Suppression of High-$p_\perp$ Hadron Production in Au+Au Collisions @ RHIC

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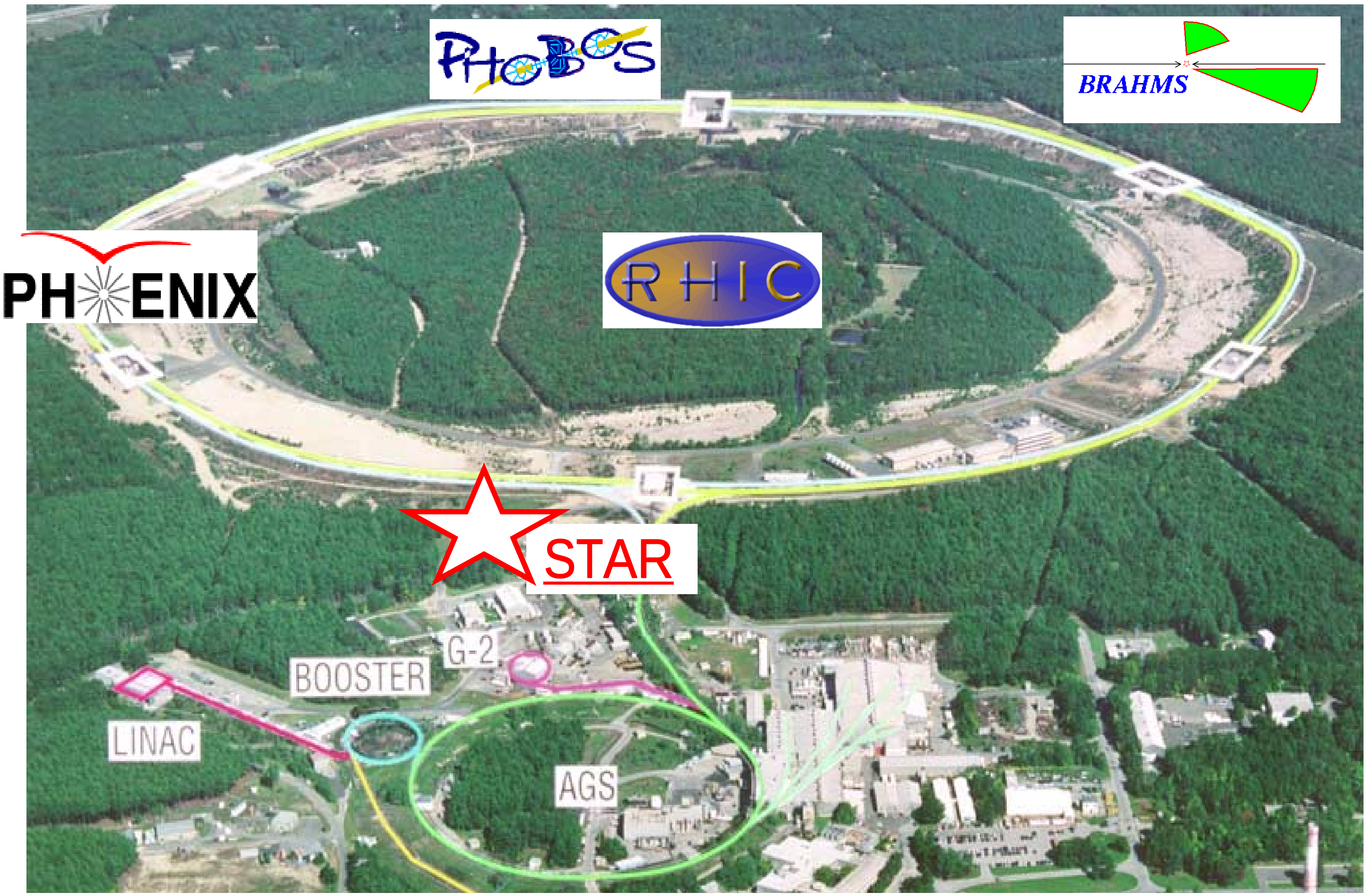
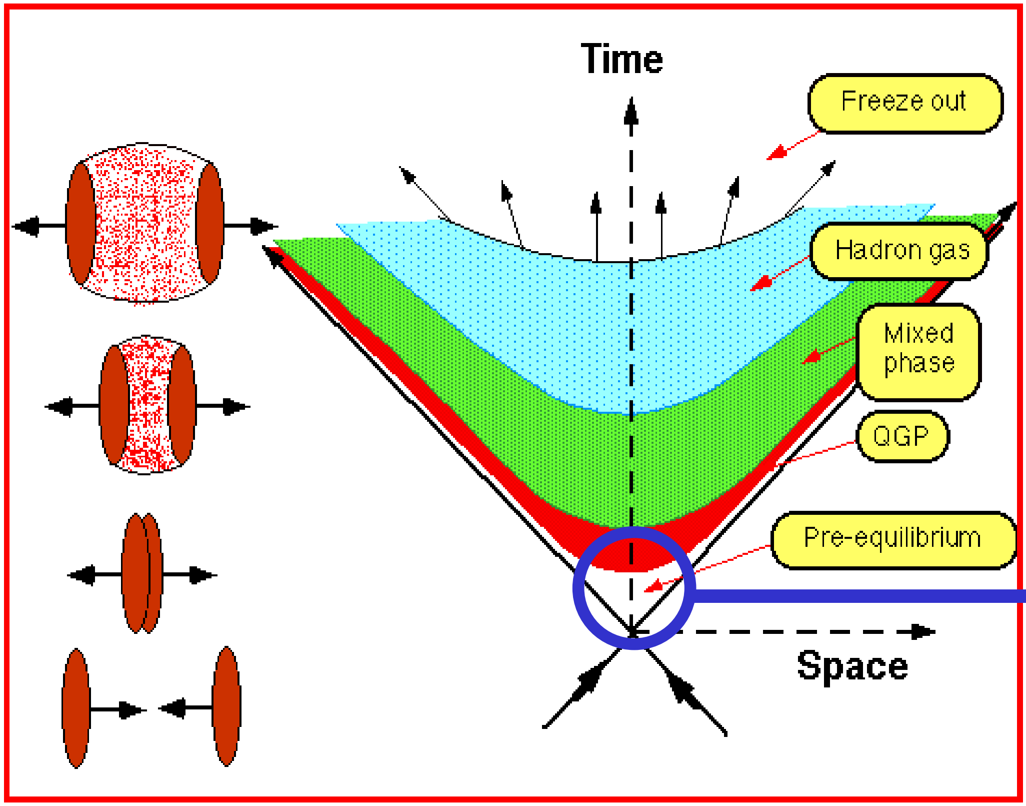
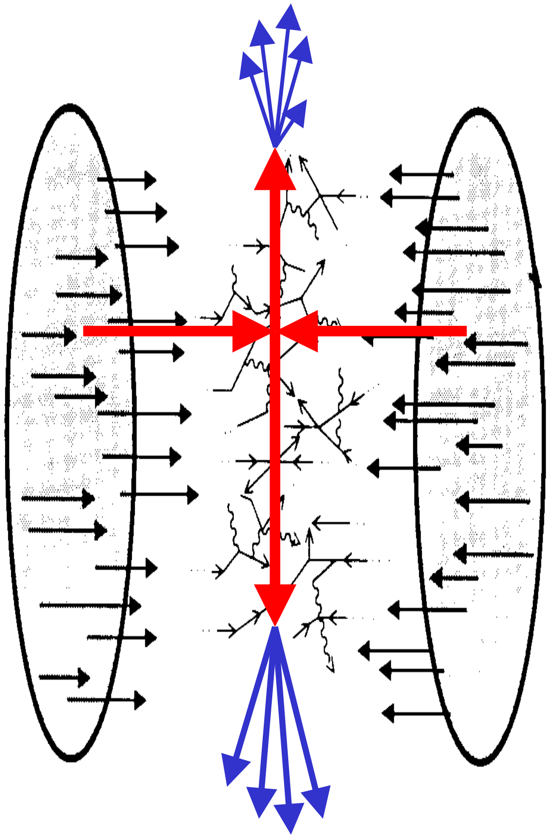


Probing Initial Conditions @ RHIC

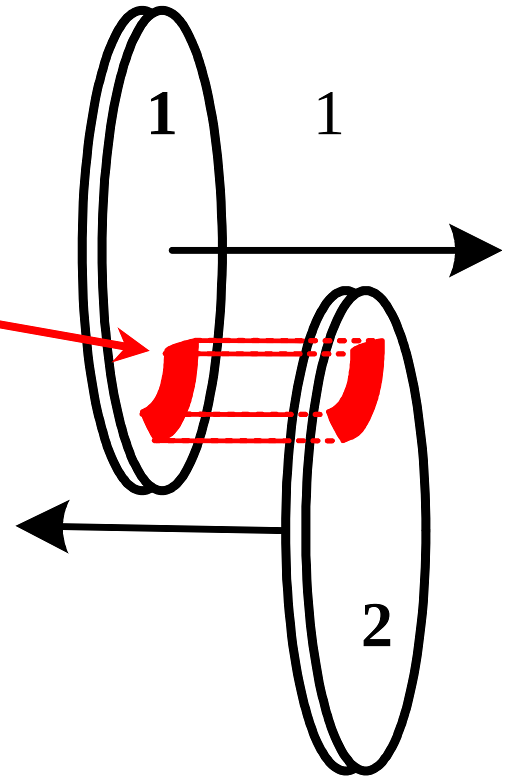
- Initial conditions due to semi-hard gluon radiation.
- Use hard-scattered quarks/gluons to probe early times
  - On shell even before the gluons.
  - Measure the fragmentation products ⇒ high-p_T hadrons
  - Above p_T = 2 GeV/c, hard production expected to dominate.





A-A Hard Interaction Phenomenology

- Assume (for moment) same parton distributions in nucleon and (Au) nucleus.
- Consider differential area *dA* in transverse plane of the collision.



- $\eta_{1/2} \equiv$ (area) density of nucleons in *dA*,
- # nucleon-nucleon collisions (N_{nn}) in *dA*
  - $dN_{nn} = dA\,\eta_1\eta_2\,\sigma_{nn}$
- # hard collisions (N_{hard}) in *dA*
  - $dN_{hard} = dA\,\eta_1\eta_2\,\sigma_{nn}^{hard} = dN_{nn}\left[\frac{\sigma_{nn}^{hard}}{\sigma_{nn}}\right]$
- After integrating over *dA*,
  - $N_{hard} = N_{nn}\left(\sigma_{nn}^{hard} / \sigma_{nn}\right)$
  - Obtain N_{nn}

Neglects

- Cronin effect (+)
- Shadowing (-) / EMC (+/-)
- "Gluon saturation" (-)
- "Collective" effects (+ ?)
- Medium induced radiation (-)

PHENIX Pioneering High ENergy Ion eXperiment

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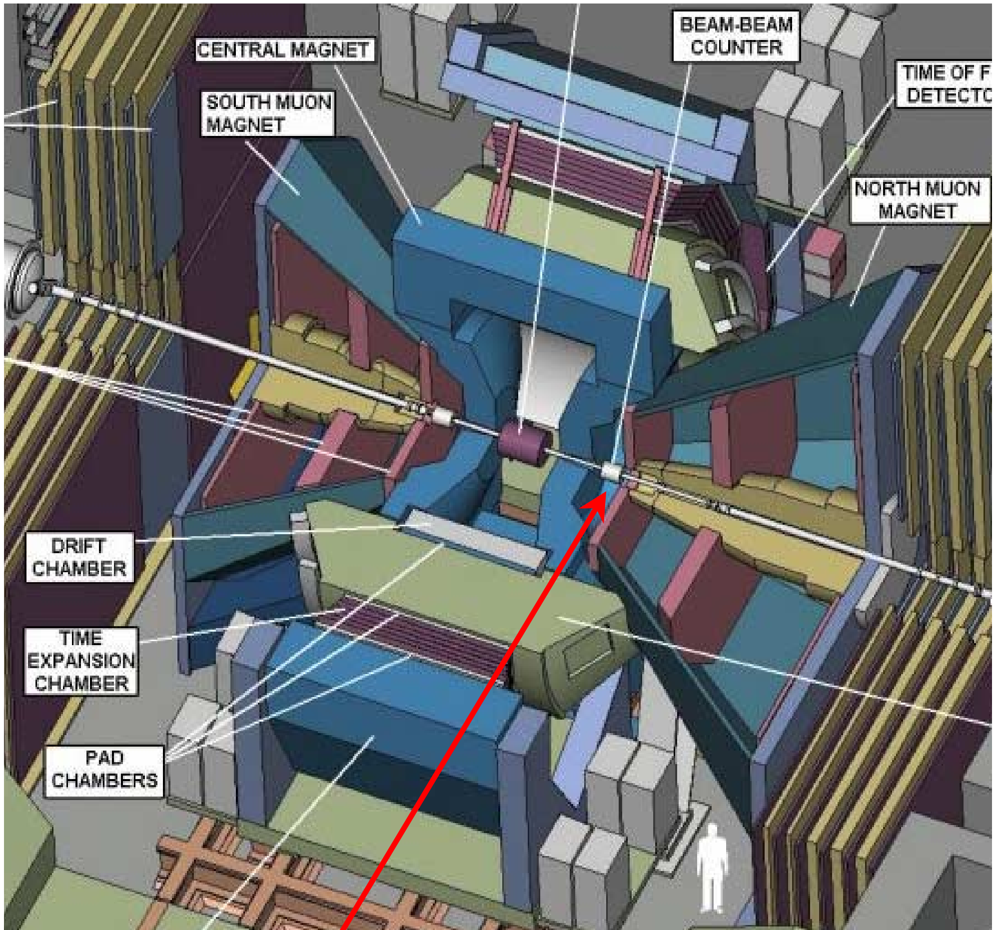
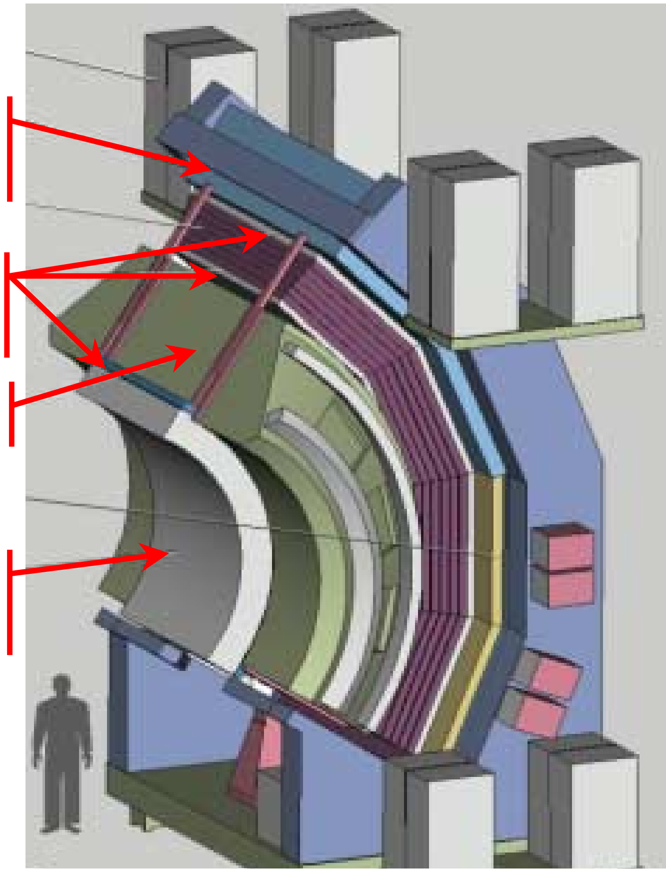
PHENIX Experiment @ RHIC



Central Arms



EM Calorimeter

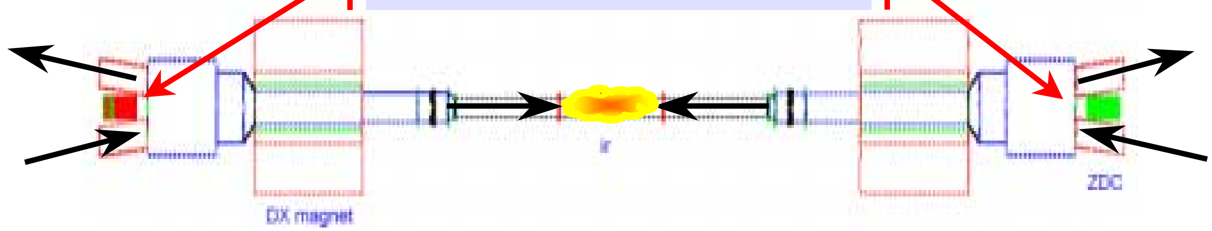
Pad Chambers

RICH

Drift Chamber

Beam-Beam Counters

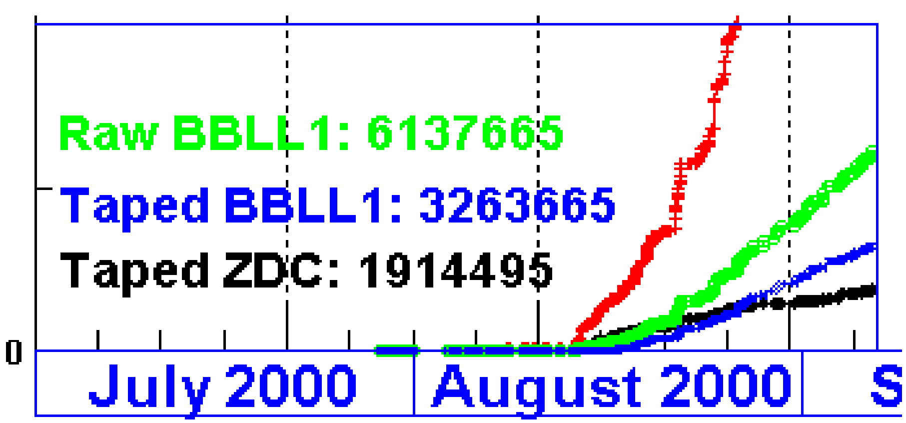
Zero degree calorimeters

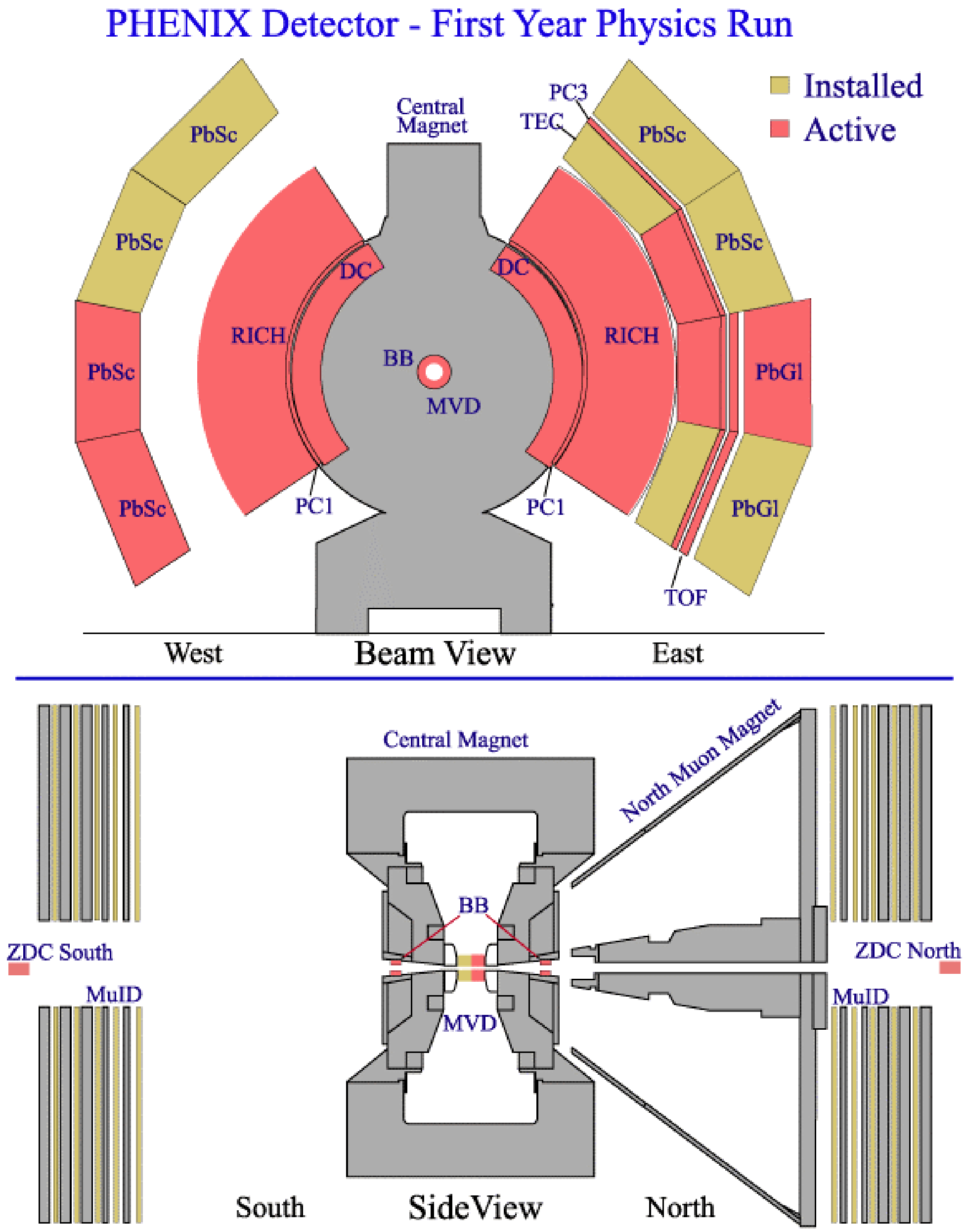


Centrality Detectors

PHENIX Run-1 Operation

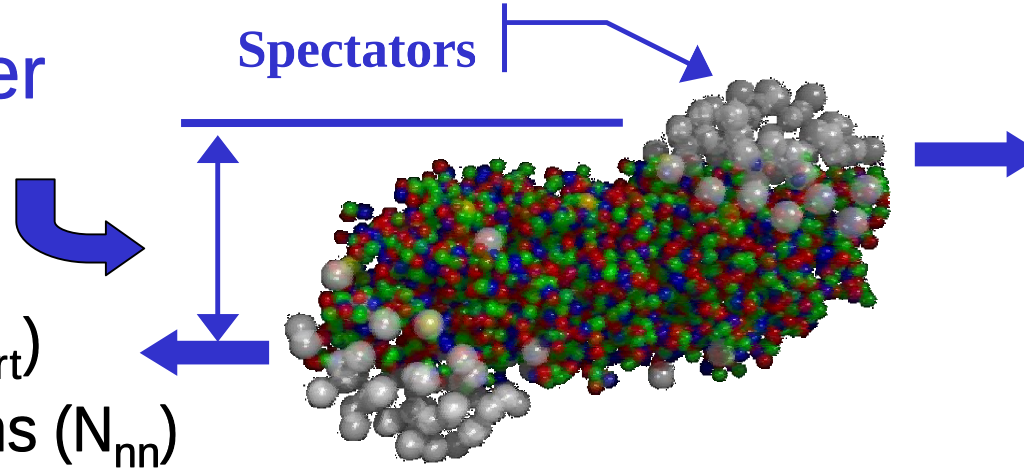
- RHIC operation
  - Au+Au @ $\sqrt{S_{NN}}$ = 130 GeV
  - Attained ≈ 10% of design L
- PHENIX operation
  - ~ ½ central arms active
  - Beam-beam trigger
    - Accepts 92 ± 4% of σ_{hadr}
    - 3.2 million events recorded
    - ≈ ½ with $|\Delta z| \leq$ 20 cm



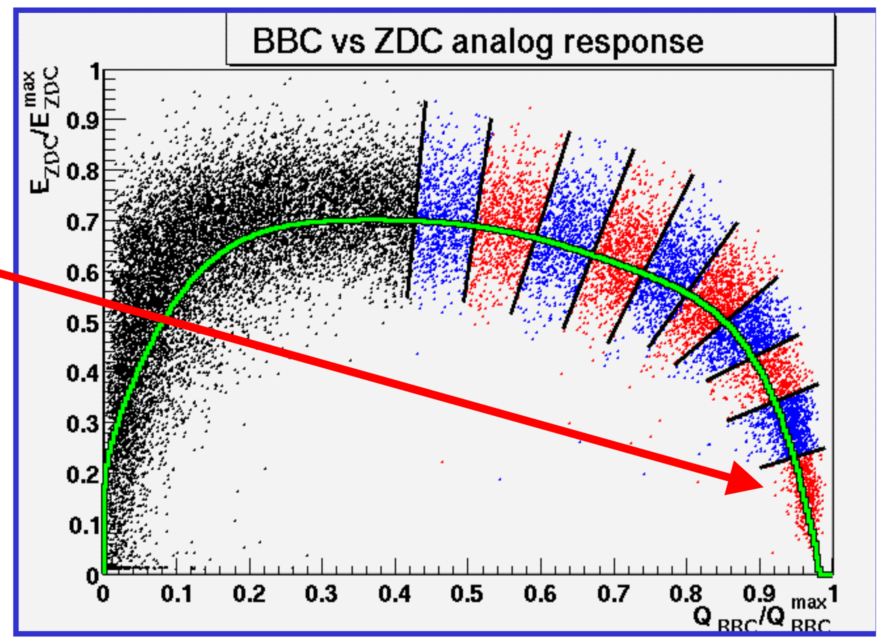


Event Characterization

- Collision impact parameter determines “everything”
  - Nuclear overlap
  - # participant nucleons (N_{part})
  - # nucleon-nucleon collisions (N_{nn})

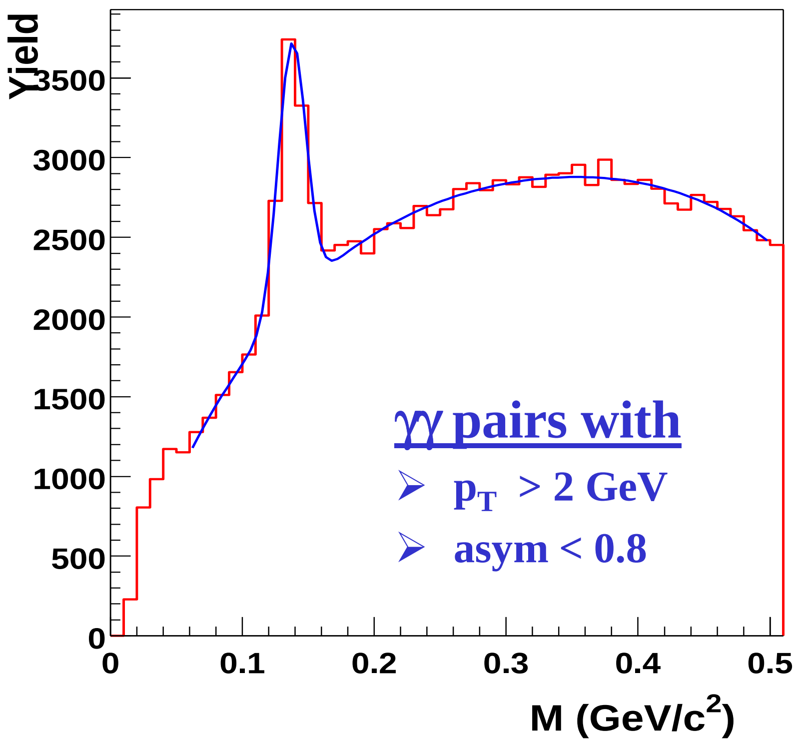


- Plot E_{ZDC} vs Q_{BBC}
  - Follow the “ridge”
- Classify by fraction of σ_{hadr}
  - e.g. 0-5% $\Rightarrow$ 5% of σ_{hadr} with smallest impact param’s
- To determine $\langle N_{nn} \rangle$
  - Relate Q_{BBC} to N_{part}
  - Use nuclear geometry to relate # participants to N_{nn}

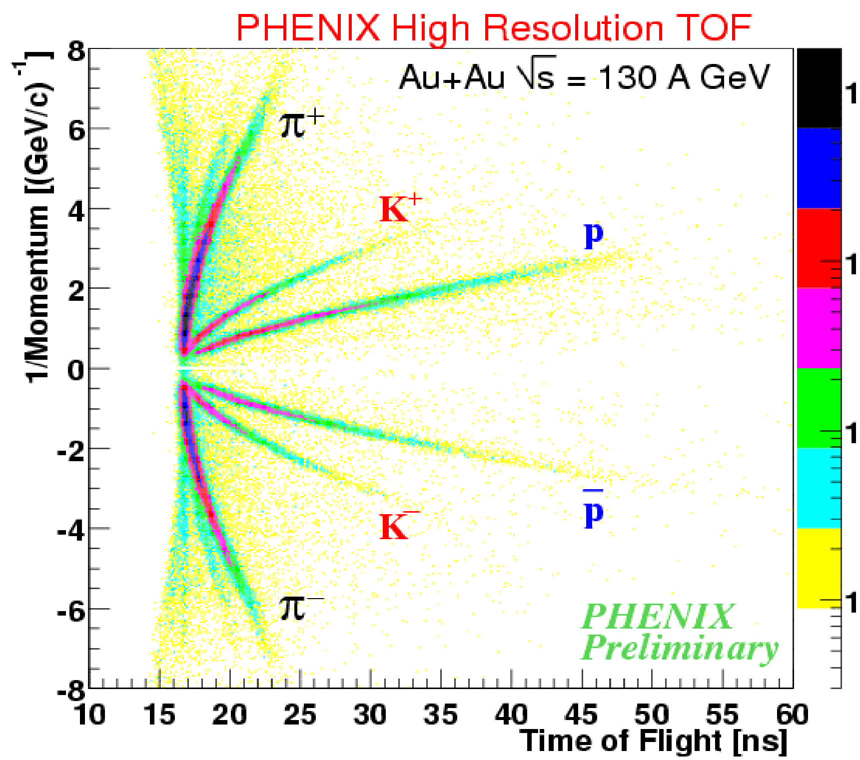


Hadron Identification in PHENIX

- $\pi^0 \rightarrow \gamma\gamma$ reconstruction with electromagnetic calorimeter.
  - Statistical identification in A-A.
  - S/B increases with p_T.
  - π^0 identification for p < 20 GeV/c.
  - EMCal energy scale error < 1.5%.

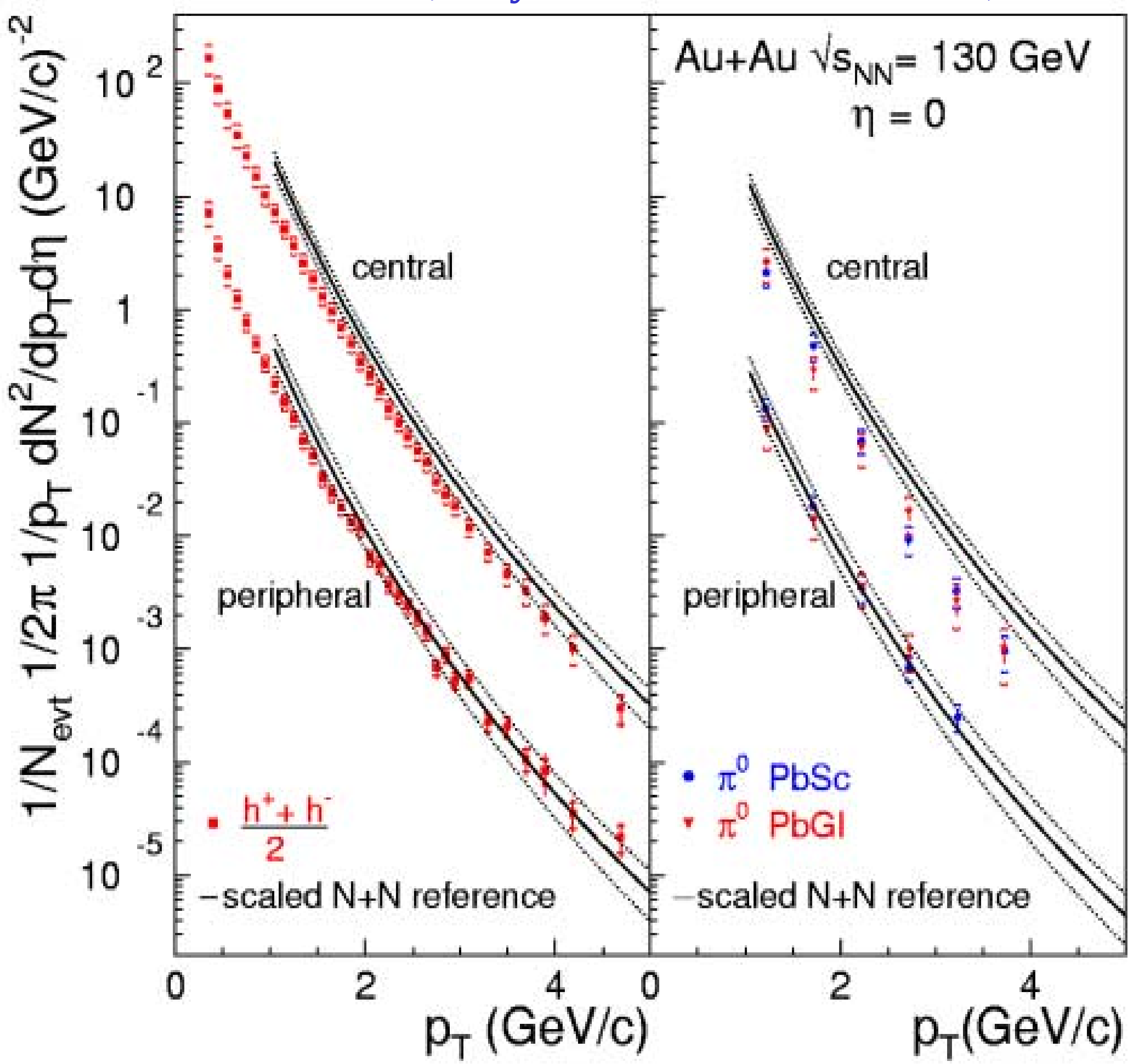


- Charged particle tracking
  - $\delta p/p = 0.6\% \oplus 3.6\%$ p.
- $\pi^\pm$, $K^\pm$, p, p-bar via time-of-flight
  - $\sigma_{TOF} \approx$ 115 ps over ~ 5m path.
  - $\Rightarrow$ π identification for $p \leq 2.5$ GeV/c.
  - $\Rightarrow$ p/p-bar identification. for $p \leq 4$ GeV/c.



High-p_T Hadron Production

K. Adcox *et al.*, Phys. Rev. Lett. 88:022301, 2002



First published high-p_T data @ RHIC

- Peripheral
  - 60-80%
  - $\langle N_{nn} \rangle = 20 \pm 6$
- Central
  - 0-10%
  - $\langle N_{nn} \rangle = 905 \pm 96$
- Consistency check on π^0 data.
- Compare with N_{nn} scaling of p(bar)-p:

$$\frac{1}{N_{event}} \frac{d^2 N_{AA}}{dy\, dp_T^2} = \frac{\langle N_{nn} \rangle}{\sigma_{total}} \frac{d^2 \sigma_{nn}}{dy dp_T^2}$$

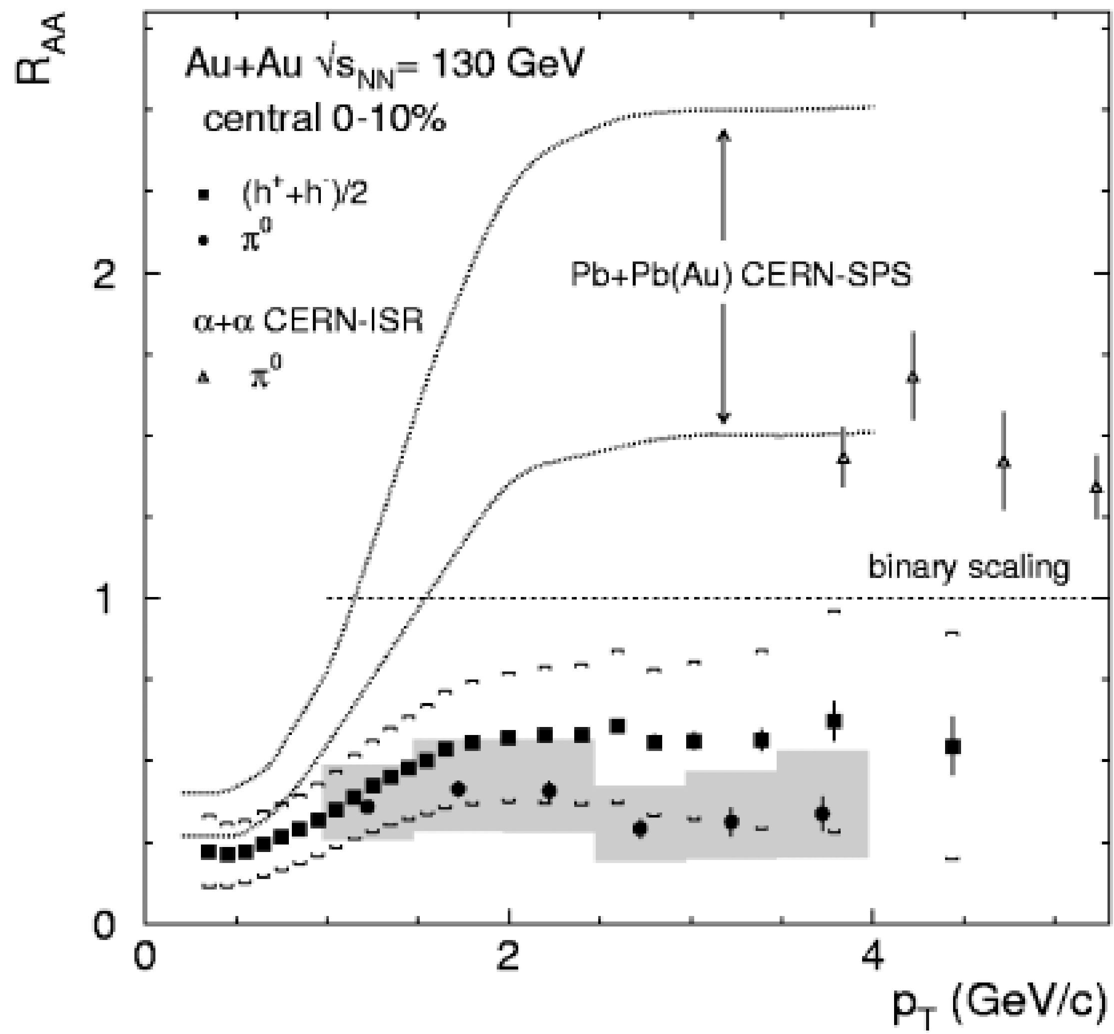
"Suppression" at High-p_T

- Nuclear modification factor

$$R_{AA} \equiv \frac{\dfrac{1}{N_{event}} \dfrac{d^2N_{AA}}{dy\,dp_T^2}}{\dfrac{\langle N_{nn} \rangle}{\sigma_{total}} \dfrac{d^2\sigma_{nn}}{dy\,dp_T^2}}$$

- $R_{AA} << 1$ for $p_T < 1$
  - $\Rightarrow$ soft production
- For $p_T > 2$ GeV/c
  - Hadron $R_{AA} \rightarrow 0.6$
  - π^0 $R_{AA} \rightarrow 0.4$
- Systematic errors include
  - Normalization
  - Uncertainty on N_{nn}
  - p(bar)-p interpolation to 130 GeV

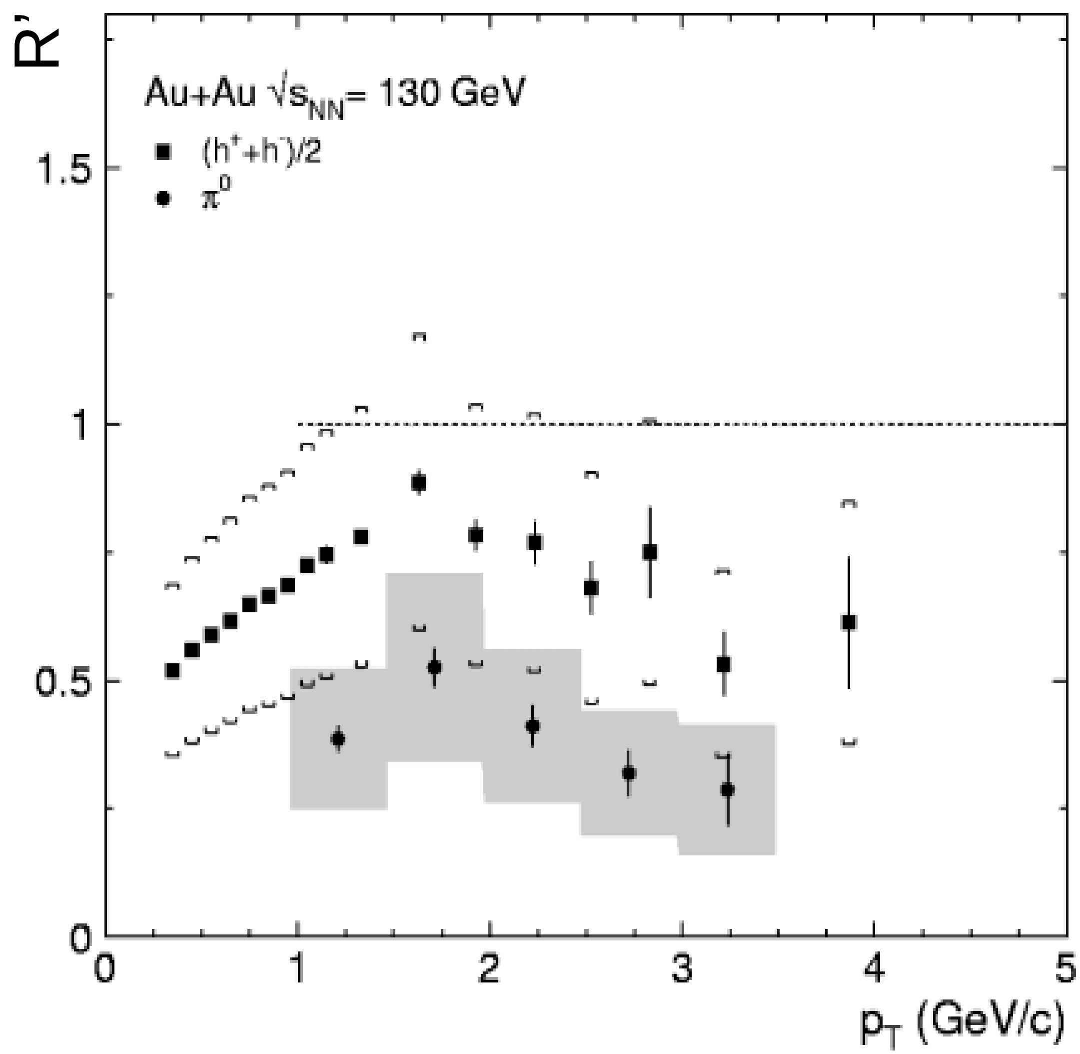
K. Adcox *et al.*, Phys. Rev. Lett. 88:022301, 2002



Suppression: Another Approach

- Compare peripheral and central Au+Au data
  - –Different systematics than above comparison to p(bar)-p.
- Define ratio (R')

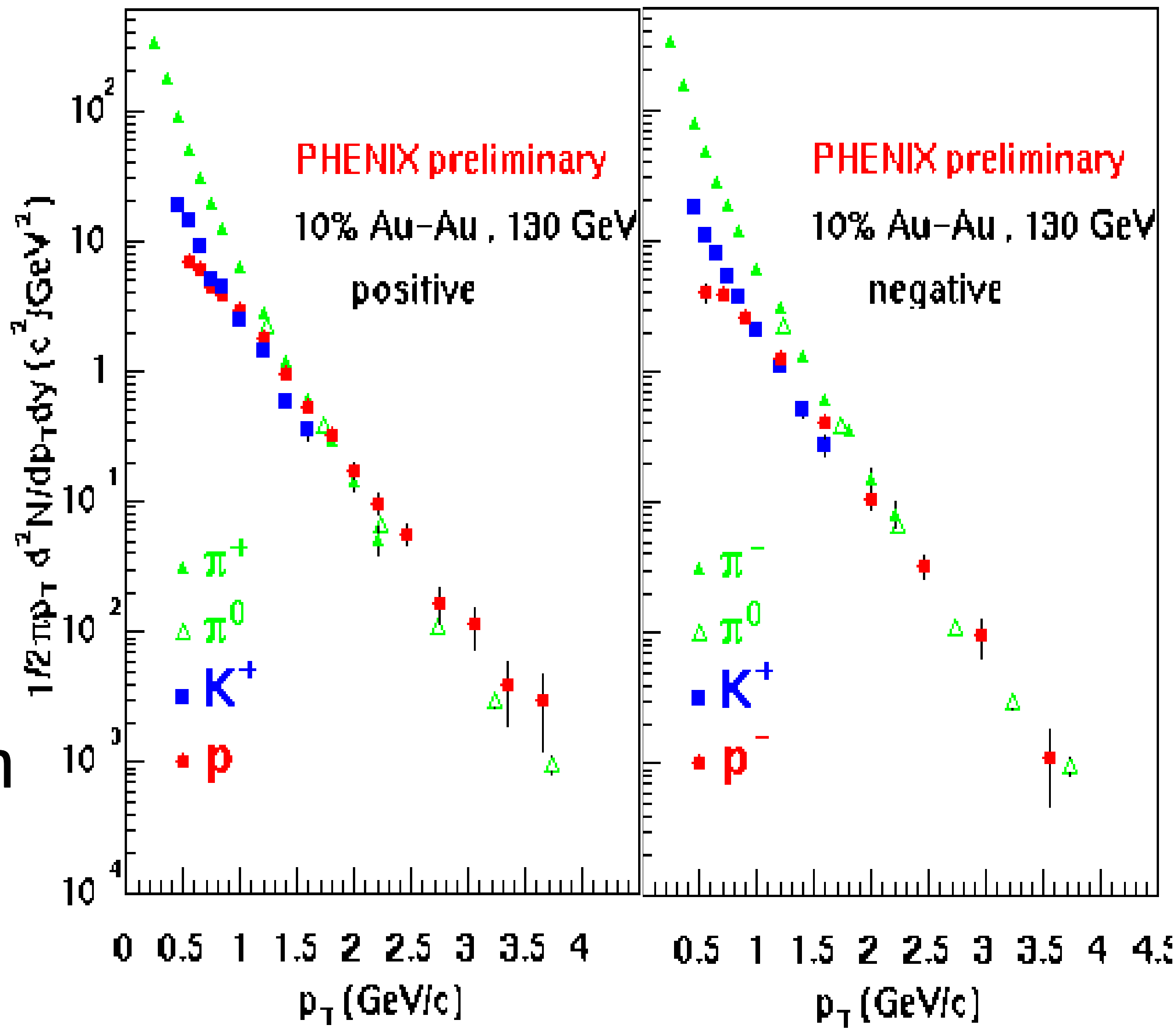
$$R' = \frac{\langle N_{nn} \rangle^{periph}}{\langle N_{nn} \rangle^{cent}} \frac{\frac{d^2 n^{cent}}{dy dp_T^2}}{\frac{d^2 n^{periph}}{dy dp_T^2}}$$



- Similar observations as above:
  - Even within Au-Au data, high-p_T yields don't scale with N_{nn}
  - Larger deviation for π^0
  - Also more significant.

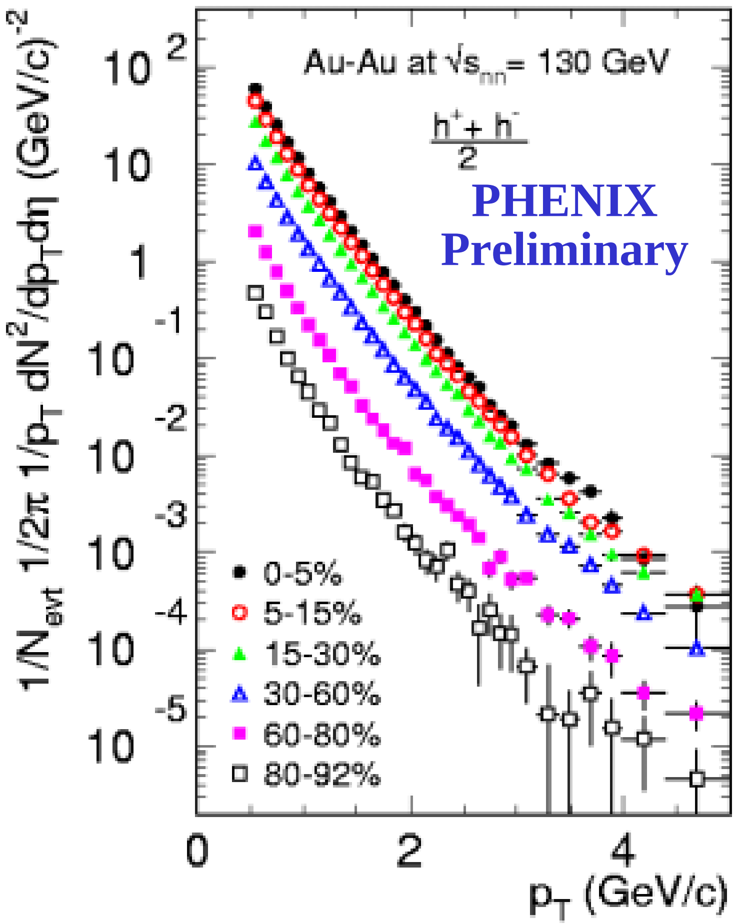
Hadron Composition at High-p_T

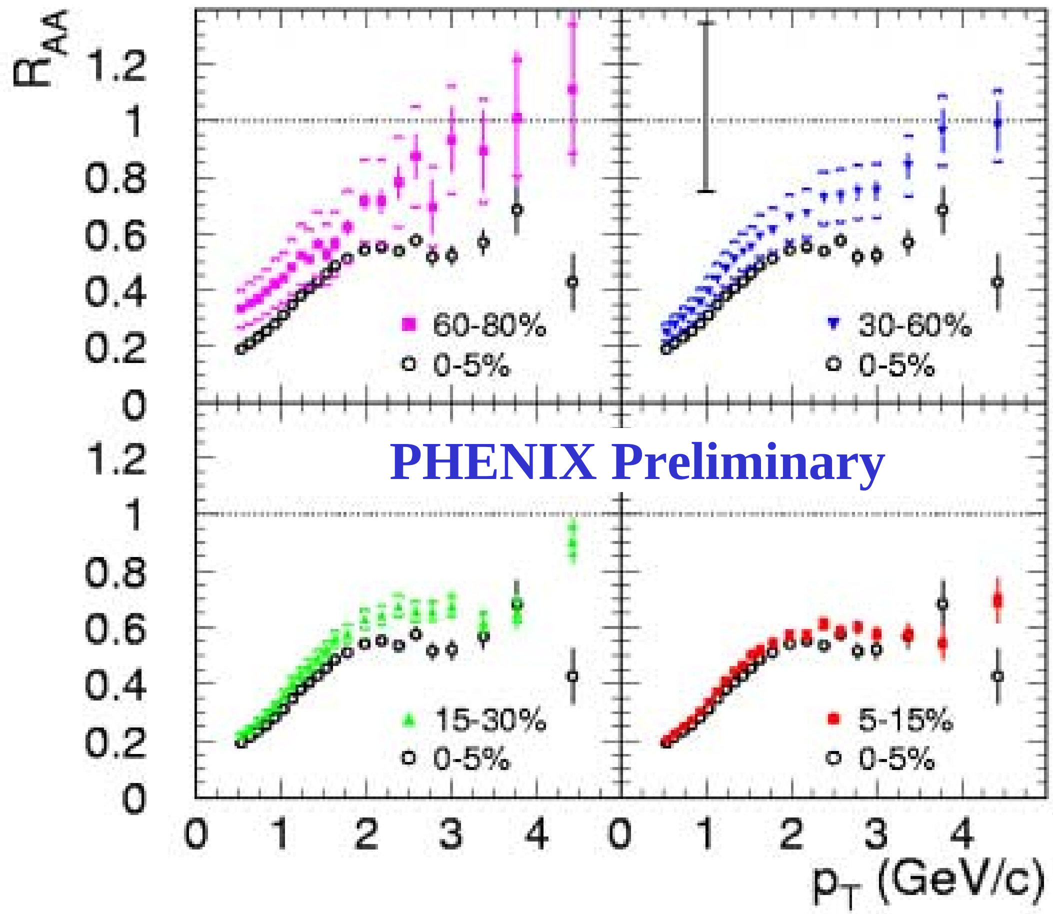
- Why the difference between hadrons and π^0's ?
- Look at hadron composition.
- Observe
  - $\pi^{\pm}$, π^0 consistent
  - Large p & p-bar contribution.
  - p(bar) yield > π @ p_T > 2 GeV / c.
- High p_T p(bar)'s thought to be from non-pert. sources.
  - "Background" to the hard physics.



Chg'd Hadrons -- Centrality Dependence

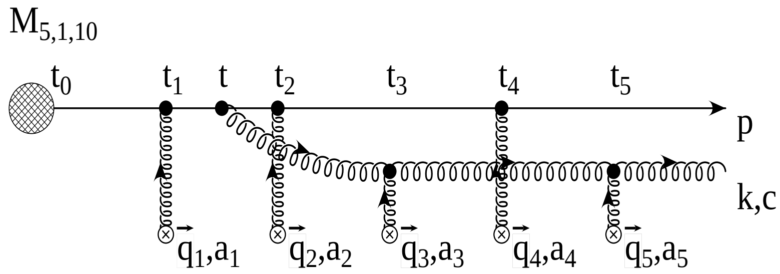
- In peripheral collisions $R_{AA} \rightarrow 1$ (where is the Cronin effect?)
- In more central collisions $R_{AA} \approx$ constant for $p_T > 2$ GeV/c.
  - $R_{AA} \rightarrow \approx 0.6$ (consistent with values above)
- Change in behavior in 30-60% centrality bin ?

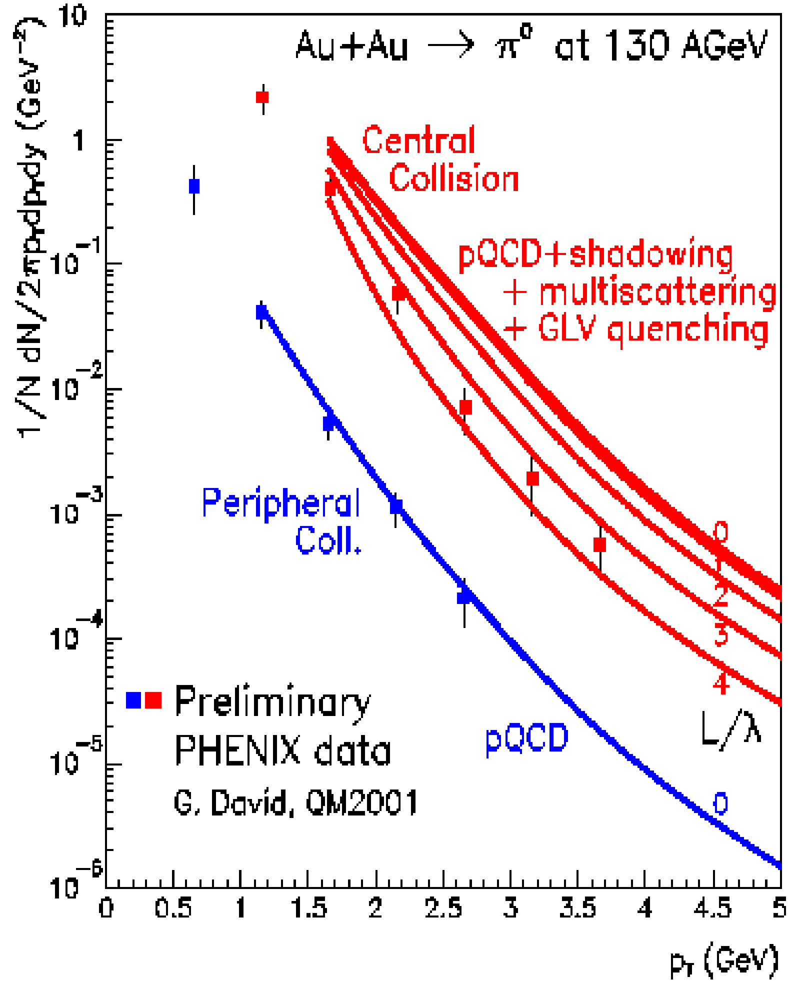




Why Suppression at High-p_T ?

- One possibility: medium-induced gluon radiation
  - Coherent multiple scattering of outgoing q/g
    - ➢ larger k_T gluons radiated.
  - Reduces outgoing q/g energy.
  - Reduces momenta of frag. products – high-p_T hadrons.
- E.g. Gyulassy, Levai, Vitev
  - Perturbative QCD calculation
    - ➢ LO + K_T (w/ A dep.) + shadowing
  - And calculation of gluon radiation for modest L/λ.





Not so fast ...

- ∃ other possible reasons for high-p_T suppression.
  - Shadowing.
    - We should be in a safe x range – $x > 2\ p_T\ /\sqrt{s} = 0.06$ for $p_T = 4$ GeV/c.
    - But radial dependence of shadowing/EMC hasn't been measured.
  - Initial state gluon saturation
    - Modification of gluon "density" & k_T in highly boosted nucleus.
  - Other violations of factorization
    - $g(x, Q^2)$ or $f(x, Q^2)$ aren't what we think they are.
- Experimentally
  - We have ~ 100 increase in statistics from Run-2 (2001).
  - We just took high-statistics p-p data set @ $\sqrt{s}$ = 200 GeV.
  - We will take d-A data in Run-3 (2002-2003).
- We haven't "discovered" anything yet.
  - We have & will continue to make careful measurements.

p-p Comparison Data

- Compilation of p(bar)-p charged-hadron data.
- Parameterize by power-law p_T dependence
  - $d^2N/dp_t^2 = A\,(p_0+p_t)^{-n}$
- Interpolate to 130 GeV
  - P_0 = 1.72 Gev/c.
  - n = 12.4.
  - A = 330 mb.
- Also π/h = 0.63 @ ISR
- Assign 20% systematic error on normalization of p-p d^2N/dp_t^2.

Analysis by A. Drees, Stonybrook