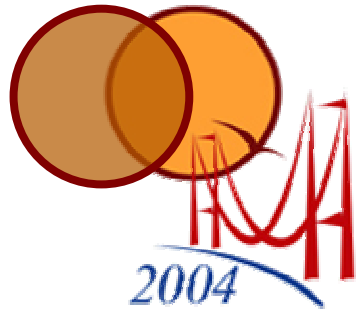

IMHO…

(In Mike's Humble Opinion)

- what have we learned (so far)?
- what is exciting (to me)?
- what do I tell my condensed-matter colleagues in the coffee room?

Mike Lisa

Ohio State University

What have we learned at RHIC?
~~An~~ *This* experimentalist's Perspective *

- Wise "forefathers" designed complex detectors in anticipation of a complex problem

* complete with bias/ignorance

Time to Physics

Again, learn from the past:

First CDF publication:

Transverse-Momentum Distributions of Charged Particles Produced in p-pbar Interactions at 630 and 1800 GeV, F. Abe et al., Phys. Rev. Lett. 61, 1819 (1988).

- ~One year from data-taking.
- Much simpler final state!

➡ *We will be hard-pressed to reach this goal*

➡ *And much harder-pressed to maintain "CDF-like" rate*

VOLUME 61, NUMBER 16 PHYSICAL REVIEW LETTERS 17 OCTOBER 1988

Transverse-Momentum Distributions of Charged Particles Produced in $\bar{p}p$ Interactions at $\sqrt{s}$ = 630 and 1800 GeV

F. Abe,[(10)] D. Amidei,[(3)] G. Apollinari,[(11)] G. Ascoli,[(7)] M. Atac,[(4)] P. Auchincloss,[(14)] A. R. Baden,[(6)] A. Barbaro-Galtieri,[(9)] V. E. Barnes,[(12)] F. Bedeschi,[(11)] S. Belforte,[(11)] G. Bellettini,[(11)] J. Bellinger,[(15)] J. Bensinger,[(2)] A. Beretvas,[(4)] P. Berge,[(4)] S. Bertolucci,[(5)] S. Blusk,[(9)] M. Bickley,[(4)] R. Blair,[(1)] C. Blocker,[(2)] J. Bofill,[(3)] A. W. Booth,[(4)] G. Brandenburg,[(6)] D. Brown,[(6)] A. Byon,[(12)] K. L. Byrum,[(15)] M. Campbell,[(7)] R. Carey,[(6)] W. Carithers,[(9)] D. Carlsmith,[(15)] J. T. Carroll,[(4)] R. Cashmore,[(4)] F. Cervelli,[(11)] K. Chadwick,[(4,12)] T. Chapin,[(13)] G. Chiarelli,[(11)] W. Chinowsky,[(9)] S. Cihangir,[(4)] D. Cline,[(15)] D. Connor,[(10)] M. Contreras,[(2)] J. Cooper,[(4)] M. Cordelli,[(5)] M. Curatolo,[(5)] C. Day,[(4)] R. DeFaccio,[(14)] M. Dell'Orso,[(11)] L. DeMortier,[(6)] T. Devlin,[(13)] D. DiBitonto,[(15)] R. Diebold,[(1)] F. Ditton,[(6)] A. DiVirgilio,[(11)] J. R. Dixon,[(7)] R. Ely,[(9)] S. Errede,[(7)] B. Esposito,[(5)] A. Feldman,[(6)] R. Flaugher,[(4)] R. Focardi,[(11)] G. W. Foster,[(4)] M. Franklin,[(4,7)] J. Freeman,[(4)] H. Frisch,[(3)] Y. Fukui,[(8)] A. F. Garfinkel,[(12)] P. Giannetti,[(11)] N. Giokaris,[(13)] P. Giromini,[(5)] L. Gladney,[(10)] M. Gold,[(9)] K. Goulianos,[(13)] C. Grosso-Pilcher,[(3)] C. Haber,[(9)] S. R. Hahn,[(4)] R. Handler,[(15)] R. M. Harris,[(9)] J. Hauser,[(2)] T. Hessing,[(13)] R. Hollebeek,[(14)] L. Holloway,[(7)] P. Hu,[(14)] B. Hubbard,[(9)] P. Hurst,[(7)] J. Huth,[(4)] H. Jensen,[(4)] R. P. Johnson,[(6)] U. Joshi,[(4)] R. W. Kadel,[(4)] T. Kamon,[(12)] S. Kanda,[(8)] D. A. Kardelis,[(7)] I. Karliner,[(7)] E. Kearns,[(6)] R. Kephart,[(4)] P. Kesten,[(2)] H. Keutelian,[(7)] S. Kim,[(8)] L. Kirsch,[(2)] K. Kondo,[(8)] U. Kruse,[(7)] S. E. Kuhlmann,[(1)] A. T. Laasanen,[(12)] W. Li,[(1)] T. Liss,[(5)] N. Lockyer,[(10)] F. Marchetto,[(11)] R. Markeloff,[(15)] L. A. Markosky,[(15)] P. McIntyre,[(12)] A. Menzione,[(11)] T. Meyer,[(13)] S. Mikamo,[(8)] M. Miller,[(3)] T. Mimashi,[(8)] S. Miscetti,[(5)] M. Mishina,[(8)] S. Miyashita,[(8)] N. Mondal,[(15)] S. Mori,[(8)] Y. Morita,[(8)] A. Mukherjee,[(4)] C. Newman-Holmes,[(4)] L. Nodulman,[(1)] R. Pestotnik,[(4)] A. Pier,[(4)] J. Patrick,[(4)] T. J. Phillips,[(6)] H. Piekarz,[(5)] R. Plunkett,[(4)] L. Pondrom,[(15)] J. Proudfoot,[(1)] G. Punzi,[(11)] D. Quarrie,[(4)] K. Ragan,[(10)] G. Redlinger,[(3)] J. Rhoades,[(15)] F. Rimondi,[(5)] L. Ristori,[(11)] T. Rohaly,[(10)] A. Roodman,[(3)] A. Sansoni,[(5)] R. Sard,[(5)] V. Scarpine,[(7)] P. Schlabach,[(7)] E. E. Schmidt,[(4)] P. Schoessow,[(1)] M. H. Schub,[(12)] R. Schwitters,[(6)] A. Scribano,[(11)] S. Segler,[(4)] M. Sekiguchi,[(16)] P. Sestini,[(11)] M. Shapiro,[(6)] M. Sheaff,[(15)] M. Shibata,[(16)] M. Shochet,[(3)] J. Siegrist,[(9)] P. Sinervo,[(10)] J. Skarha,[(15)] D. A. Smith,[(7)] F. D. Snider,[(2)] R. St. Denis,[(14)] A. Stefanini,[(11)] Y. Takaiwa,[(16)] K. Takikawa,[(16)] S. Tarem,[(3)] D. Theriot,[(4)] A. Tollestrup,[(4)] G. Tonelli,[(11)] Y. Tsay,[(3)] F. Ukegawa,[(14)] D. Underwood,[(1)] R. Vidal,[(4)] R. G. Wagner,[(1)] R. L. Wagner,[(4)] J. Walsh,[(10)] T. Watts,[(13)] R. Webb,[(12)] T. Westhusing,[(7)] S. White,[(13)] A. Wicklund,[(1)] H. H. Williams,[(10)] T. Yamanouchi,[(9)] A. Yamashita,[(16)] K. Yasuoka,[(16)] G. P. Yeh,[(4)] J. Yoh,[(4)] and F. Zetti,[(11)]

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[(5)] *Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, Frascati, Italy*
[(6)] *Harvard University, Cambridge, Massachusetts 02138*
[(7)] *University of Illinois, Urbana, Illinois 61801*
[(8)] *National Laboratory for High Energy Physics (KEK), Tsukuba-gun, Ibaraki-ken 305, Japan*
[(9)] *Lawrence Berkeley Laboratory, Berkeley, California 94720*
[(10)] *University of Pennsylvania, Philadelphia, Pennsylvania 19104*
[(11)] *Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore of Pisa, Pisa, Italy*
[(12)] *Purdue University, West Lafayette, Indiana 47907*
[(13)] *Rockefeller University, New York, New York 10021*
[(14)] *Rutgers University, Piscataway, New Jersey 08854*
[(15)] *Texas A&M University, College Station, Texas 77843*
[(16)] *University of Tsukuba, Ibaraki 305, Japan*
[(17)] *University of Wisconsin, Madison, Wisconsin 53706*

(Received 8 June 1988; revised manuscript received 5 September 1988)

Measurements of inclusive transverse-momentum spectra for charged particles produced in proton-antiproton collisions at $\sqrt{s}$ of 630 and 1800 GeV are presented and compared with data taken at lower energies.

PACS numbers: 13.85.Ni

Bill Zajc, "Day-1 Physics @ RHIC"
RHIC Winter Workshop, LBL '99

09-Jan-98

W.A. Zajc

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- ~One year from data-taking.
- Much simpler final state!

➡ *We will be hard-pressed to reach this goal*

➡ *And much harder-pressed to maintain "CDF-like" rate*

~1 year after
Y1 "End of Major Operations":
14 RHIC physics papers

To date: ~80 (expt) physics papers

Bill Zajc, "Day-1 Physics @ RHIC"
RHIC Winter Workshop, LBL '99

09-Jan-98

W.A. Zajc

What have we learned at RHIC?
~~An~~ *This* experimentalist's Perspective *

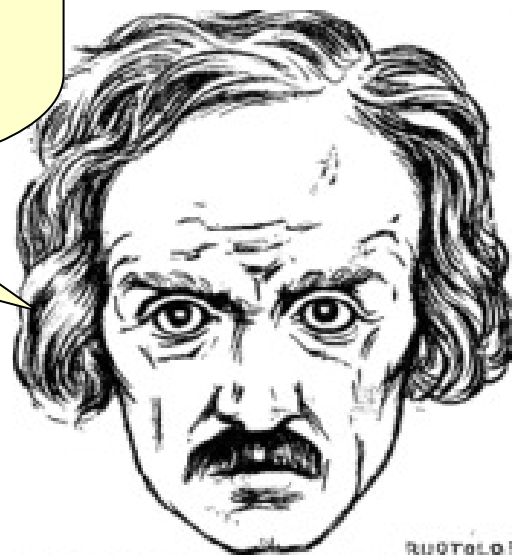
- Wise "forefathers" designed complex detectors in anticipation of a complex problem
- Tremendous output since late 2000 – ~80 physics papers / 3 years!
- Huge diversity of results
  - hard probes (J/ψ, D, jets…)
  - momentum-space shapes (spectra, v_2, v_4…)
  - femtoscopy (HBT, non-id correlations, cluster/coalescence…)
  - fluctuations ($\langle p_T \rangle$, net charge…)
  - chemistry (yields, resonances, strangeness…)
- Huge systematics
  - particle type (mass, quark content, σ, collision stage)
  - rapidity (parton x)
  - $\sqrt{s_{NN}}$ (ε)
  - centrality (ε, **shape**)
  - system (A-A, p/d-A, p-p) – "clean" (?) references

* complete with bias/ignorance

Sophisticated tools to study a complex system

A warning from the king of dour…

"[In a system] where the pieces have different and bizarre motions, with various and variable values, what is only complex is mistaken (a not unusual error) for what is profound."



Edgar Allen Poe, in *Murders in the Rue Morgue* (1841)
discussing chess enthusiasts

PID'd access to range of p_T scales

Most compelling observations so far: **[hard]**

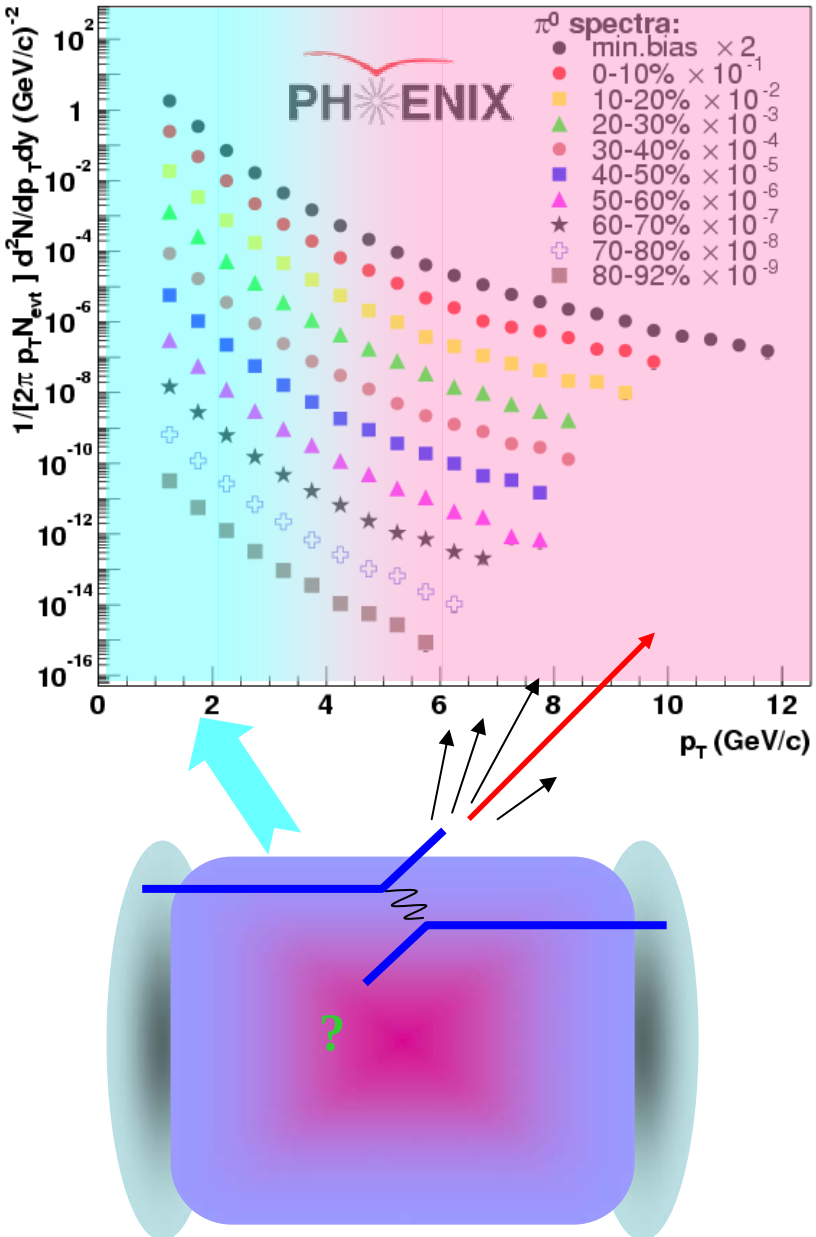
- hard probes of bulk medium
  - probes "calibrated"/calculable at high p_T
  - medium decays (99.5%) to low p_T particles
    - QGP: low-Q phenomenon

Most frustrating observations so far: **[soft]**

- less clear "new" message from medium *itself*
  - dynamic/timescale/chemistry systematics
  - importance of understood reference

Most exciting observations so far: **["firm"]**

- particle-identified intermediate-p_T R_{AA}, v_2
  - *non-trivial* interaction of probe – medium?
  - evidence towards partonic medium
  - towards a more unified picture?



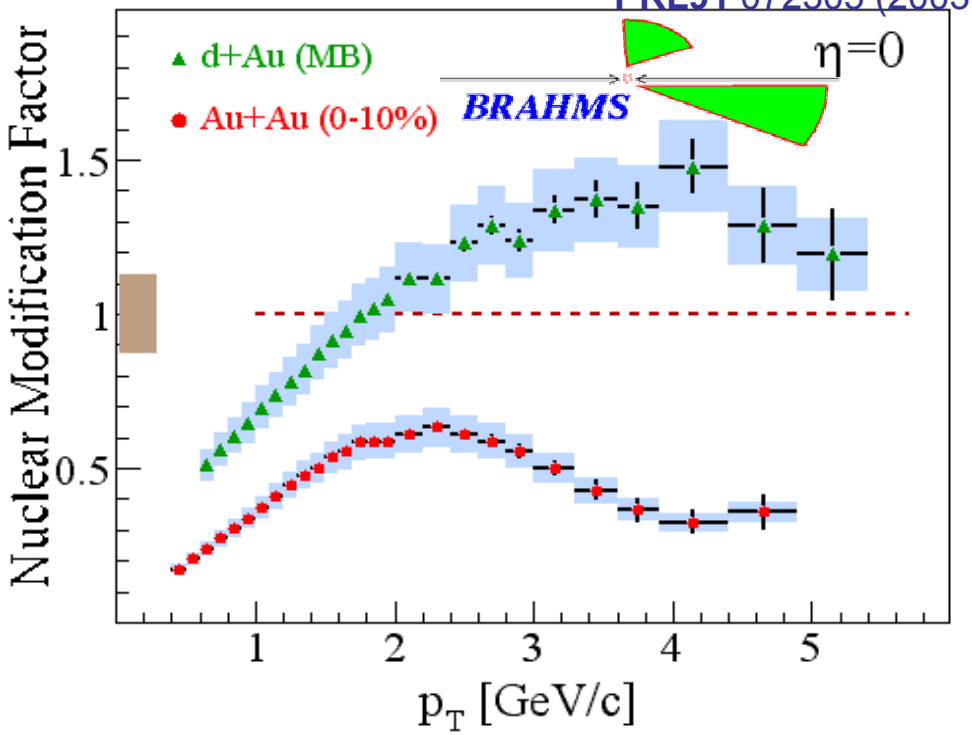
[hard] On the right track…

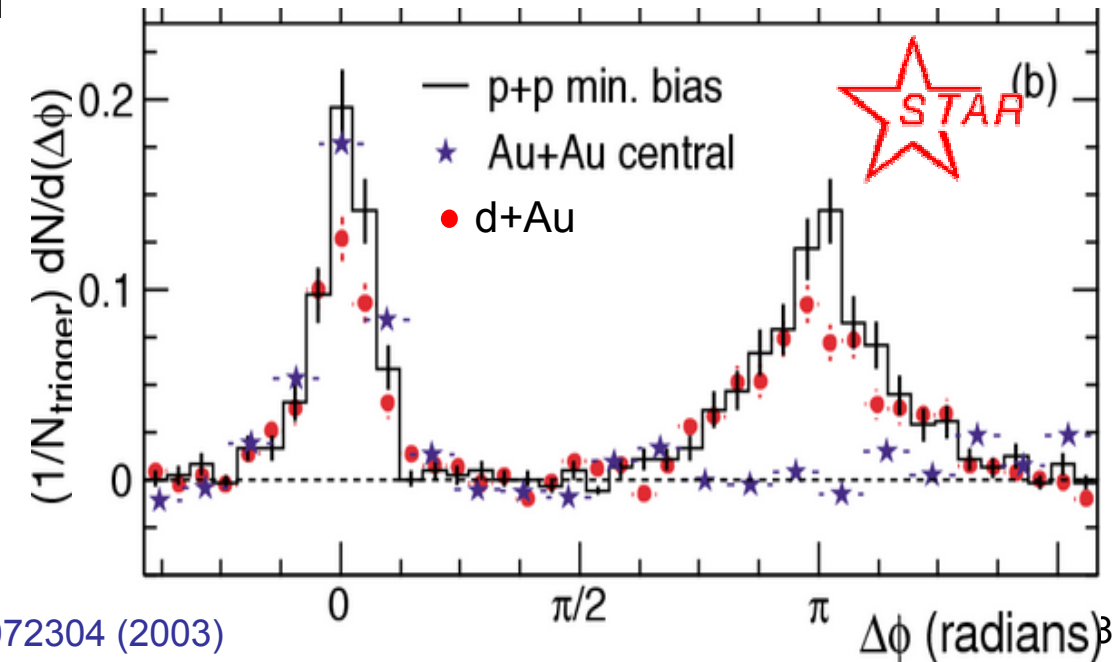
Singles spectra:
clear difference to references

- pp – a medium effect
- dAu – a final state effect
- lower √s – a new final state medium effect

more differential: $\Delta\phi$ distributions

- "calibrated" probe suppression (jets)
- near-side structure *suggests* parton ΔE (?)

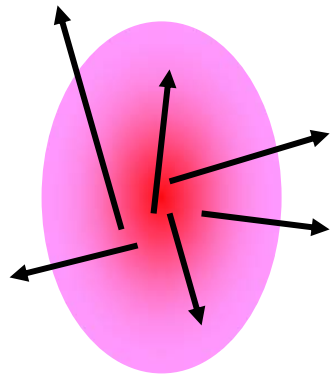




PRL91 072304 (2003)

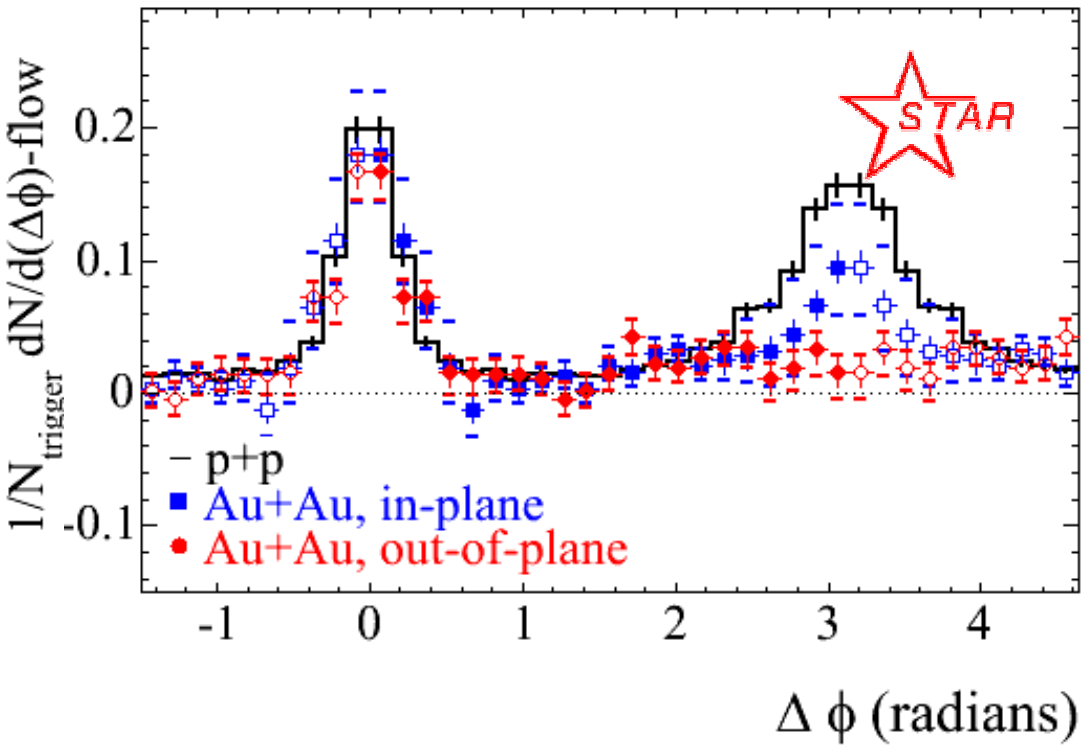
[hard] On the right track…

Singles spectra & $\Delta\phi$ distributions
- final state medium-induced jet "quenching"



important: lower $p_{T,assoc}$
- jets poking through?

even more differential: jets vs. RP
- expected from above inferences
- "self-referential"
- consistent picture?
- nail down $\Delta E(L)$ contribution



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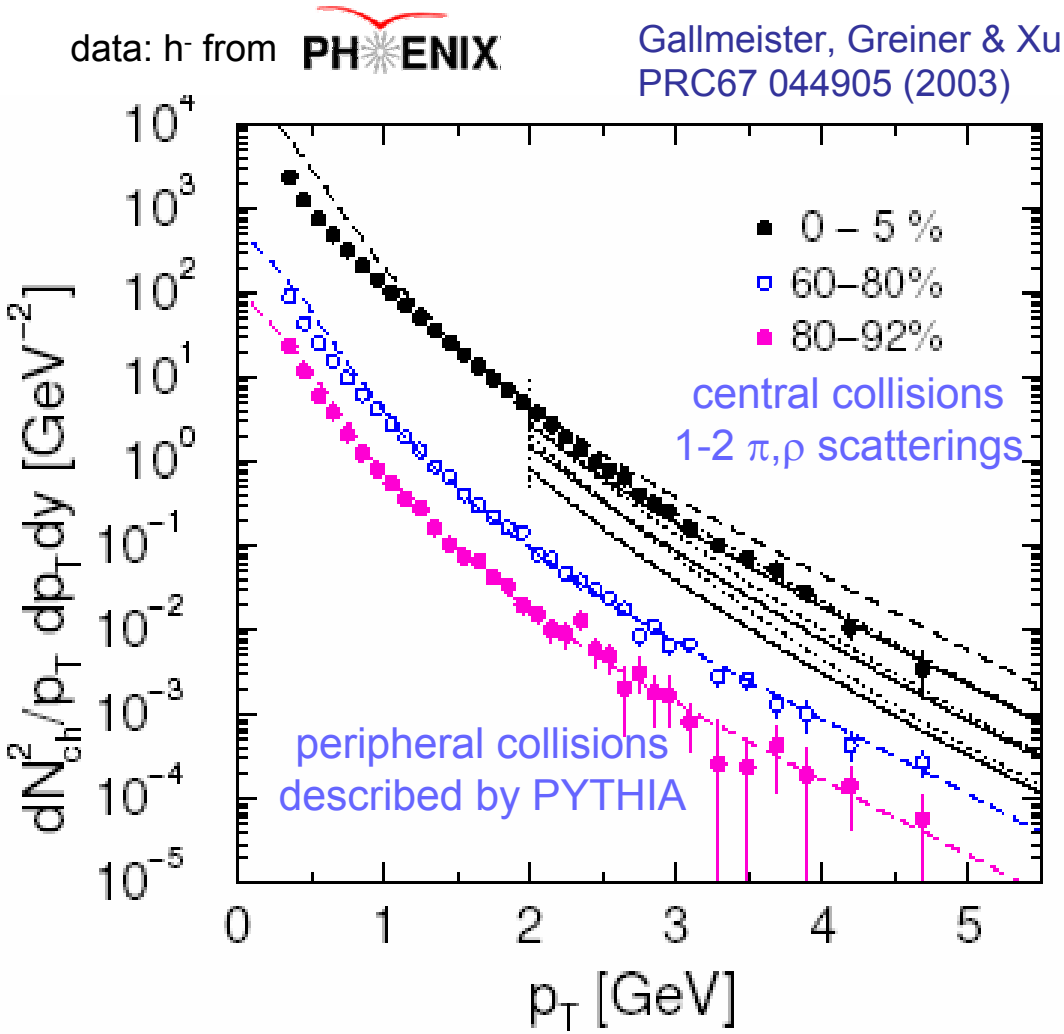
Could it be ("pre-")hadronic?
- unscientific to dismiss it outright



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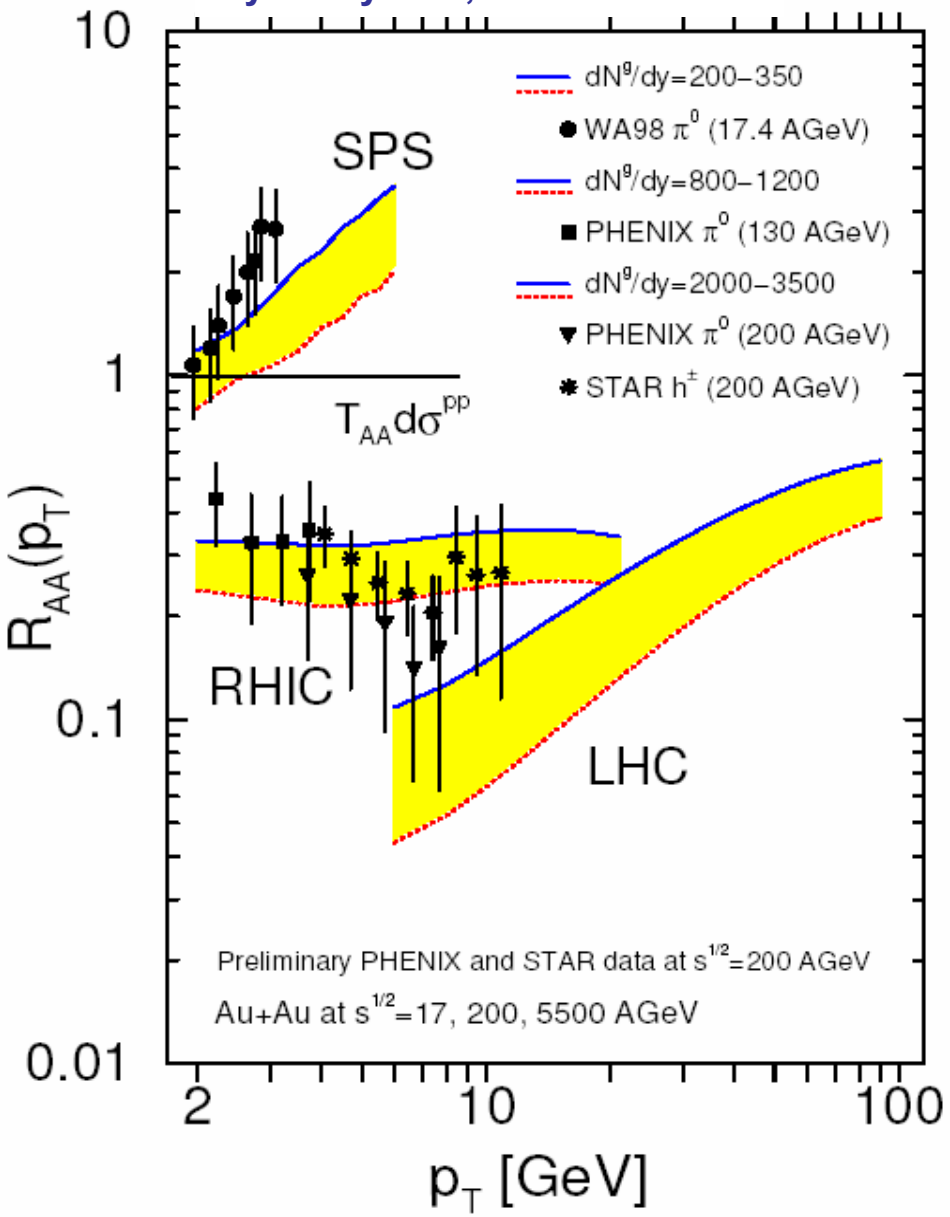
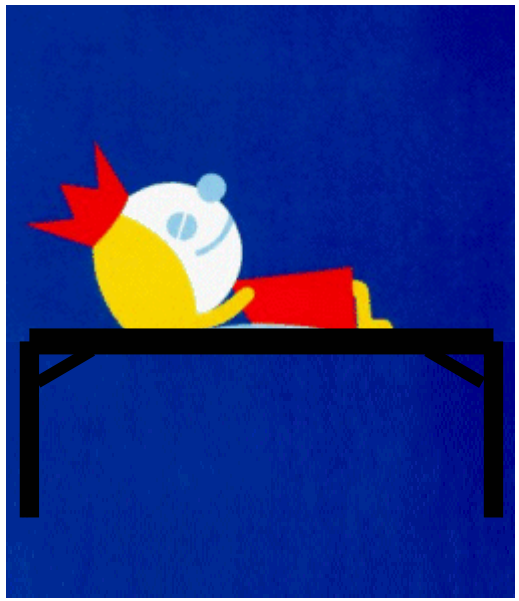
Could it be ("pre-")hadronic?
- unscientific to dismiss it outright
- OTOH, my $$: partonic ΔE

For now: limited information content

Gyulassy et al, nucl-th/0302077





[hard] → [firm] → [soft]

Dense

Compelling!

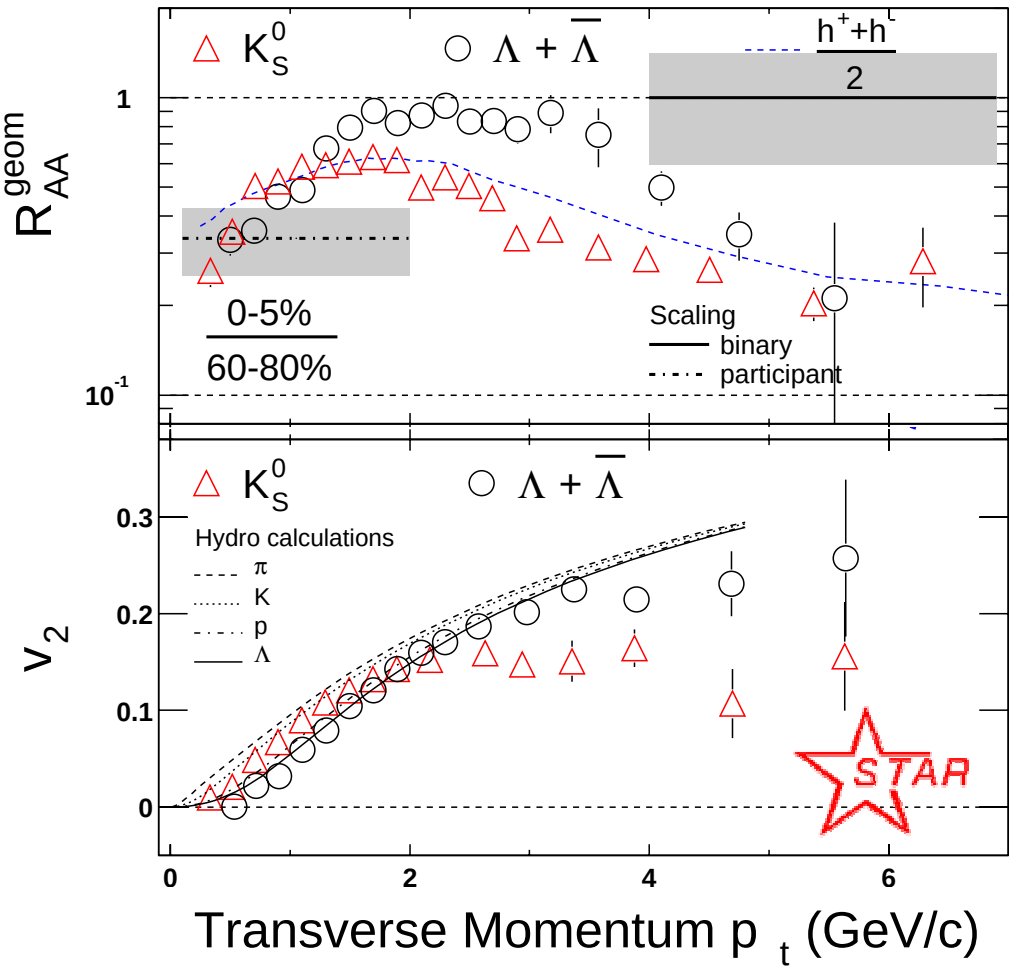
Explore further!

With PID - [firm]
Definitely on the right track…

hadronic ΔE?

- lots of theory arguments, but…
- $R_{AA}[\Lambda] > R_{AA}[K]$ $(\Delta E_\Lambda < \Delta E_K)$
  - related: "anomolous" B/M
- $v_2[\Lambda] > v_2[K]$ $(\Delta E_\Lambda > \Delta E_K)$
- hadron absorption

  → (almost) "too large" v_2

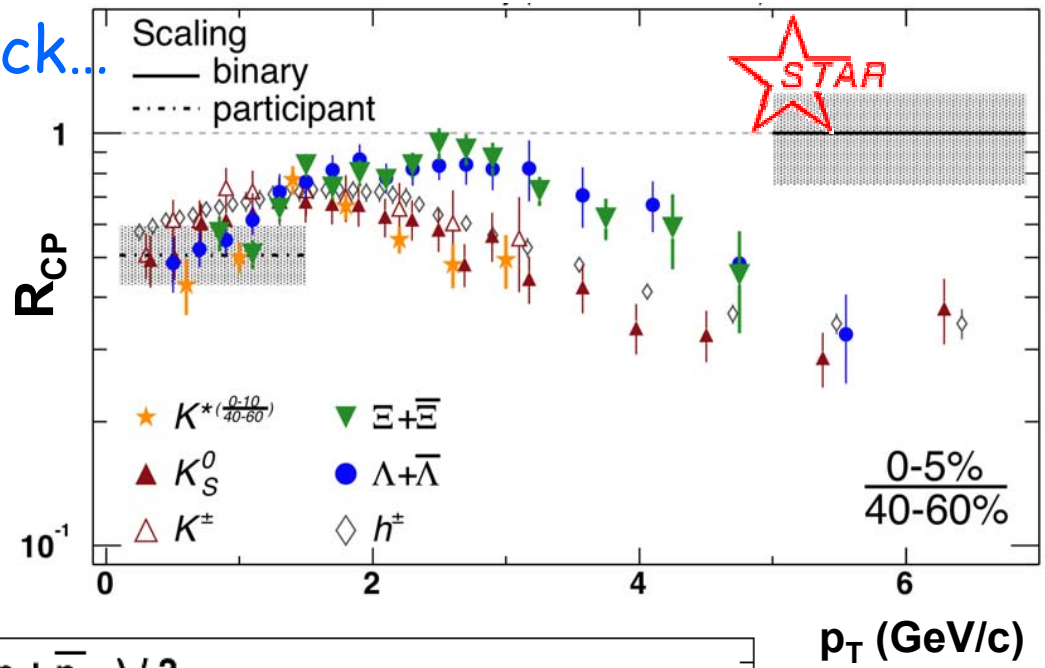


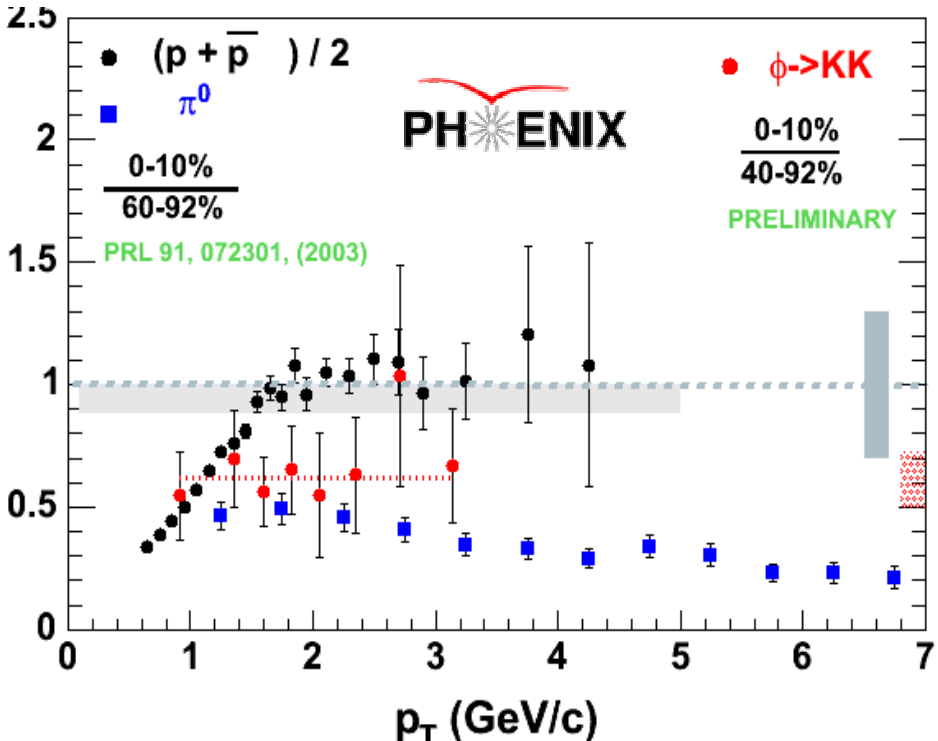
nucl-ex/0306007

With PID - [firm]
Definitely on the right track...

hadronic ΔE?
- no

soft (hydro) + hard (parton ΔE)?
- would imply *mass* systematics
- (better stats on ϕ impt)





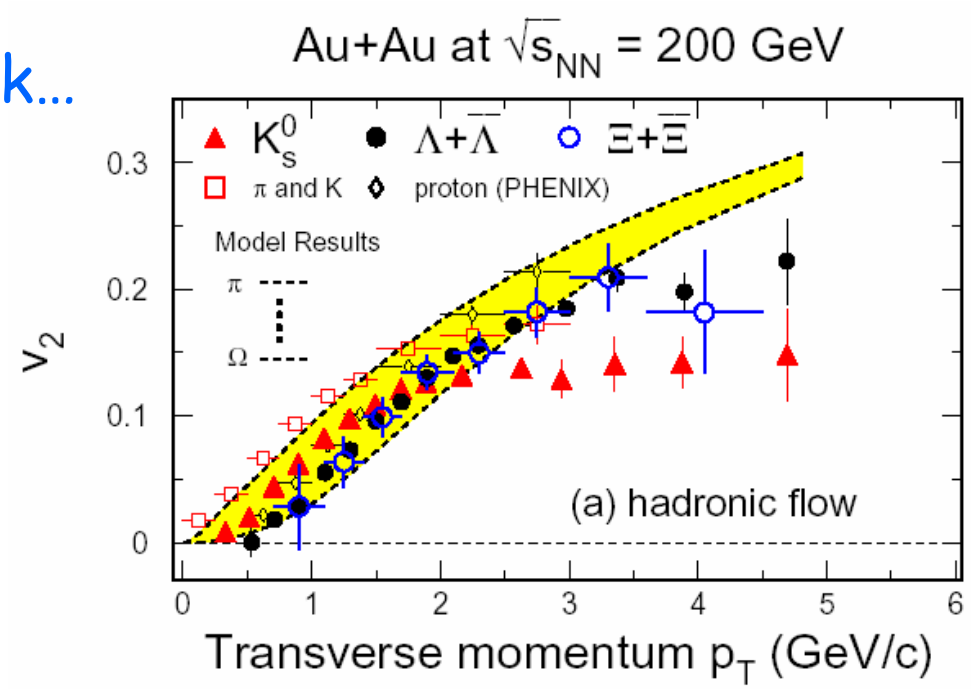
With PID - [firm]
Definitely on the right track…

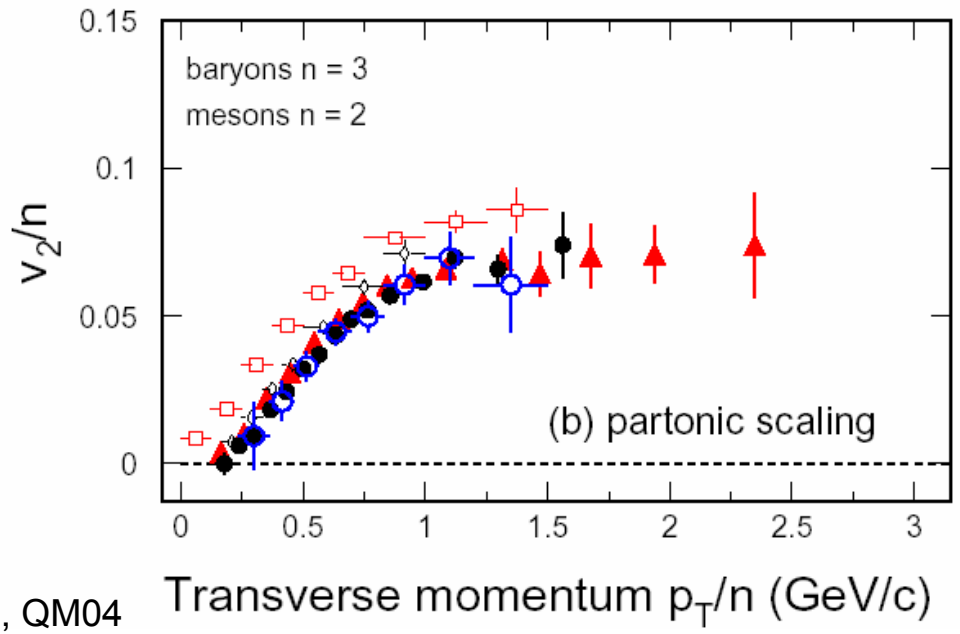
hadronic ΔE?
- no

soft (hydro) + hard (parton ΔE)?
- not only

In azimuth: v_2 "n scaling"
- partonic systematics
- ($v_2[\eta]$ will be nice)

→ very suggestive of coalescence scenario





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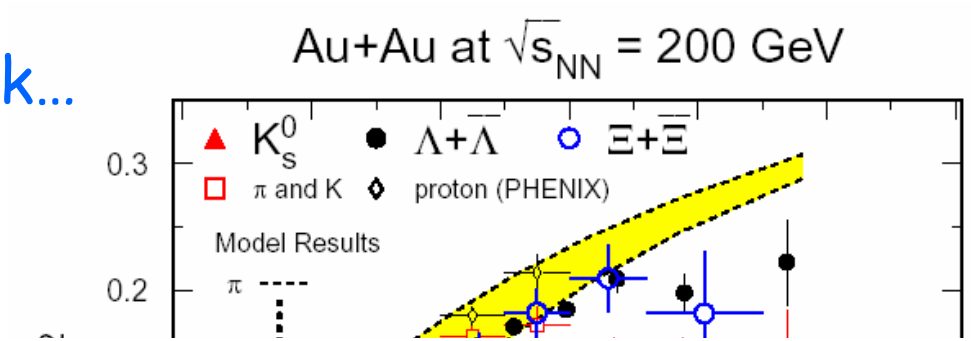
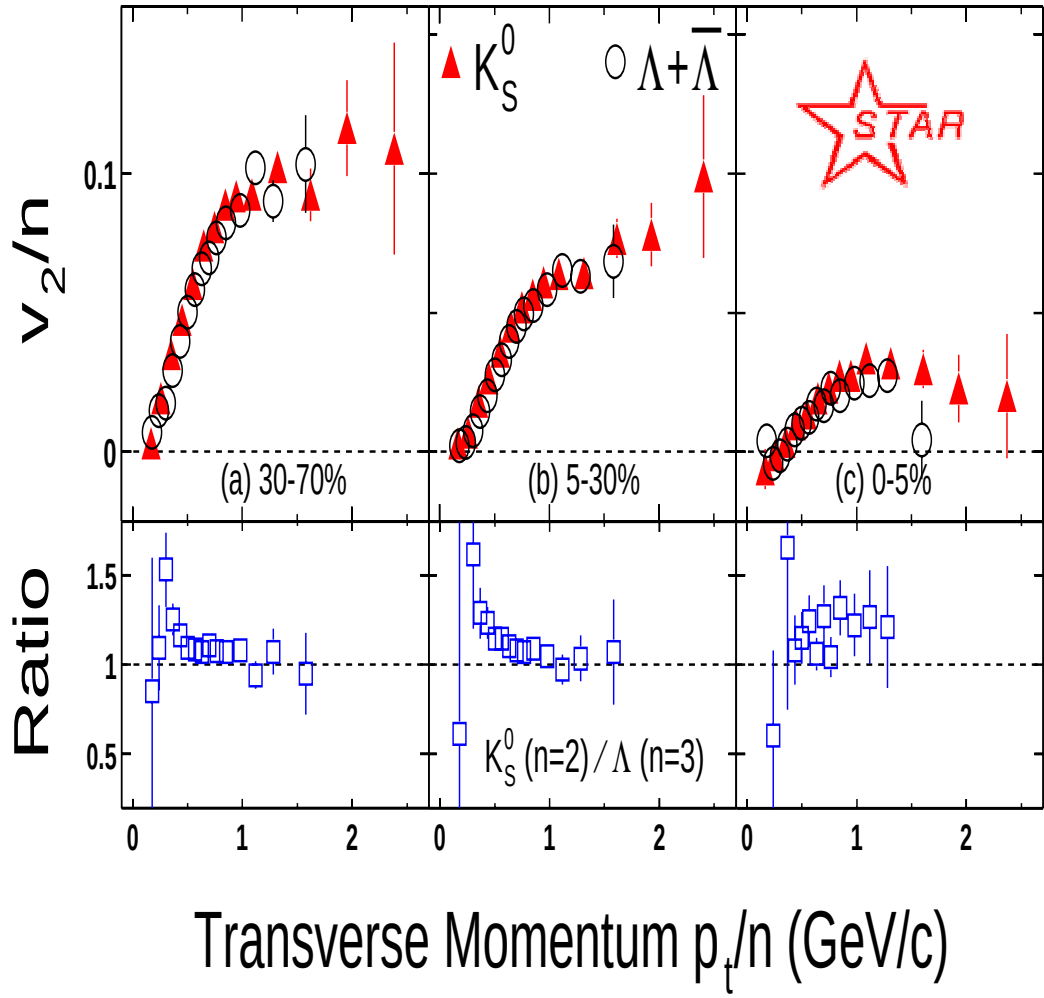
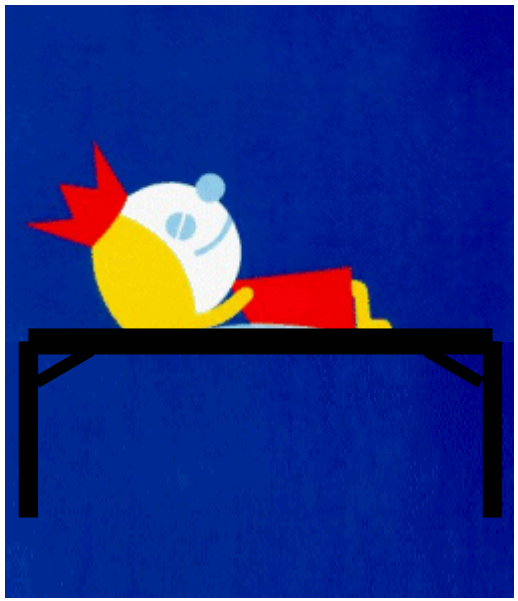
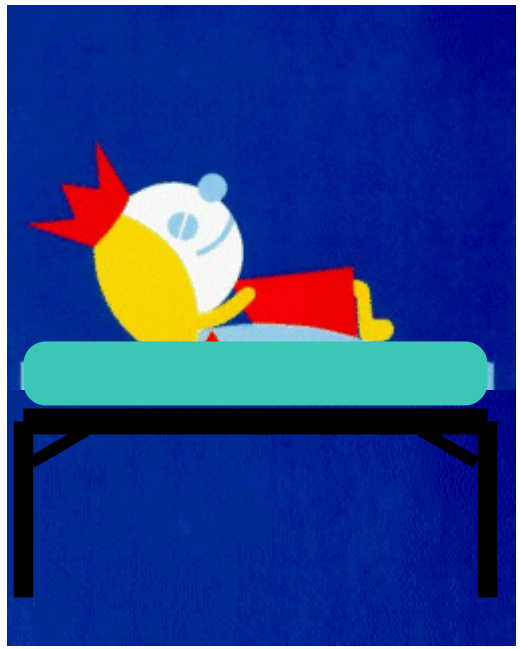
- push down in p_T?
  - "works" to p_T^q ~ 500 MeV ~$3T^q$









[hard] → [firm] → [soft]

Dense, partonic

Compelling!

Explore further!

hadronization of thermal (?) quarks

delve into the medium!

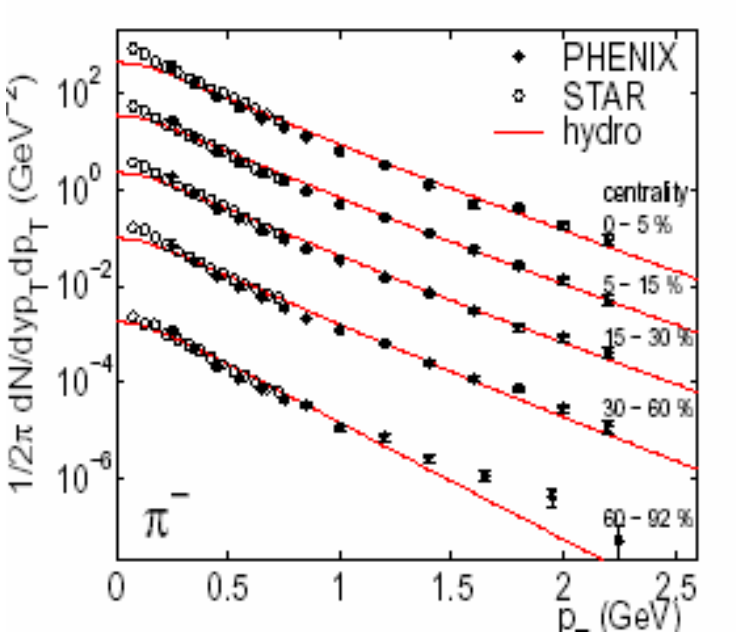
the medium…!

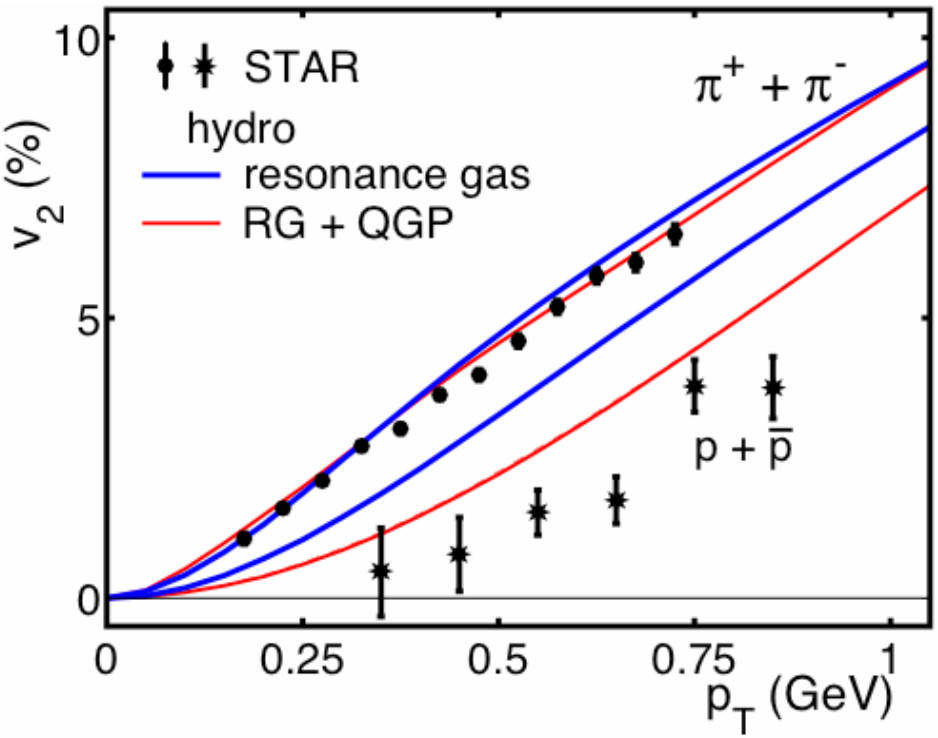
[soft] On the right track to…what?

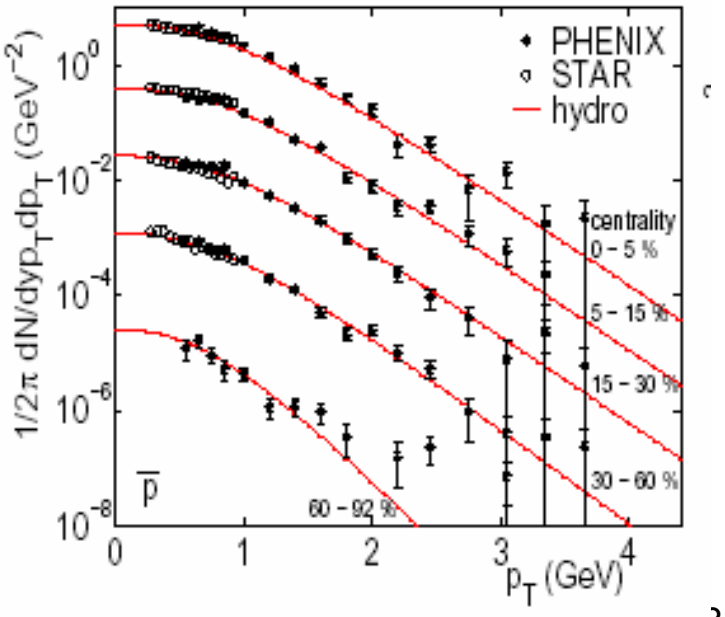
Dominant soft sector theme:

- soft sector is flow-dominated ["fact"]
  - $dN(m)/p_T$, $v_2(p_T,m)$, HBT, non-id…
- hydro – works well in p-sector
  - probably early thermalization claim is correct [opinion]

Kolb and U. Heinz (2002)







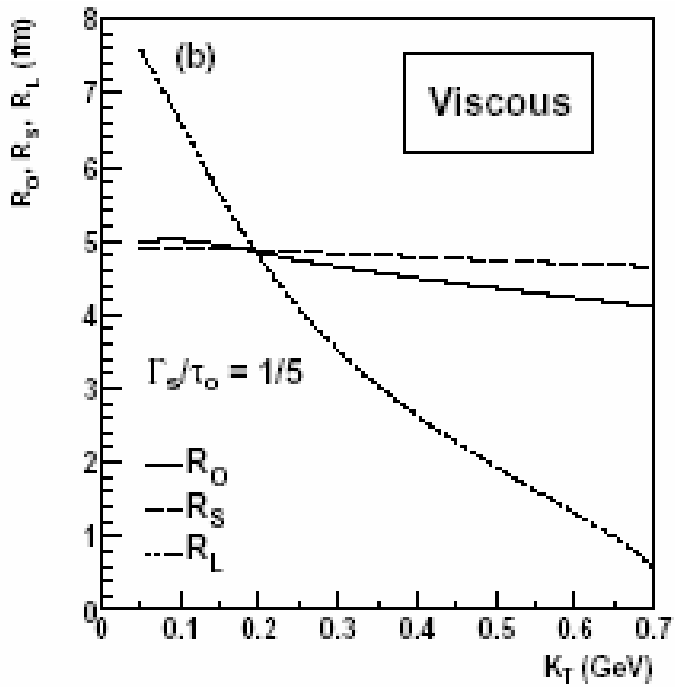
[soft] On the right track to…what?

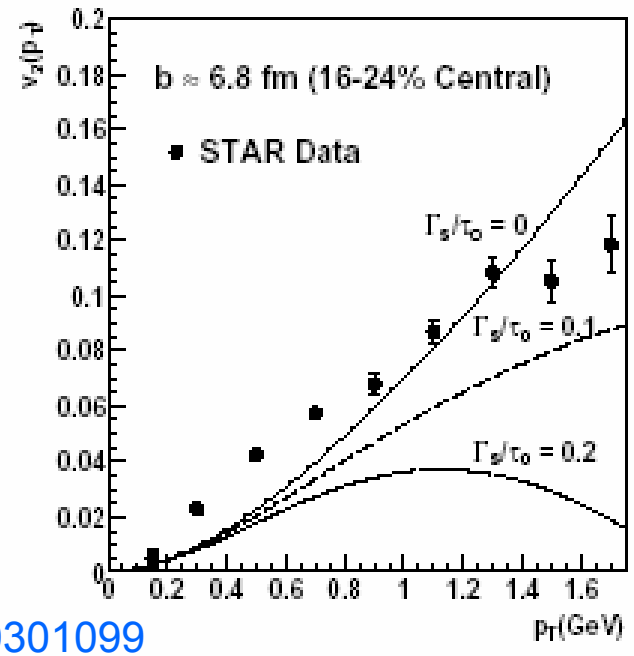
Dominant soft sector theme:

- hydro-like flow describes p-sector

Bugaboo: space-time (HBT, etc.)

- very difficult to describe simultaneously p- and x-space in “real” models





D. Teaney, nucl-th/0301099

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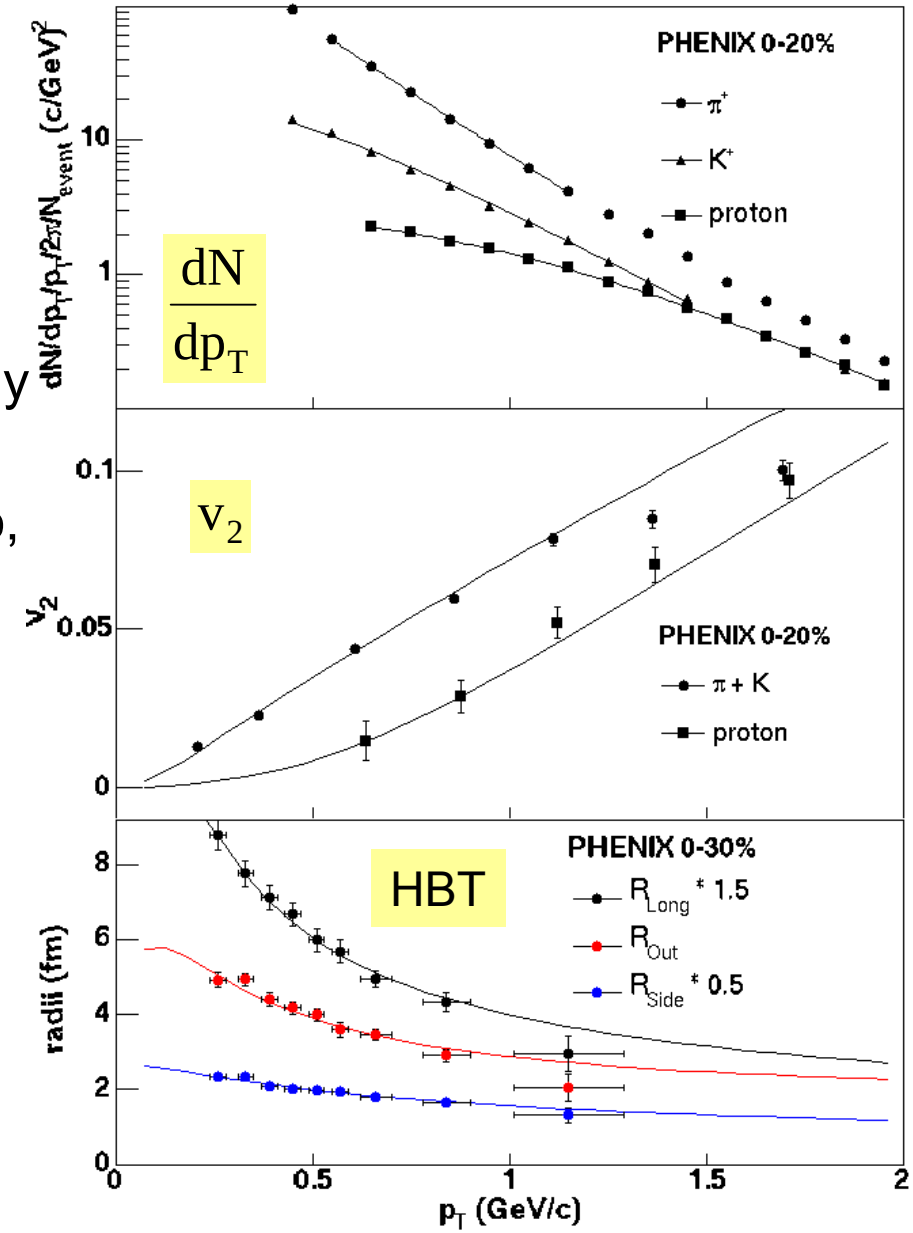
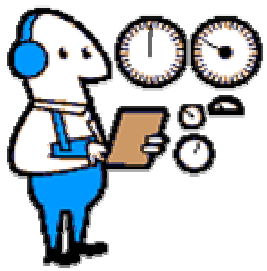
- to make progress: *parameterize* hydro, twiddle knobs of underlying physics

“BlastWave” fits





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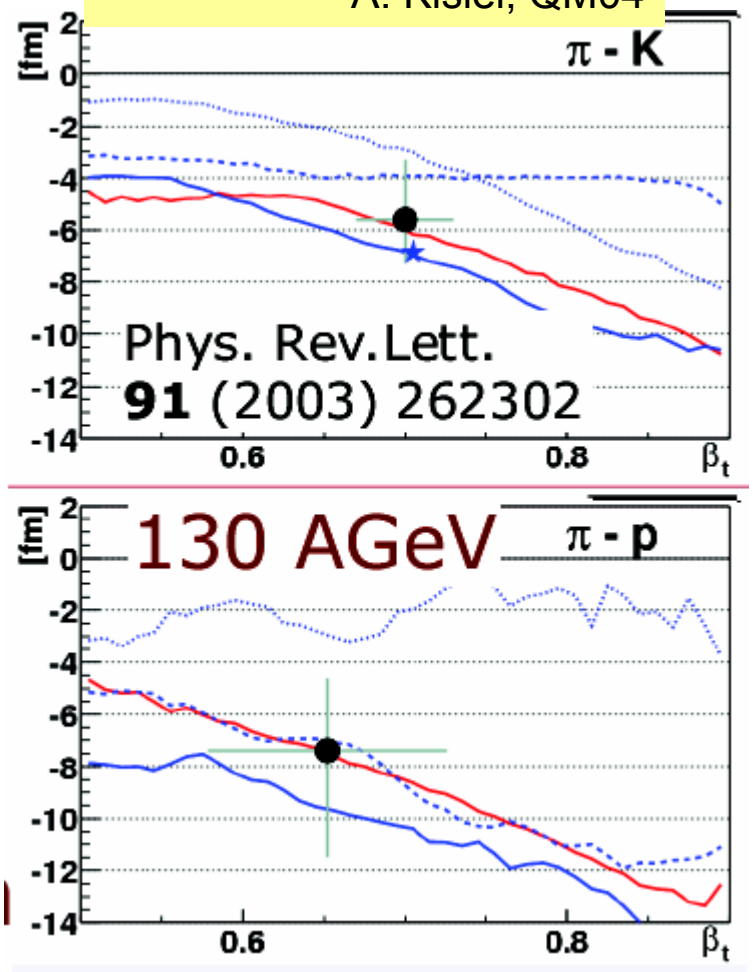
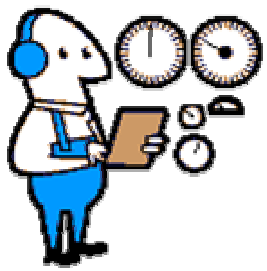
Shift in emission points

A. Kisiel, QM04





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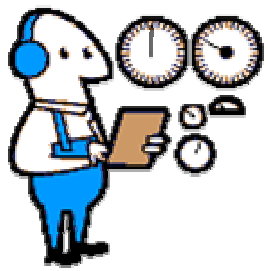
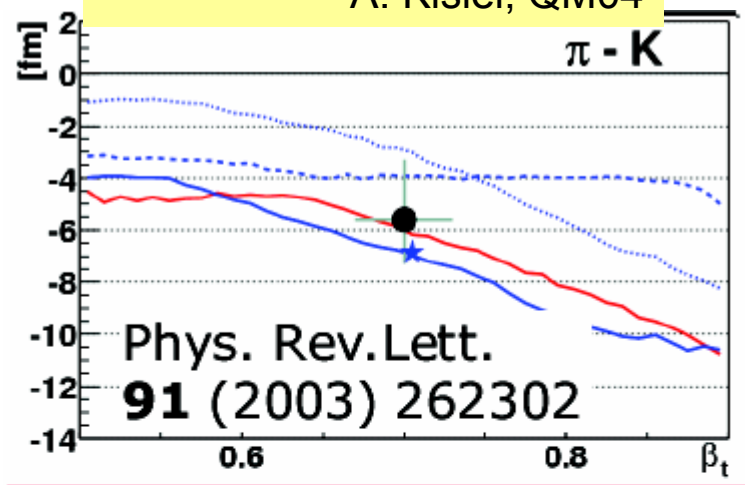
Bugaboo: space-time (HBT, etc.)

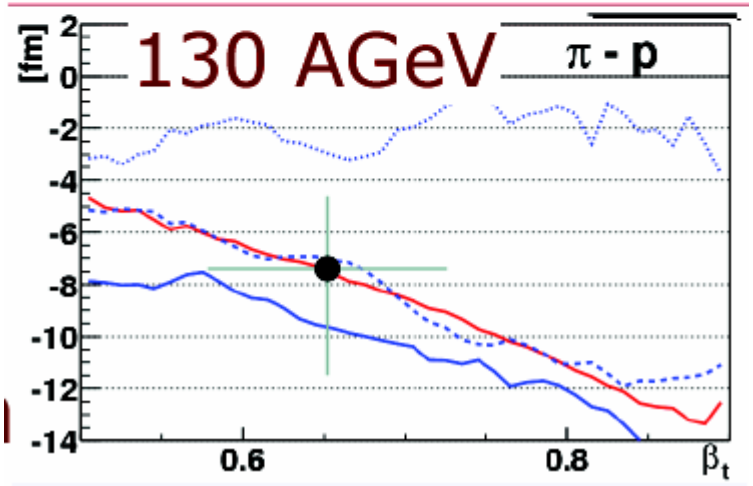
- very difficult to describe simultaneously p- and x-space in "real" models
- to make progress: *parameterize* hydro, twiddle knobs of underlying physics
  - short timescales!



Shift in emission points

A. Kisiel, QM04





[soft] On the right track to…what?

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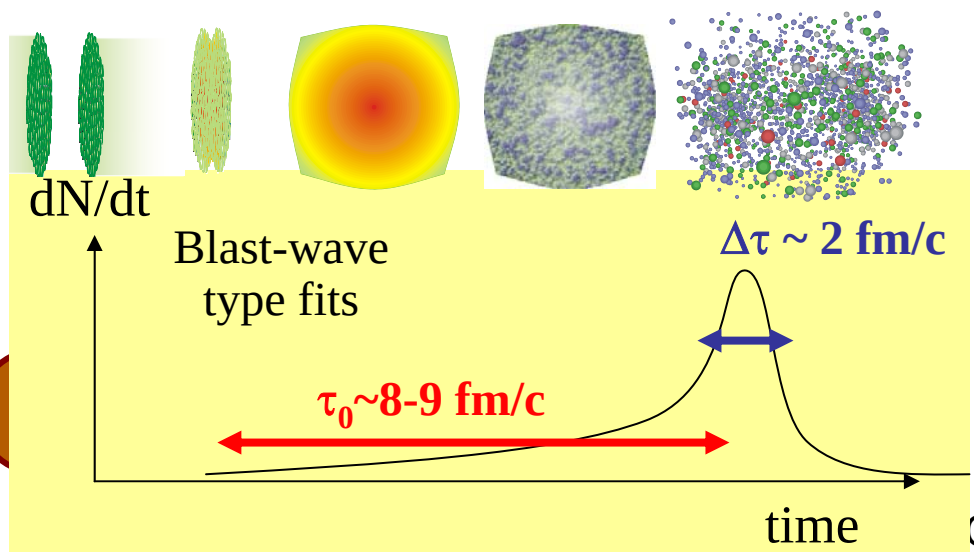
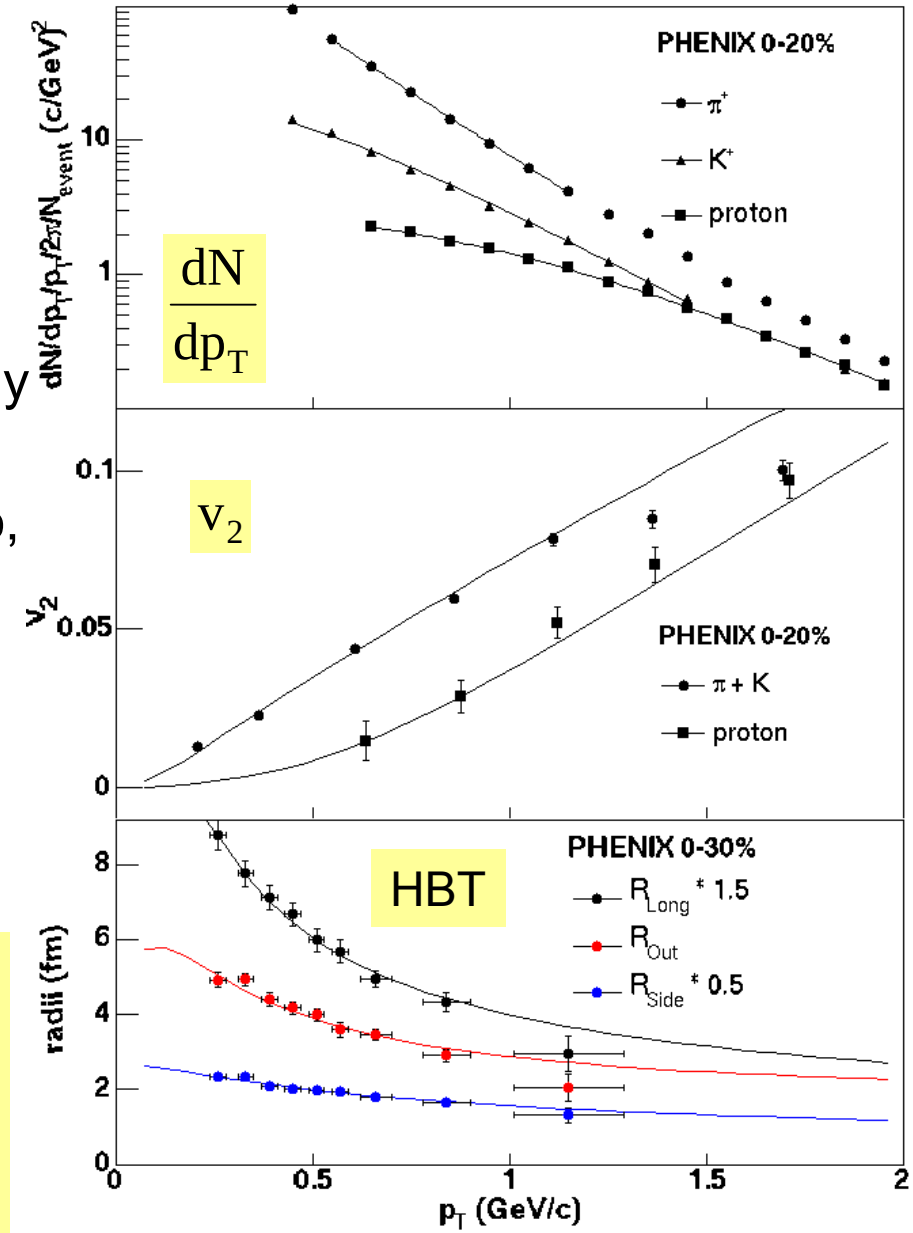


"BlastWave" fits



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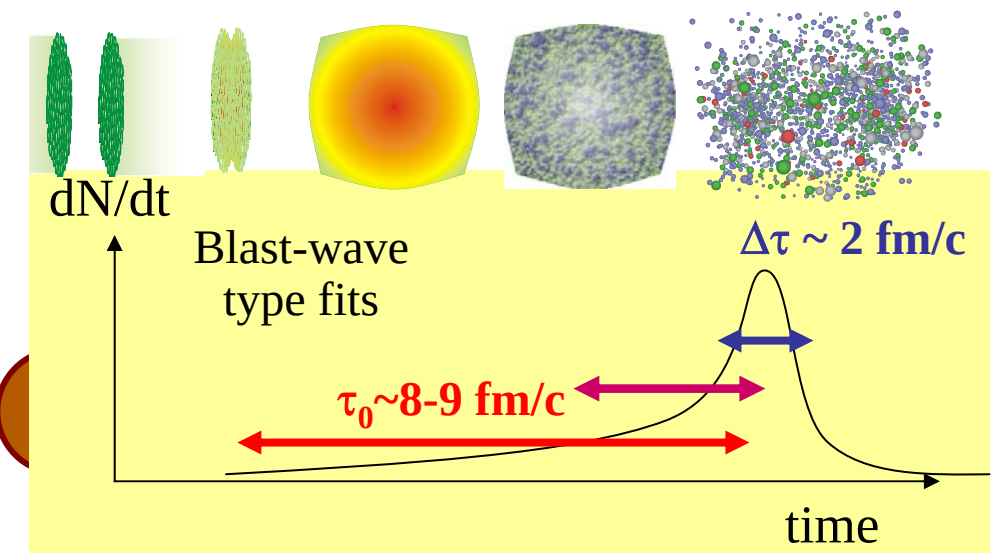
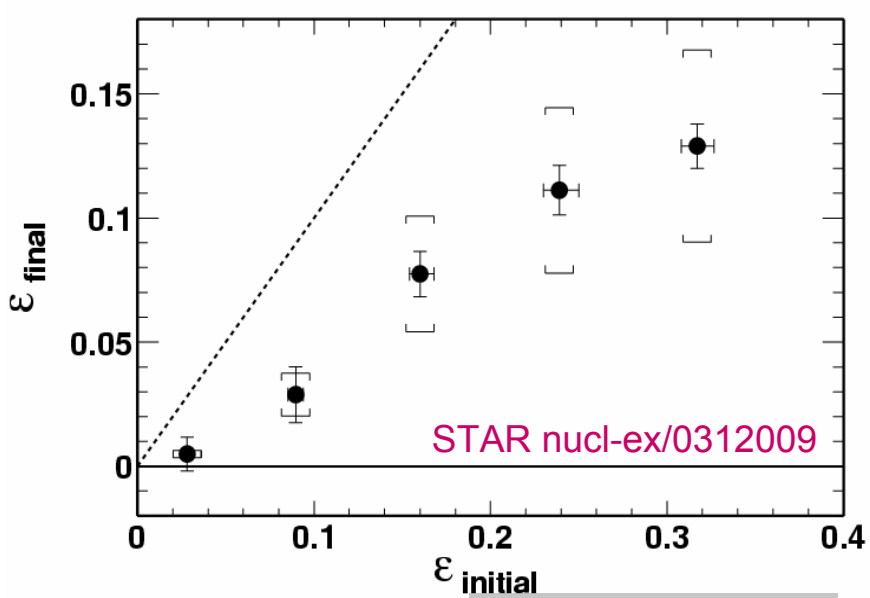
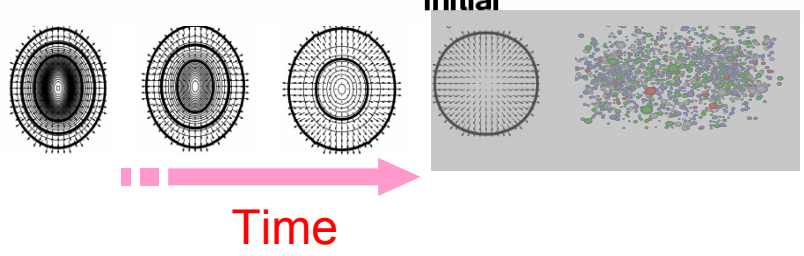


More hints of short timescales

- azimuthally-sensitive HBT
  - source shape!!





- t_K-t_{Ch} ≈ 5 fm/c (entropy, K*/K)

O. Barannikova, P. Fachini

[soft] On the right track to…what?

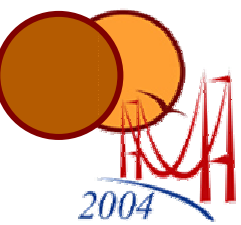
Dominant soft sector theme:

- hydro-like flow describes p-sector

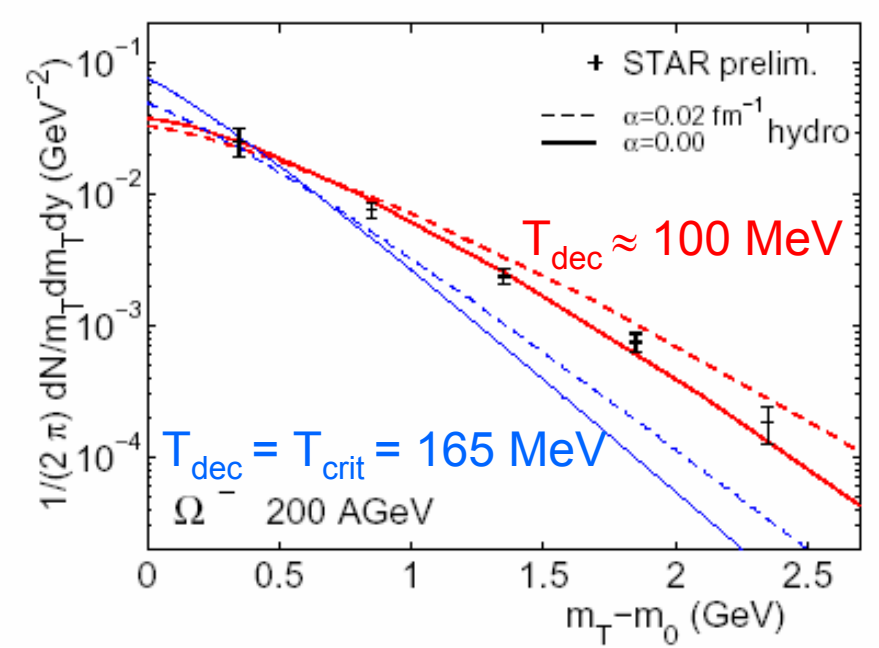
Bugaboo: space-time (HBT, etc.)

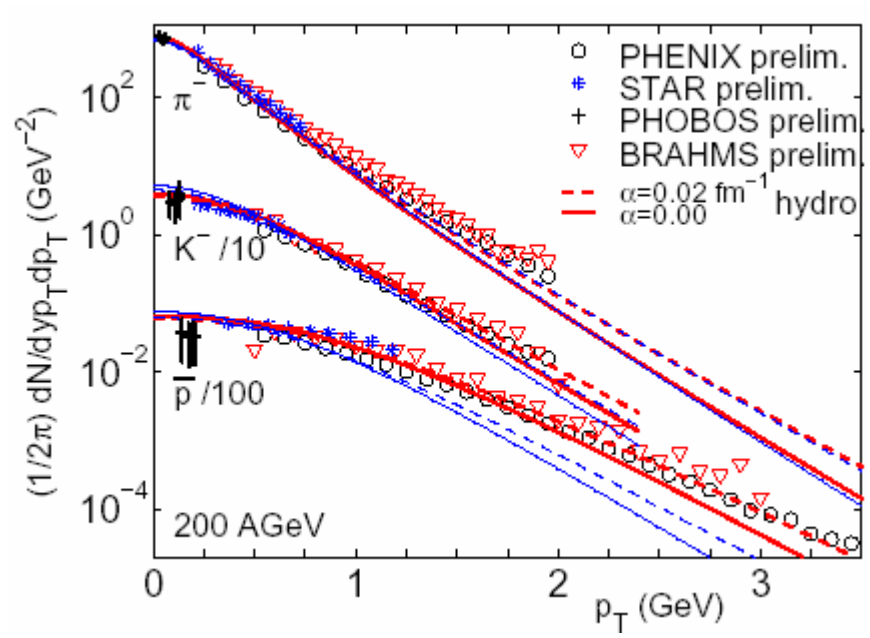
- (admittedly) *simple* estimates indicate shorter timescales than naturally turn up in models
- IMHO, these simple models contain a kernel of truth, and should not be discarded

- certainly, there is no indication for *long* timescales (originally expected / hoped for) in the data



side comment:
BlastWave models are useful, but do not abuse



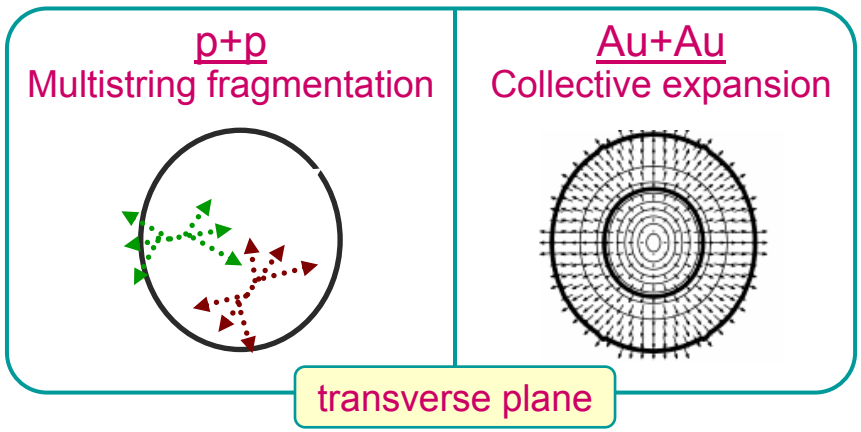


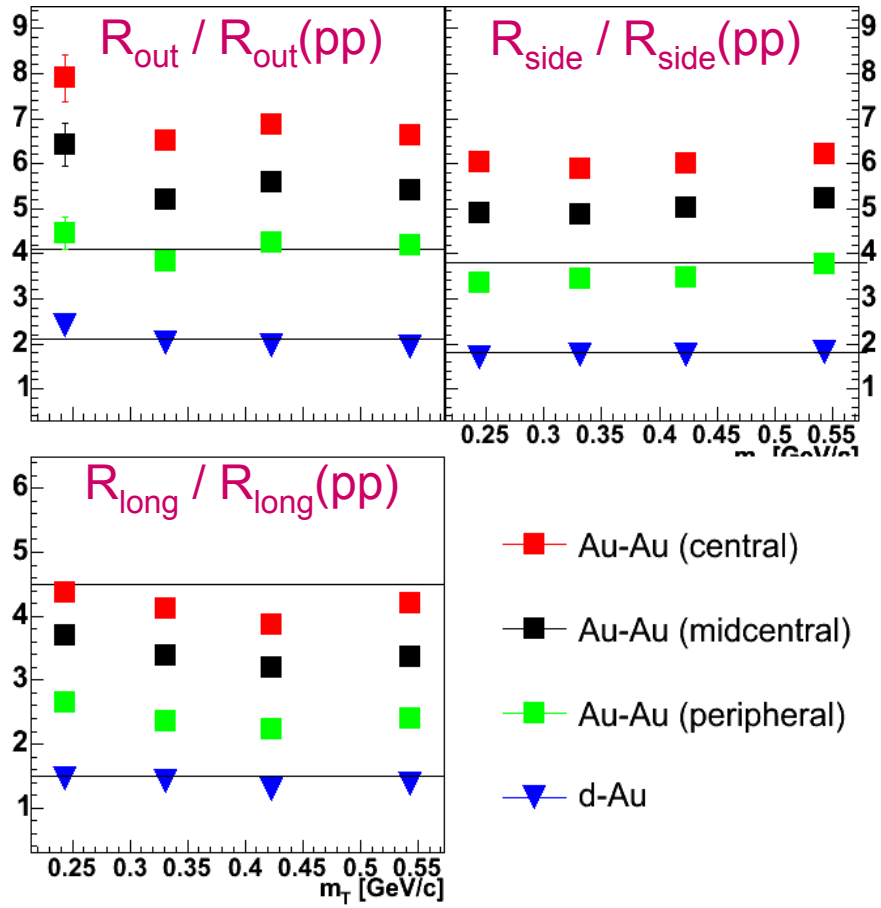
- hydro seems to “work” for multistrange particles as for the rest
- FO hypersurface matters especially for heavy particles [Heinz&Kolb]
- [opinion]: if (!) “real” model (hydro) works for Ξ, Ω, why trust instead a parameterization?
  - may be early FO, but BW fits are not evidence for it

Kolb & Rapp, PRC67 044903 (2003)

soft sector- do we have a clean reference?

- HBT R(k_T) in AA and pp *presumably* (?) due to different physics
- Flat AA/pp ratio ?!?
- experimentalists hate “coincidences” ☹





T. Gutierrez for STAR Coll, poster

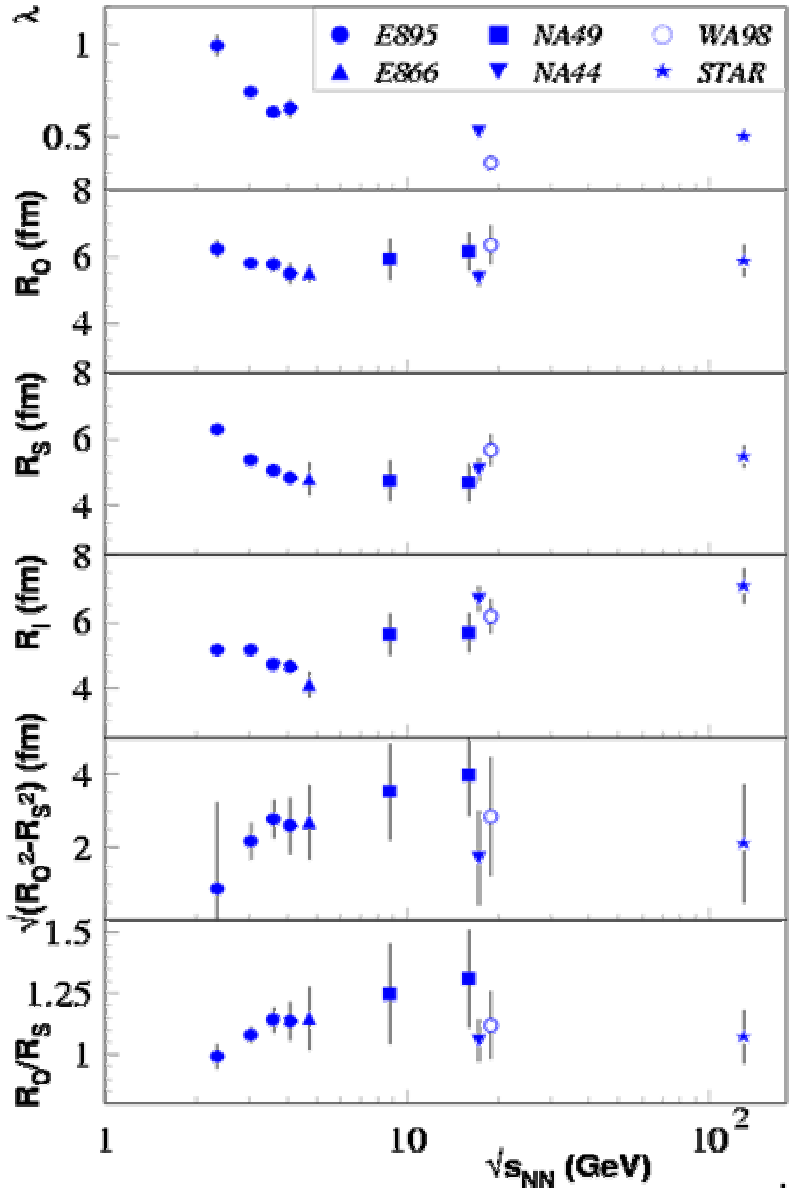
soft sector- do we have a clean reference?

HBT and soft-sector variables in general:

- relatively featureless terrain *
- usually "explainable"/describable by unremarkable physics (e.g. λ_{FO}= 1 fm)

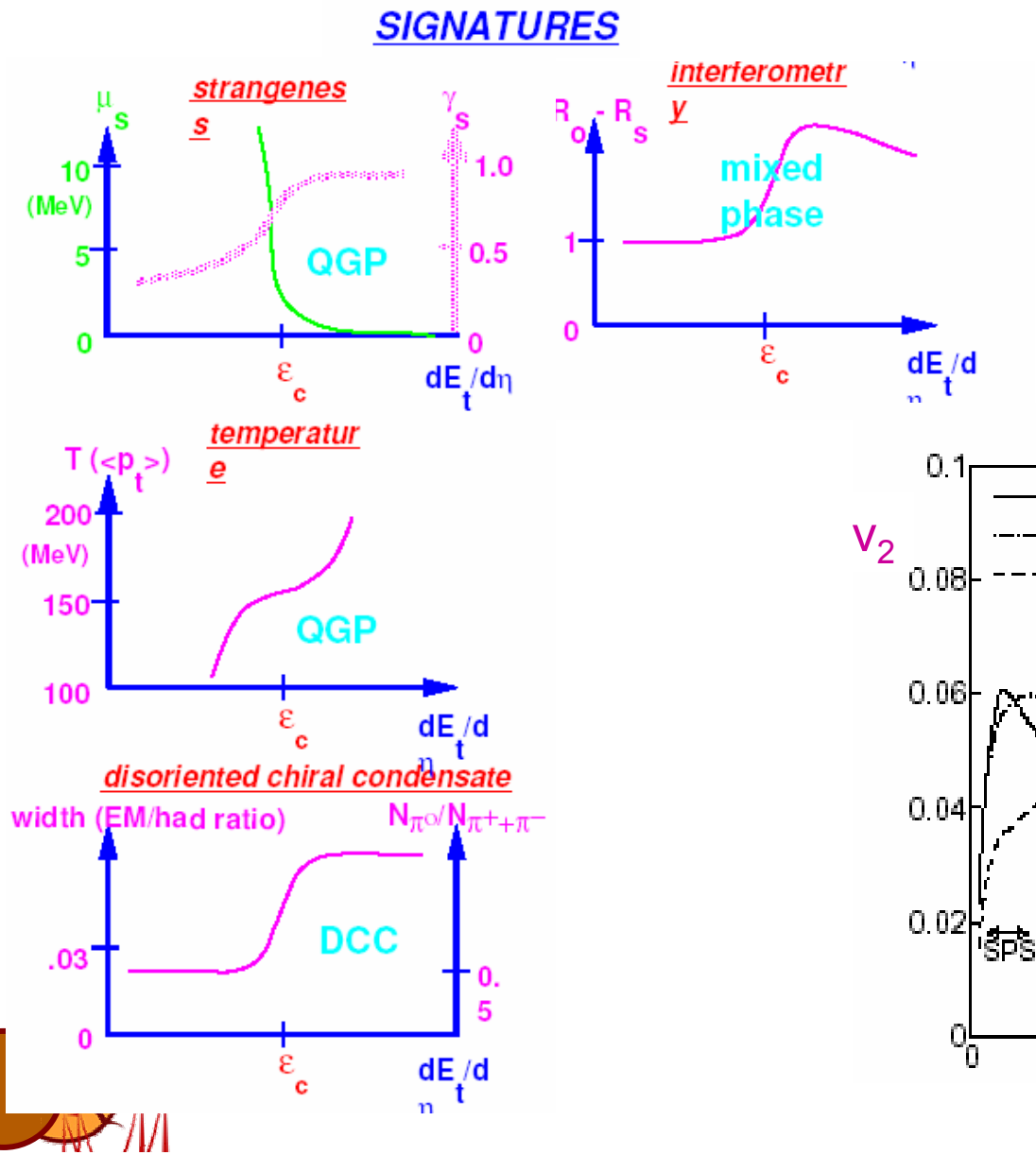
- similar for flow, strangeness, dN/dy

- often similar problems at lower √s
  - where to hang one's hat?

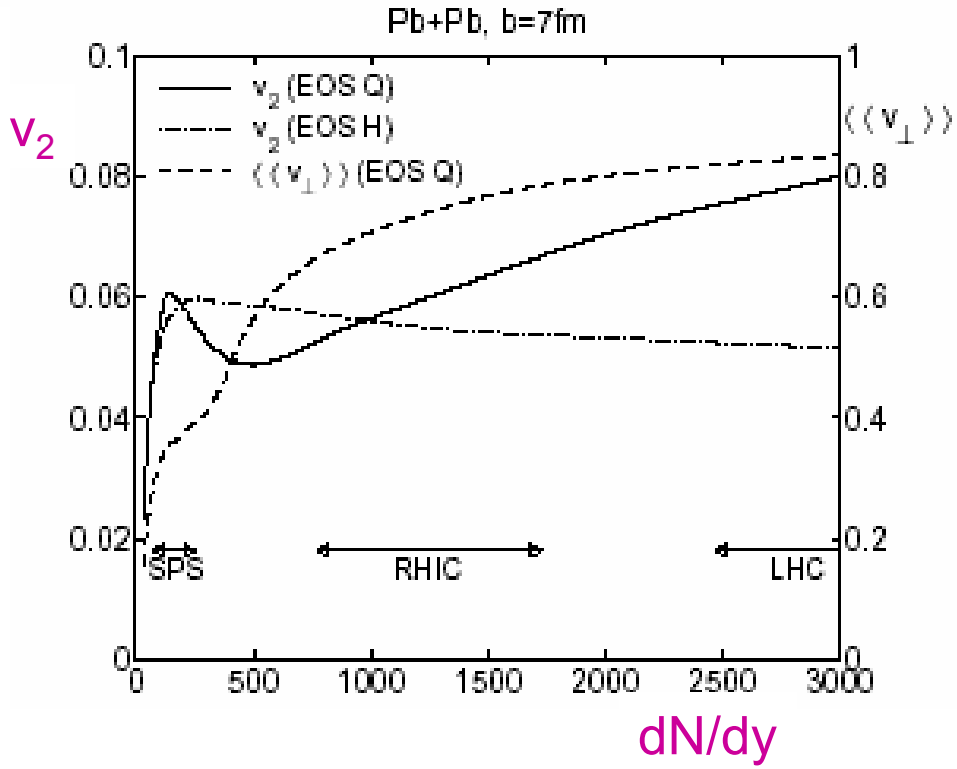


* but: horns et al.

soft-sector dreams…



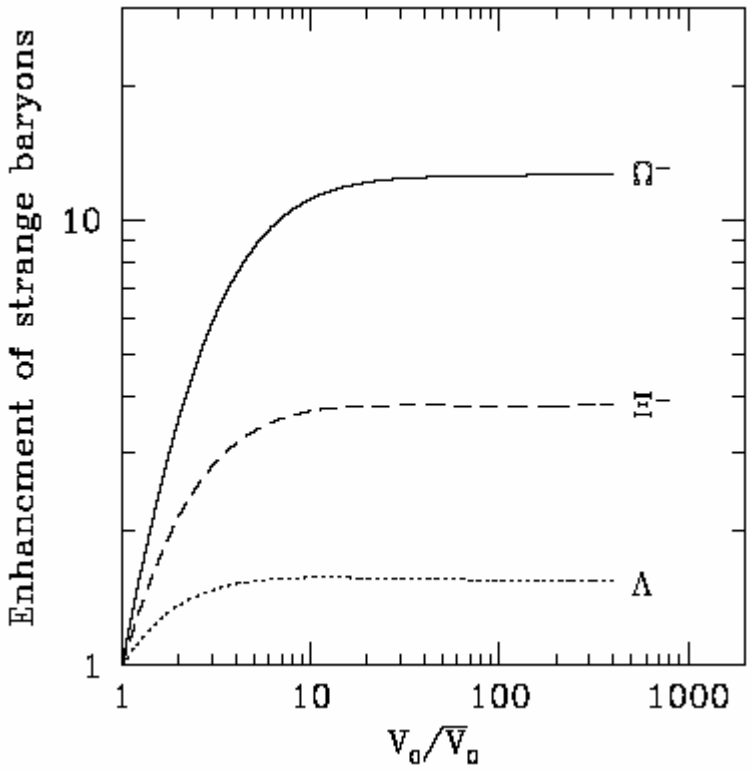
"we were naïve"

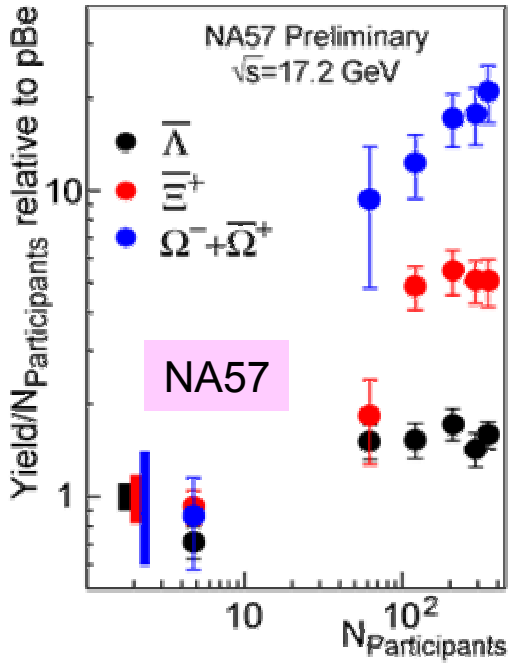


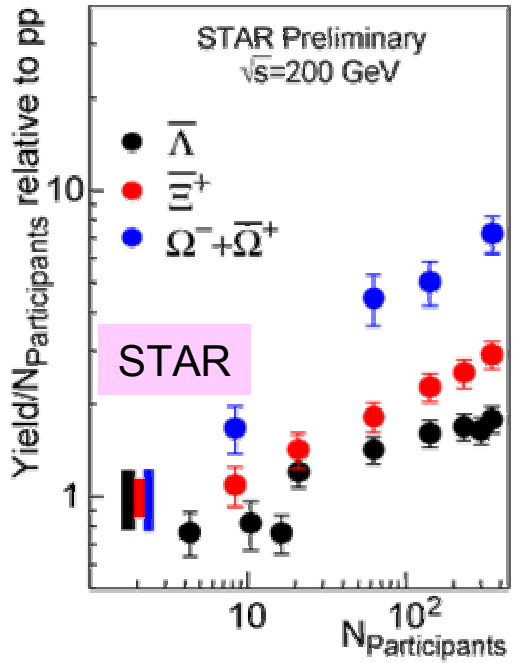
Harris & Mueller AnnRevNuclPartSci '96

Kolb, Sollfrank, Heinz, PRC62 054909 (2000)

Strangeness thermalization/equilibration?



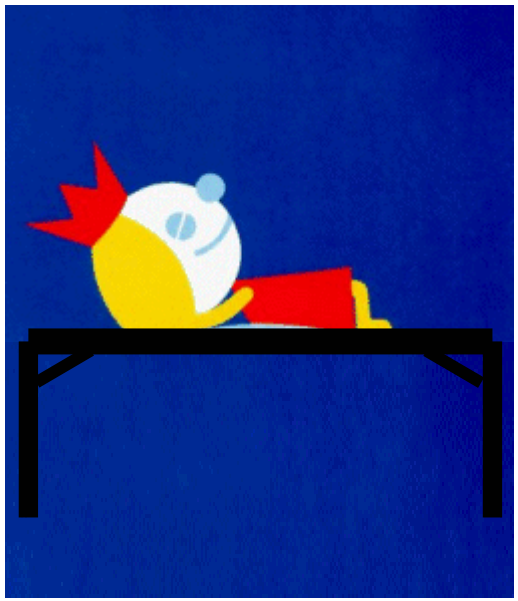


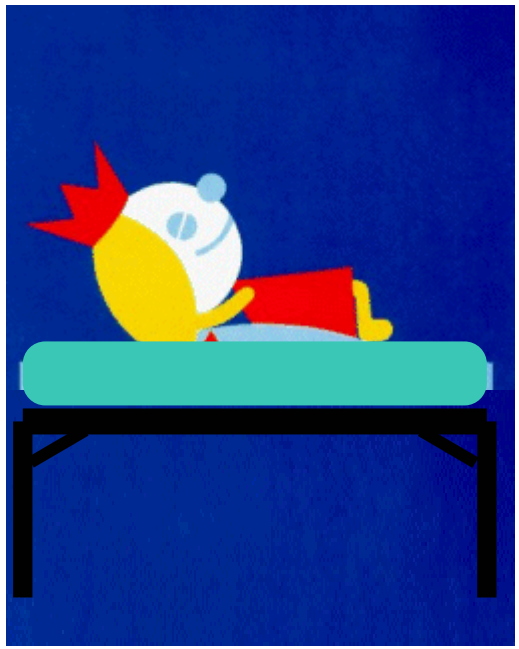


Hamieh, Redlich, Tounsi
PLB486 61 (2000)

1. it saturates, but just at the very end
2. it equilibrates, but in addition, we have contributions from hard processes?

Do we understand our reference systematics (centrality)?





[hard] → [firm] → [soft]

Dense, partonic

Compelling!

Explore further!

hadronization of thermal (?) quarks

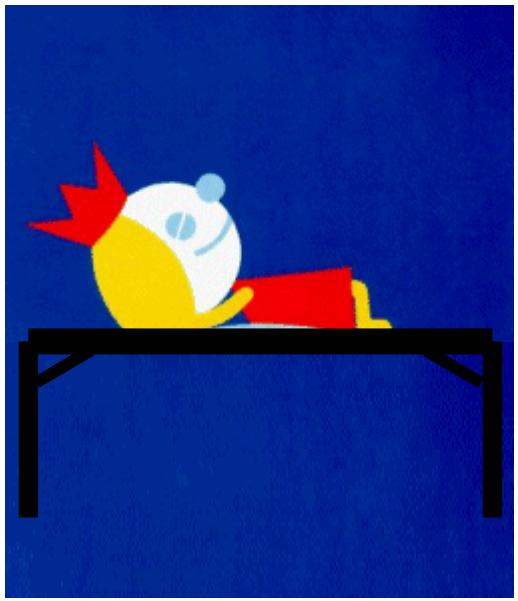
delve into the medium!

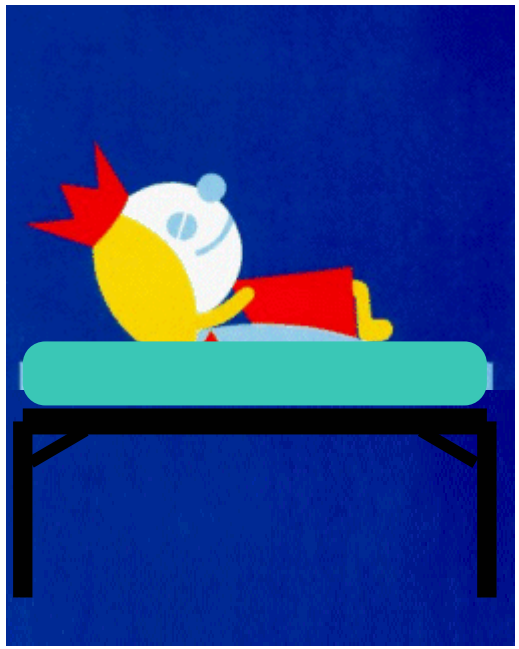
high ε

high pressure

short τ's [IMHO]

no clear indication of something really "new"





cup half full:

- *beautiful measurements*
- will be exciting to systematically learn why/how this most important sector hides its secrets

[hard] → [firm] → [soft]

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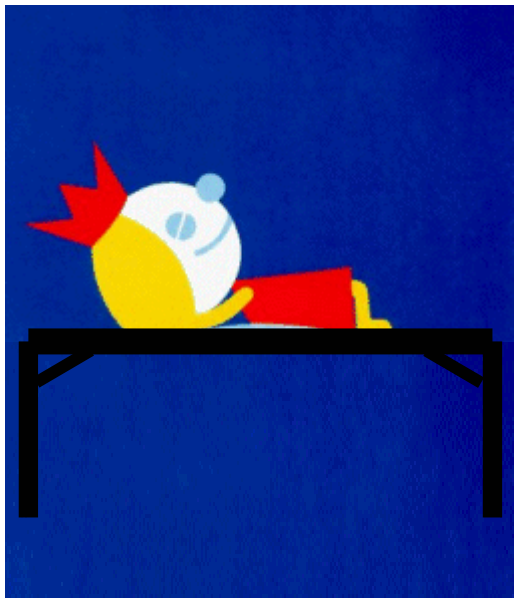

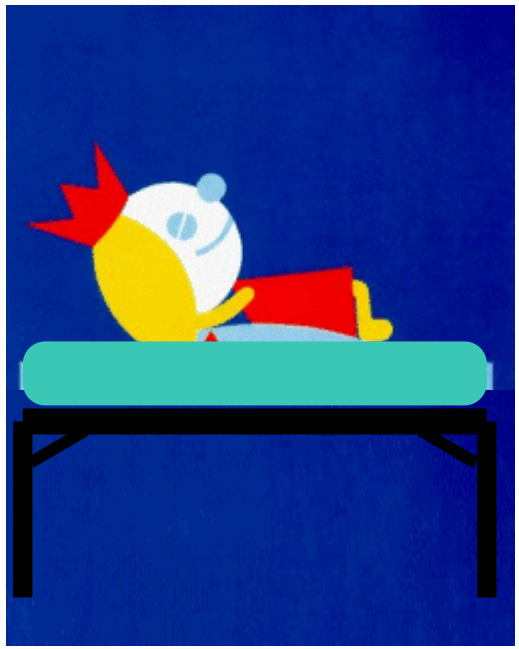

[hard] → [firm] →

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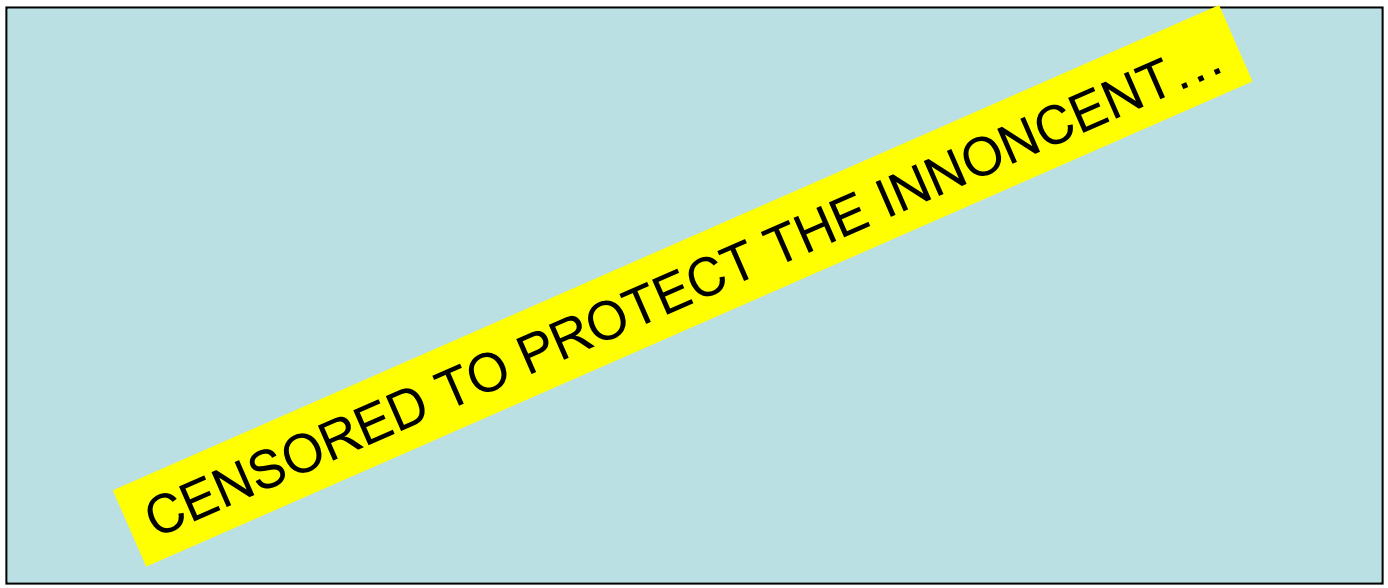
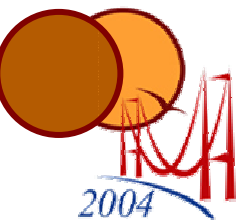
Sorry I couldn't mention *your* favourite observations…

Special thanks to…

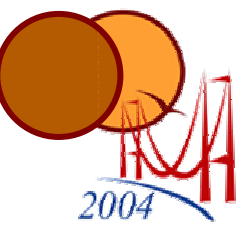


David Scott 1979

"In the development of RHI studies, a form of intellectual Ludditism appears to be prevalent. There is a tendency to assume that no significant progress is being made, when in fact intriguing and unexplainable phenomena exist, the ultimate understanding of which is likely only to come from sustained research"

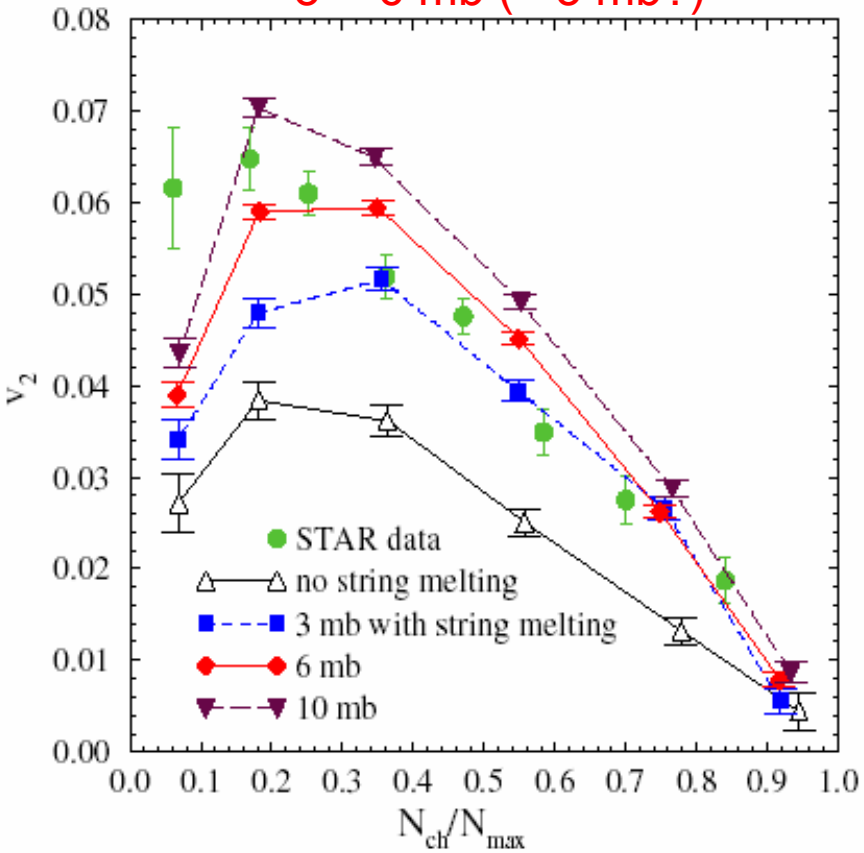


The End

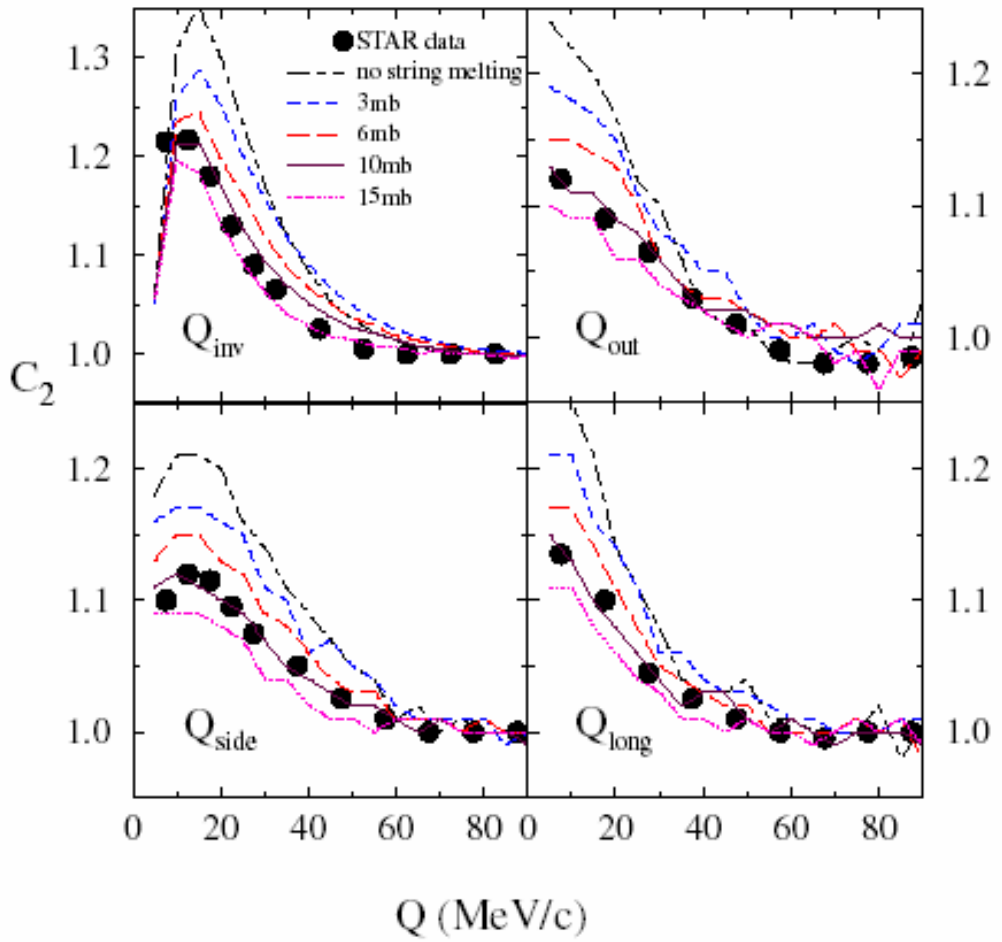


v2 and HBT from AMPT?

σ < 6 mb (~ 3 mb?)



σ ~ 10 mb



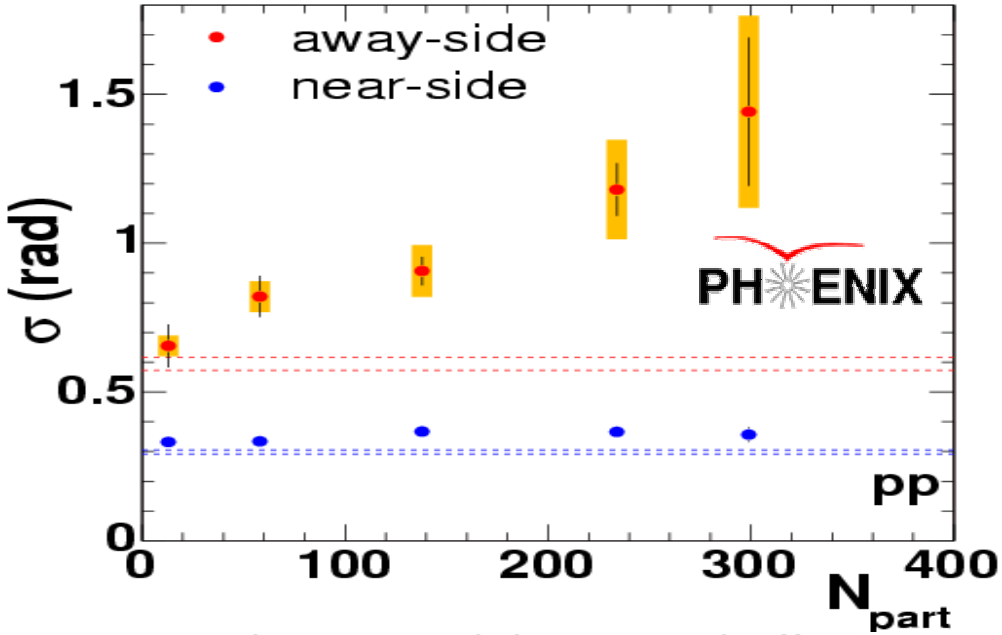
[hard] On the right track…

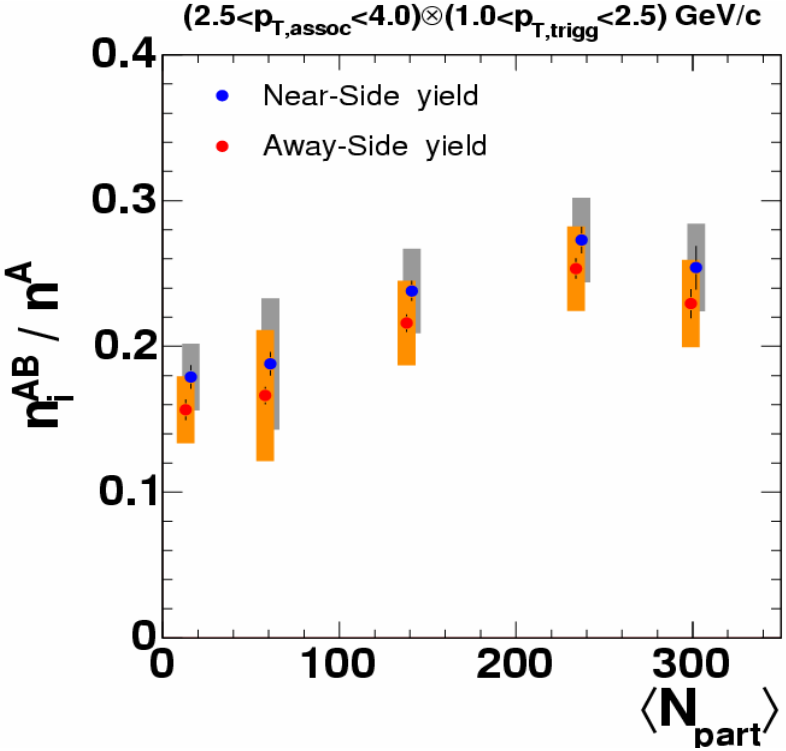
Singles spectra & $\Delta\phi$ distributions

- final state medium-induced jet "quenching"

important: lower $p_{T,assoc}$

- jets poking through?





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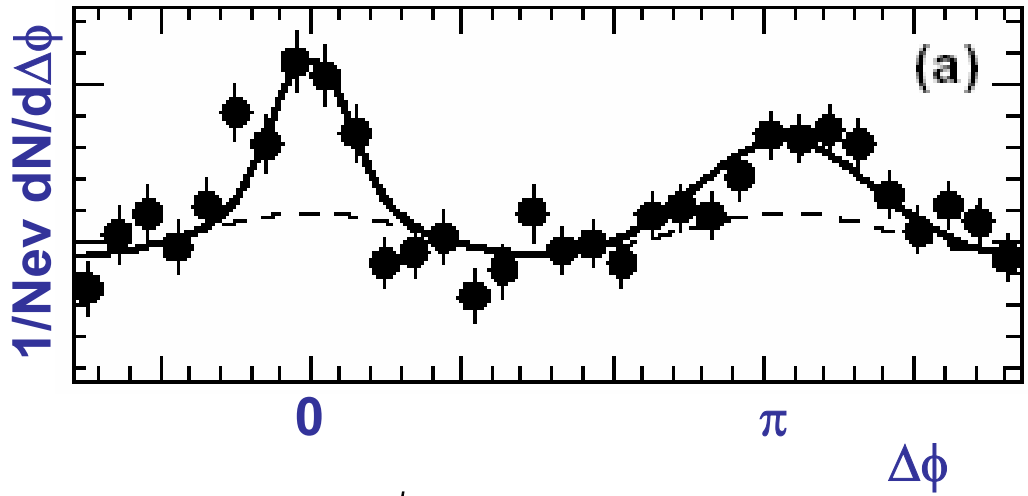
Singles spectra & $\Delta\phi$ distributions

- final state medium-induced jet "quenching"

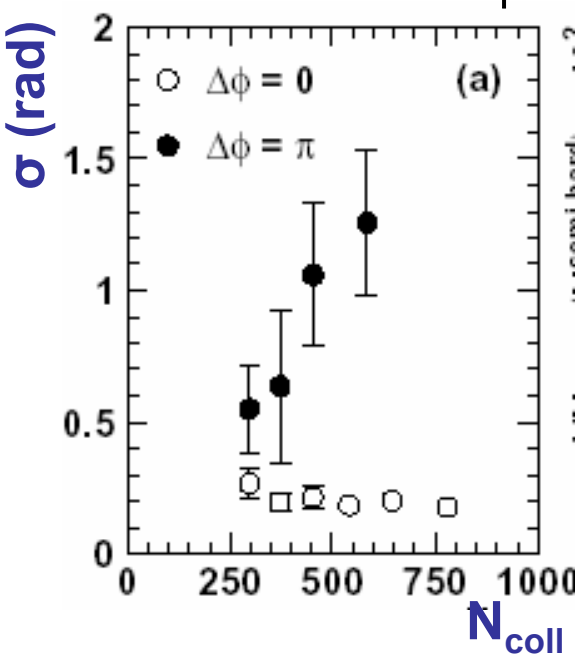
important: lower $p_{T,assoc}$

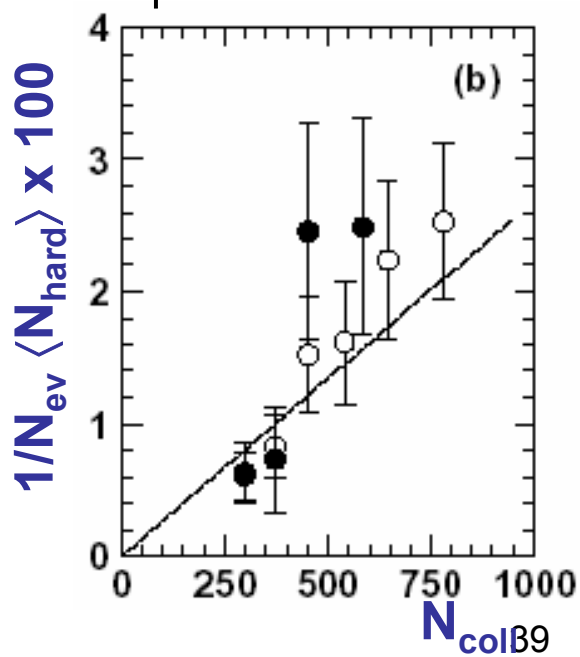
- jets poking through?
- low $\sqrt{s}$ reference: broadening; no suppression
  - jets ?
  - new effect at RHIC



Pb+Pb $\sqrt{s}$=18 GeV

○ Δφ= 0 ● Δφ=π



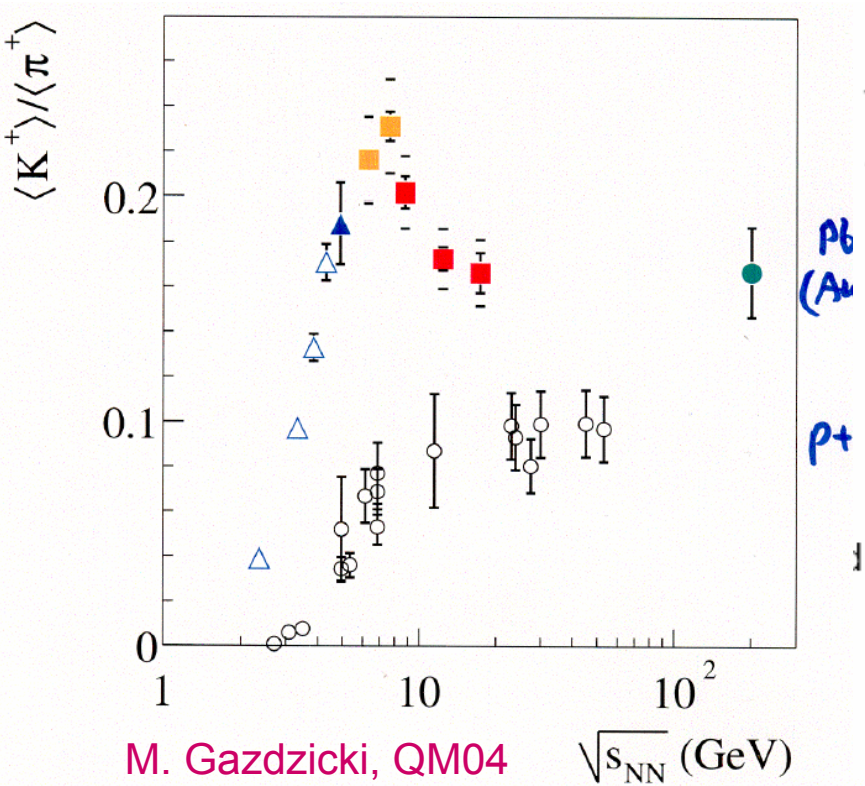


CERES @ SPS nucl-ex/0303014

horns, steps, kinks

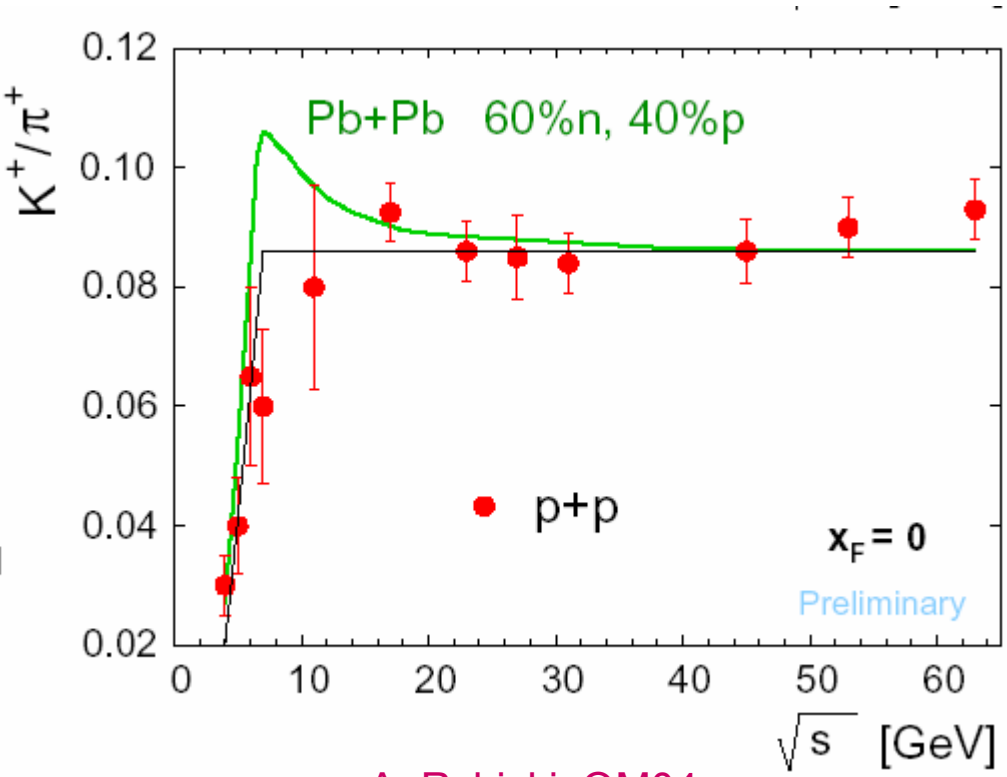
- How could an experimentalist *not* be intrigued by a sharp horn!?
- troubling coincidence of microhorn
- IMHO, I don't have a well-formed opinion

A+A – The Matterhorn



M. Gazdzicki, QM04

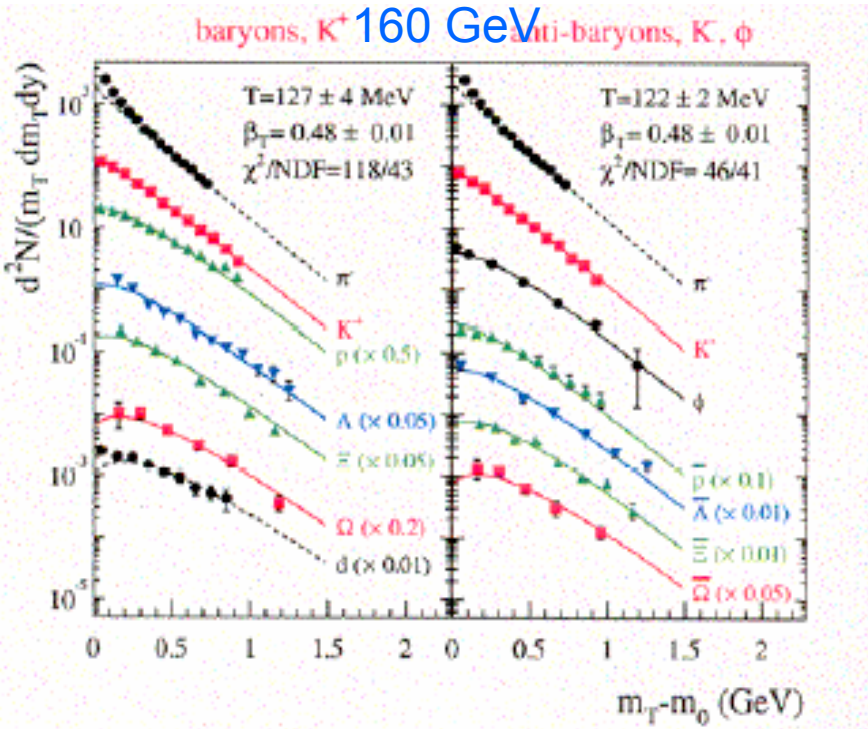
isospin weighted N+N ≠ p+p : the microhorn

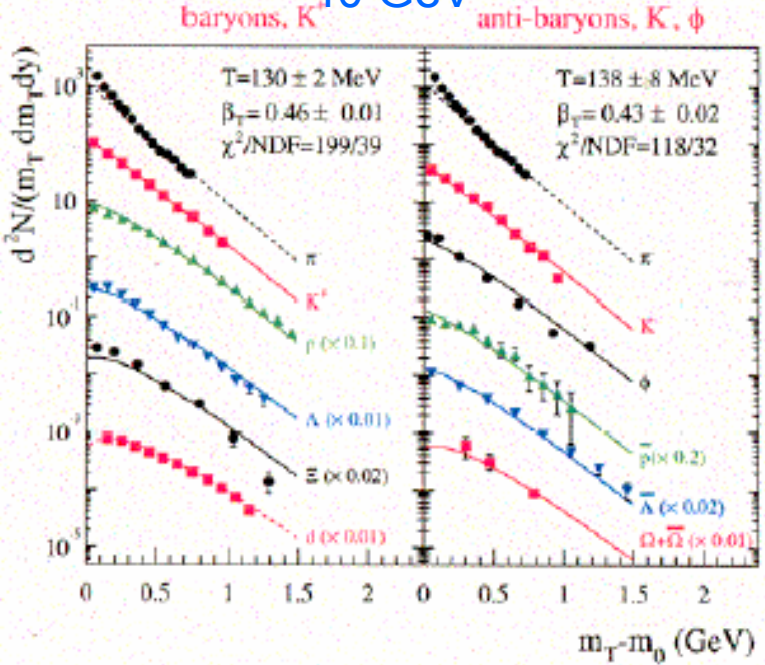


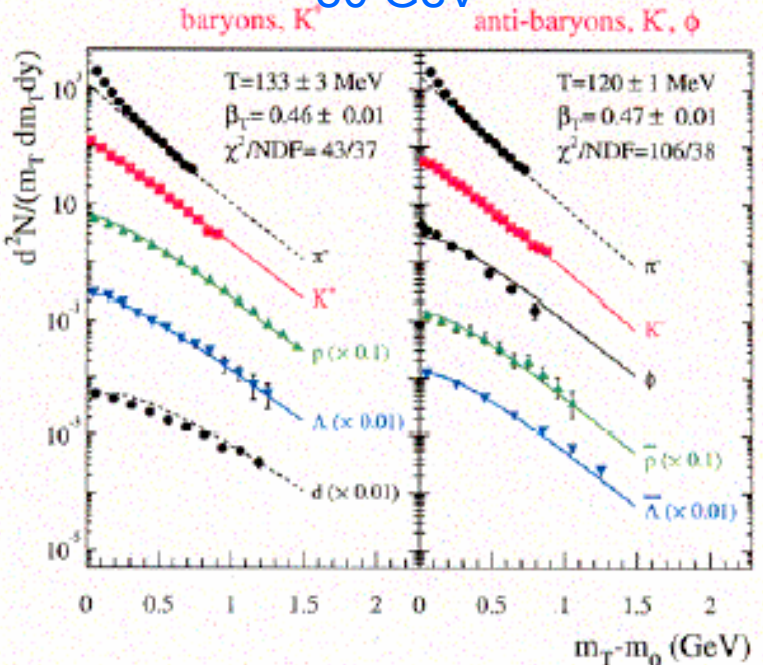
A. Rybicki, QM04

horns, steps, kinks

- Unclear to me why exponential fit just to K^+ is appropriate
- OTOH, claim is ~2 MeV variation with fit range

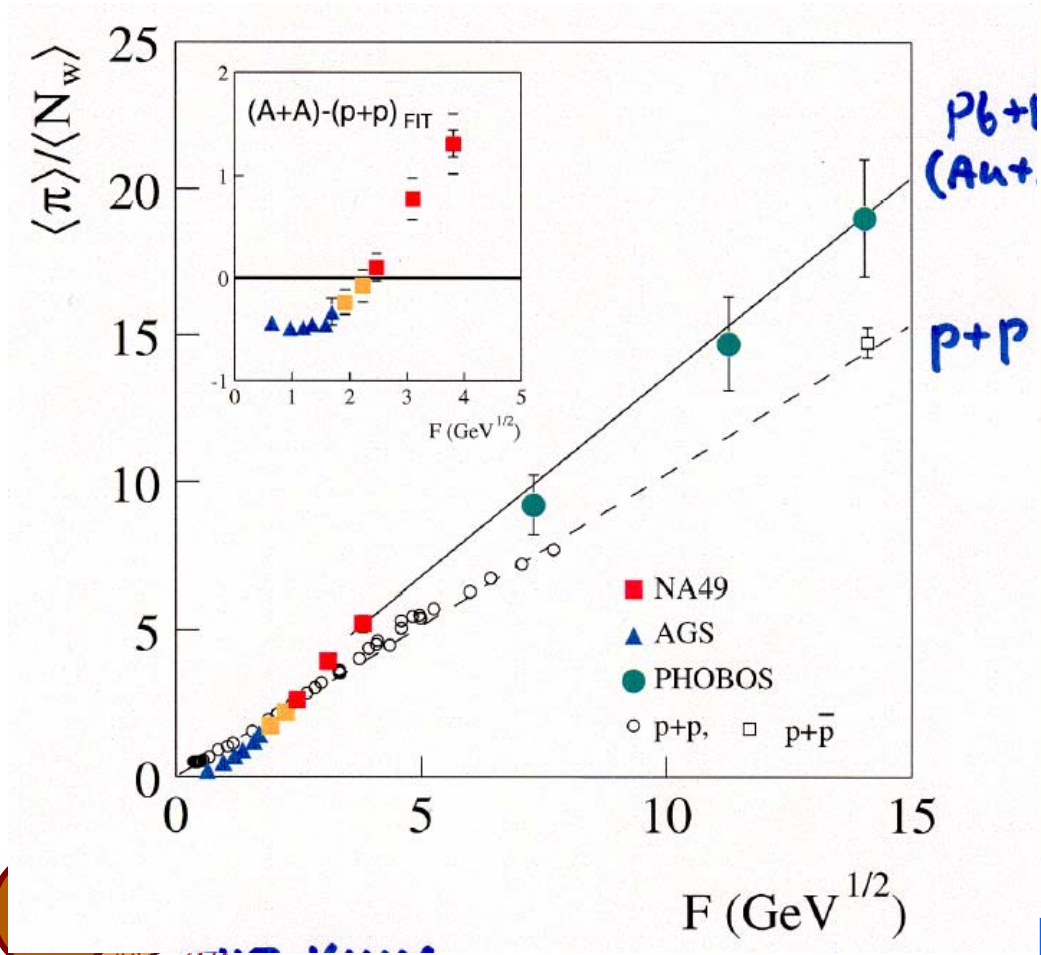


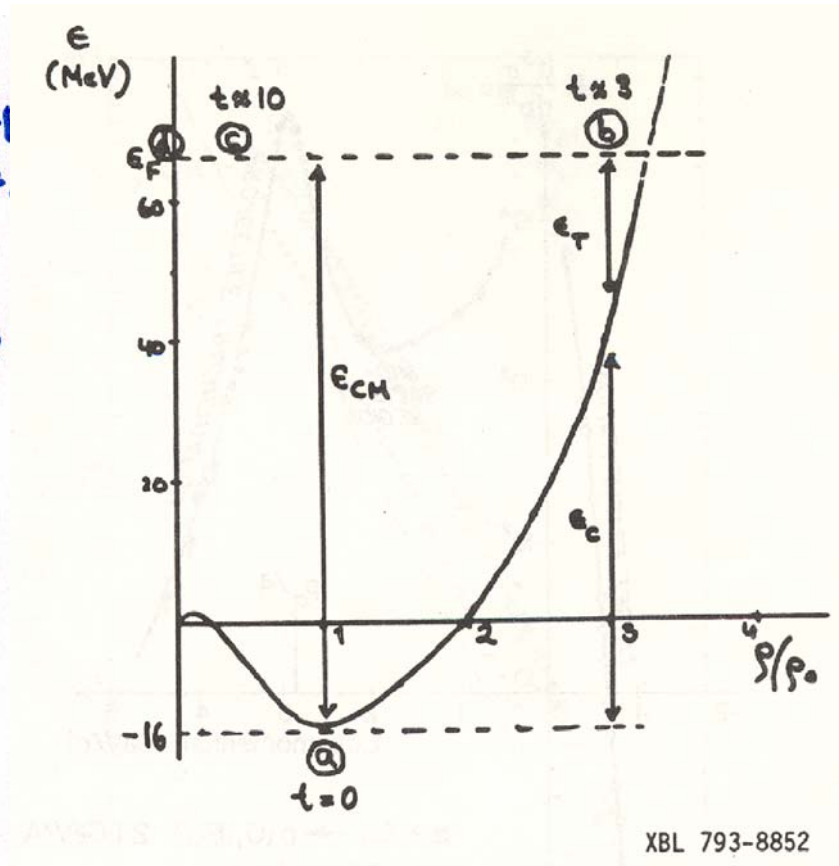




horns, steps, kinks

- not connected to old (Bevalac) ideas of EoS, compression, energy conservation (and N+Δ→N+N)?

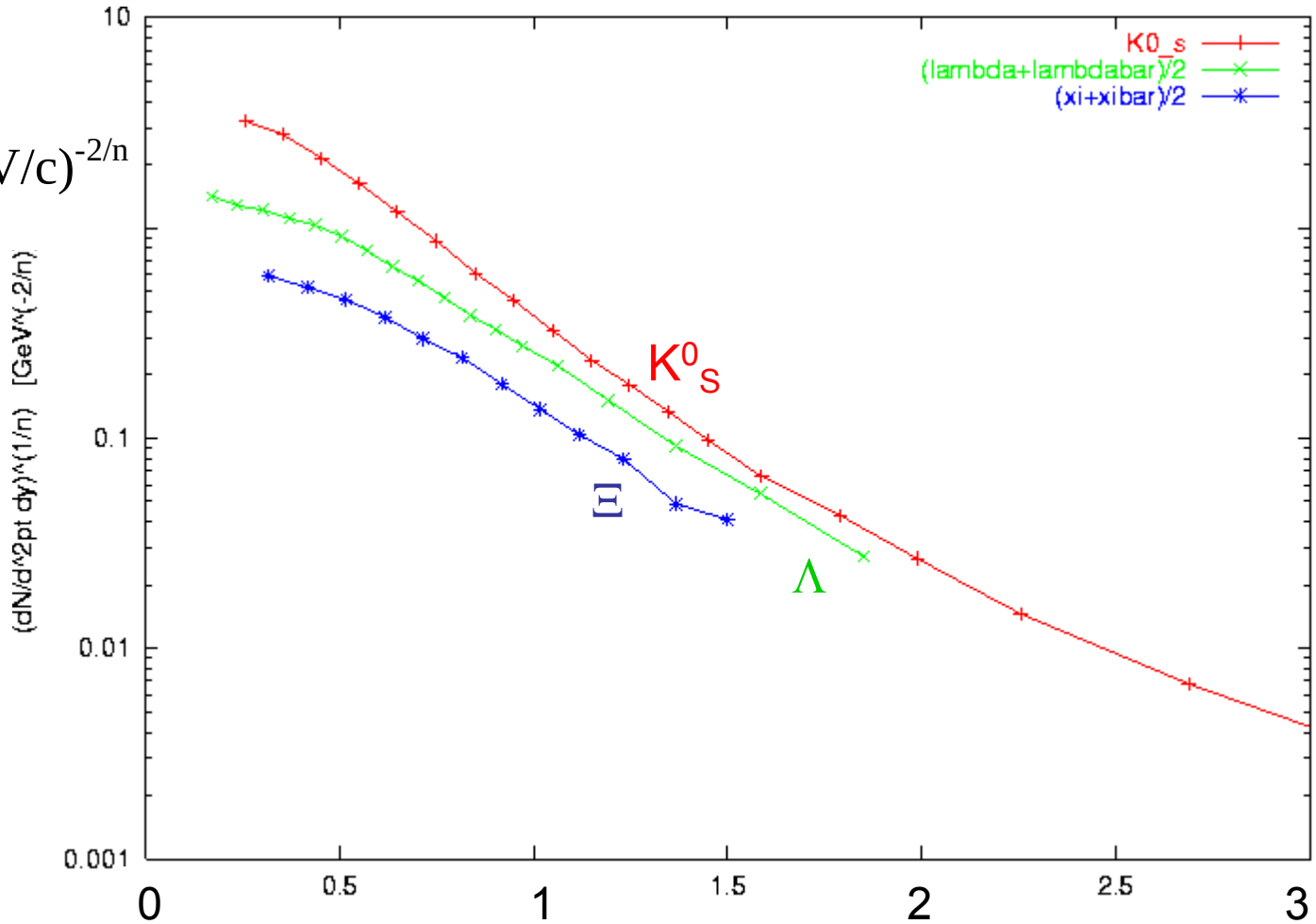




LBL Streamer chamber group 1979
c/o Reinhardt Stock

scaled pT spectra – c/o Molnar & Voloshin

$$\left(\frac{dN}{d^2p_T}\right)^{1/n} \quad (\mathrm{GeV/c})^{-2/n}$$

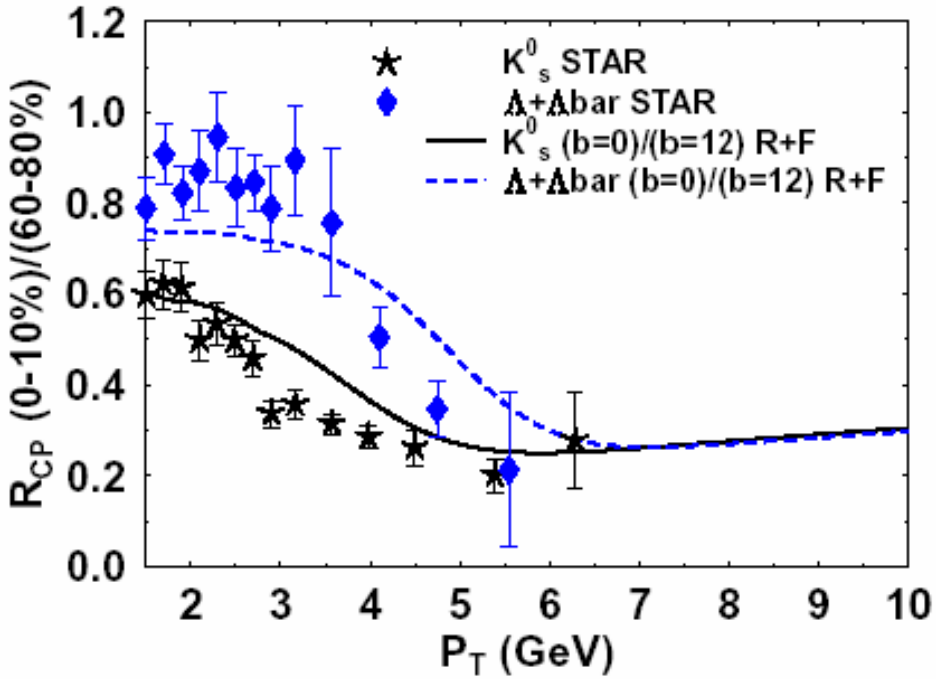


p_T^q (GeV/c) $\quad [p_T^q \equiv p_T / n]$

With PID - [firm]
Definitely on the right track...

Fries et al, PRC68 044902 (2003)

Coalescence models (various flavors)



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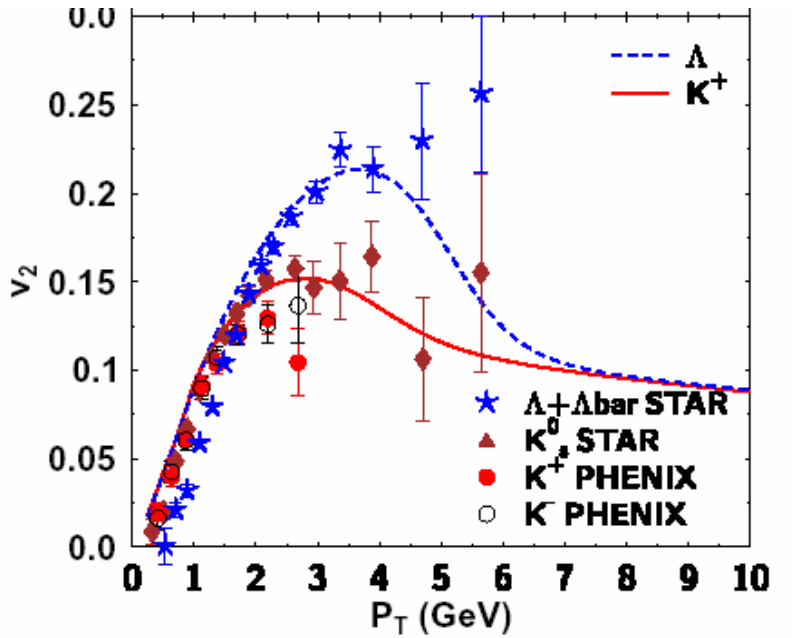
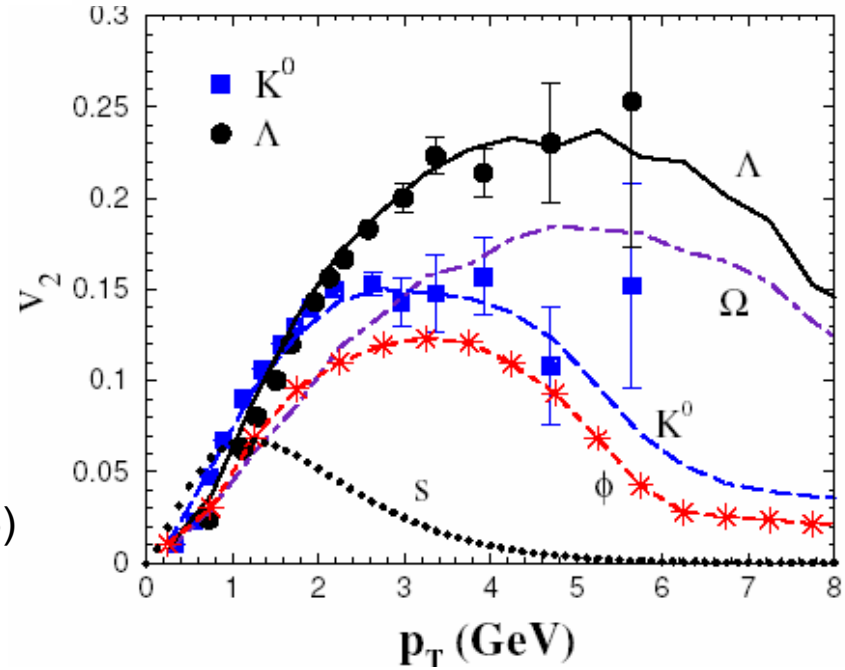


Coalescence models (various flavors)

- promising, distinguishable models
  - $v_2[s] = v_2[u,d]$?
  - interaction b/t hard/soft quarks?
  - dynamics of hadronization!!
- Molnar parton cascade
  - $\sigma \approx 3$ mb ($\neq 10$ mb)
  - $dN/d\eta \approx 1500$-3000 (~ Gyulassy)



Greco, Ko, Levai PRC68 034904 (2003)

With PID - [firm]
Definitely on the right track…

Coalescence models (various flavors)

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  - $v_2[s] = v_2[u,d]$?
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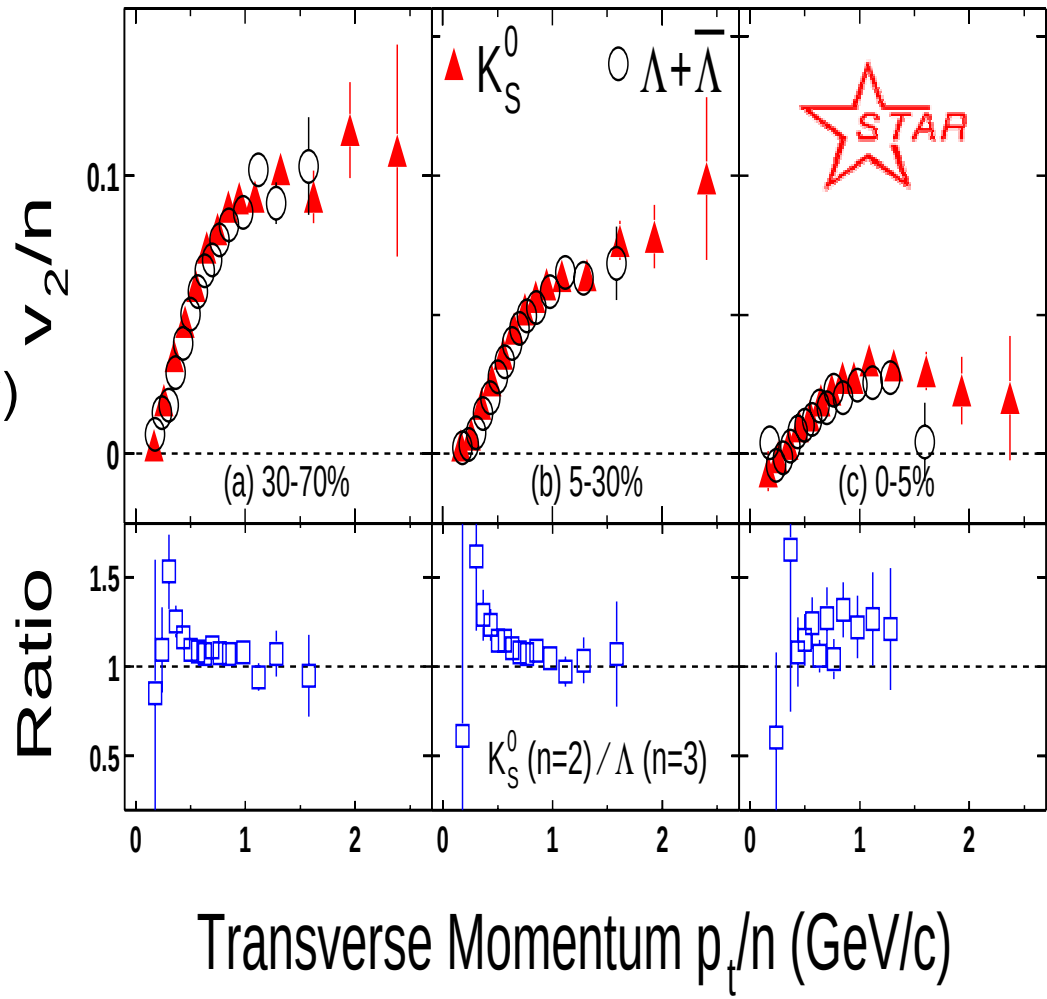
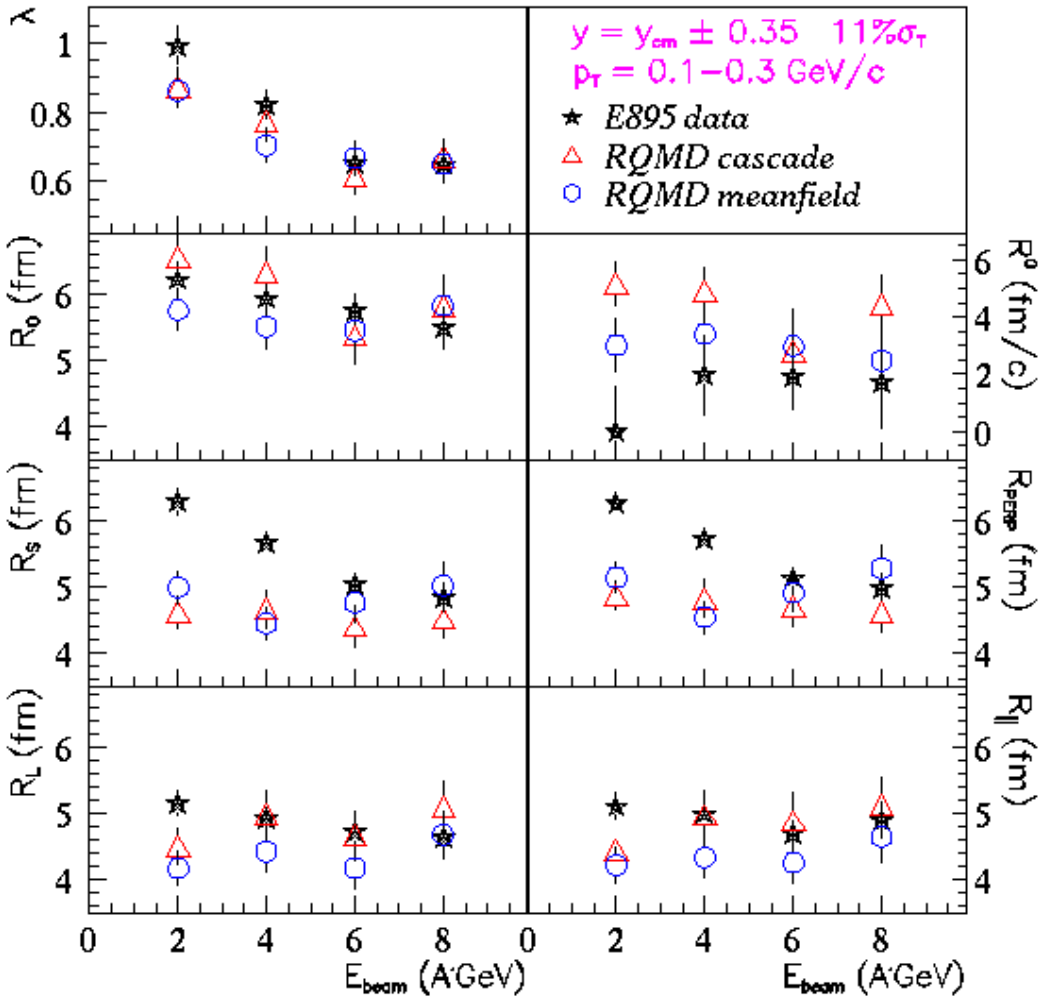
  - dynamics of hadronization!!
- Molnar parton cascade
  - $\sigma \approx 3$ mb ($\neq 10$ mb)
  - $dN/d\eta \approx 1500$-3000 (~ Gyulassy)
- push down in p_T?
  - "works" to $p_T^q \sim 500$ MeV $\sim 3T^q$



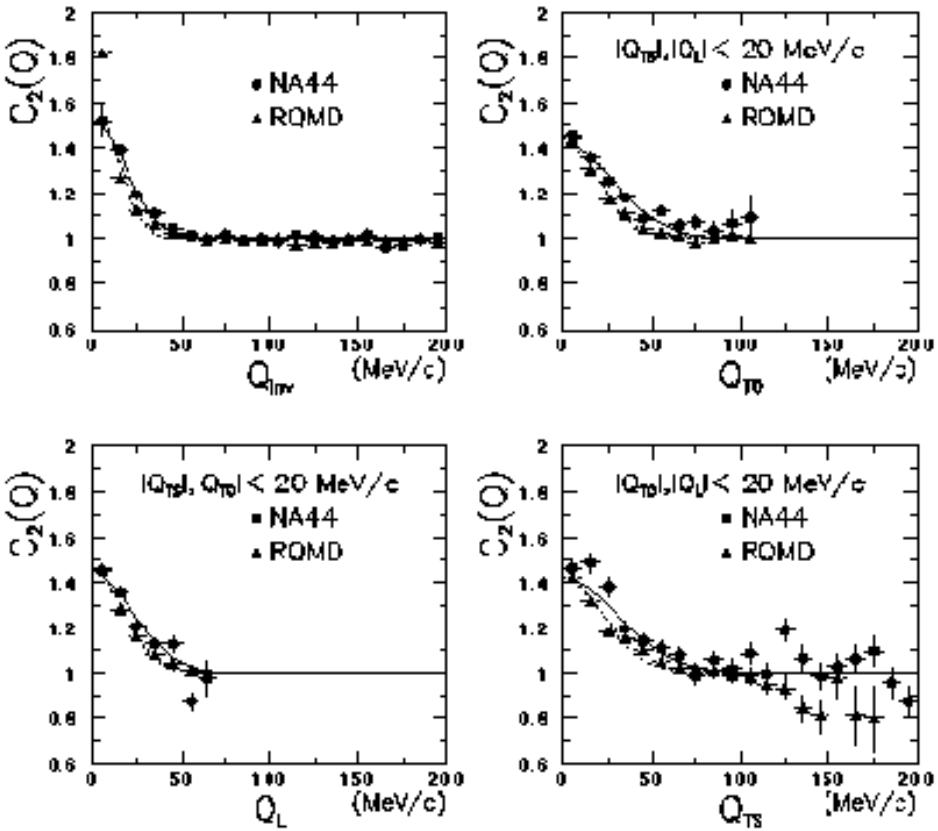
problems at lower √s… AGS



E895 Collab, PRL 84 2798 (2000)

Testing the model at the SPS

- For π^-...
- Model *under*predicts apparent size below 10 AGeV...
- *over*predicts size at 158 AGeV
-
- Extrapolation to RHIC???

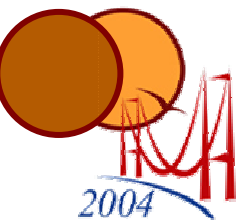


I.G. Bearden et al (NA44)
PRC**58**, 1656 (1998)
D. Hardtke, Ph.D. thesis (1997)

	NA44	RQMD
R_{out}	4.88 ± 0.21	6.96 ± 0.14
R_{side}	4.45 ± 0.32	6.23 ± 0.20
R_{long}	6.03 ± 0.35	7.94 ± 0.21

soft - cont

- equilibration – no saturation of multistrange w/ Npart:
  - argument 1:
    - it *does* saturate, but only for last 1-2 datapoints
    - GCE works (but maybe only for last datapoint)
    - if only we had higher Npart points, we'd see it flatten out
    - [opinion] strikes me as strange – I hate coincidences
  - argument 2:
    - it *does* equilibrate, so *would* flatten, but Nbinary contributions are added on top
    - but then wouldn't there be too *much* of strangeness for GCE in central?
  - [opinion] reference (low Npart collisions) systematics not understood



soft sector– do we have a clean reference?

- more HBT “puzzles”?
  - R(kT) in AuAu attributed to flow – seems reasonable & jibes w/ p-space
  - R(kT) in pp *presumably* arises from different physics (tilted strings etc)
  - why R(kT)AA / R(kT)pp is flat? – As experimentalist, I hate coincidences!
  - not-understood reference ☹

- strangeness
  - steps, kinks, horns – as an experimentalist, I *am* intrigued by the *data*, but
    - kink: explainable by “old” concepts of EoS / compressibility energy conservation
    - step: I do not find exponential fit to just K+ spectrum “model-independent”
    - horn: Rybicki’s isospin arguments ring true: Again, I hate coincidences
      - again, reference system (NN) details may not be properly accounted for