Day-1 Physics at RHIC

RHIC Winter Workshop at LBNL

Not a conference summary

Not a "review" of Day-1 Physics

Roughly: a review of my prejudices

W.A. Zajc

Workshop Themes

- From http://www-rnc.lbl.gov/rww99.html :

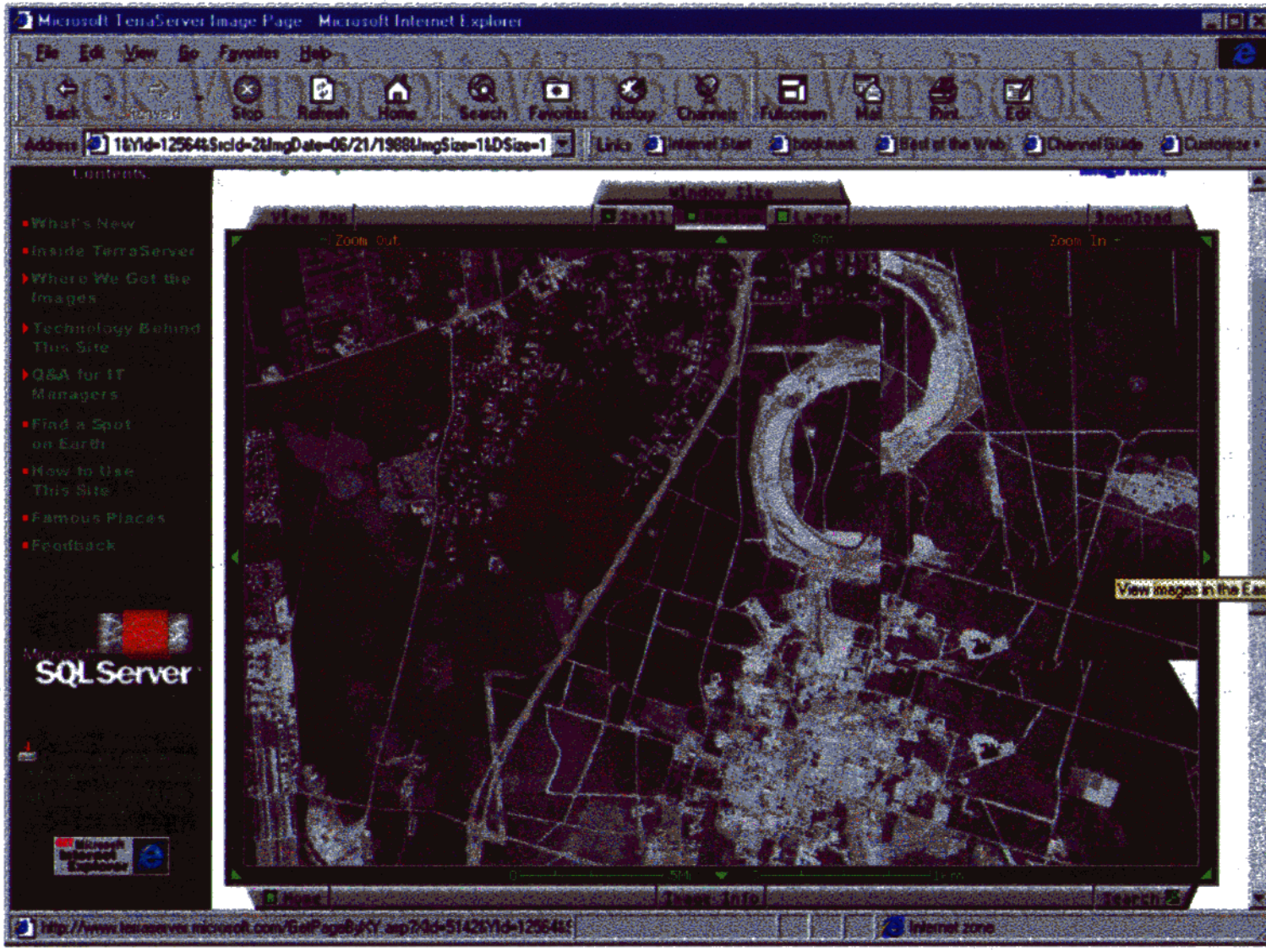
Prospects for Year-1 Physics at RHIC

1. Initial Conditions
2. Collective Behavior
3. Flavor Dynamics

- From the agenda :
  1. pQCD
  2. Flow, Flow, Flow, Flow, Flow, Flow, Flow
  3. Flavor dynamics
  4. Exotica

RHIC Site

- Precision in ring surveying is outstanding
- Accuracy could be improved…
- Credit: MS Terraserver



Why RHIC is Grand

- It's ***dedicated:***

  (~ 37 weeks per year of running)

- It's ***flexible:***
  - All species from protons to Au colliding with all species from protons to Au
  - Energies from ~ injection to 200 A * Gev
- It's a ***collider:***
  - ➨ Center-of-mass stays put when energy is varied
- It's ***diverse:***

  Four complementary experiments with
  - Common event characterization (ZDC's)
  - Common channels (e.g. ϕ to K^+K^-)
- It's (almost) ***available:***
  - ➨ Can say ~now:
    - RHIC: 6 months
    - LHC : 6 years

The Other Side of Grand

- Much of the interesting physics is luminosity limited
- (Single-species) colliders can take years to reach their full luminosity:

ISR
(Mike Tannenbaum)

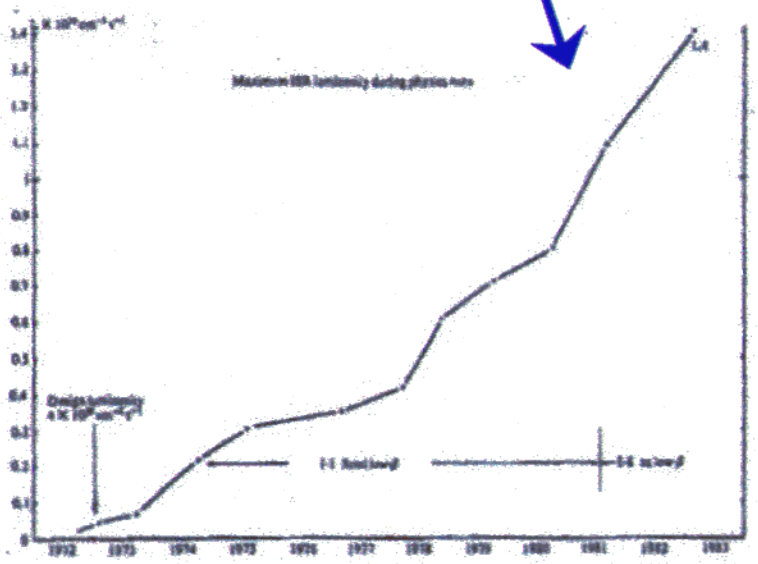
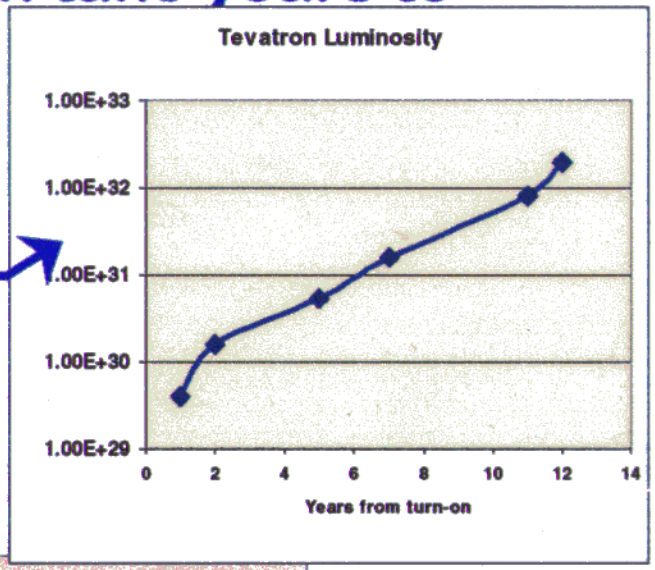
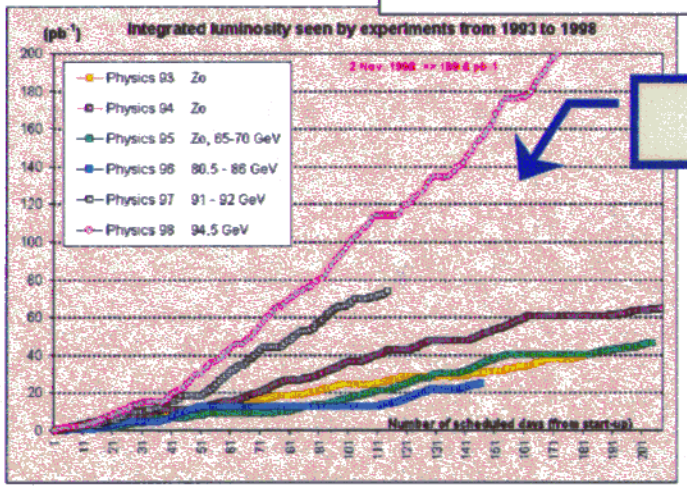


Fig. 9 ISR luminosity during physics runs: September 1971 -- first ISR experiment to be completed. 8101: maximum luminosity = 1.3 x 10^30 cm^-2 s^-1. December 1982 -- Highest luminosity achieved for physics (8807) = 1.4 x 10^32 cm^-2 s^-1.

FNAL
(Steve Holmes)





LEP

W.A. Zajc

Experimental Status

- All four experiments will be ready with a rich Day-1 program.

  (Characterization by Glenn Young, as modified by WAZ.)

- *None* of the four experiments will be whole in Year-1

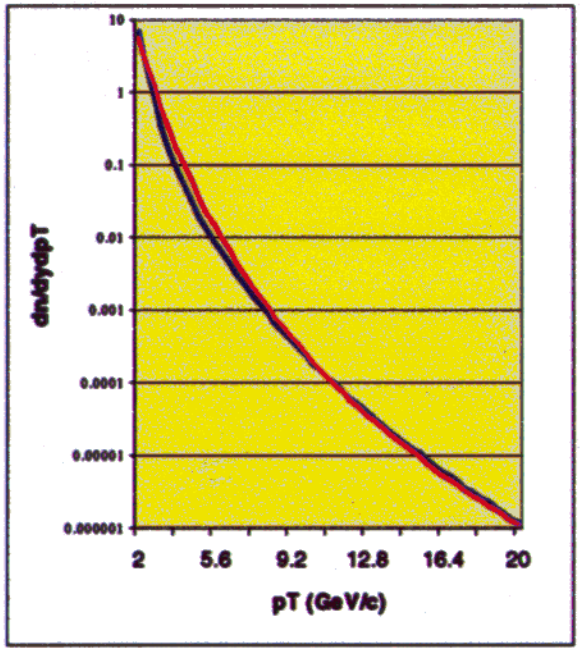
Timescale	Probe	STAR	PHOBOS	BRAHMS	PHENIX
Initial Collision	***Hard Scattering***				
	Single jet via leading particle	trigger?			yes
	photon + jet	trigger?			yes
	jet + jet	> 5 Gev/c			
Deconfinement	***High-Mass Vector Mesons***				
	J/ψ, ψ′ screening				yes
	Υ (non)screening				yes
Chiral Restoration	***Low-Mass Vector Mesons***				
	ρ, ϖ, φ mass, width	φ to KK	φ to KK	φ to KK	yes
	φ branching ratios				yes
QGP Thermalization	***Photons***				
	π^0, η, η′				yes
	continuum direct; very soft				yes
QGP Thermalization	***Dileptons***				
	non-resonant: 1-3 GeV				yes
	soft continuum, <1 GeV				yes
QGP Thermalization	***Heavy Quark Production***				
	open charm	w/SVT?			e-mu?
	open charm via single lepton				e or mu
Hadronization	***Hadrons***				
	HBT Interferometry, π/K	yes	low p_T	large-y	yes
	strangeness production: K, φ	yes	low p_T	large-y	yes
	spectra of identified hadrons	yes	low p_T	large-y	yes
Hydrodynamics	***Global Variables***				
	E_T, dN/dy	yes	yes	yes	yes

09-Jan-98

W.A. Zajc

Initial Physics

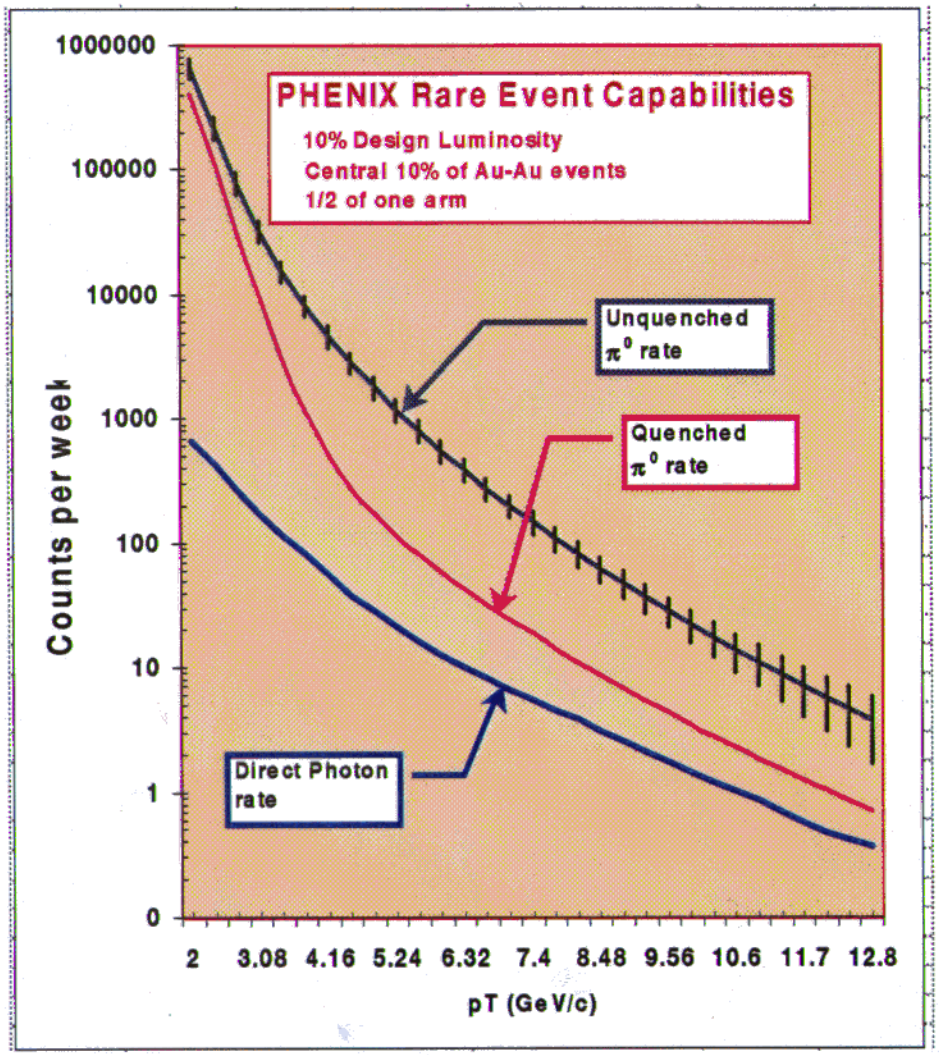
- As noted by many speakers: Rates are large:
- Assume:
  - Luminosity is 1% of design R_{MB} ~ 10 Hz
  - dn_c/dy ~ 1000
- Then calculate *production* rates for ~all species in $\Delta y = 1$:
  - Pions: ~500 /charge/event/Δy ➡ 5.0kHz
  - ρ/π ~ 0.5 ➡ 2.5 kHz,
    $B(e^+e^-) = 5 \times 10^{-5}$ ➡ 0.1 Hz
  - Kaons: K^-/π^- ~ 5% ➡ 250 Hz
  - Protons: p/K ~ 1 ➡ 250 Hz
  - Phi's: ϕ/ K^- ~ 0.1 ➡ 10 Hz (KK)
    $B(e^+e^-) = 3 \times 10^{-4}$ ➡ 20 /hr
  - High p_T: > 5 GeV ~ 5×10^{-5} ➡ 0.15 Hz
  - J/Y's: $Bd\sigma_{pp}/dy$ ~ 40 nb,
    $A^{2\alpha}$ ~ 20,000, ➡ 5 /hr



Example of Year-1 Physics

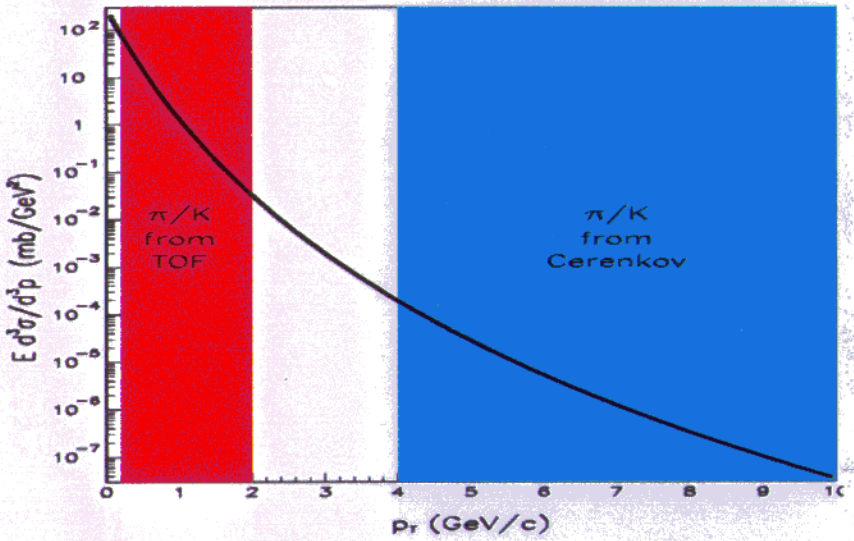
Measurement of hard processes:

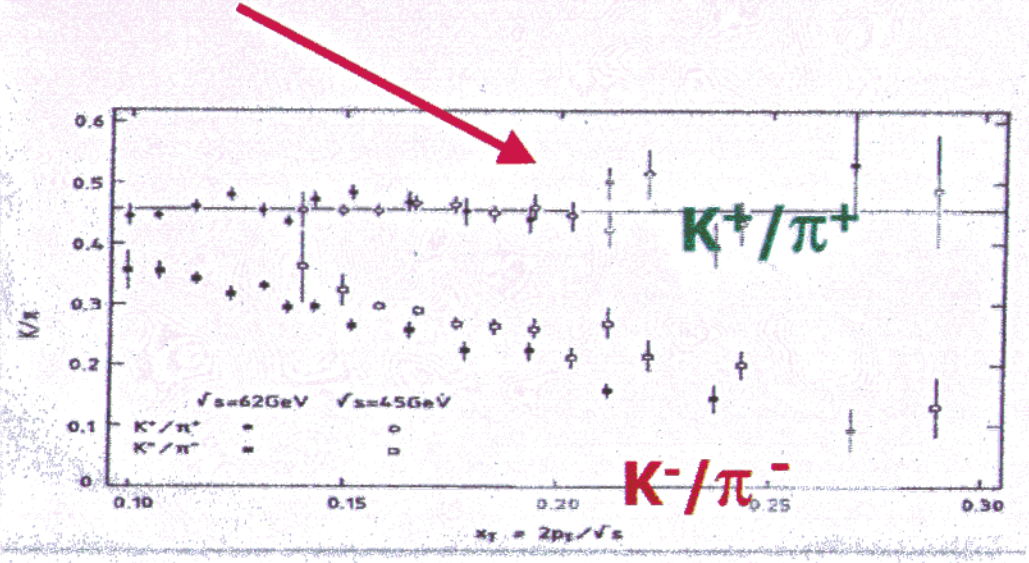
- General: an auto-generated plasma diagnostic
- Specific: Prediction that dE/dx in deconfined phase ~10 x larger than normal nuclear matter
  - BDMPS, Nucl. Phys. B483, 265 (1997)
    Nucl. Phys. B484, 291 (1997)
- ➨ Measure high p_T π^0's, γ / π^0, ...
- Will measure
  - with an open trigger
  - study as a function of centrality



Leading K^- as a Gluon Probe

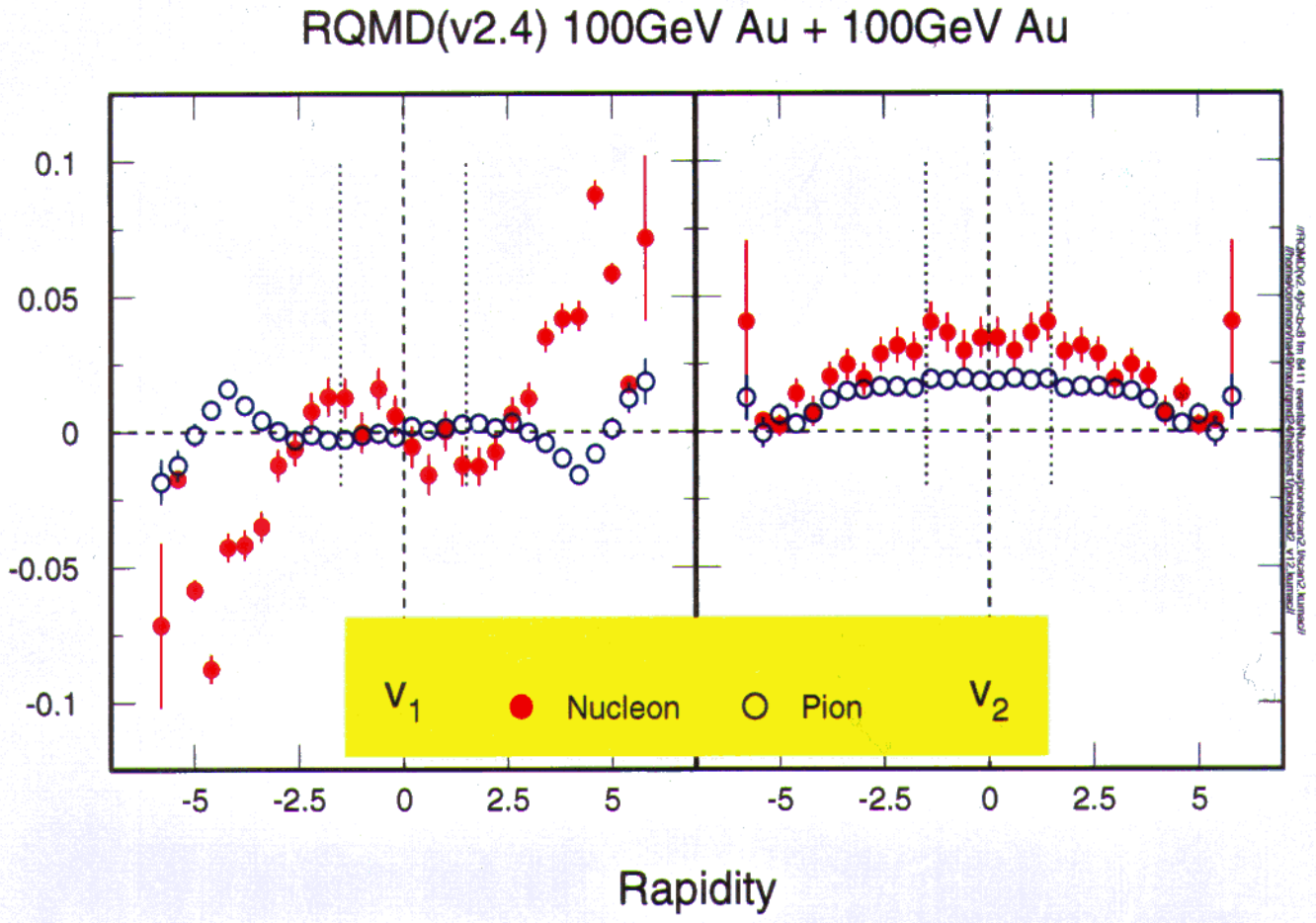
- "High p_T $K^{\pm}/\pi^{\pm}$ Production in p-p Collisions at the ISR: Strangeness Suppression and Gluon Effects", A. Breakstone *et al., Phys. Lett.* B135, 512 (1984).





- PHENIX has good PID capabilities for K^- :
- Perhaps takes on additional significance in a medium which *enhances* strangeness…
- Anti-proton "backgrounds" to K^- are good (B.A. Cole)

Flow at RHIC



Dashed lines: STAR TPC acceptance

- Directed Flow - V_1
  - Nucleon "Antiflow" around mid-rapidity
  - Very small values for pions at mid-rapidity
  - Opposite flow of pions and nucleons at beam rapidities
- Elliptic Flow - V_2
  - In-plane emission of both nucleons and pions
  - Larger signal for nucleons

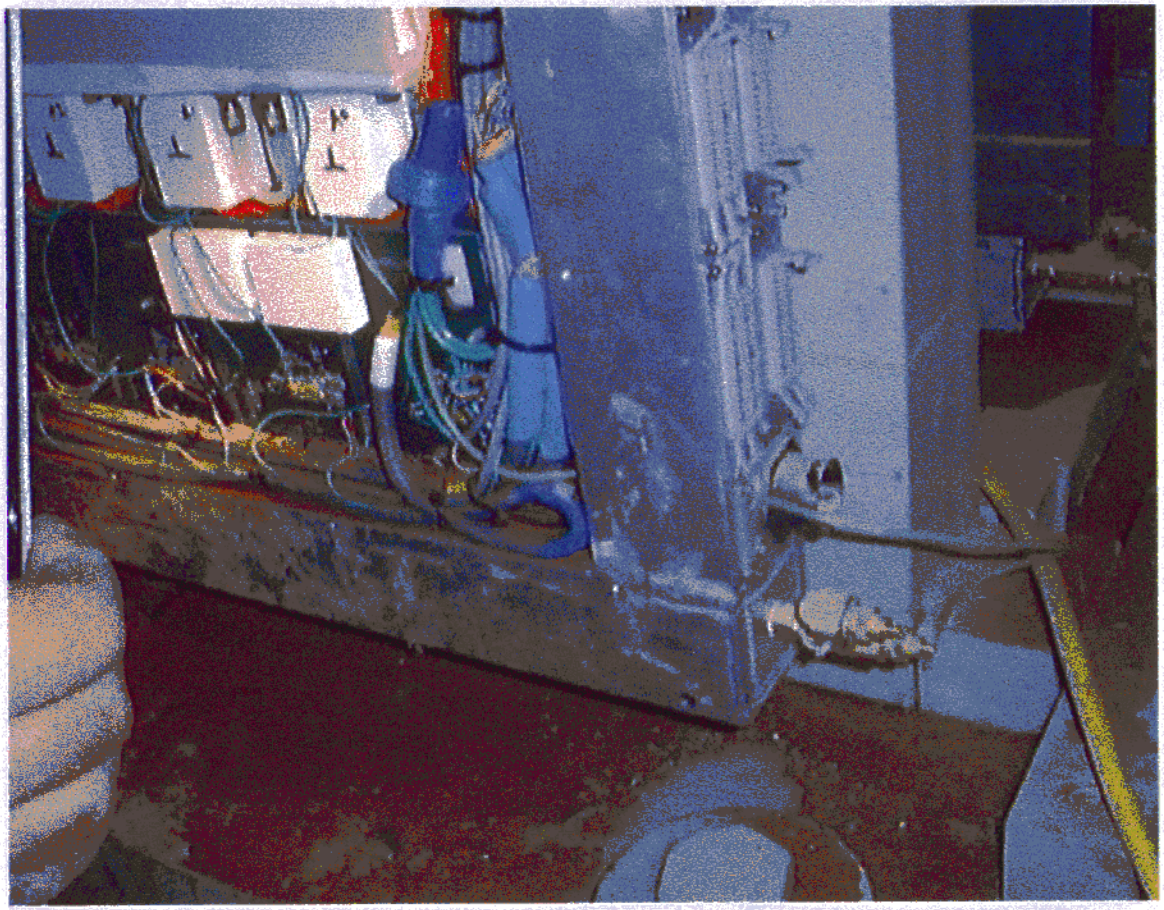
RQMD (v2.4) predicts signal similar to observed at SPS

Flow

- **Good news:**
  - PHENIX has the first installed detector components at RHIC
  - They've already discovered flow
- **Bad news:**
  - It was true hydro
  - Many co-movers in transport
  - Persisted to final state
- **Fervent hope:**

  "Some day we'll look back on this and it will all seem funny"

  -- (The Boss)



Initial Conditions

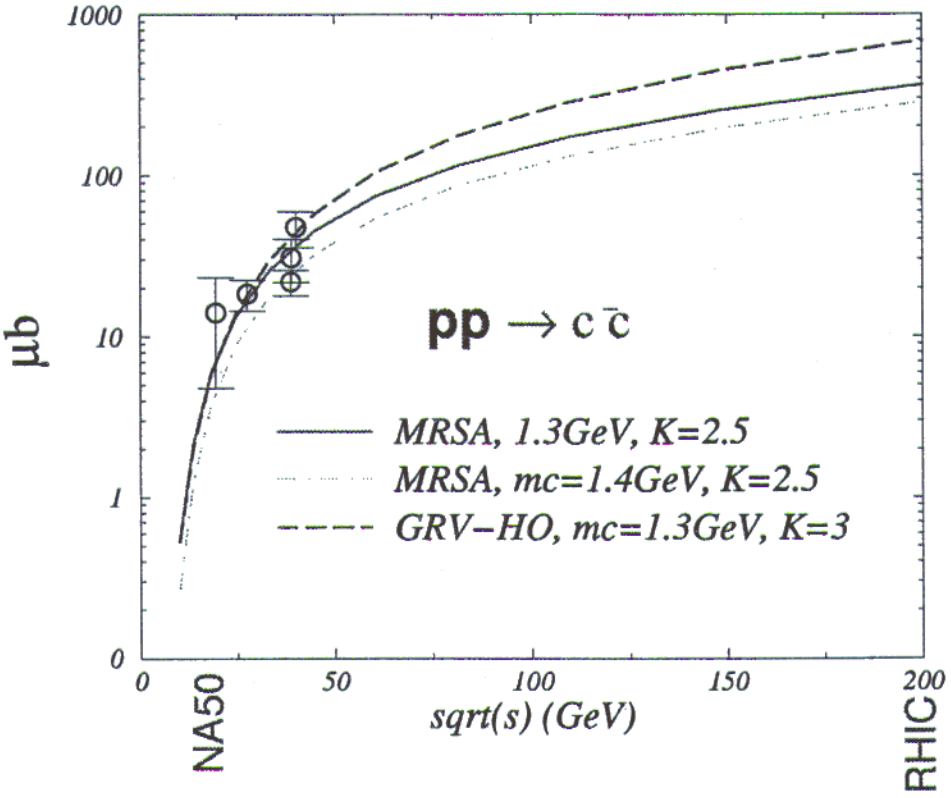
- **Distribution functions:**
  - Be prepared to:
    - measure *in situ*
    - adjust as necessary
- **Partonic cascades**
  - Essential mission of RHIC:
  - Demonstrate that most of entropy is generated at partonic, not hadronization, level
  - Clear case for penetrating probes
- **Tools at hand:**
  - ✔ High p_T single particles (hadrons and photons)
  - ✔ Angular correlations of same
  - ✔ Flavor tagging of same
  - ✖ Jets

Open Charm Production in AA

Scaling from pp to AA

(*shadowing* on nuclear structure function will be discussed later)

$$\frac{d\sigma_{AB}^{c\bar{c}}}{d^2b} \propto T_{AB}(b) * \sigma_{pp}^{c\bar{c}}$$



$\sigma_{pp}^{c\bar{c}} \simeq 350\mu b$ (at 200GeV), $\quad T_{AA}(0) \simeq 30/mb$

$\Rightarrow$ large open charm production at RHIC!

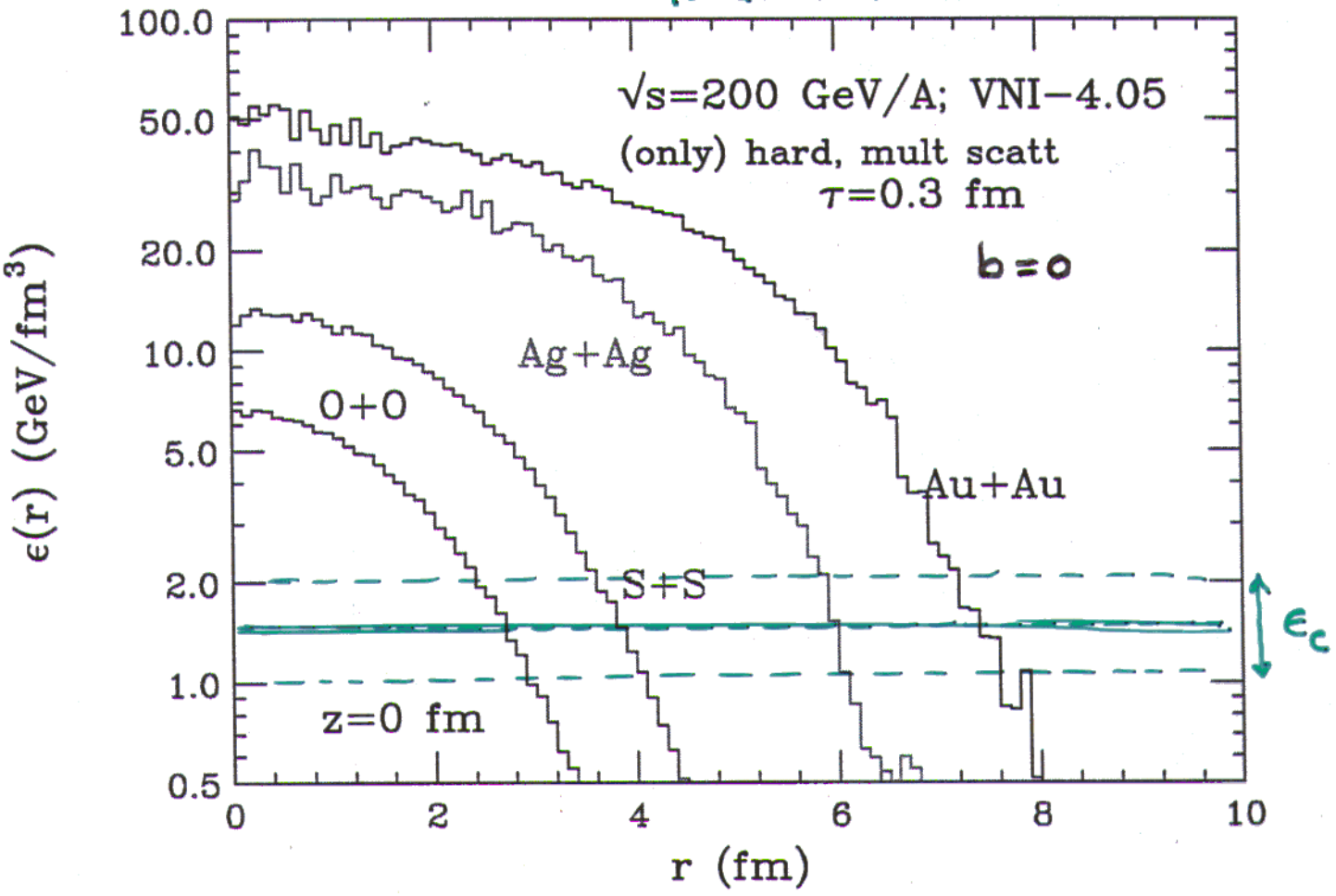
For an average central $Au + Au$ event:

$$N^{c\bar{c}}(\vec{b}{=}0) = T_{AA}(0) * \sigma_{pp}^{c\bar{c}} \simeq 10$$

PARTON CASCADE MODEL

RHIC ENERGY

GEIGER + SRIVASTAVA

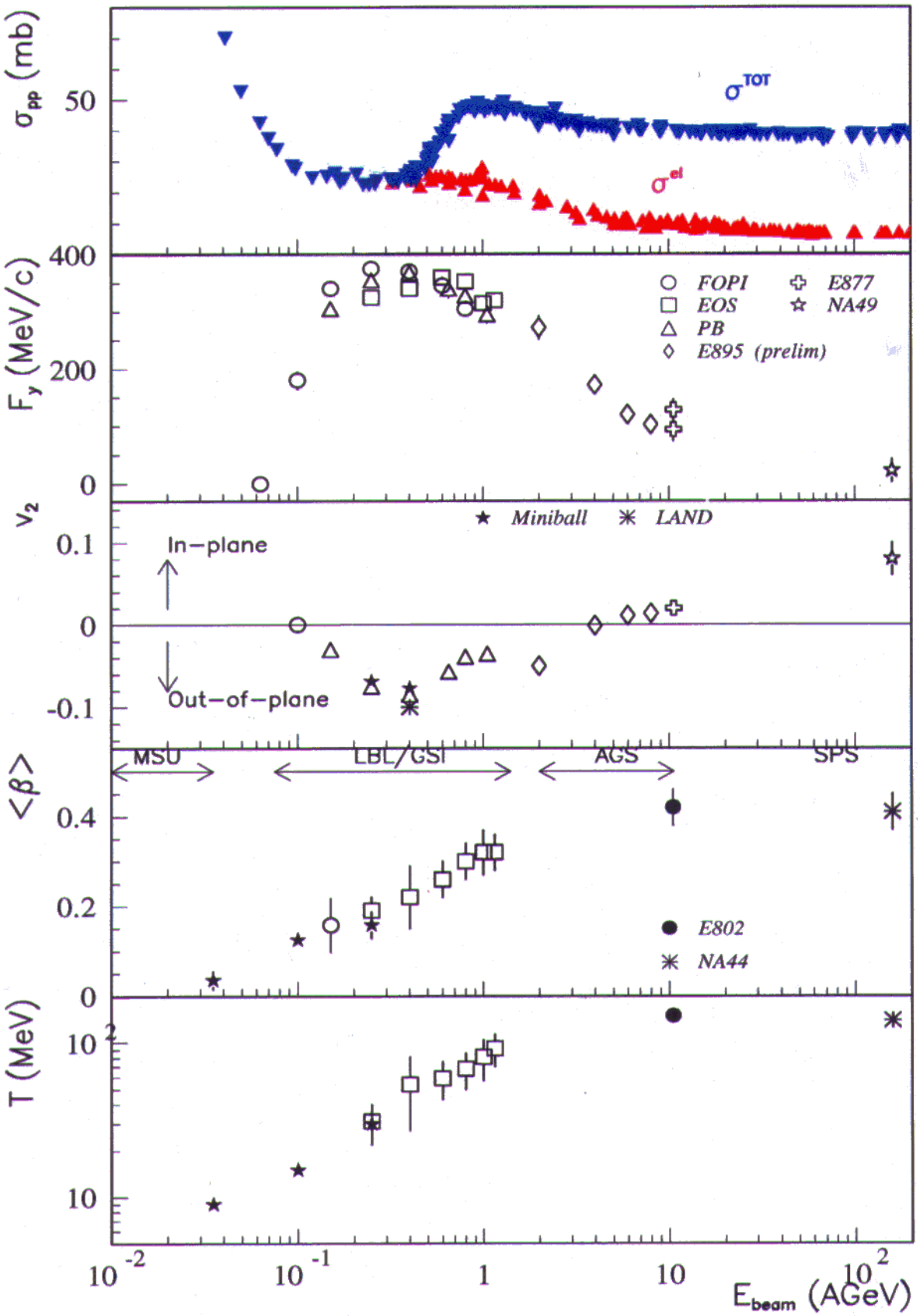


Flow

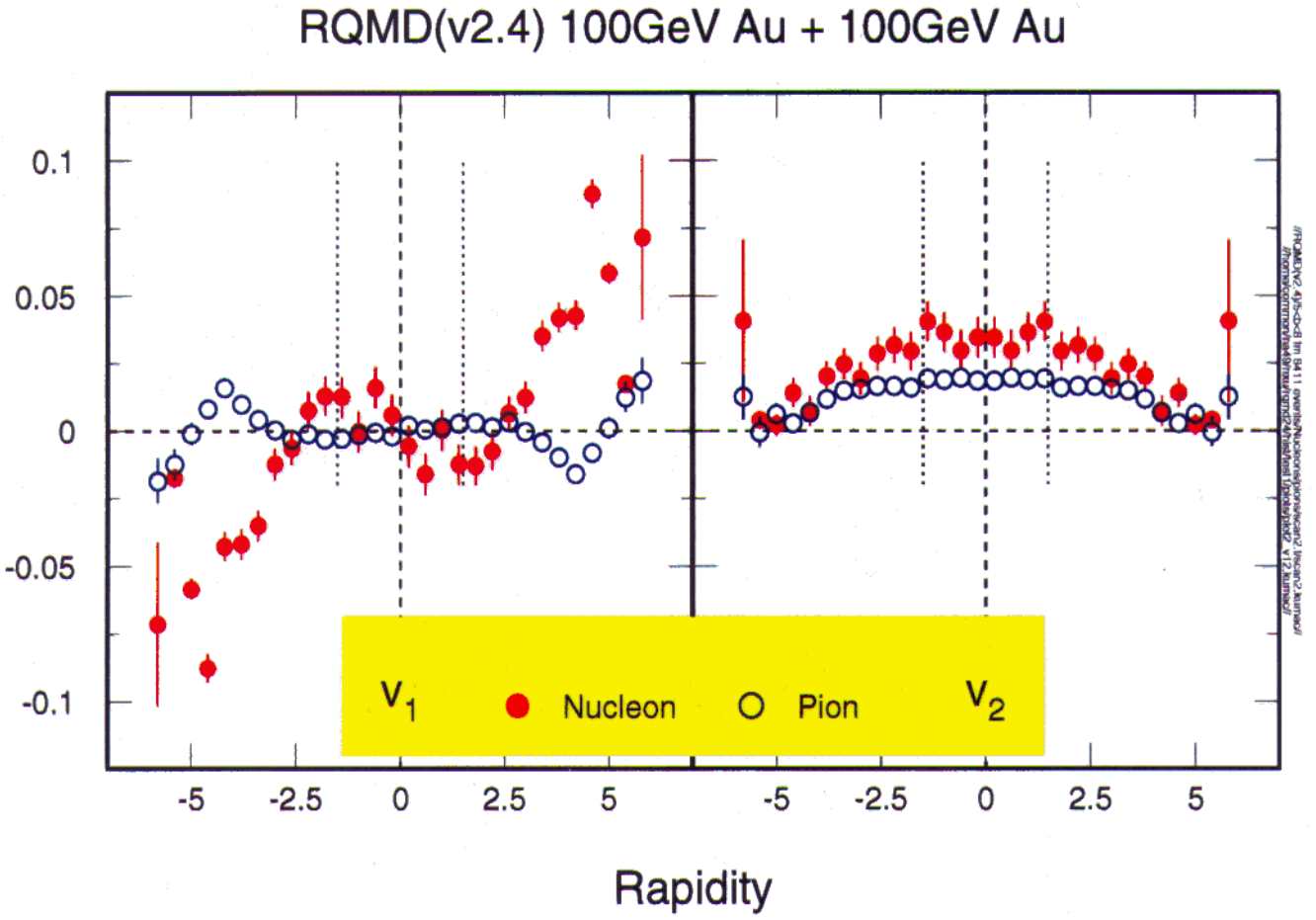
- **Radial:**
  - Will (continue to) be a very large effect
  - Essential component to understanding spectra at RHIC.
- **Directed:**
  - Already small at SPS
  - Almost irrelevant at RHIC
- **Elliptic:**
  - Zero for truly central events (at any energy)
  - Is it
    - A necessary evil for understanding events with non-zero impact parameter?

    Or
    - An essential tool to our understanding of EoS+(time evolution) of (non-isotropic) initial conditions?
  - My *prejudice:*
    Effects of elliptic flow will be small at RHIC

Much of available data on heaviest systems



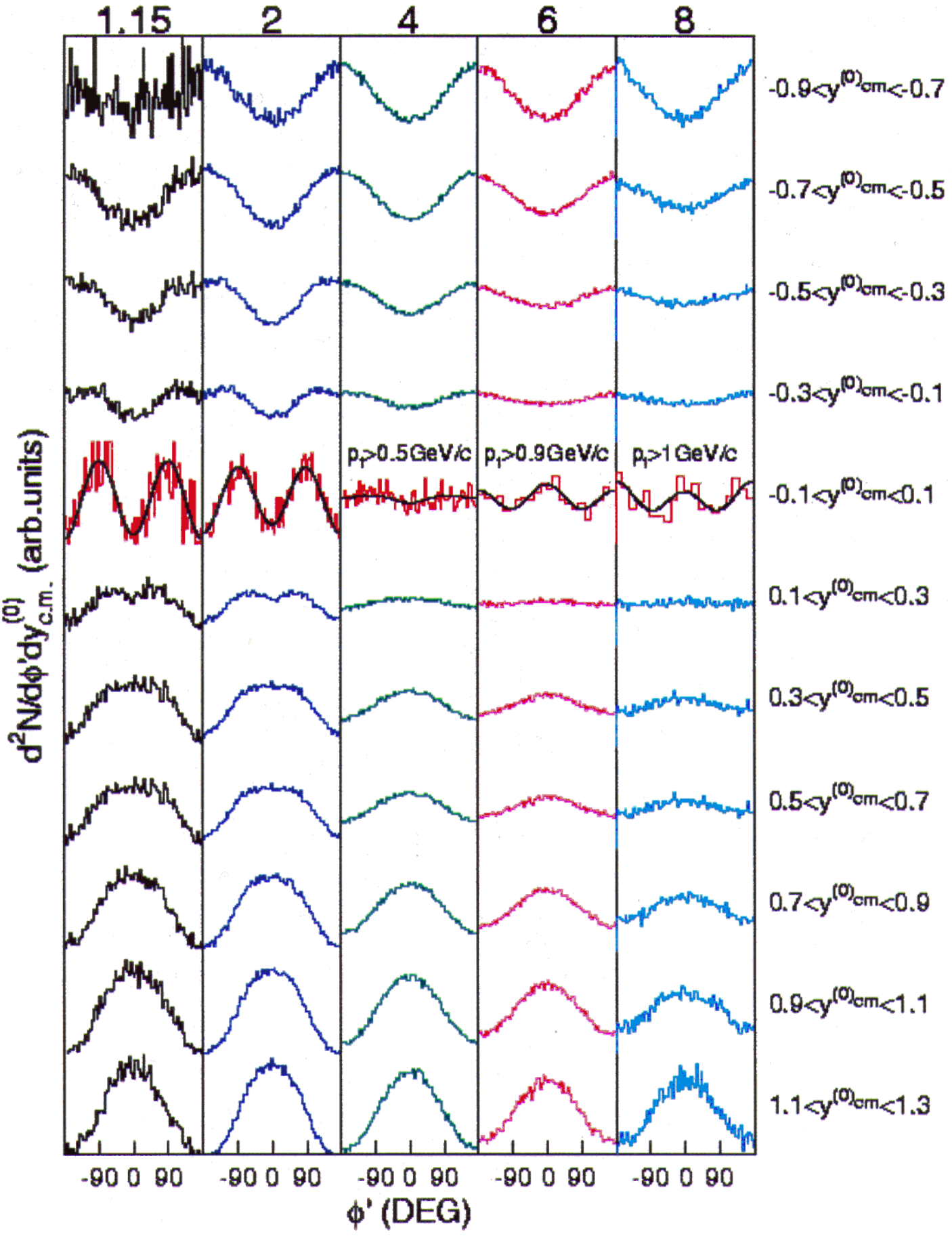
Flow at RHIC



Dashed lines: STAR TPC acceptance

- Directed Flow - V_1
  - Nucleon "Antiflow" around mid-rapidity
  - Very small values for pions at mid-rapidity
  - Opposite flow of pions and nucleons at beam rapidities
- Elliptic Flow - V_2
  - In-plane emission of both nucleons and pions
  - Larger signal for nucleons

RQMD (v2.4) predicts signal similar to observed at SPS


1.15
2
4
6
8
p_T>0.5GeV/c
p_T>0.9GeV/c
p_T>1 GeV/c
-0.9<y$^{(0)}_{cm}$<-0.7
-0.7<y$^{(0)}_{cm}$<-0.5
-0.5<y$^{(0)}_{cm}$<-0.3
-0.3<y$^{(0)}_{cm}$<-0.1
-0.1<y$^{(0)}_{cm}$<0.1
0.1<y$^{(0)}_{cm}$<0.3
0.3<y$^{(0)}_{cm}$<0.5
0.5<y$^{(0)}_{cm}$<0.7
0.7<y$^{(0)}_{cm}$<0.9
0.9<y$^{(0)}_{cm}$<1.1
1.1<y$^{(0)}_{cm}$<1.3
d^{2}N/dϕ'dy$^{(0)}_{c.m.}$ (arb.units)
-90 0 90
ϕ' (DEG)

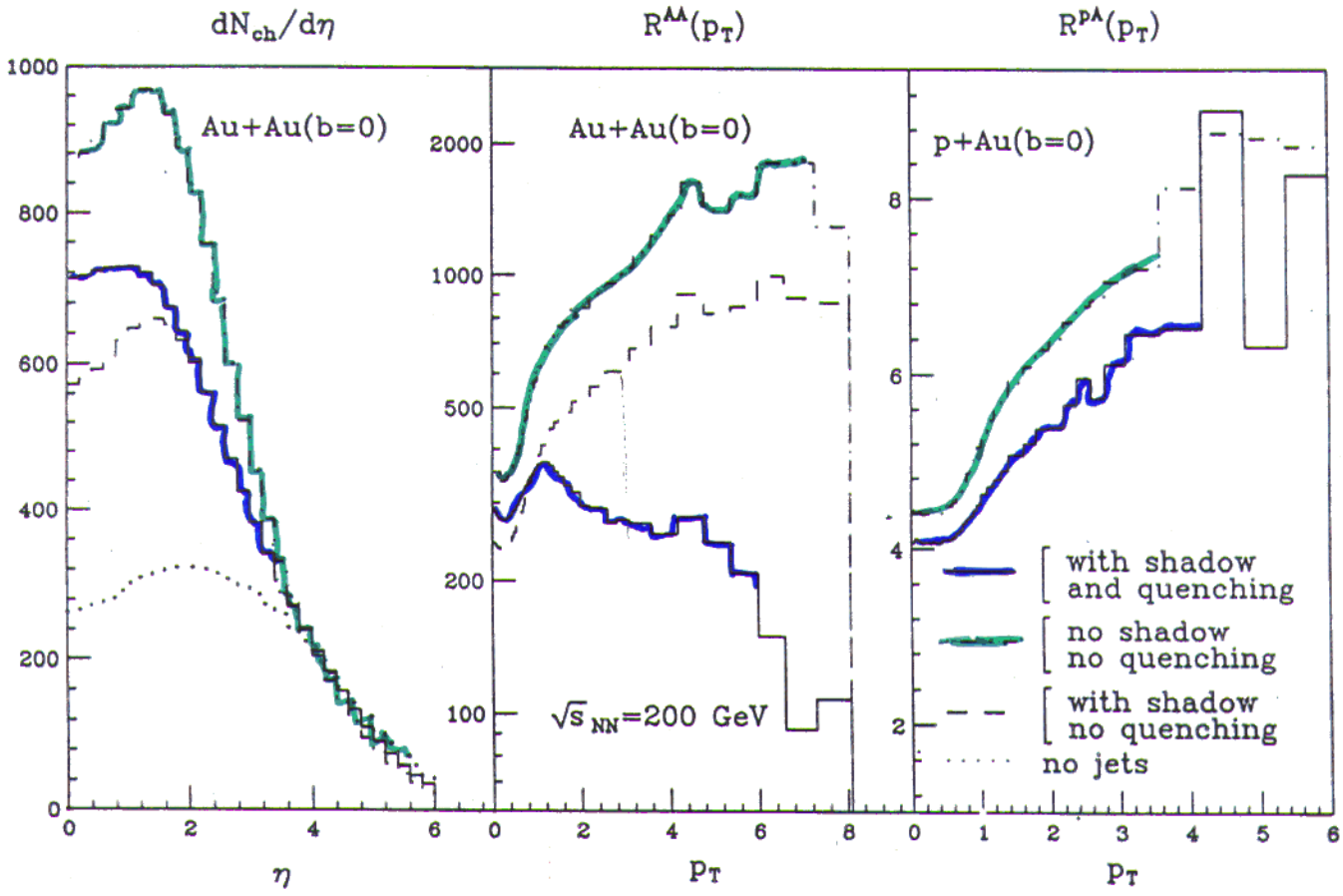
"Flavor" Dynamics

- **End of Day-1 (*sample*)**
  - $dN/d\eta$
  - $\langle p_T \rangle$
  - $dE_T/d\eta$
  - charged/neutral ratios
  - Start on fluctuation spectra
- **End of Year-1 (*sample*)**
  - Identified π/K/p/... spectra
  - "HBT" for above
  - $\langle p_T \rangle$ vs. mass
  - hadro-chemical analyses of above
  - ϕ to KK
  - low-mass vector mesons
  - Pion (charged and neutral) p_T spectra to > 10 GeV
  - Extensive E-by-E (e.g., R_{inv} vs T)

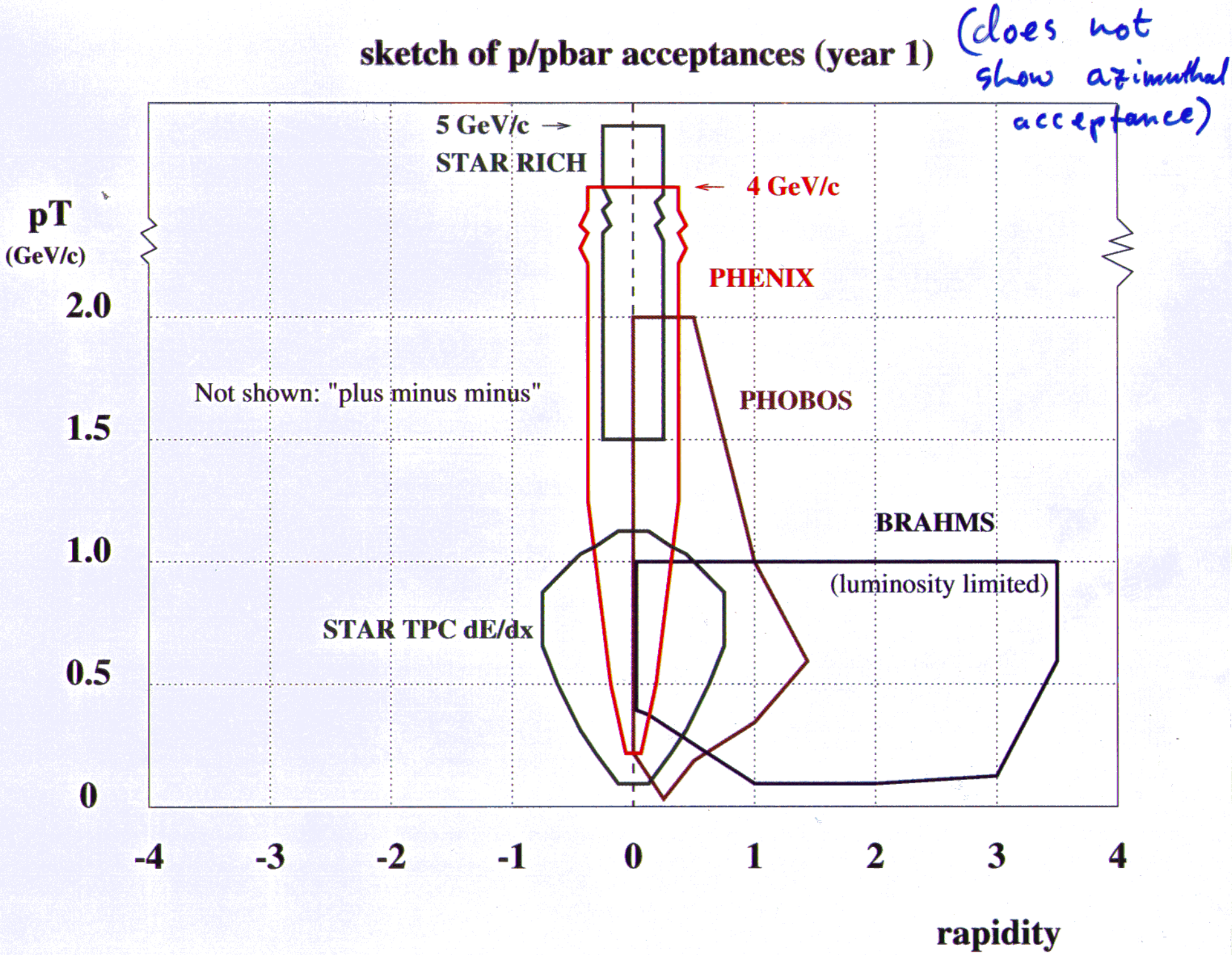
Effects of Hard Processes

The Picture that started it all...

CAN WE UNDERSTAND INTERACTION OF A PARTON IN MEDIA?.....



XN Wang
M Gyulassy
PRL 68 (1992) 1480


sketch of p/pbar acceptances (year 1)
(does not show azimuthal acceptance)
5 GeV/c →
STAR RICH
← 4 GeV/c
PHENIX
PHOBOS
BRAHMS
(luminosity limited)
Not shown: "plus minus minus"
STAR TPC dE/dx
pT
(GeV/c)
2.0
1.5
1.0
0.5
0
-4
-3
-2
-1
0
1
2
3
4
rapidity

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,[16] 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,[17] J. Bensinger,[2] A. Beretvas,[4] P. Berge,[4] S. Bertolucci,[5] S. Bhadra,[7] M. Binkley,[4] R. Blair,[1] C. Blocker,[2] J. Bodill,[4] A. W. Booth,[4] G. Brandenburg,[6] D. Brown,[6] A. Byon,[12] K. L. Byrum,[17] M. Campbell,[3] R. Carey,[6] W. Carithers,[9] D. Carlsmith,[17] 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,[15] D. Cline,[17] D. Connor,[10] M. Contreras,[2] J. Cooper,[4] M. Cordelli,[5] M. Curatolo,[5] C. Day,[4] R. DeFabbro,[11] M. Dell'Orso,[11] L. DeMortier,[2] T. Devlin,[14] D. DiBitonto,[15] R. Diebold,[1] F. Ditton,[4] A. DiVirgilio,[11] J. E. Elias,[4] R. Ely,[9] S. Errede,[7] B. Esposito,[5] A. Feldman,[6] B. Flaugher,[14] E. 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,[16] R. Handler,[17] R. M. Harris,[9] J. Hauser,[3] T. Hessing,[15] R. Hollebeck,[10] L. Holloway,[7] P. Hu,[14] B. Hubbard,[9] P. Hurst,[7] J. Huth,[4] H. Jensen,[4] R. P. Johnson,[6] U. Joshi,[14] R. W. Kadel,[4] T. Kamon,[15] S. Kanda,[16] D. A. Kardelis,[7] I. Karliner,[7] E. Kearns,[6] R. Kephart,[4] P. Kesten,[2] H. Keutelian,[7] S. Kim,[16] L. Kirsch,[2] K. Kondo,[16] U. Kruse,[7] S. E. Kuhlmann,[12] A. T. Laasanen,[12] W. Li,[12] T. Liss,[3] N. Lockyer,[10] F. Marchetto,[15] R. Markeloff,[17] L. A. Marsonky,[17] P. McIntyre,[15] A. Menzione,[11] T. Meyer,[15] S. Mikamo,[8] M. Miller,[3] T. Mimashi,[16] S. Miscetti,[5] M. Mishina,[8] S. Miyashita,[16] N. Mondal,[17] S. Mori,[16] Y. Morita,[16] A. Mukherjee,[4] C. Newman-Holmes,[4] L. Nodulman,[1] R. Paoletti,[11] A. Para,[4] J. Patrick,[4] T. J. Phillips,[6] H. Piekarz,[3] R. Plunkett,[4,3] L. Pondrom,[17] J. Proudfoot,[1] G. Punzi,[11] D. Quarrie,[4] K. Ragan,[10] G. Redlinger,[3] J. Rhondes,[17] F. Rimondi,[4] L. Ristori,[11] T. Rohaly,[10] A. Roodman,[3] A. Sansoni,[5] R. Sard,[7] 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. Sehgal,[15] P. Sestini,[11] M. Shapiro,[6] M. Sheaff,[17] M. Shibata,[16] M. Shochet,[3] J. Siegrist,[9] P. Sinervo,[10] J. Skarha,[17] D. A. Smith,[7] F. D. Snider,[3] R. St. Denis,[6] A. Stefanini,[11] Y. Takaiwa,[16] K. Takikawa,[16] S. Tarem,[2] D. Theriot,[4] A. Tollestrup,[4] G. Tonelli,[11] Y. Tsay,[3] F. Ukegawa,[16] D. Underwood,[1] R. Vidal,[4] R. G. Wagner,[1] R. L. Wagner,[4] J. Walsh,[10] T. Watts,[14] R. Webb,[15] T. Westhusing,[7] S. White,[15] A. Wicklund,[1] H. H. Williams,[10] T. Yamanouchi,[9] A.Yamashita,[16] K. Yasuoka,[16] G. P. Yeh,[4] J. Yeh,[4] and F. Zetti,[11]

[1]*Argonne National Laboratory, Argonne, Illinois 60439*
[2]*Brandeis University, Waltham, Massachusetts 02254*
[3]*University of Chicago, Chicago, Illinois 60637*
[4]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[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

09-Jan-98

W.A. Zajc

Exploration Path

- We will have to choose wisely how to proceed in the first years of RHIC running:
  - Study A-A vs. A ?
  - Study p-A vs. A ?
  - Vary energy? (for all A-A, p-A combinations?)
  - Increase luminosity/running time?
  - Continue building/installing?
- Please keep in mind:
  - Early analyses will be crude
  - Patience is a virtue
- Most desirable:
  - Coordinated, collaborative effort based on
    - Experimental conditions
    - (Updated!) theoretical input
  - Balance of rigor and vigor

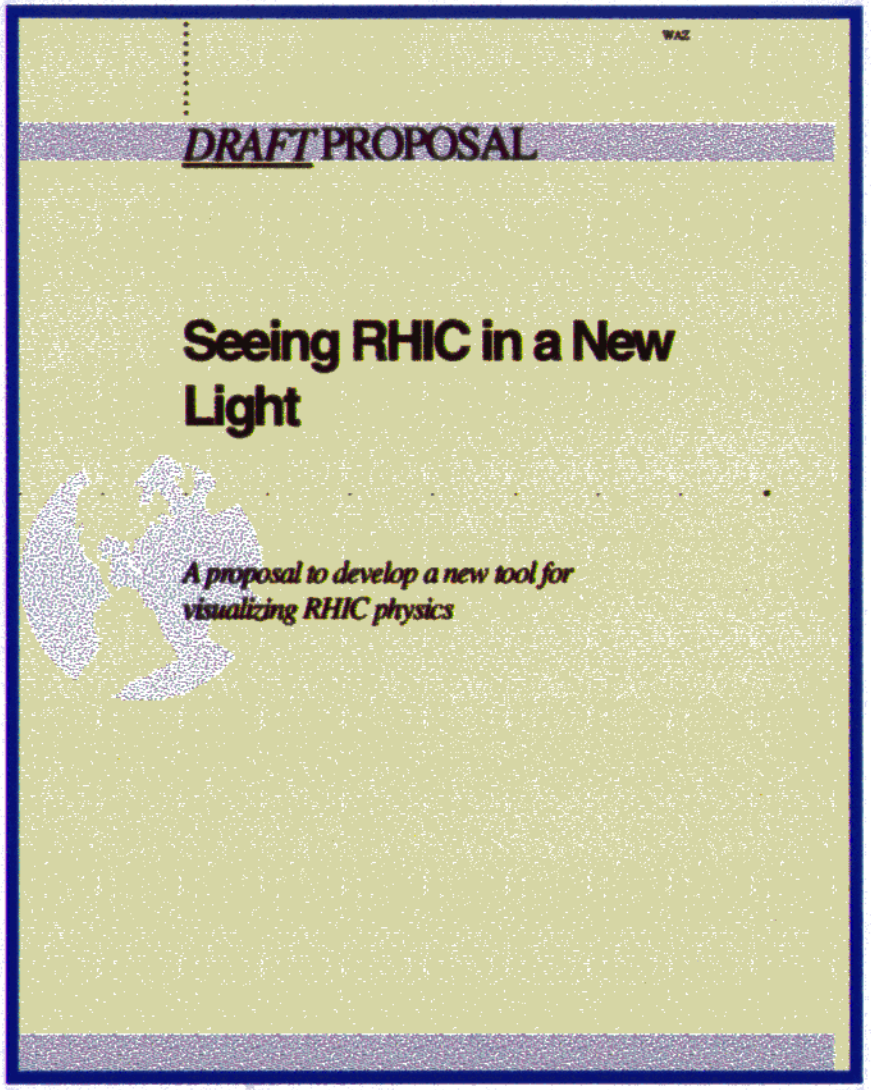
"Exotica"

- Spin physics
  - Not exotic at all
  - Fundamental
  - An integral part of the program
- Peripheral production
  - $\gamma\gamma$
  - γp
  - pp
- CP violation in hot QCD
  - Again, fundamental
  - Again, directly related to program

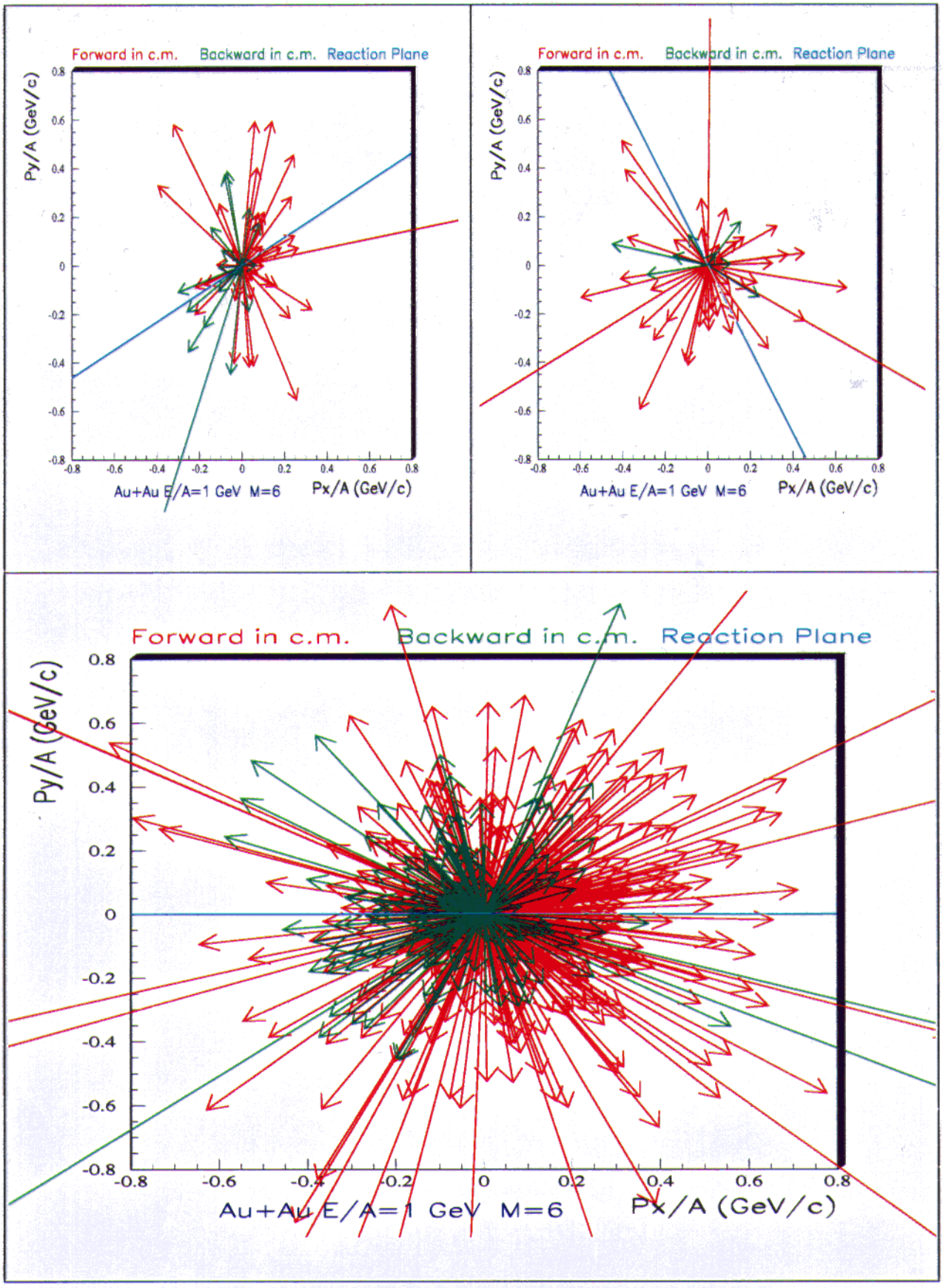
➨ An embarrassment of RHIChes

Wanted

- RHIC data are
  - complex
  - intrinsically different from p-p data
    (Many particles in *phase* space)
- ➡ We need much better tools for *visualizing* these data to understand
  - Time evolution
  - Lorentz properties
  - Flow
  - ...
- Also a *critical* feature of effectively communicating results to larger community



EVENTWISE SIDEWARD FLOW AT 1 AGeV

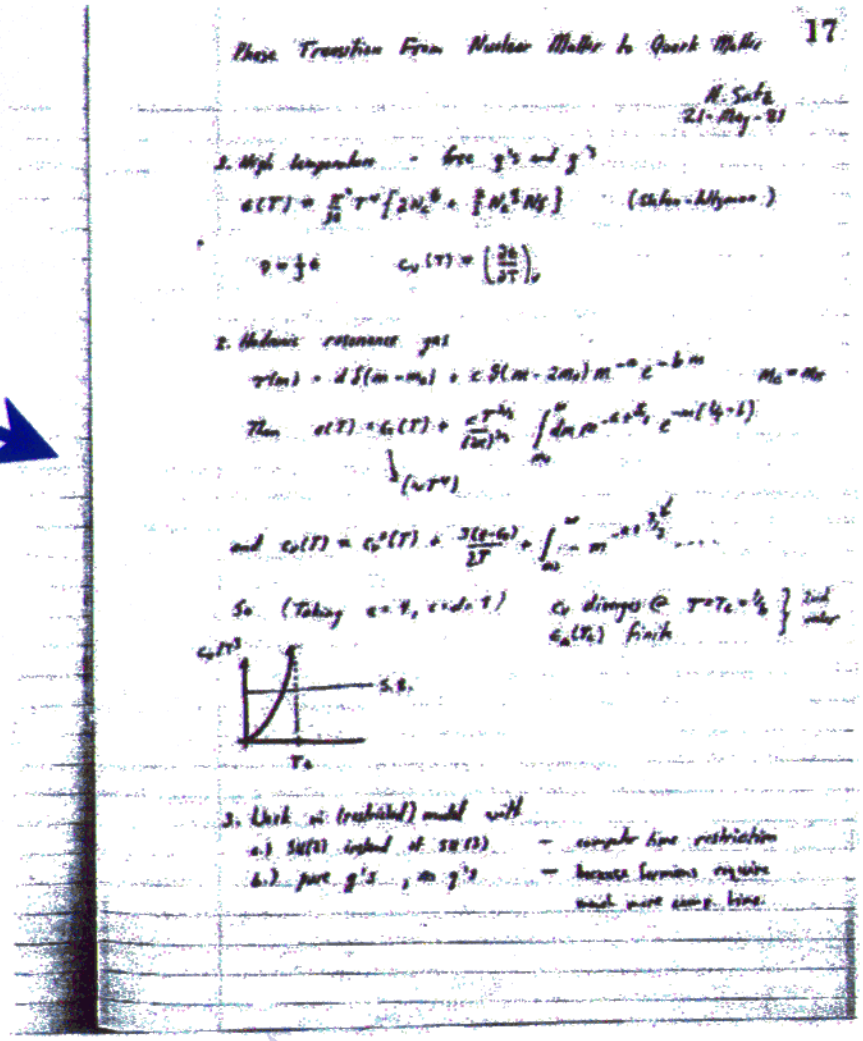


(EOS)

Ancient History

The interest in "RHIC" physics has been with us for some time:

E.g., from *5th High Energy Heavy Ion Study*, May 18-21, 1981 (LBL).



- ***BUT***, in 1981:
  - Limited opportunity to test experimentally
  - Limited community
  - Limited analyses

Closing Thoughts

- This is the last RHIC Winter Workshop without RHIC data!

- It's not the start of a new machine--
- It most definitely is the start of a new era:
  - In "nuclear physics" at BNL
  - In the exploration of QCD in statistical systems
  - In investigations of the spin structure of the proton
  - In study of exotica

- Many many thanks to Nu Xu for his efforts in organizing this meeting.