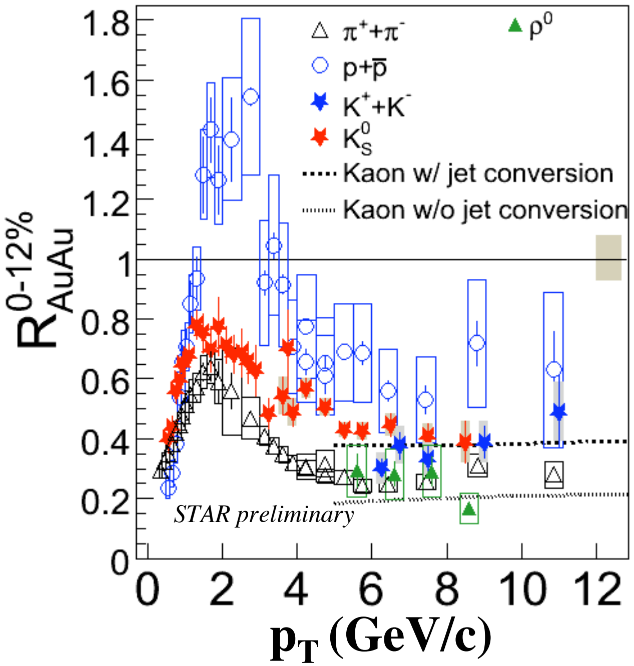


IDENTIFIED PARTICLES

Nuclear modification factor of identified particles





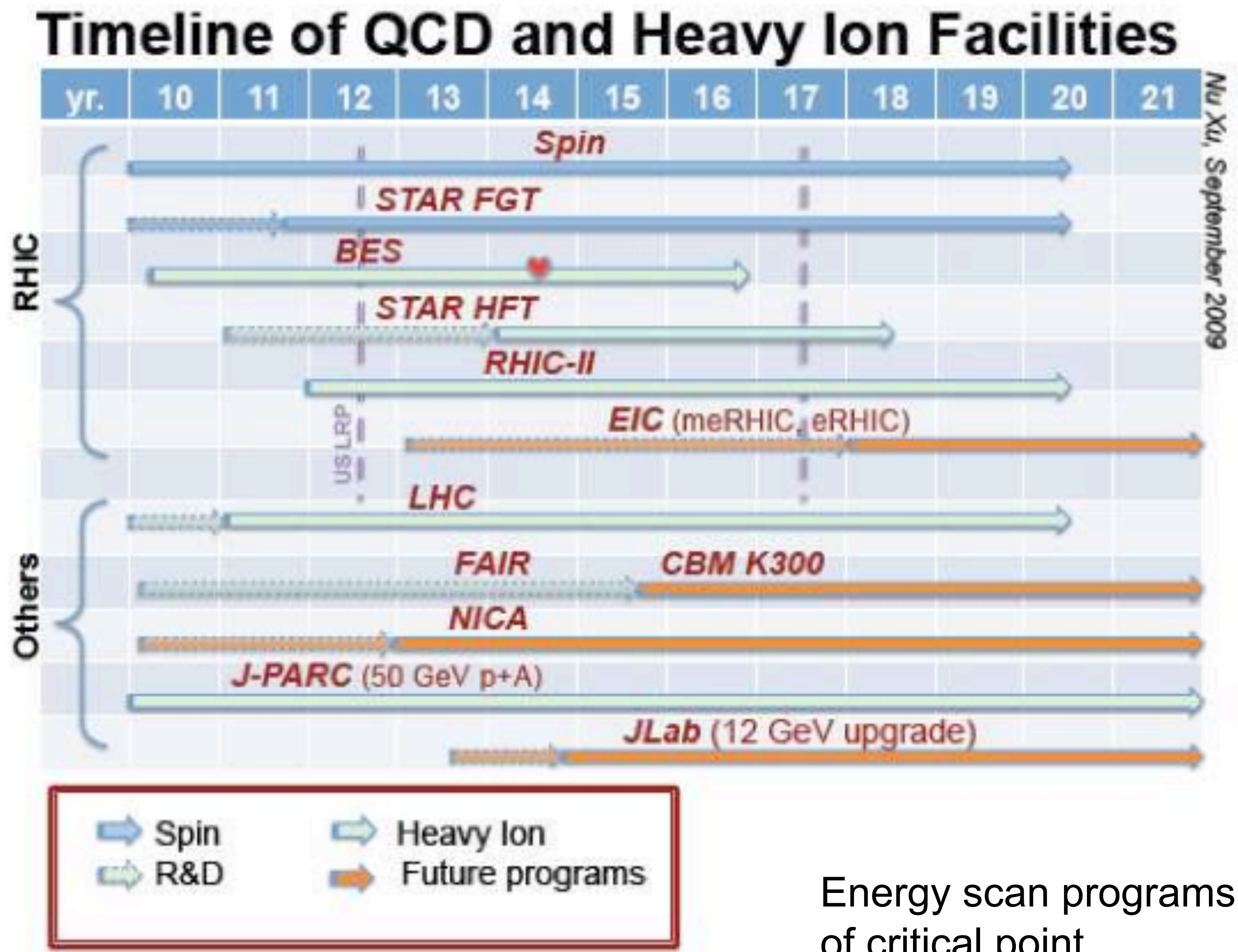


- At intermediate p_T
  - Not a mass effect
  - Not a baryon/meson effect
  - quark flavor dependence !?
- At Higher p_T
  - No unification!

K. Kijima
L. Ruan
Y. Xu

NEXT HI PROGRAMS

The next future



Energy scan programs and search of critical point