Re-Hardening of Hadron Spectra at RHIC

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in collaboration with
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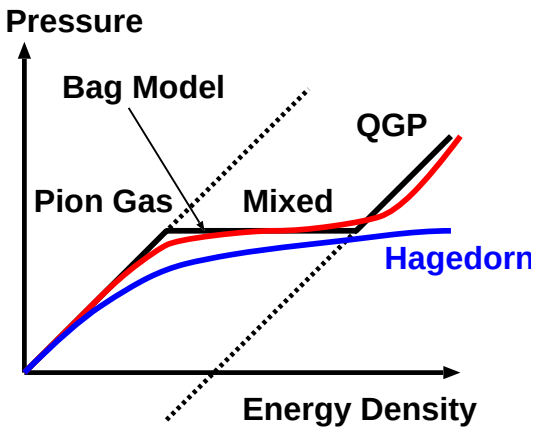
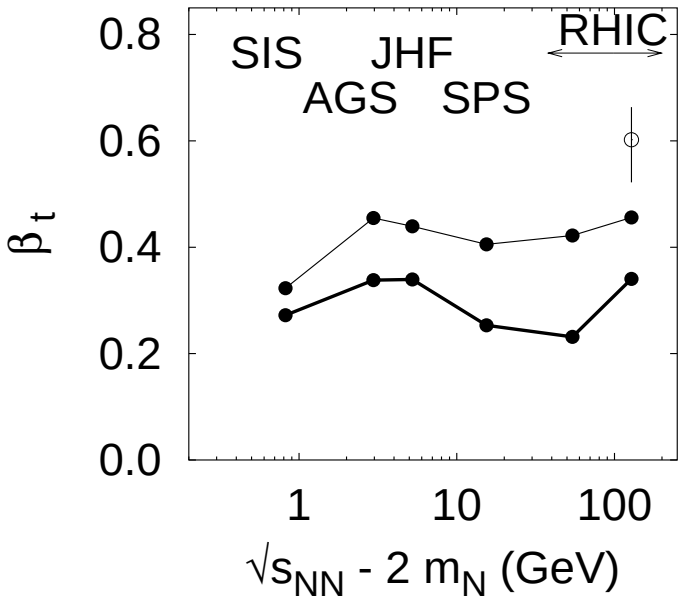
1. Re-Hardening: a QGP signal ?
2. Is Softening seen in AGS-SPS energies ?
3. Can We Explain Re-Hardening in Hadron-String Cascade ?
4. Can We Explain Re-Hardening with Mini-Jet Production ?
5. Summary





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Eprint: nucl-th/0102051

⋆ Re-Hardening: a QGP signal ?

- Proposed and Observed Signals up to SPS

  ⋆ Anomalous J/ψ supression: Uncertain $\sigma(hh)$

  ⋆ Strangeness Enhancement: Uncertain $\sigma(hh)$

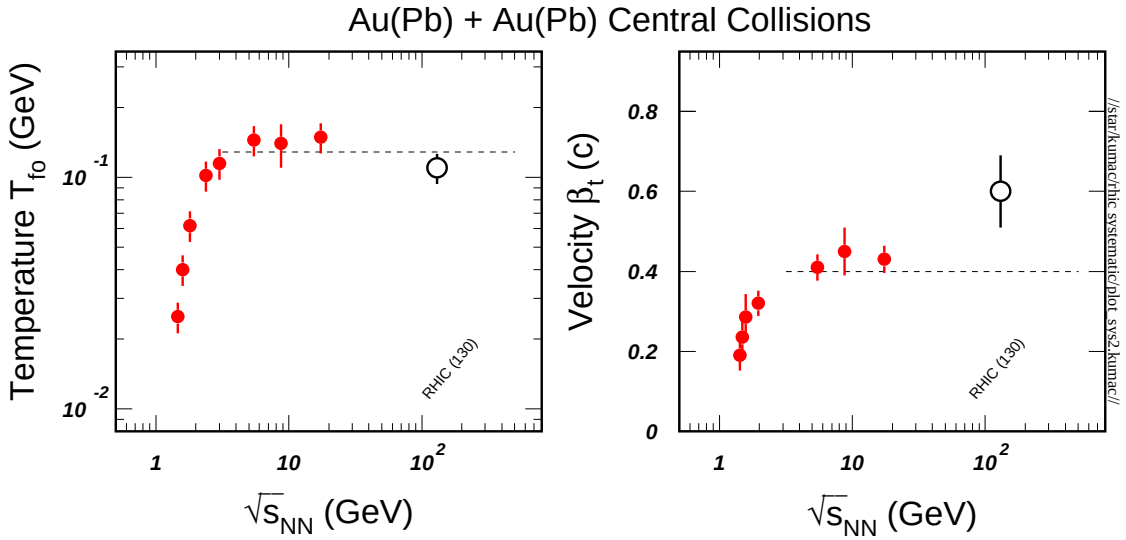
  ⋆ Low-E Dilepton Enh.: Chiral Restoration

  ⋆ Softening of particle spectra: Hagedorn Gas

  ☞ Clear Bulk/Hydrodynamical Signal is desired.

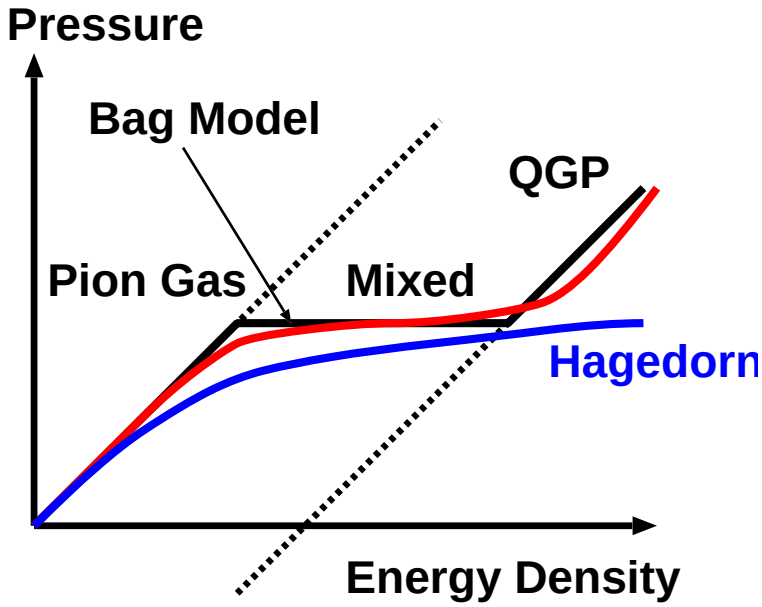
- Observed Re-Hardening Signature

Nu Xu and M. Kaneta, nucl-ex/0104021



Re-Hardening is seen at RHIC !

- Naive Expectation from Bag Model



Does it really signal QGP ?

⋆ Is Softening already seen at AGS-SPS energies ?

→ Reduction of Repulsive Pot.
and Increase of Hadron-String DOF

⋆ Can We Explain Re-Hardening
in Hadron-String Cascade ?

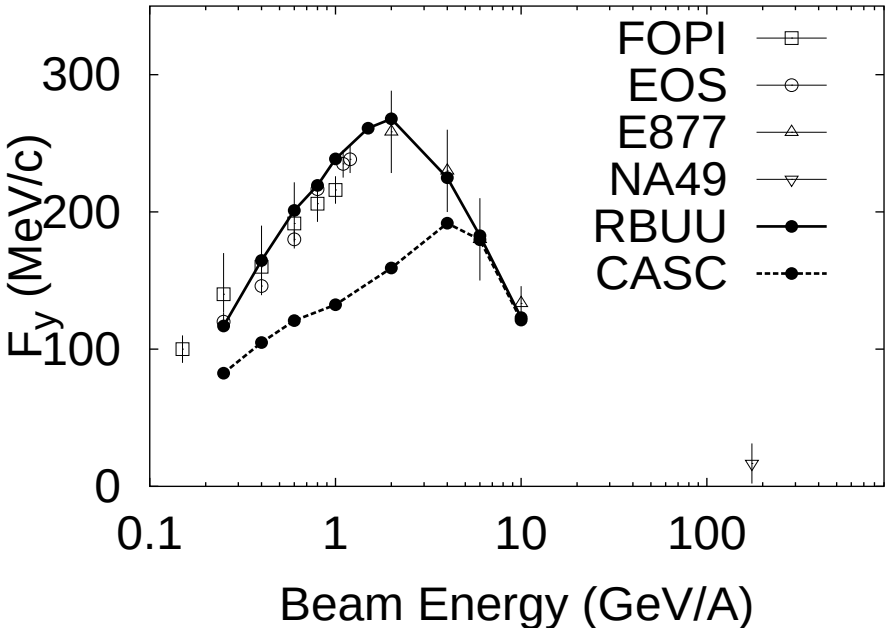
· · · Elementary σ must be reproduced at RHIC energy
→ Comparison of JAM with AGS-SPS-RHIC data

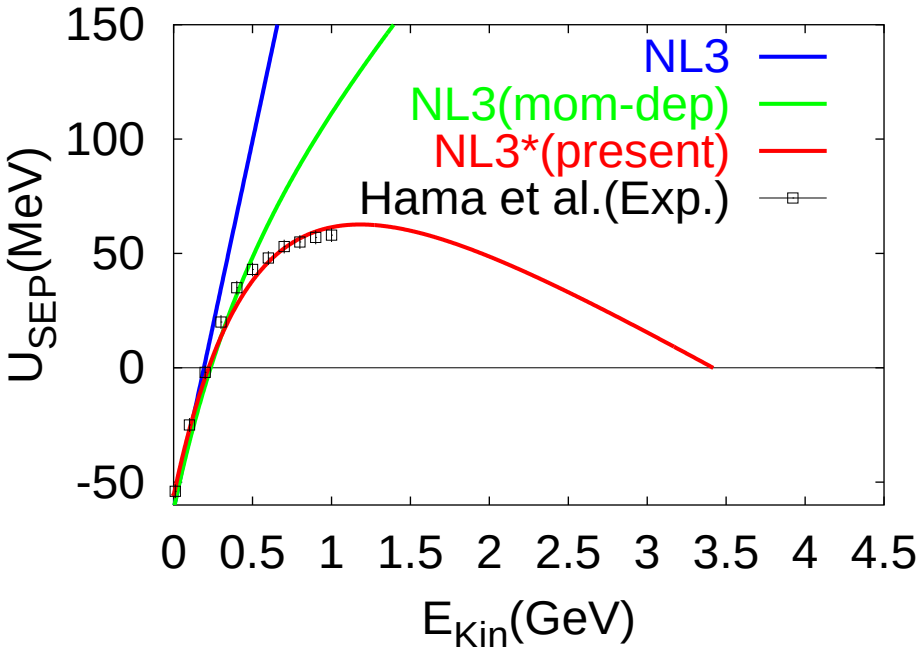
⋆ Can We Explain Re-Hardening
with Mini-Jet Production ?

· · · Treatment of Jet production may be uncertain.
→ Comparison of JAM and HIJING

⋆ Softening at AGS-SPS energies

- Reduction of Repulsive Int. $\longrightarrow$ Softening
  P.K.Sahu et al., NPA672(2000)376;

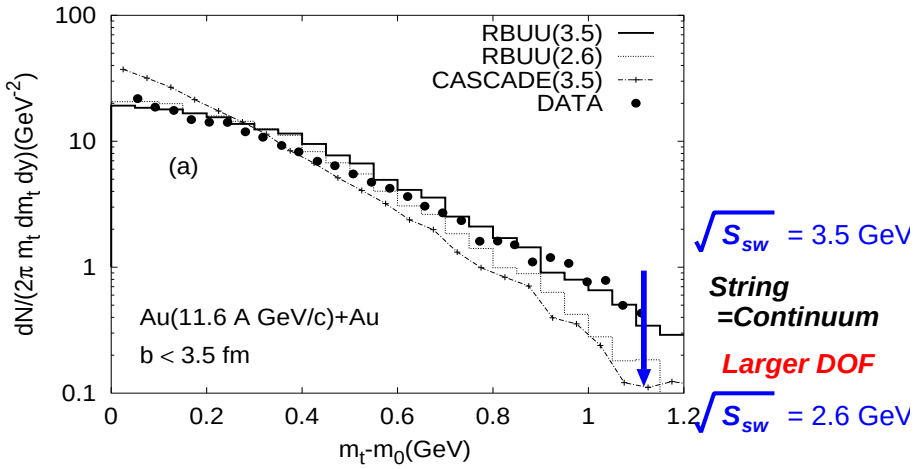




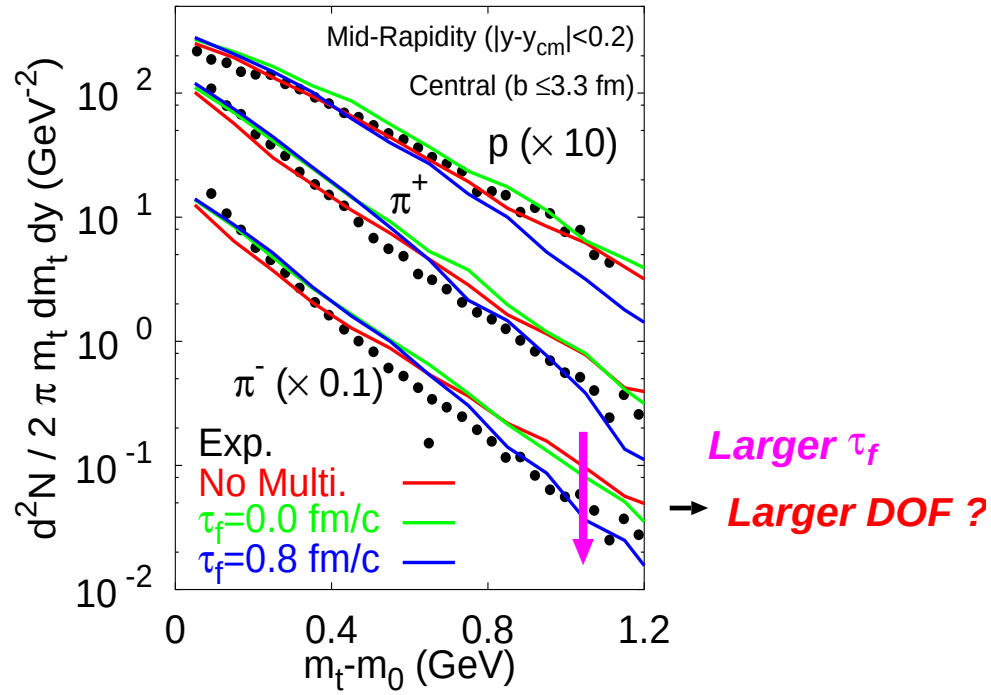
Repulsive Nuclear Interaction Should be Supperssed at Higher Momentum
$\longrightarrow$ Softening up to AGS energies

• Increase of Hadronic DOF → Softening

Y.Nara et al., PTP Suppl. 129(1997)33; P.K.Sahu et al., NPA672(2000)376; N.Otuka, Thesis; to be submitted.



Au(11.6 A GeV/c)+Au → p,π^+,π^-



Large Hadronic DOFs are necessary, either

- ⋆ Explicitly (RQMD, RBUU, URASiMA, JAM, ...)
- ⋆ or Implicitly (ARC, ART, HANDEL) through Multiparticle Prod. with Finite τ

→ Softening above AGS energies

⋆ Hadron-String Cascade at RHIC

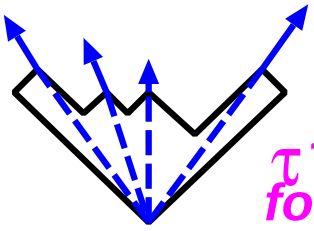
· · · Elem. Cross Sections must be reproduced.

JAM (Jet Aa Microscopic transport model)

Y. Nara et al., PRC61('00), 024901.

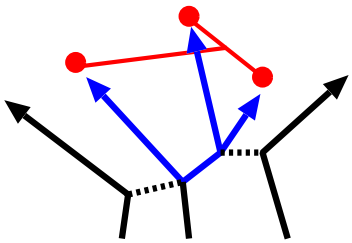
⋆ DOF: h(B, B*, M, M* (m $\leq$ 2 GeV)) + s(Strings)
+ Partons (at higher energies)

⋆ σ: Hadronic ($hh \leftrightarrow hh$, $hh \leftrightarrow h$)
+ Soft ($hh \leftrightarrow s$, $hh \rightarrow hs$, $hh \rightarrow ss$, $s \rightarrow hhh$... [1]
$ch \leftrightarrow ch$, $ch \rightarrow cs$ (c= (qq), q, $\bar{q}$) [2])

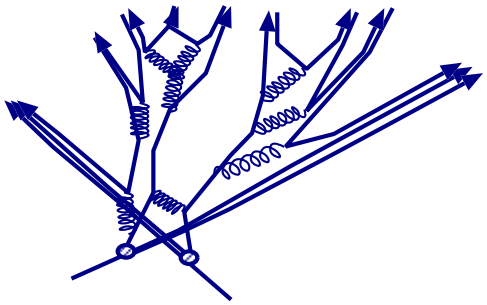


τ ~ 1 fm/c
for κ ~ 1 GeV/fm

Diquark Breaking



Resonance
+ String
+ Jet

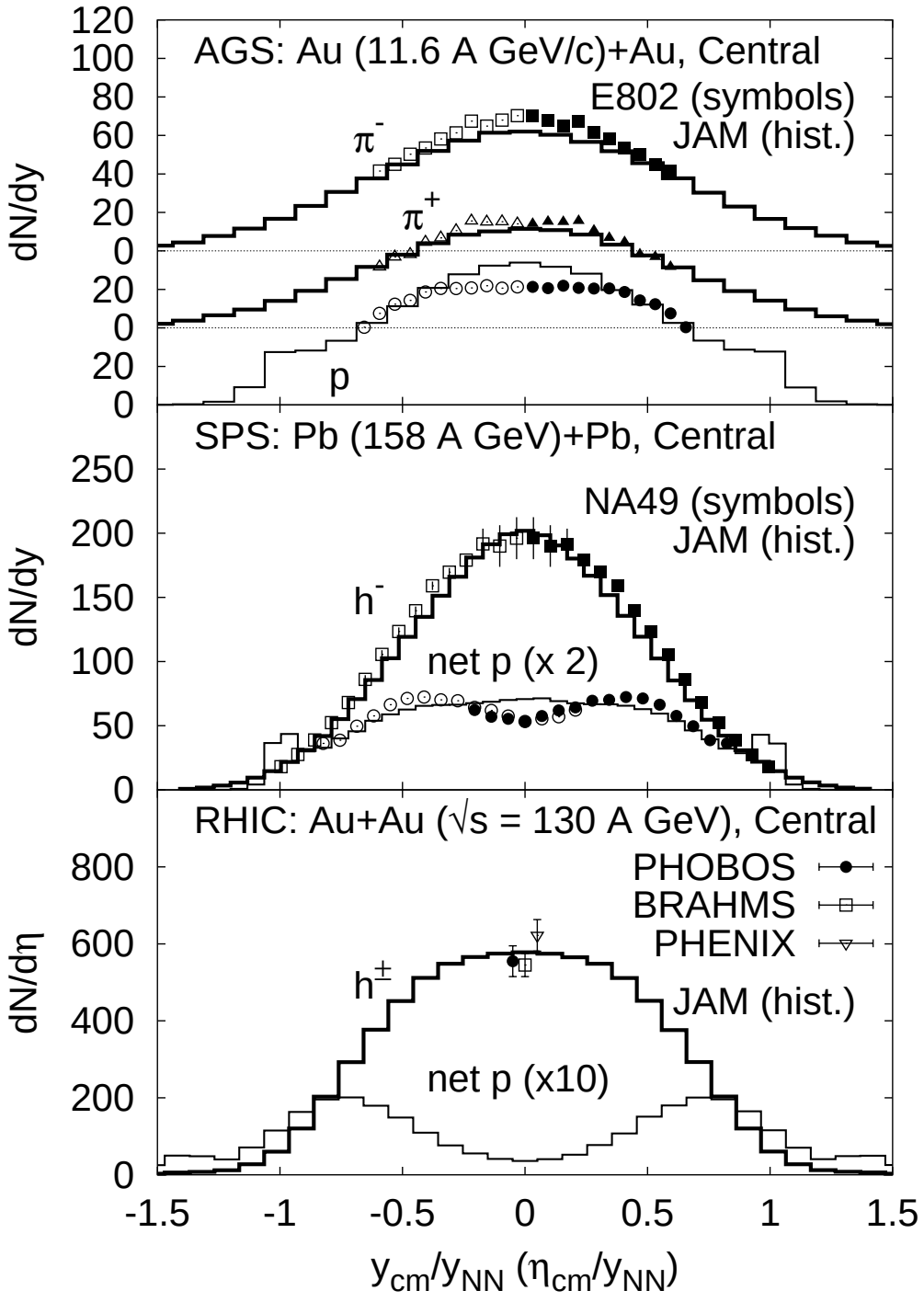


+ Hard (Jet Production, at higher energies) [3]

⋆ No Mean Field (in progress), No Medium Modification

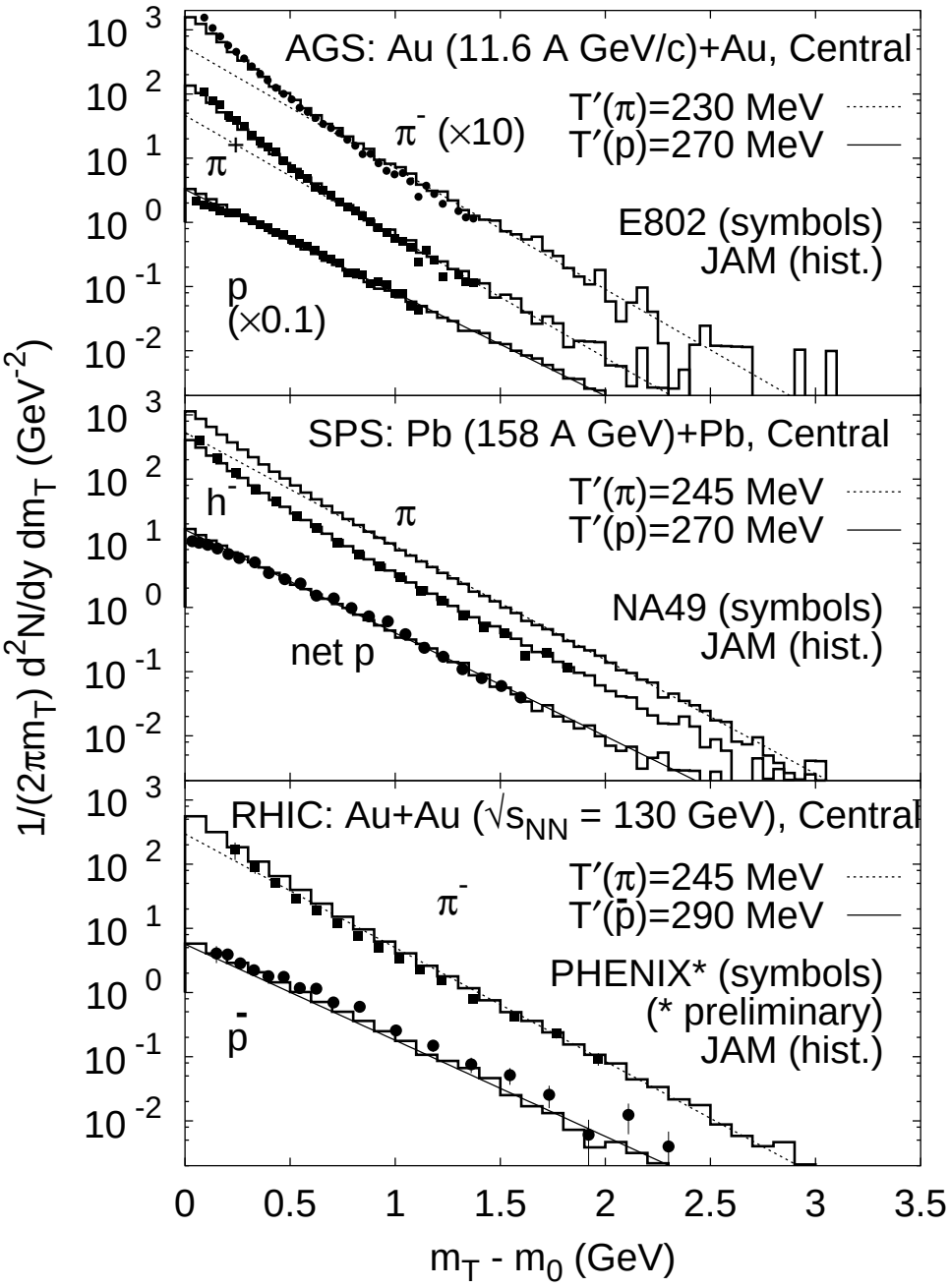
[1] "DPM + Lund" (~ HIJING) + Phase Space
[2] Consituent Rescattering (~ RQMD), c= (qq), q, $\bar{q}$
[3] Jetset (Pythia)

- Rapidity Distributions: Hadron Yields



⋆ Globally Good, except for
Systematically Larger Stopping Power of Protons.

- M_t Spectra: Measure of Generated Pressure

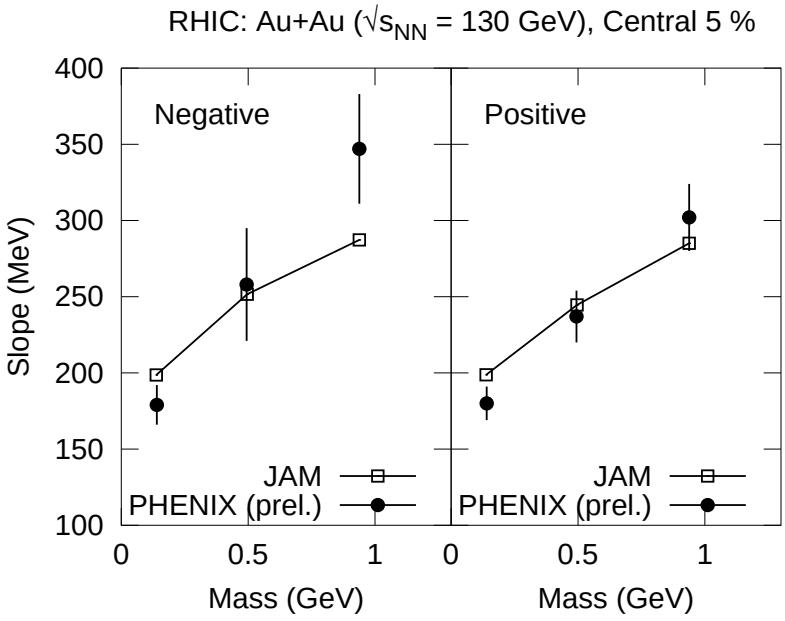


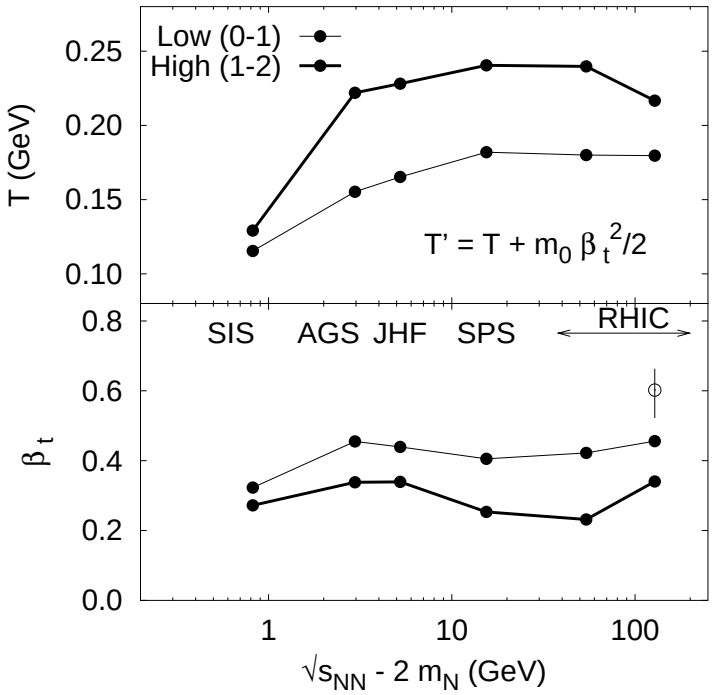
Nicely Reproduced at AGS and SPS, except for Low Energy Protons (No Mean Field).

At RHIC, JAM underestimates High Energy Protons (No Partonic Thermalization).

- Decomposition to T and β

$$\frac{d^2N}{M_t dM_t dY d\phi} \propto \exp(-M_t/T'), \quad T'(M) = T + \frac{1}{2} M \beta^2$$

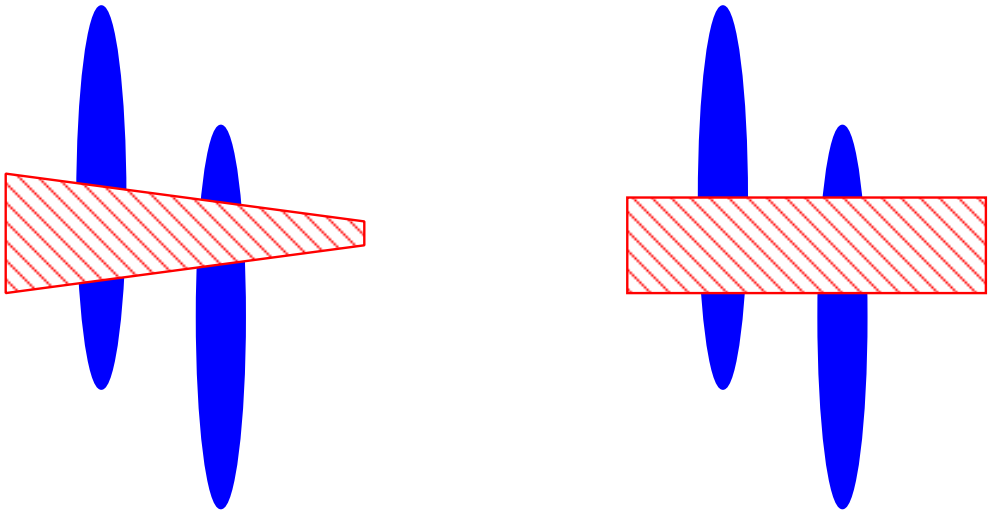




Re-Hardening in JAM is Too WEAK.

⋆ Mini-Jet Production: Hijing

X.N.Wang and M.Gyulassy, CPC83('94),307;
X.N.Wang, PRep280(97),287



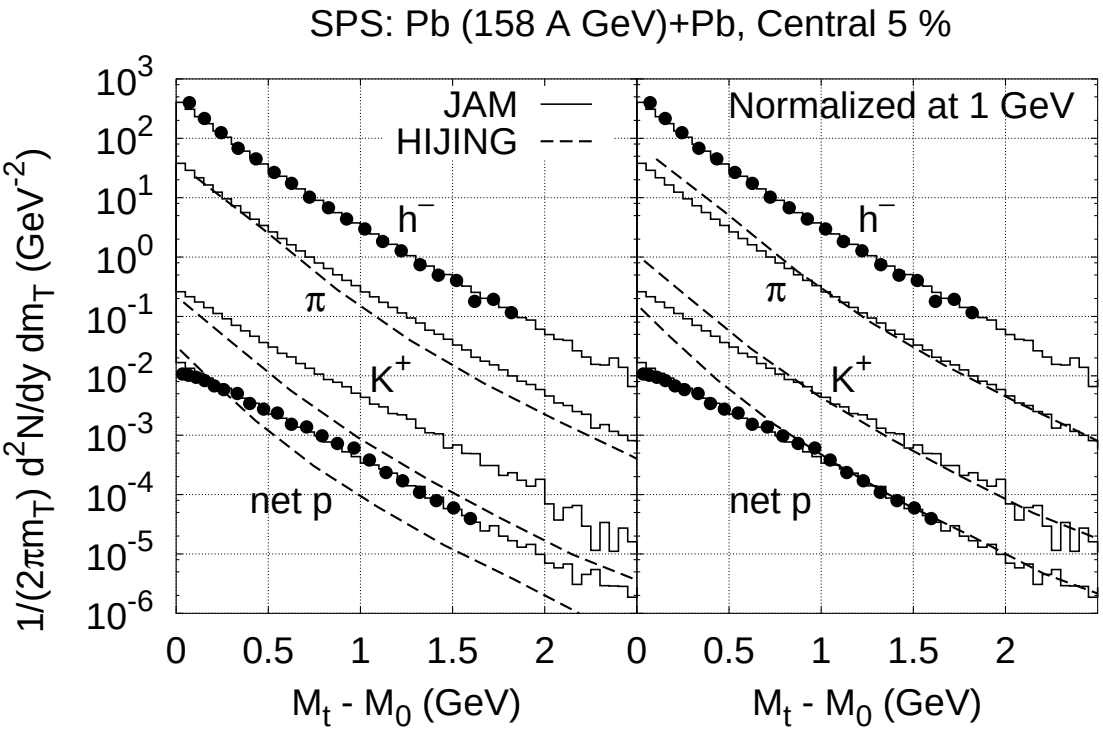
JAM: Cascade Hijing: Glauber

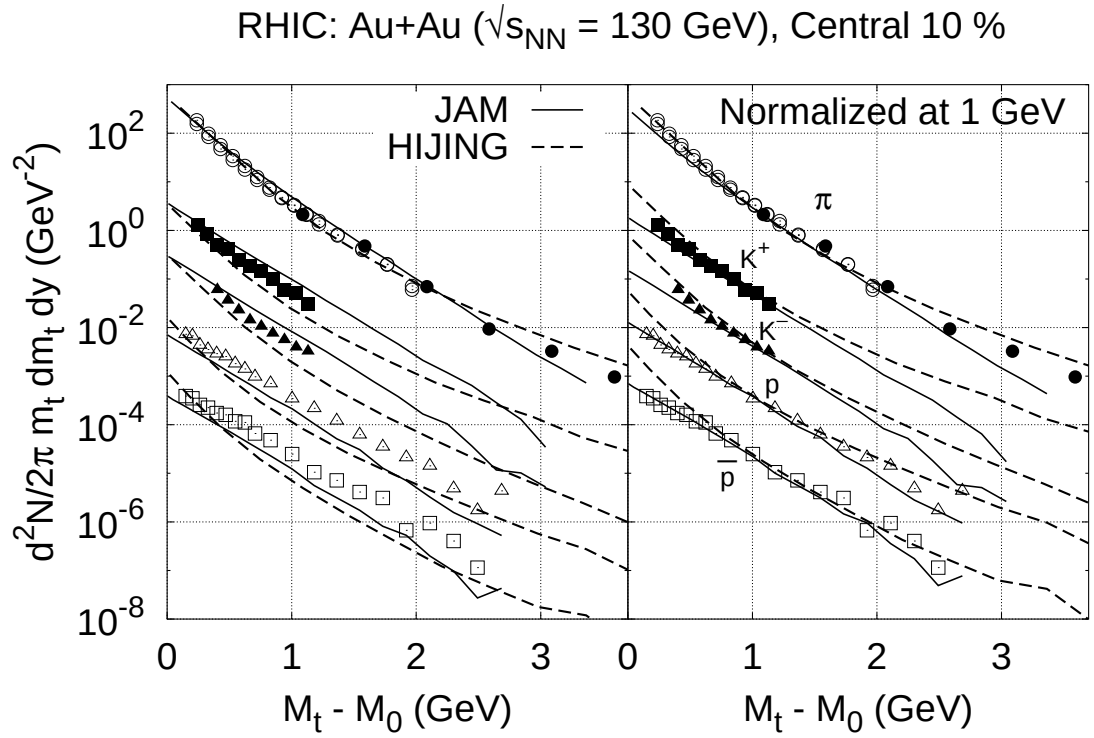
⋆ JAM: Cascade Counting of Jet
→ Initial Energy Loss and Smaller Number of Jets

⋆ Hijing: Glauber-type Counting of Jet
→ No Initial Energy Loss

☞ Does Glauber-type Counting of Jet
Strengthen Re-Hardening Signal ?

- Comparison of JAM and HIJING: SPS and RHIC



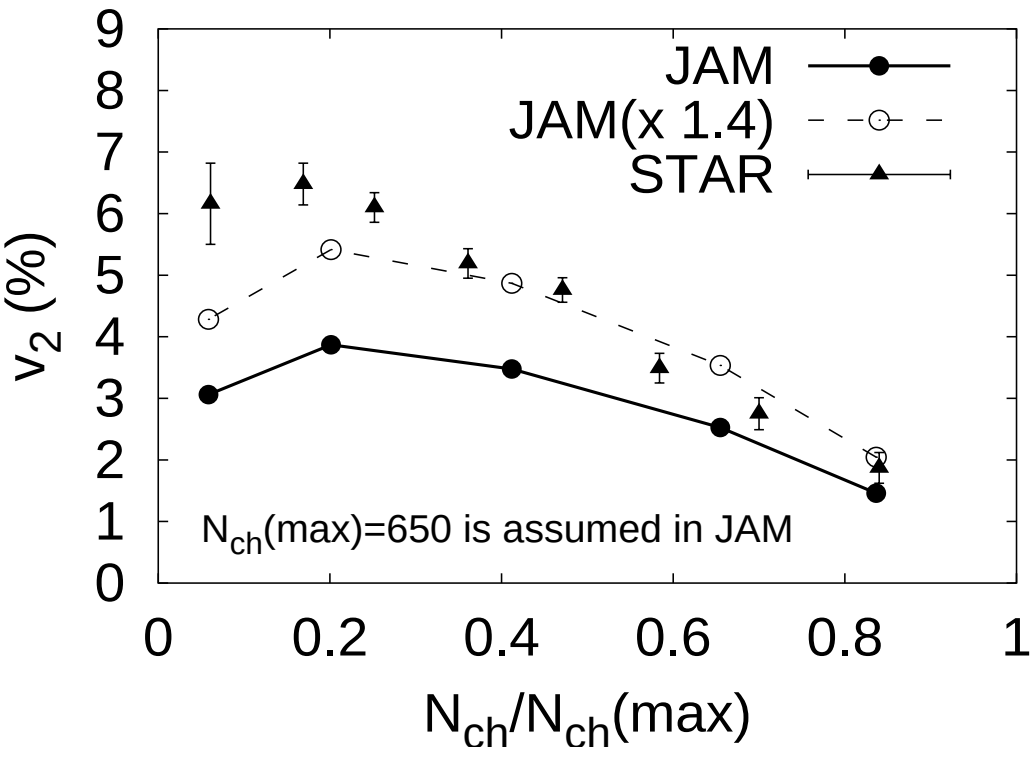


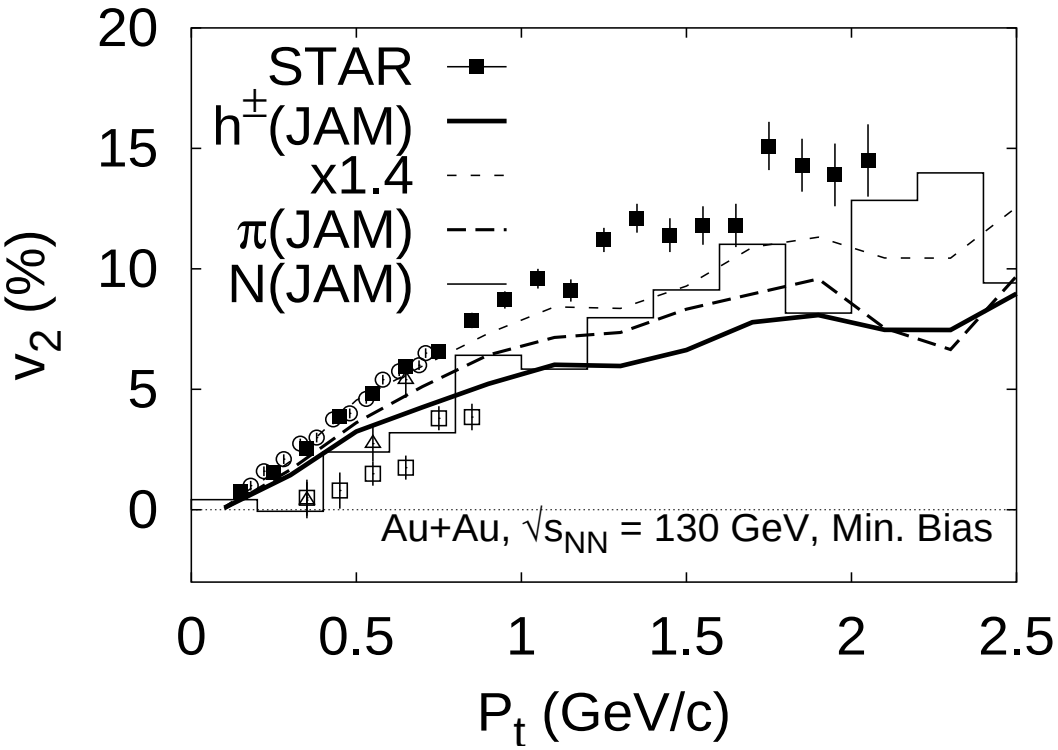
⋆ Re-Hardening cannot be explained even if Number of Jets is increased within the theoretical uncertainty.

⋆ Summary and Conclusion

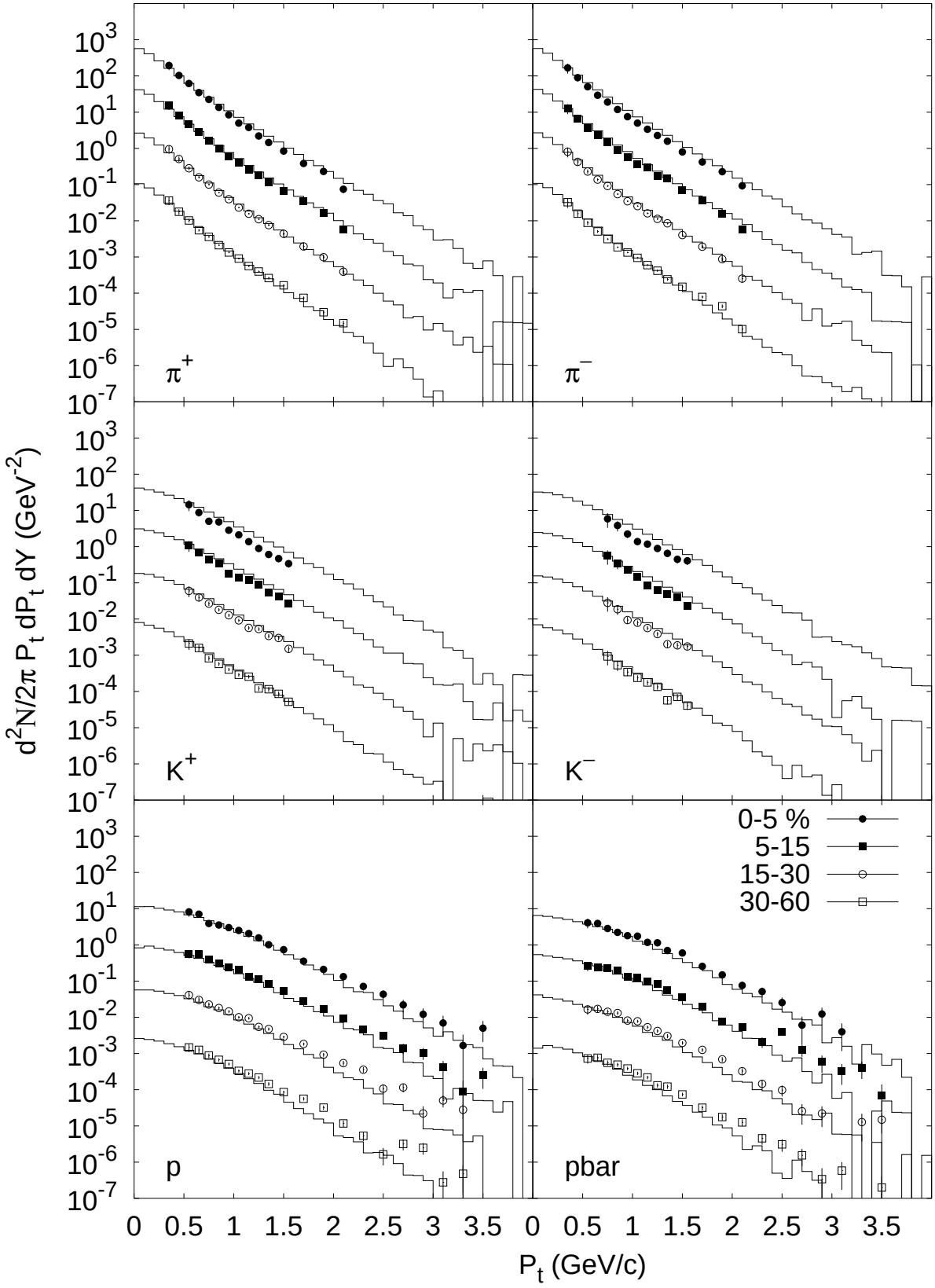
- ⋆ RHIC data show RE-HARDENING
  between SPS and RHIC energies (Kaneta-Xu).
- ⋆ Hadron Gas should become Softer and Softer
  at Higher Energy Densities than AGS energies.
  (Reduction of Repul. Int./Increase of Hadronic DOFs)
- ⋆ Re-Hardening Signature in JAM is TOO WEAK.
  (Hadron-String Cascade with Mini-jet productions, but no Parton Thermalization.)
- ⋆ Mini-Jets are NOT ENOUGH to Re-Harden.
  (Parton Cascade for Mini-Jet Partons does not help much. (Nara-Vance-Csizmadia, nucl-th0109018))
- ⋆ RE-HARDENING of Hadron Spectra
  may be a signature of bulk QGP formation,
  provided that the system is equilibrated.
- ⋆ Several Theoretical Supports
  - Hydrodynamical description of V_2
  - AMPT: Partonization of Strings + Parton Cascade
- ⋆ Problems to be solved
  - Multiple Scattering Scheme
  - Partonization: Initial Condition
  - Hadronization $\cdots$ String/Parton Coalescence
  - Parton Cascade incl. Inelastic Scattering

⋆ Elliptic Flow





⋆ Impact Parameter Dependence



⋆ To do

- ⋆ Is the QGP really formed ?
  - X Mini-Jets Only
    - ◦ Mini-Jets + Energy Loss: other than π^0 ?
    - ◦ Classical Gluon Field:
      V2, OK, How about M_t spectra ?
    - ◦ Parton Cascade (VNI): Initial Partonized Nuclei ?
    - ◦ String Melting (AMPT): At which energy density ?
- ⋆ To do = Second and Third Stages
  - ◦ Initial Condition:
    "Partonization" of Hadrons and Strings
  - ◦ Partonic Interactions (thermailzation):
    $gg \rightarrow g^{(*)}, g^{(*)} \rightarrow gg$
    (calculated in collinear case..)
  - ◦ Hadronization:
  - ◦ Hadronic Interactions: