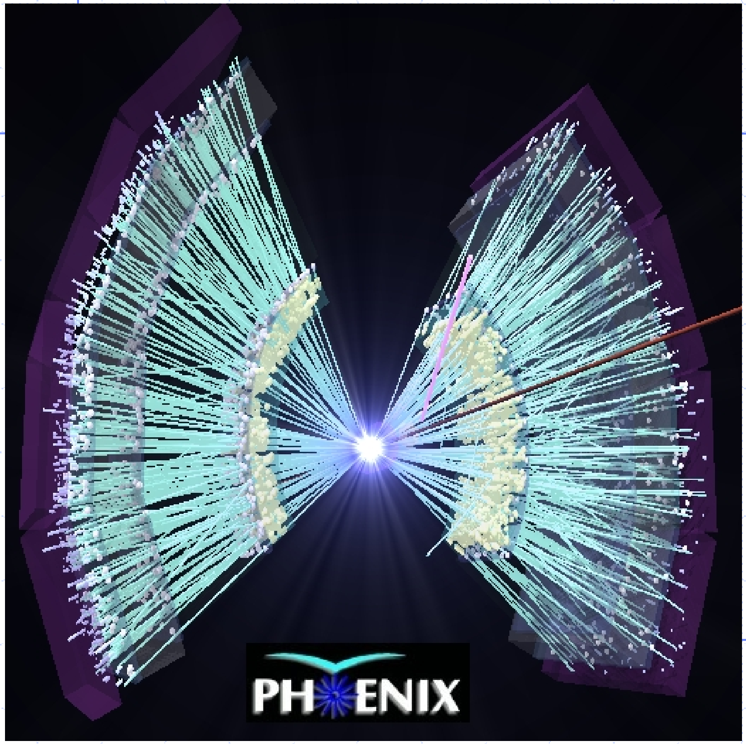
Study of Initial and Final State Effects in Ultrarelativistic Heavy Ion Collisions Using Hadronic Probes



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August 31, 2004

Ph.D Defense

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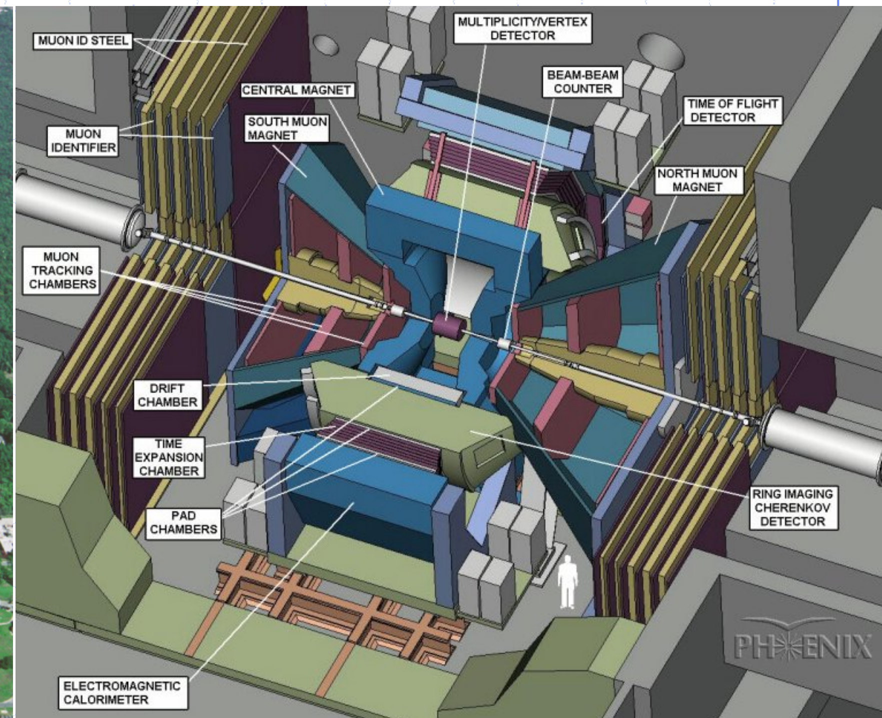
STATE UNIVERSITY OF NEW YORK

Relativistic Heavy Ion Collider (RHIC) Pioneering High Energy Nuclear Interaction eXperiment (PHENIX)

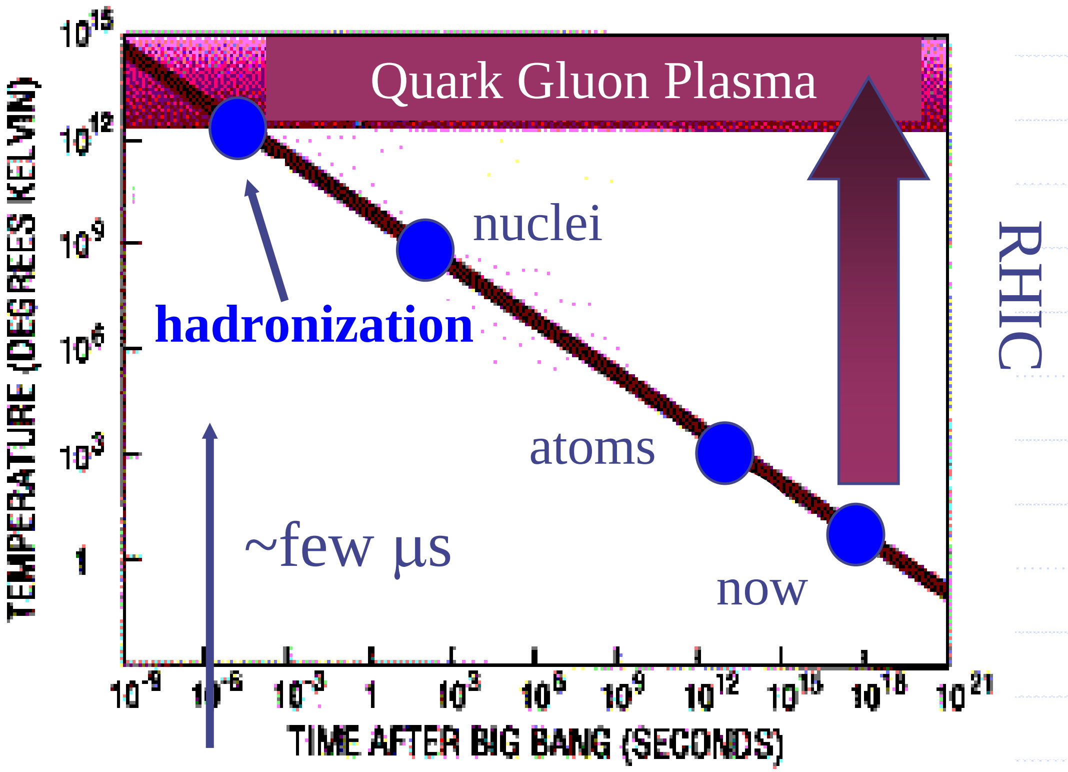


- **2 counter-circulating rings, 3.8 km circumference**
- **Any nucleus on any other.**
- **Top energies (each beam):**
  - **100 GeV/nucleon Au-Au.**
  - **250 GeV polarized p-p.**

- **Maximal Set of Observables**
  - **Photons, Electrons, Muons, ID-hadrons**
- **Highly Selective Triggering**
  - **High Rate Capability.**
  - **Rare Processes.**

Aim: To study nuclear matter under extreme conditions

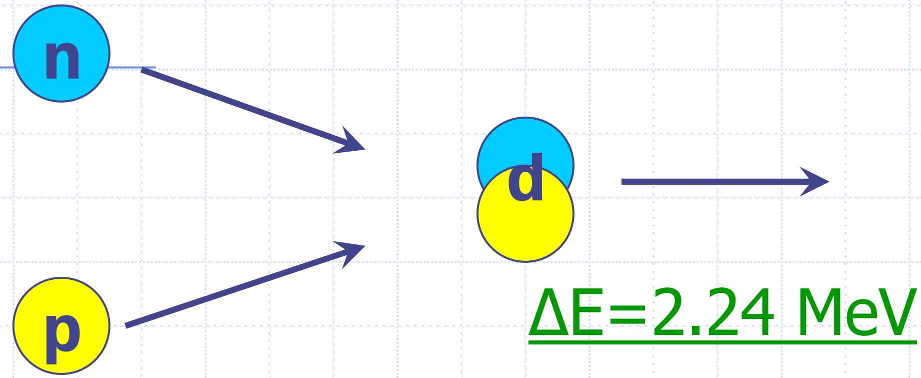
- Create a hot region of high initial energy density: $\varepsilon_0 \sim$ few GeV/fm^3.
- Quarks and gluons are expected to deconfine.
- Eventually recombine into hadrons (hadronization).



Two parts of dissertation:

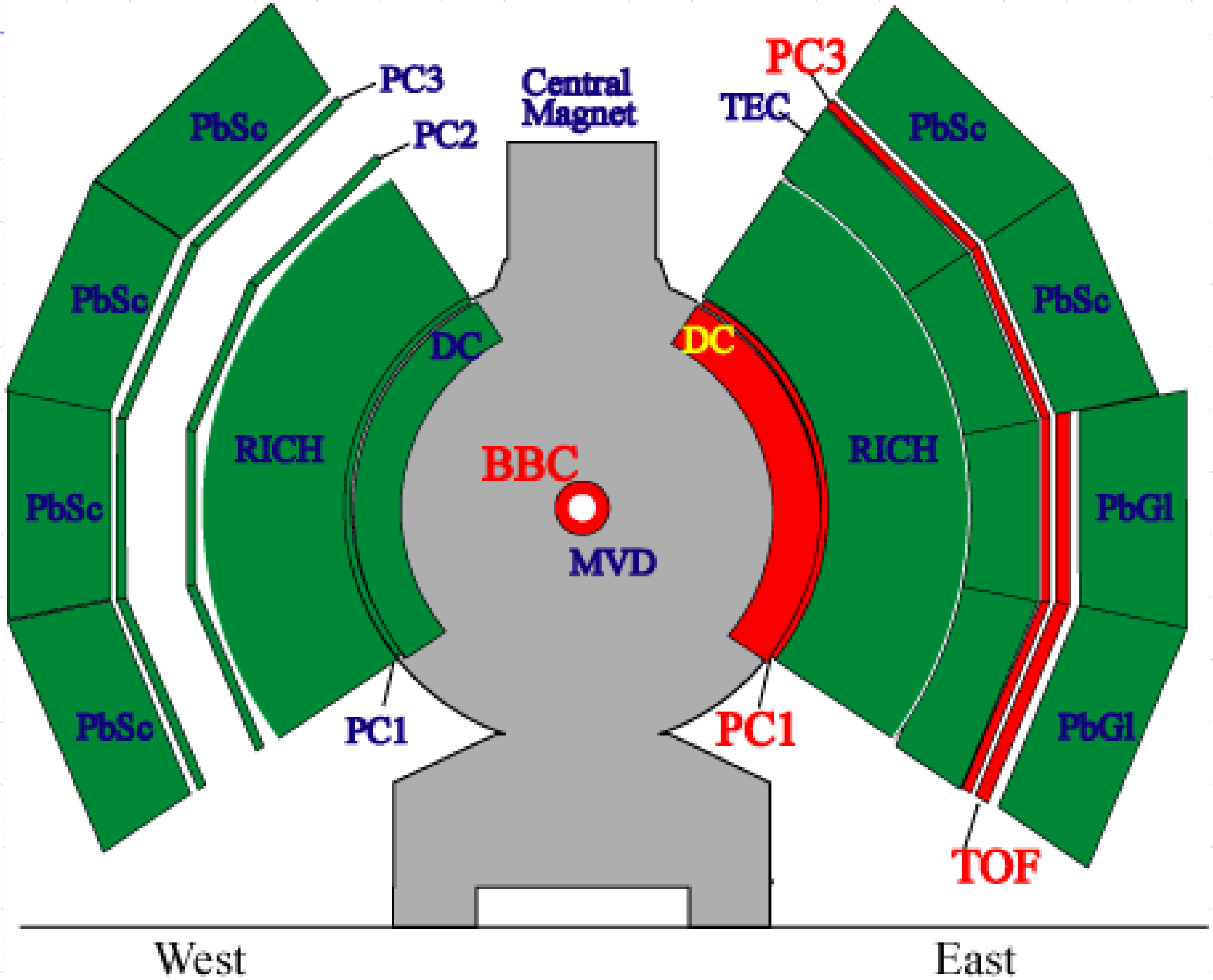
1. Study the final state of produced matter in Au+Au collisions by looking at the production of deuterons/anti-deuterons.
2. Study the initial conditions that led to this by looking at the nuclear modification factor R_{CP}

Formation of light nuclei

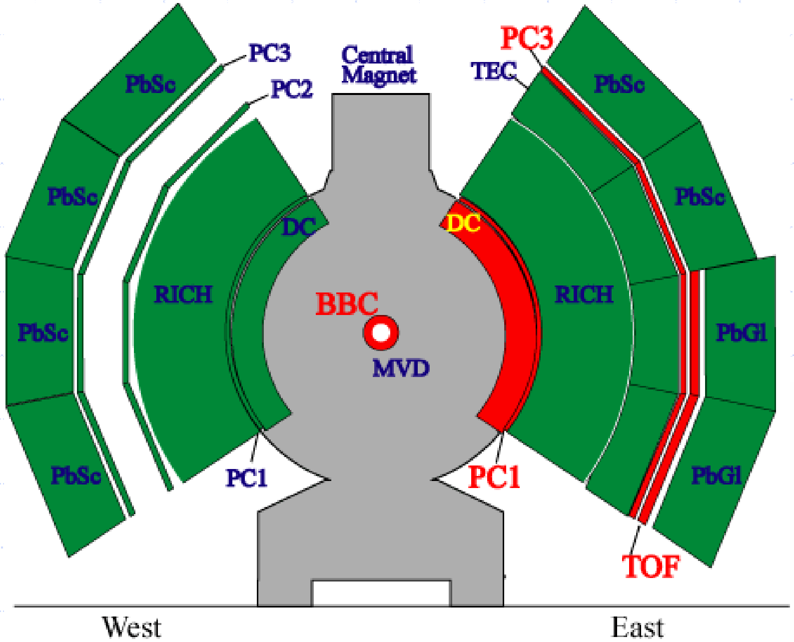


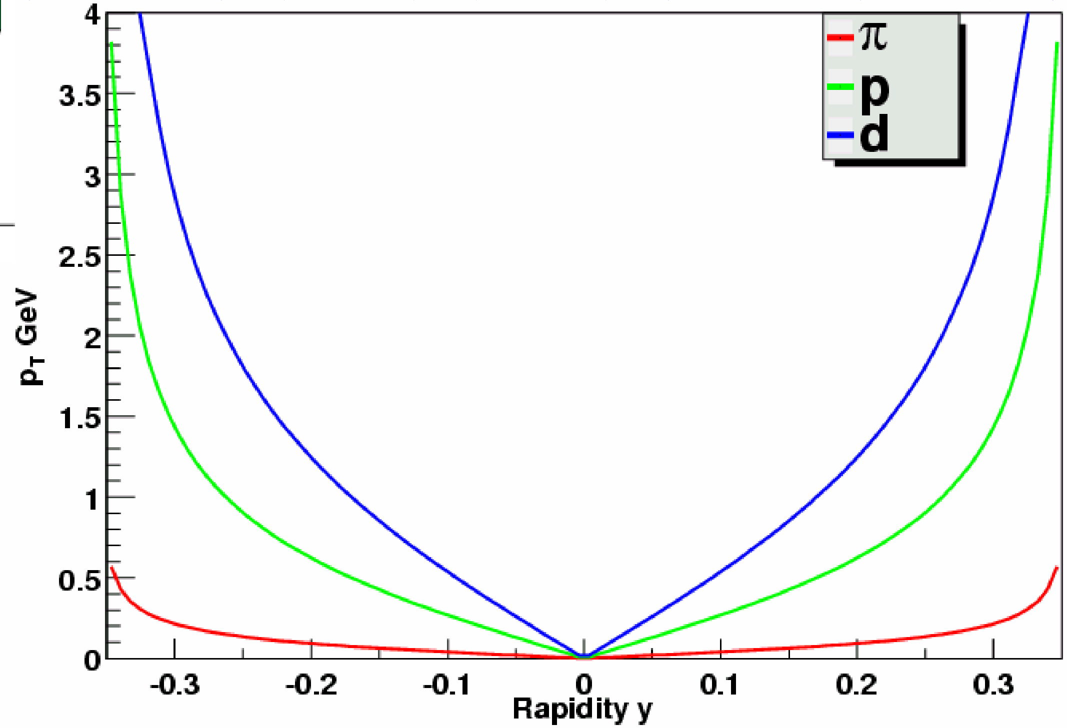
- Deuteron is loosely bound state
- Requires p, n to be closely correlated in space and momentum.
- Proportional to phase space densities of nucleons.
- Information of size and space-time evolution of the system.

The PHENIX Detector (Run 2)



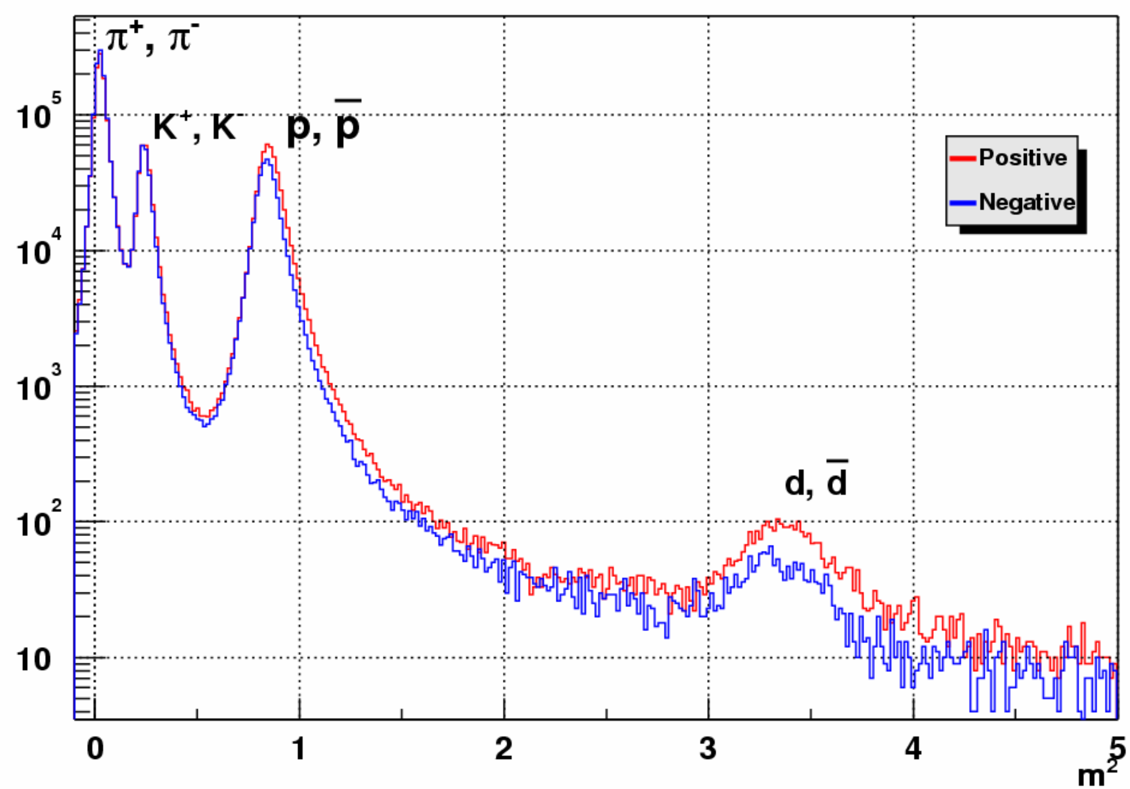
Acceptance for different particles





m^2 bands

- Using momentum p from Drift Chamber and time t from TOF, we can identify particles on basis of mass.
- Mass squared given by:

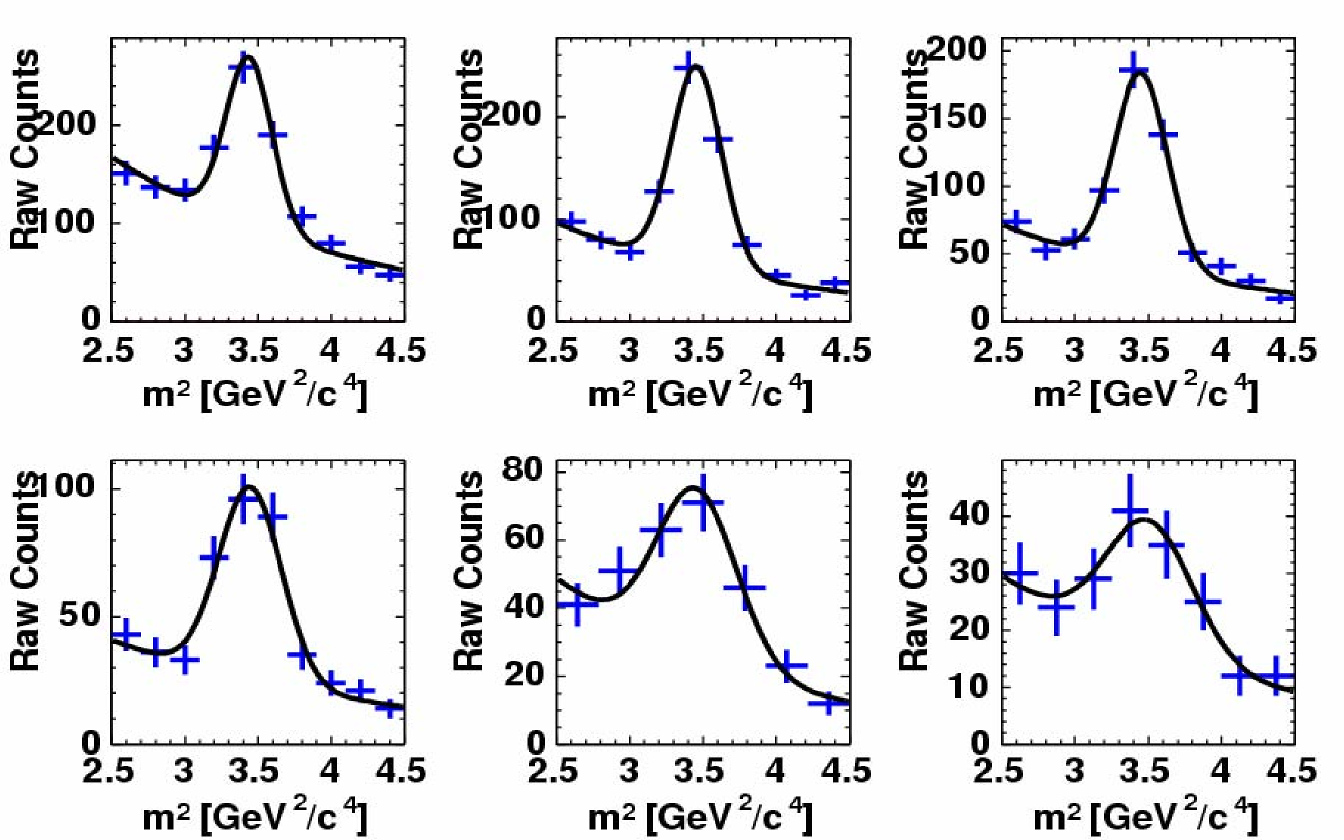


$$m^2 = p^2\left(\frac{t^2c^2}{d^2} - 1\right)$$

Particle Identification

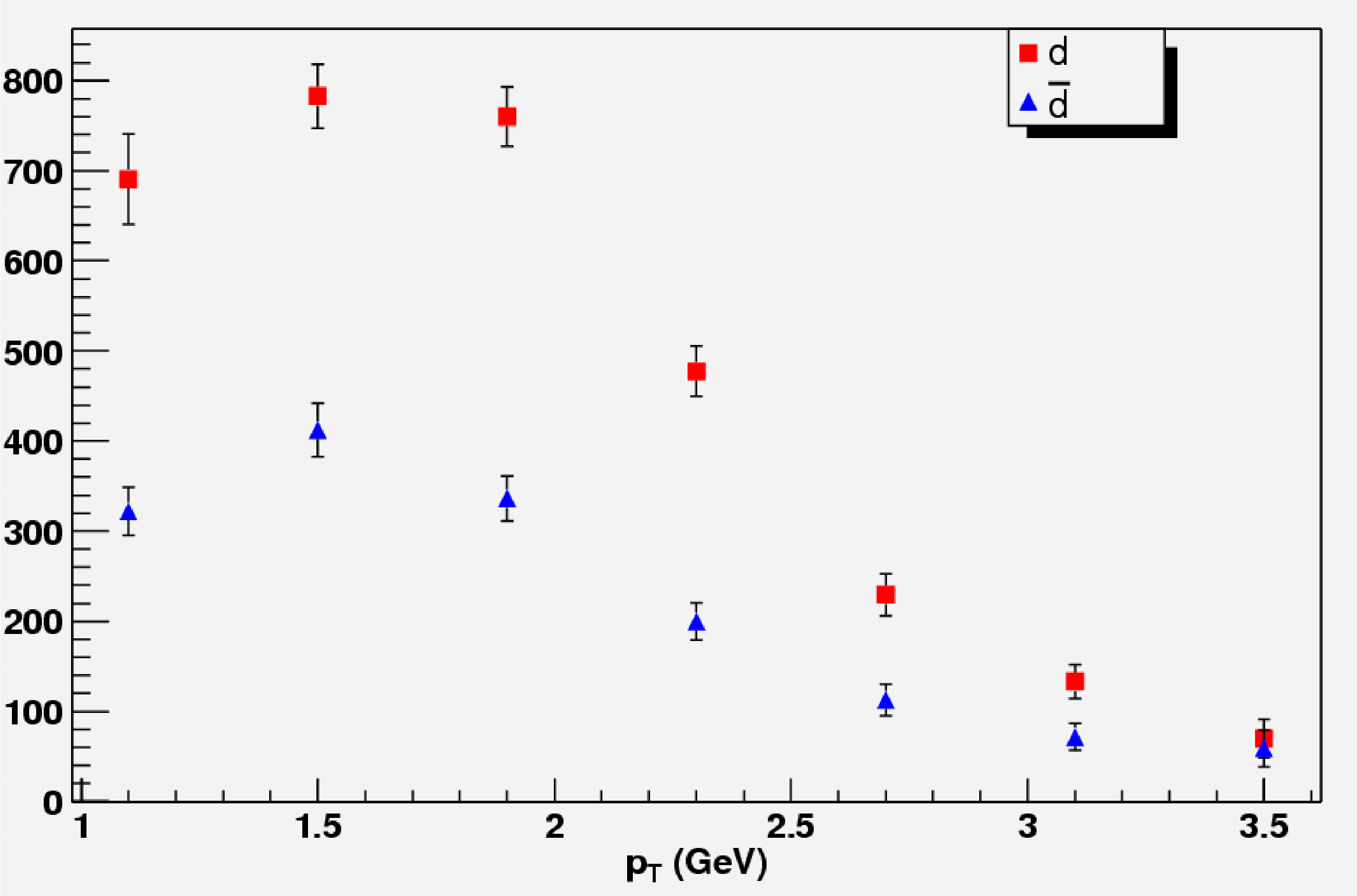
- Fit gaussian + background (e^{-x} or $1/x$)

$$\frac{N_d}{\sqrt{2\pi\sigma_d}}\exp(-\frac{x^2}{2\sigma^2})$$



Raw Yields

- 21.6 million minimum bias Au+Au events



Corrections

- Acceptance
- Detector efficiency and reconstruction

→

- GEANT simulation and detector response model.

Occupancy corrections

→

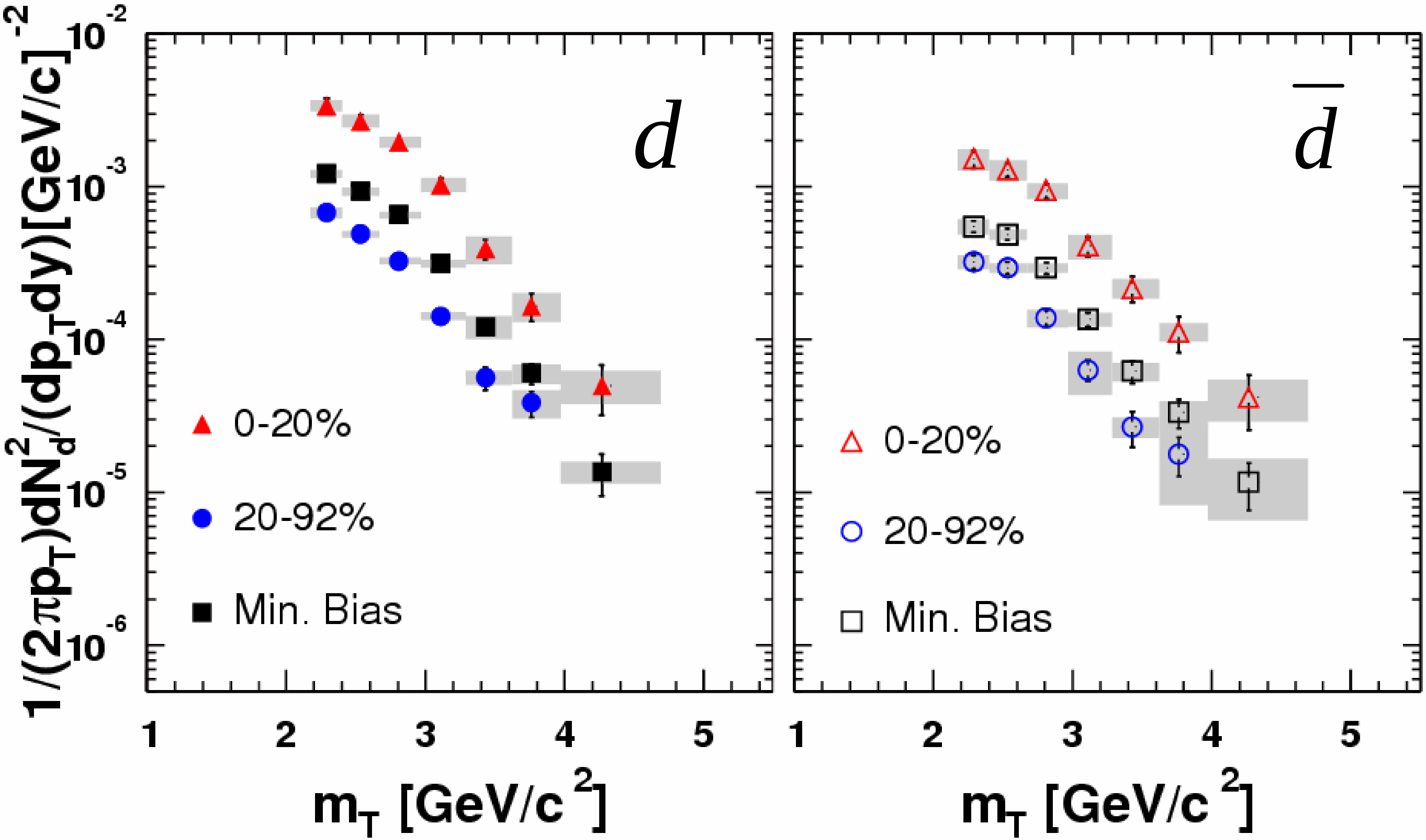
- Embedding simulated tracks in real events

Annihilation correction

→

- Parameterize anti-deuteron cross-sections.

Deuteron/Anti-deuteron Spectra



T_{eff} fits to the spectra

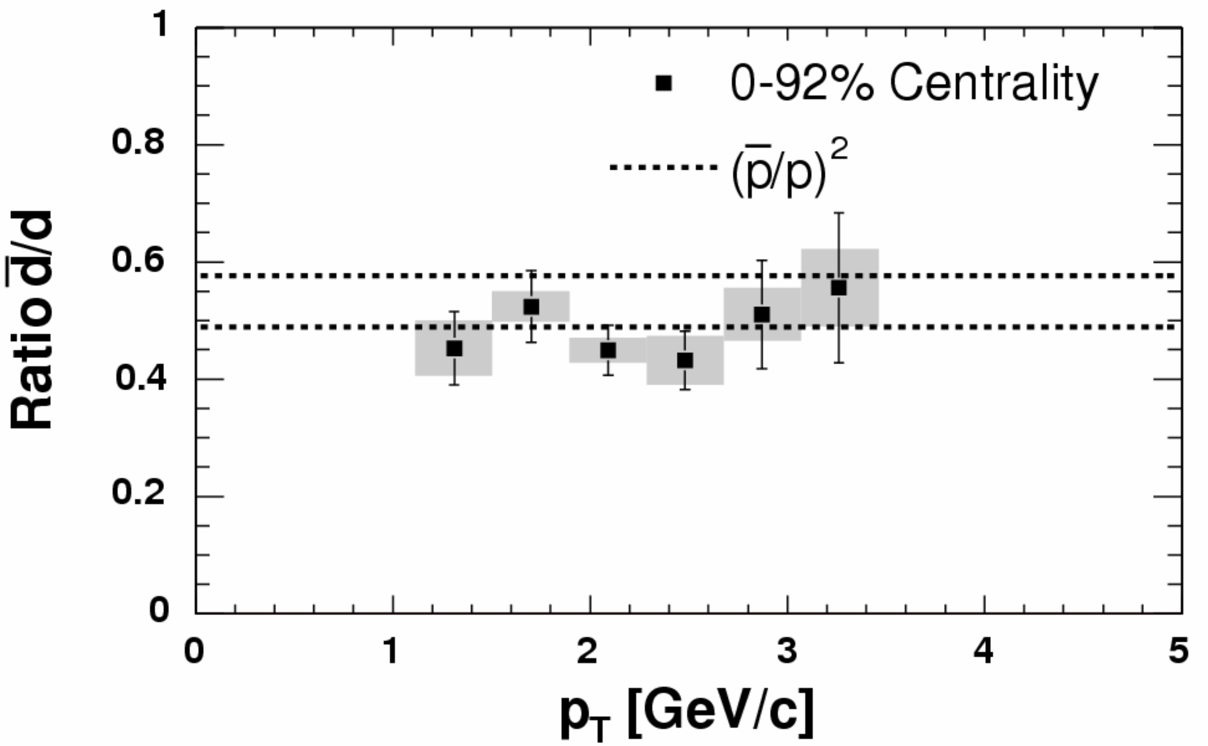
- Exponential fit:

$$\frac{d^2N_d}{2\pi N_{evt} m_t dm_t dy} = A\exp(-m_t / T_{eff})$$

T_{eff} [MeV]	Deuterons	Anti-deuterons
Minimum Bias	519 ± 27	512 ± 32
0-20%	536 ± 32	562 ± 51
20-92%	475 ± 29	456 ± 35

- Flatter as compared to proton spectra (T_{eff} = 300-350 MeV)

Anti-deuteron/deuteron ratio vs p_T

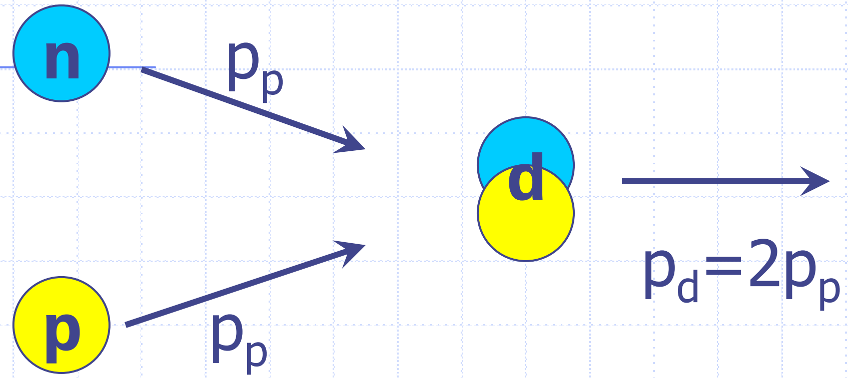


- Particle ratios indicate:

a) $\mu_n \geq \mu_p$

b) $\bar{n}/n = 0.64 \pm 0.04$

Coalescence parameter B_2



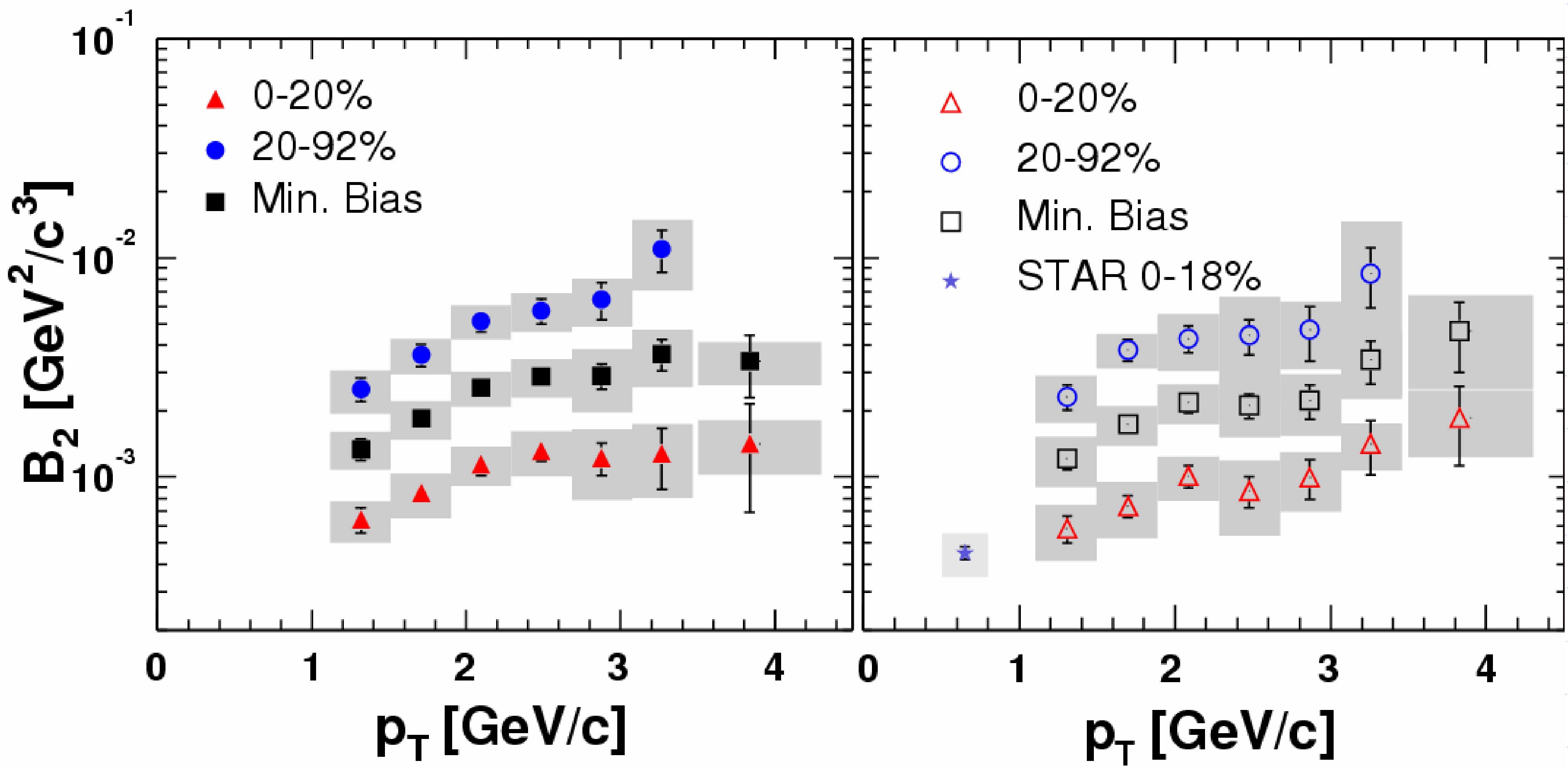
- **Defined as:**

$$E_d \frac{d^3 N_d}{dp_d^3} = B_2 \left(E_p \frac{d^3 N_p}{dp_p^3} \right)^2$$

Physical significance of B_2

- Deuterons formed late at freeze-out by nucleons in close proximity and small relative momenta.
- Like a correlation measurement (analogous to HBT).
- B_2 allows study of freeze-out configuration in phase space.
- Thermodynamic models: $B_2 \propto 1/V$

B_2 vs p_T



0-20%
20-92%
Min. Bias
B_2 [GeV^2/c^3]
10^{-1}
10^{-2}
10^{-3}
0
1
2
3
4
p_T [GeV/c]
0-20%
20-92%
Min. Bias
STAR 0-18%
0
1
2
3
4
p_T [GeV/c]

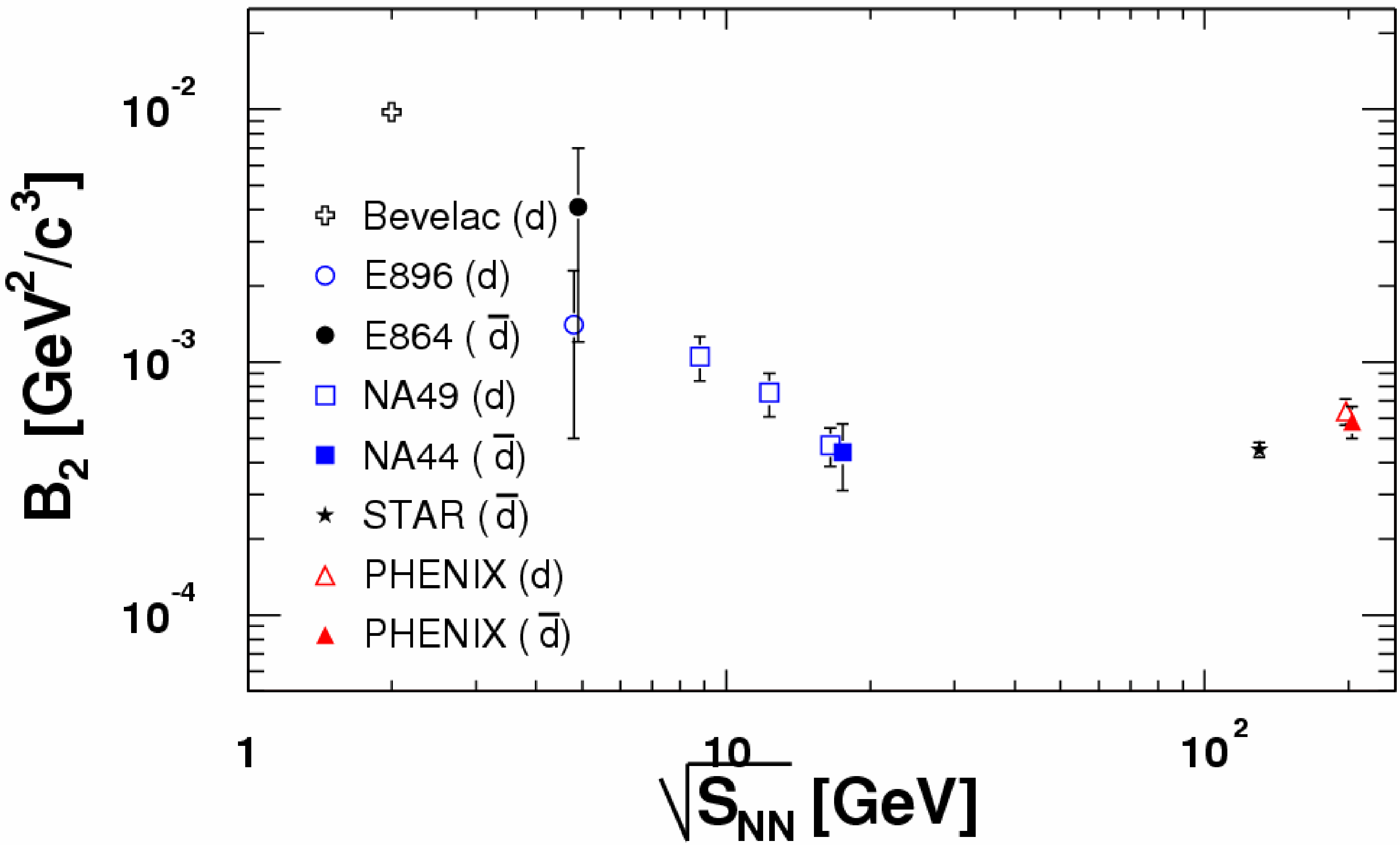
Implications of B_2

- B_2 increases with p_T: consistent with expanding source.
- p_T-dependence of B_2 can also provide information about the density profile of the source:

Gaussian source density => constant B_2 with p_T

- B_2 equal for deuterons and antideuterons indicating similar freezeout conditions for particles and antiparticles.

Comparison of B_2 vs $\sqrt{S}$ with other experiments



Summary: Part I

- Deuteron/anti-deuteron spectra flatter than proton/anti-proton: indicative of strong flow.
- Particle ratios indicate:

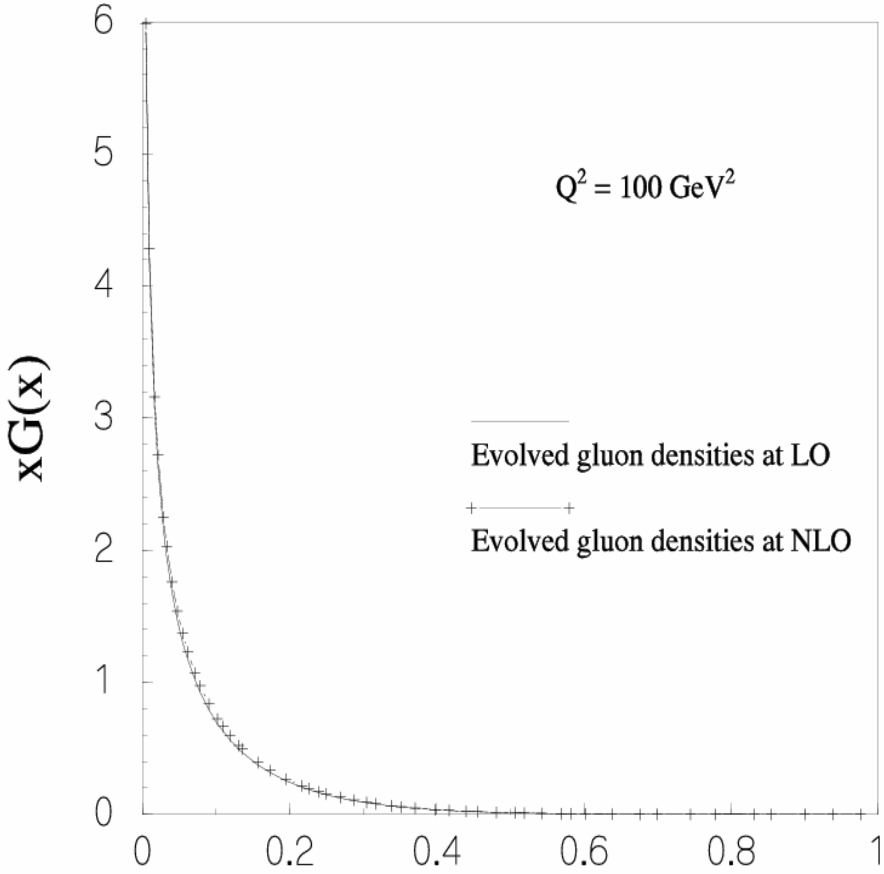
a) $\mu_n \geq \mu_p$

b) $\bar{n}/n = 0.64 \pm 0.04$

- B_2 for deuterons/anti-deuterons increases with p_T: consistent with expanding source.
- B_2 flat with energy scale indicating that source volume does not change much: similar as for HBT.

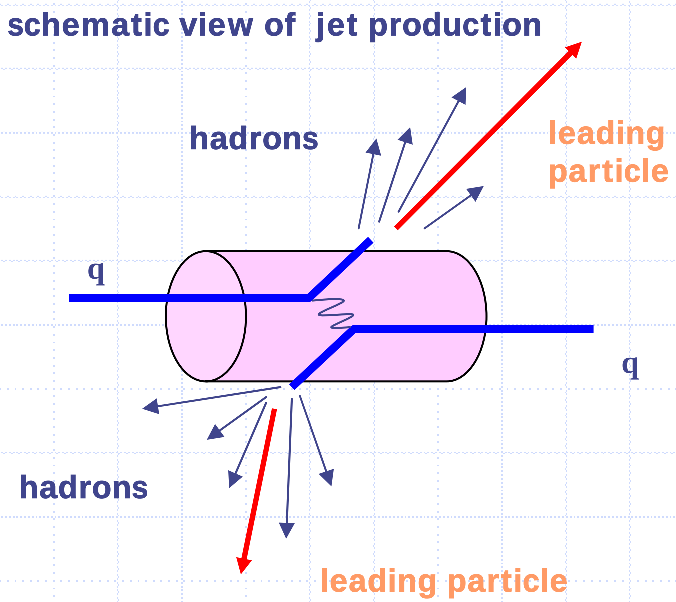
Part II: Initial state effects

- DIS experiments revealed nucleus to consist of partons.
- Parton distribution functions (PDFs) give probability of finding a given parton with momentum fraction x of nucleon momentum.
- Gluon PDFs diverge at small-x



Hard Scattering

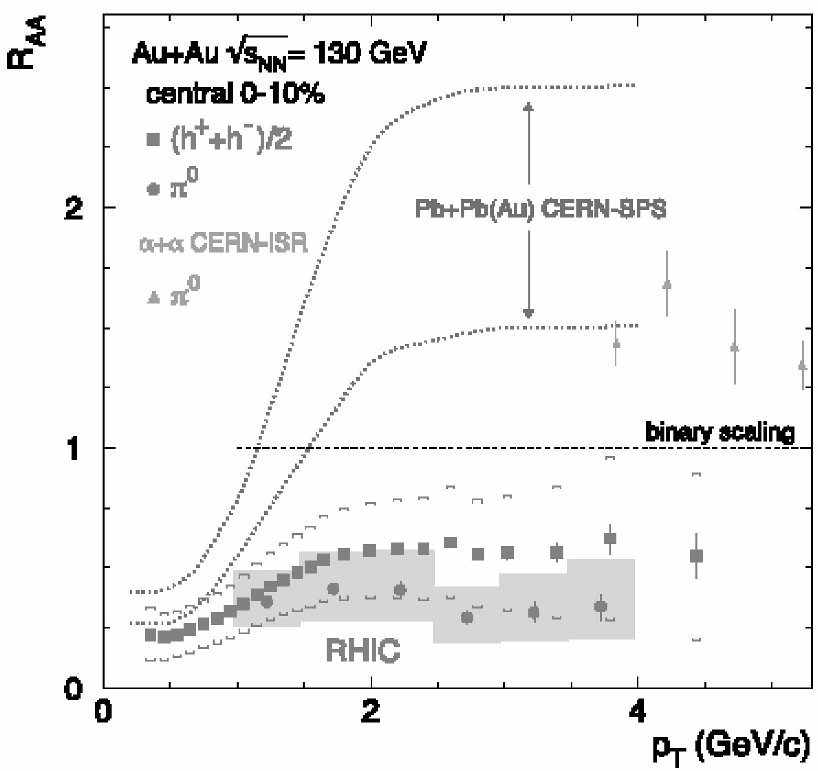
- Hard scatterings in nucleon collisions produce jets of particles.
- Depends on distribution of scattering centers.
- Can shed light into PDFs



Nuclear modification factor: R_{CP}

- R_{cp} is defined as particle yield in central collisions normalized by number of nucleon nucleon inelastic scatterings divided by particle yield in peripheral collisions normalized in the same way.
- Assumes peripheral collisions like p+p
- If Au+Au like p+p incoherent then, R_{CP} =1
- R_{CP} suppressed in Au+Au collisions!

$$R_{CP} = \frac{\frac{1}{N_{binary}^{central}}\left(\frac{dN}{d\sigma dp_T}\right)^{central}}{\frac{1}{N_{binary}^{peripheral}}\left(\frac{dN}{d\sigma dp_T}\right)^{peripheral}}$$

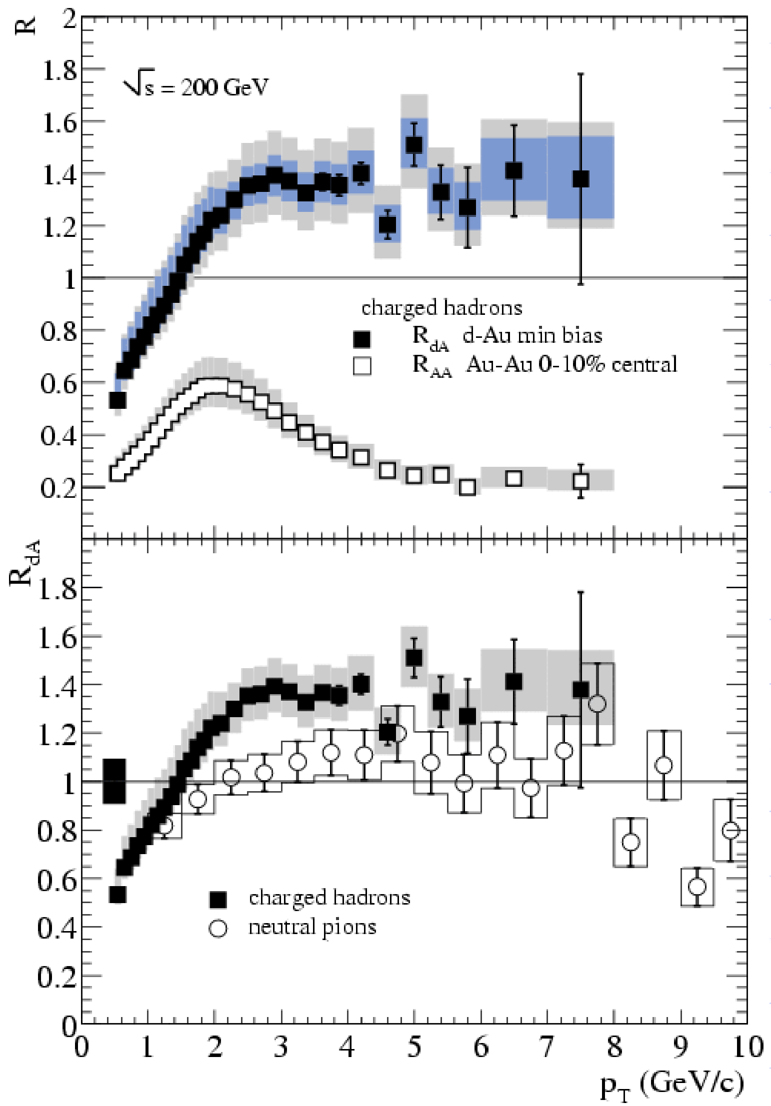


Initial or final state?

1. Jet Quenching: Partons lose energy in the presence of a color-deconfined medium, leading to suppression of energetic particles, a final state effect.
2. Color Glass Condensate: Gluon fusion processes g+g->g can deplete number of initial scatterers leading to suppression, an initial state effect.

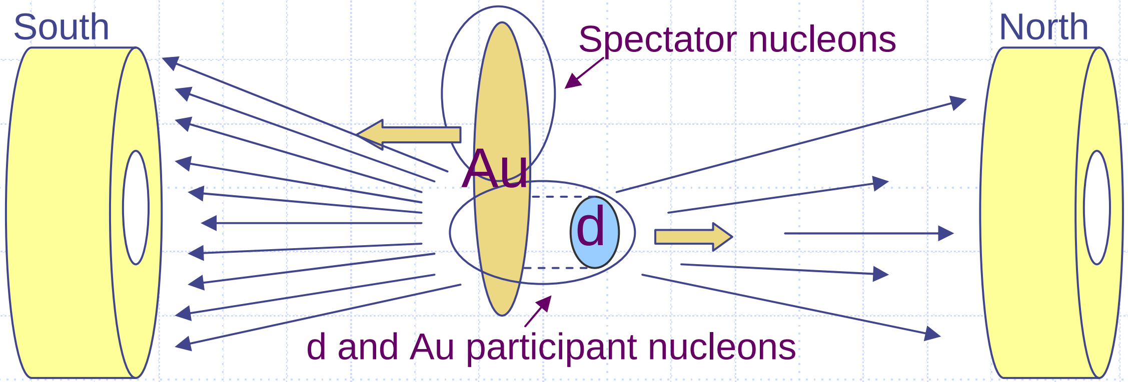
d+Au Control Experiment

- Collisions of small with large nuclei can help us to quantify cold nuclear matter effects.
- d+Au data indicated an enhancement ruling out CGC (at midrapidity).



Is CGC dead?

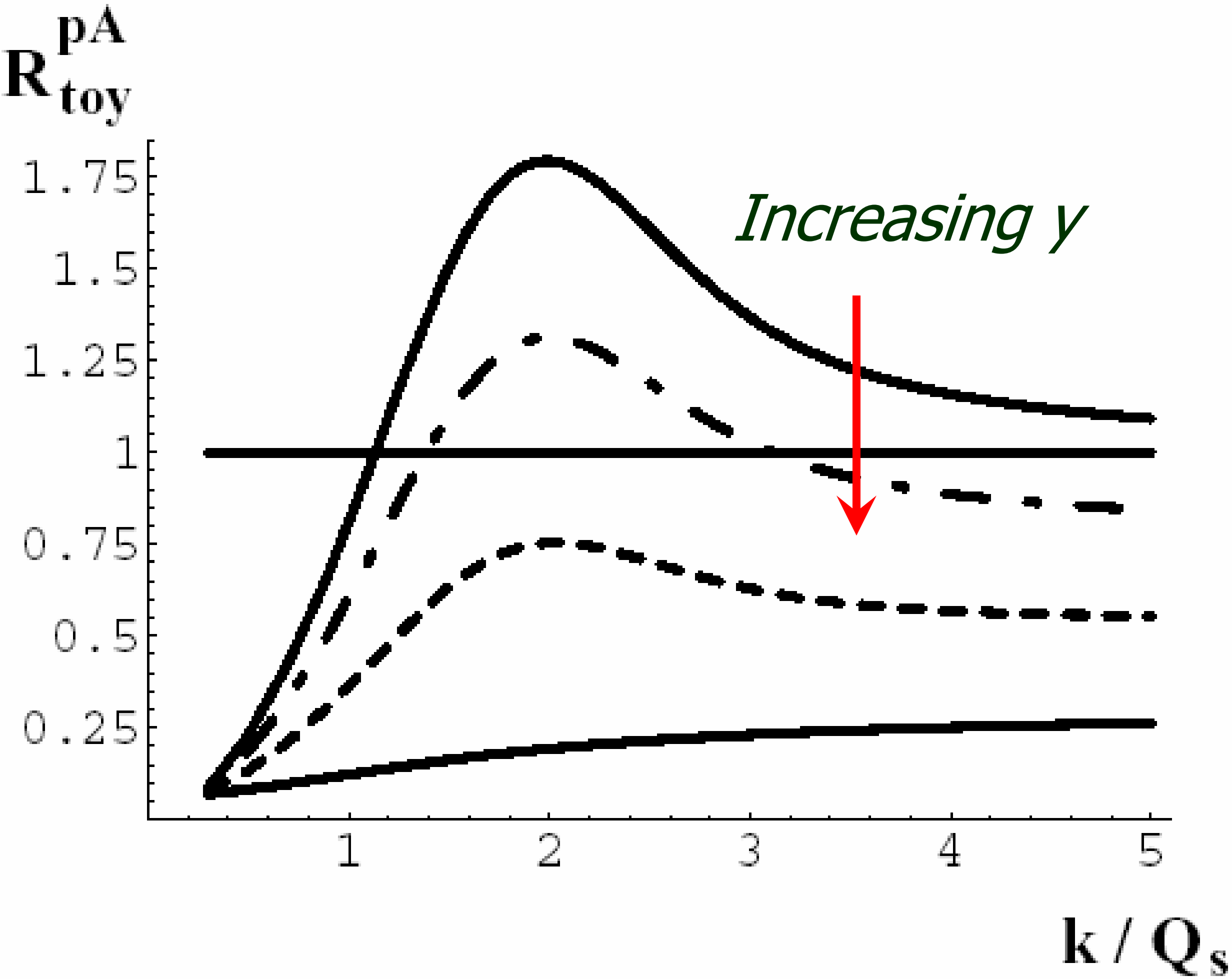
- Maybe not yet in saturation regime.
- New regime of parton physics at small-x can be reached by going to large rapidities.



- North Arm: Low x partons from Au
- South Arm: High x partons from Au

Color Glass Model Predictions

D. Kharzeev hep-ph/0307037

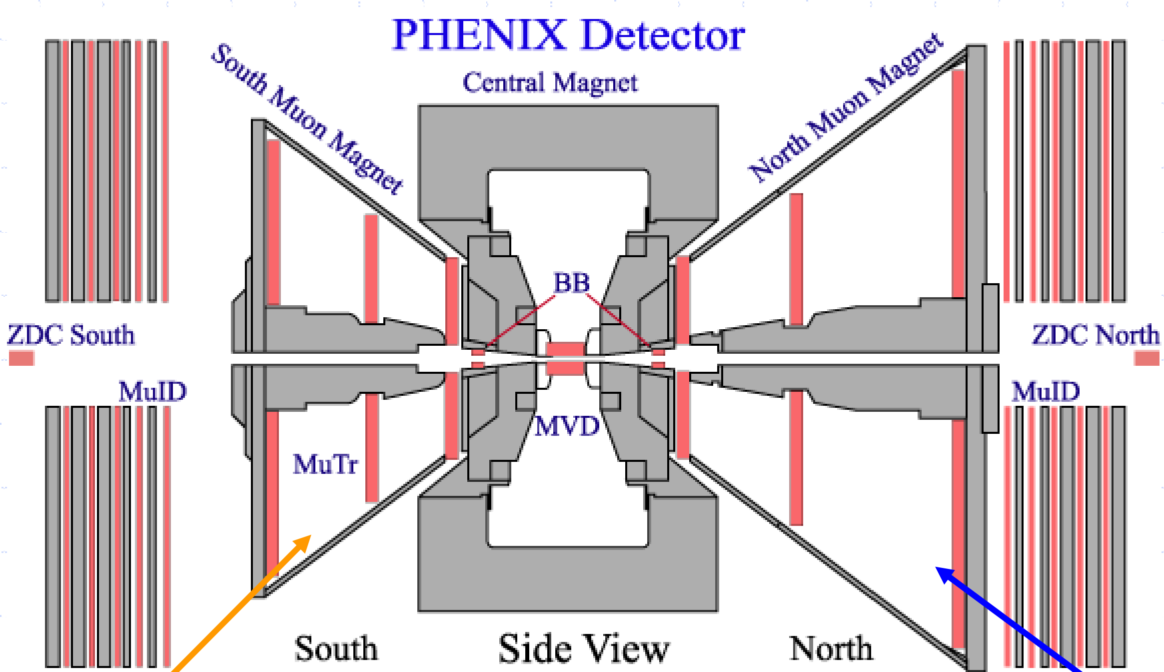


k *is transverse momentum of partons*
Q

$$Q_s(y) \approx Q_{s0}\, e^{2\,\overline{\alpha}_s\, y}$$

Side view of PHENIX detector

deuteron → ← ***gold***

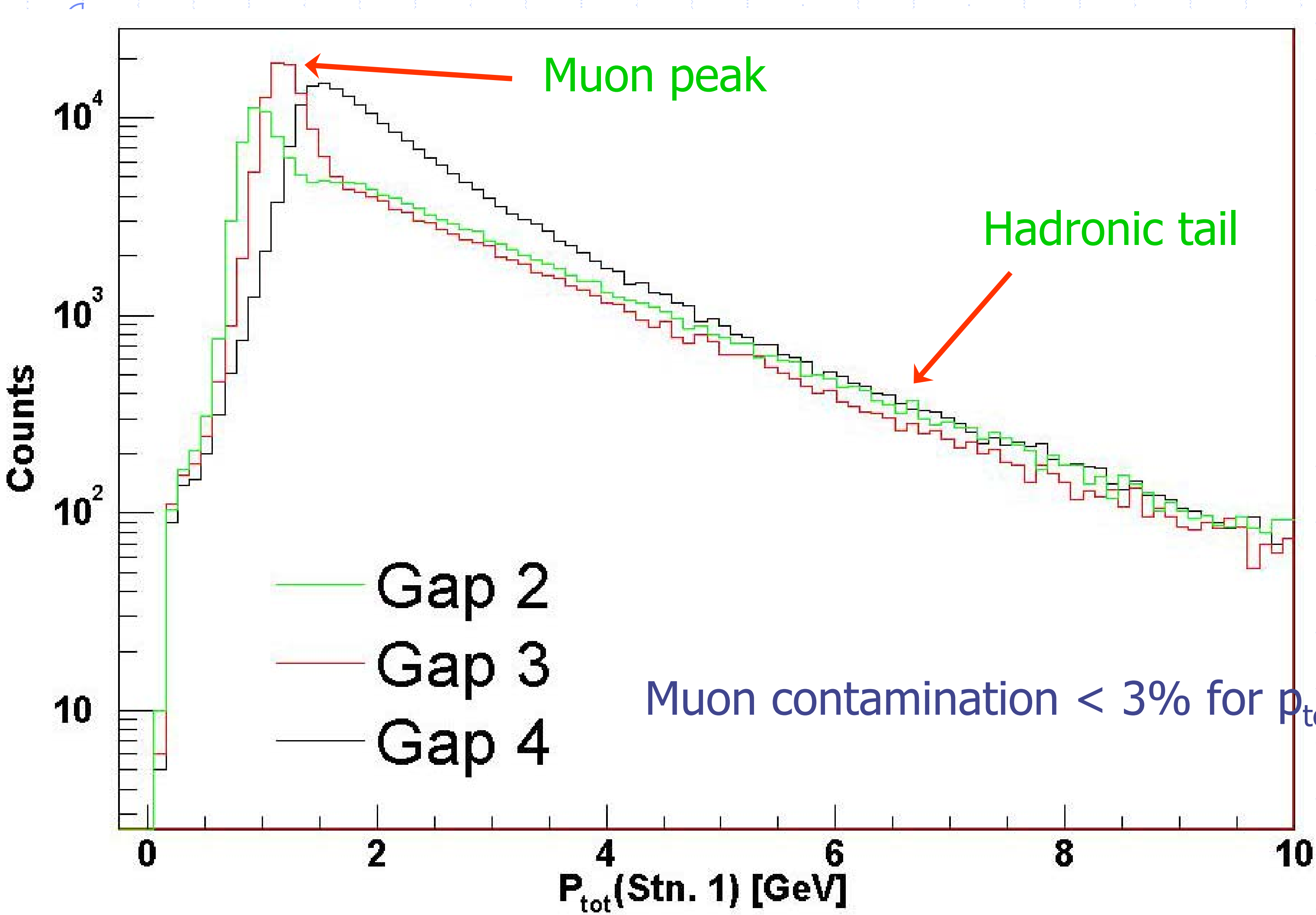


South Muon arm : -1.2 > η > -2.0

North Muon arm : 2.4 > η > 1.2

Hadron measurement

- Use shallow MuID layers to select stopped hadrons



Muon contamination < 3% for p_{tot} > 1.9 GeV

Analysis Details

- 67 million Min. Bias events for d+Au (Run 3) using Phenix North and South Muon Arms.
  - Use shallow MuID layers to select stopped hadrons
  - P_{total} > 1.9 GeV cut to remove muons.
  - $\Delta\theta$ matching cuts to remove showers.

Sources of contamination

- Muons from pi, K decays and "prompt" production: Rejected within 3% by p_T cut
- Hadronic showers: Rejected within 15% by $\Delta\theta$ cut.

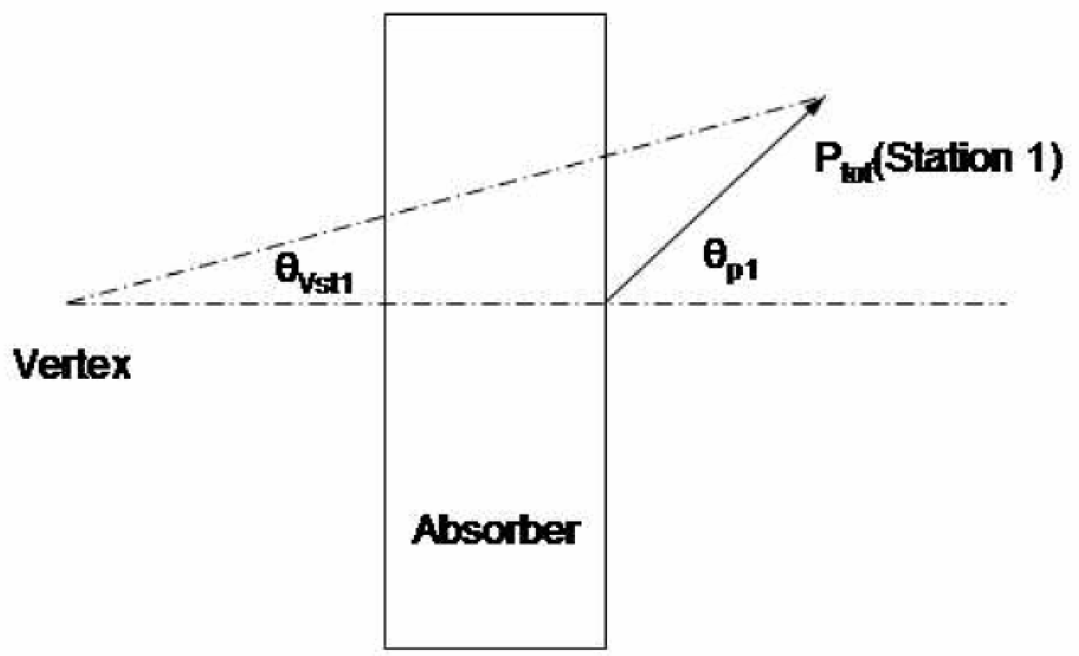
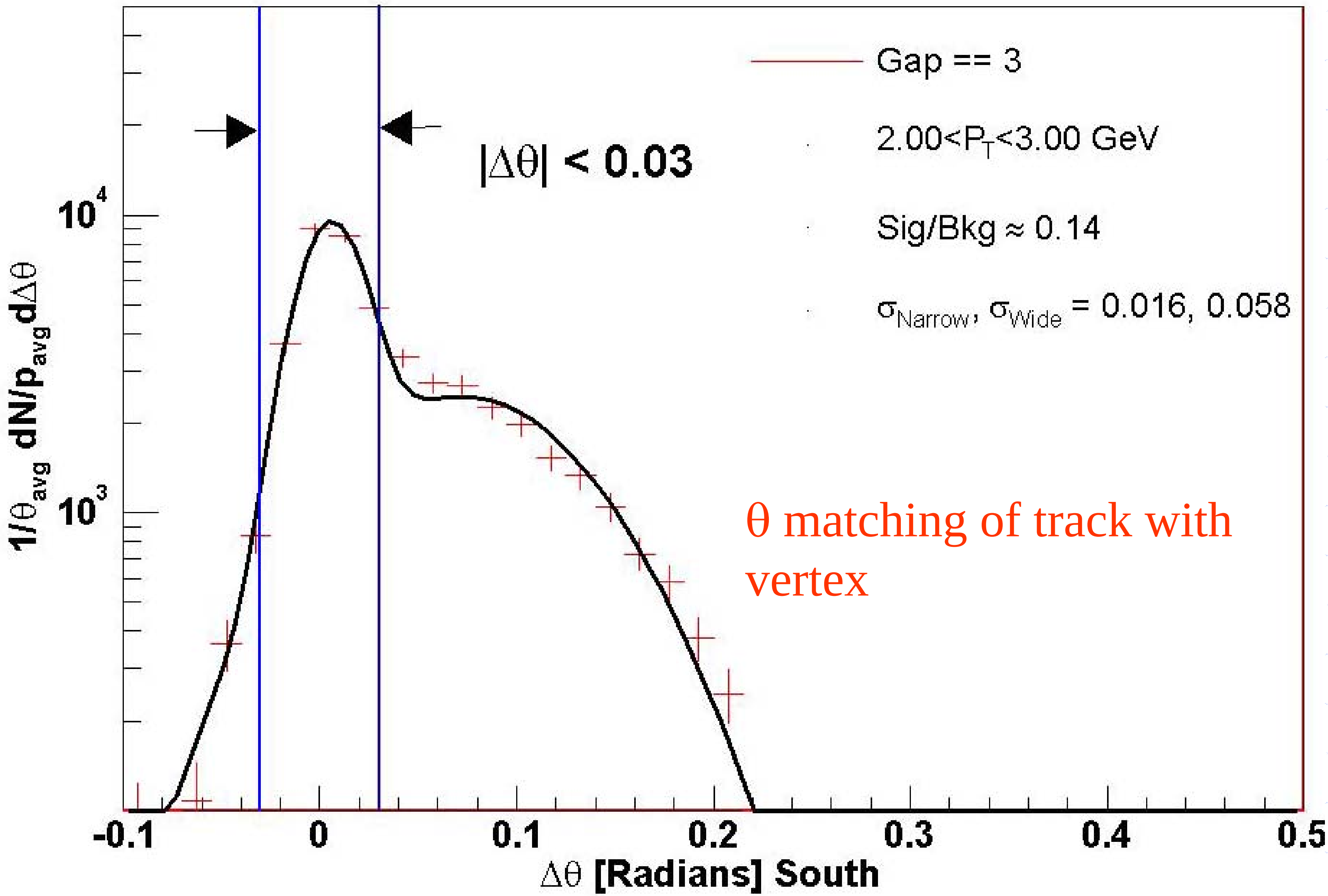
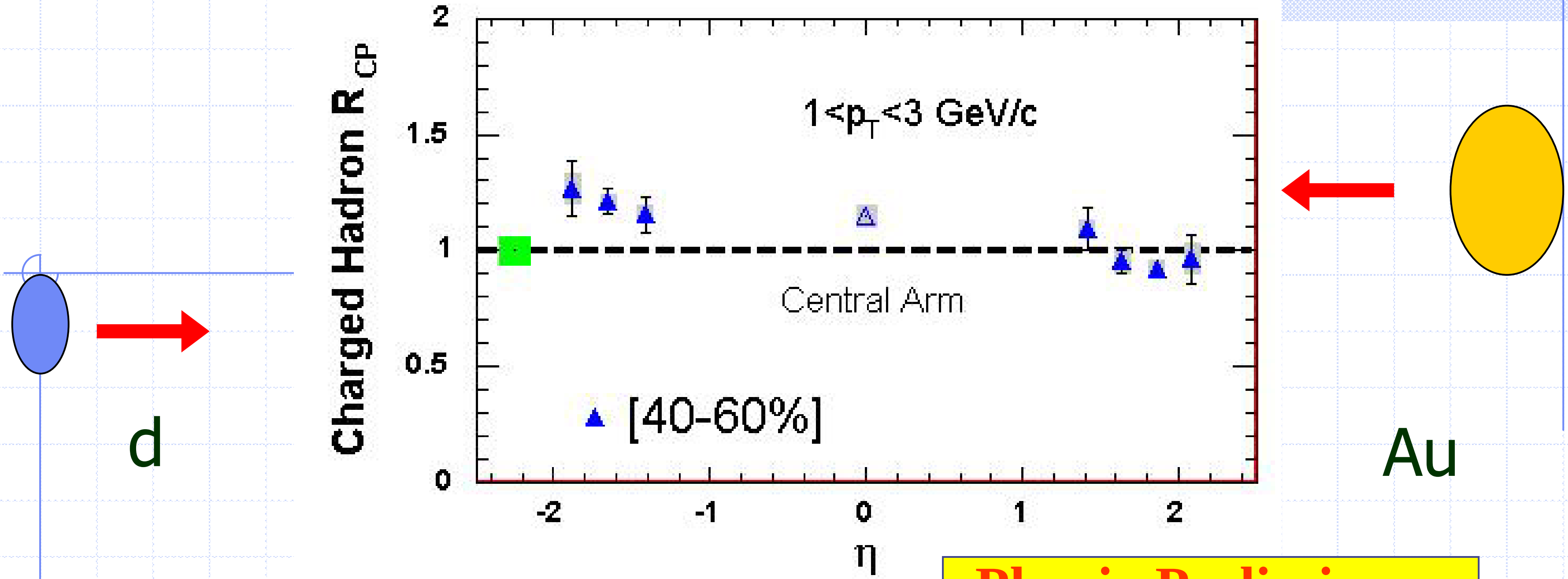


Figure 6.6: Sketch showing $\Delta\theta$ angular cut.

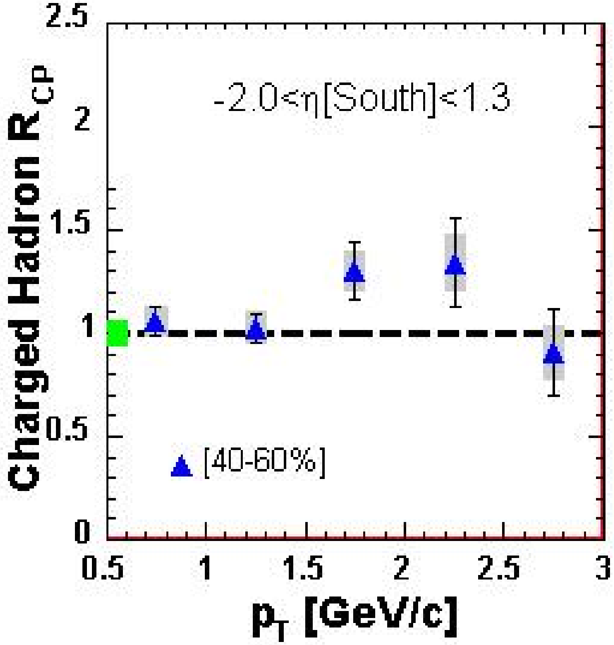
Δθ cut

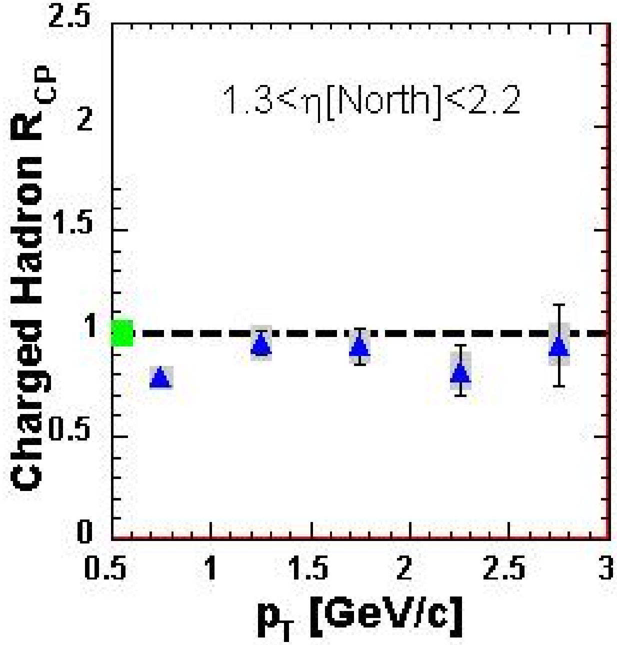


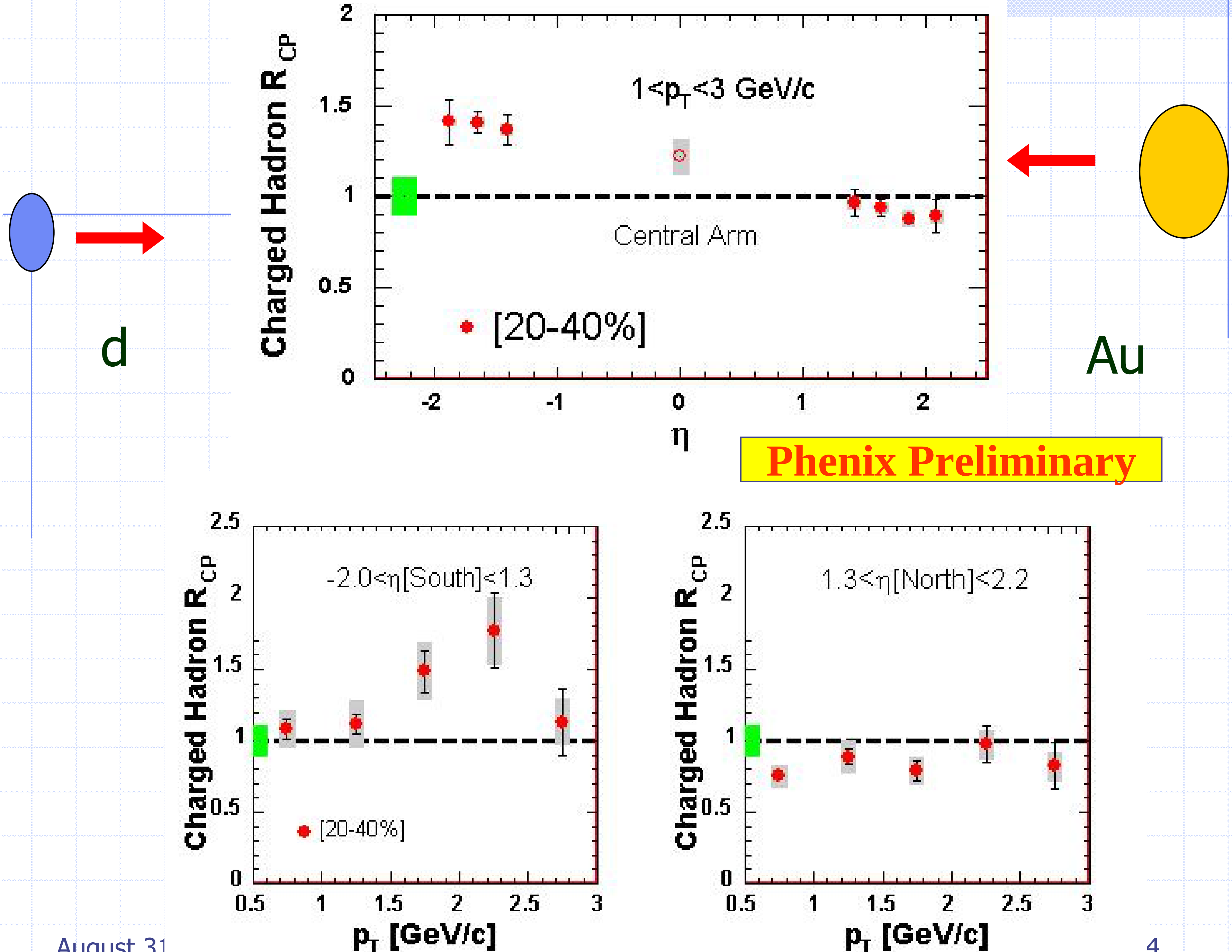
θ matching of track with vertex

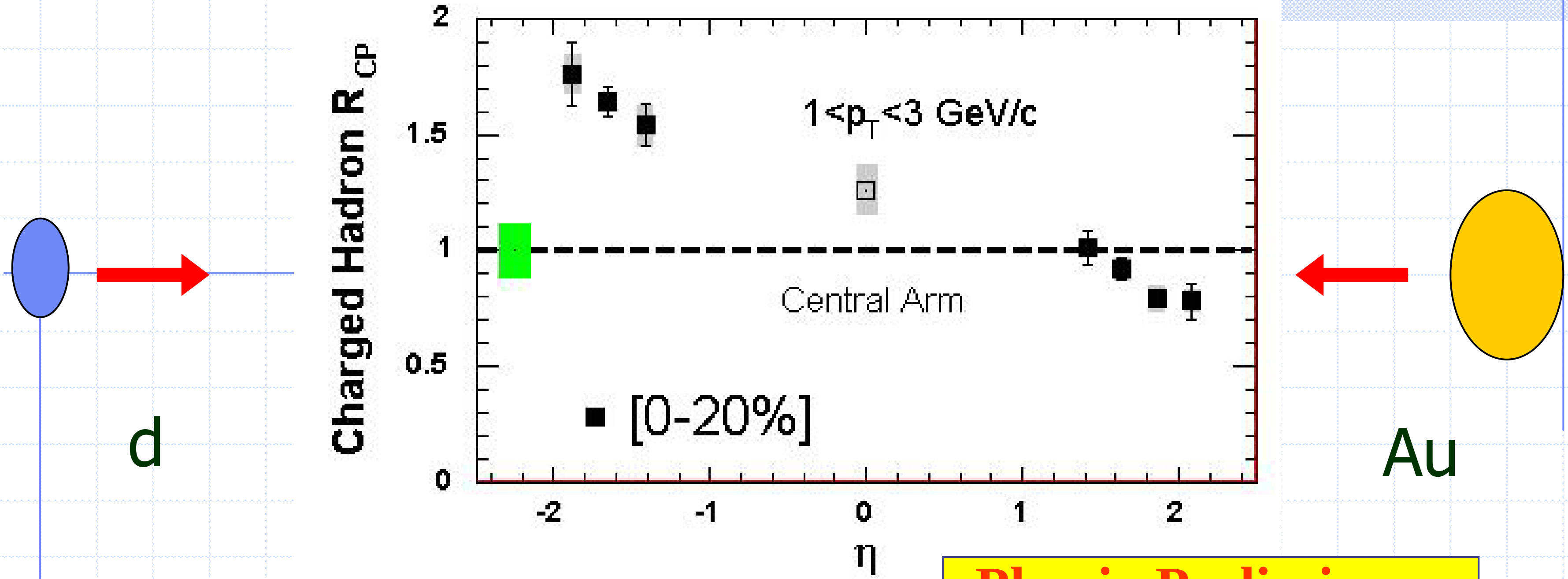


Phenix Preliminary

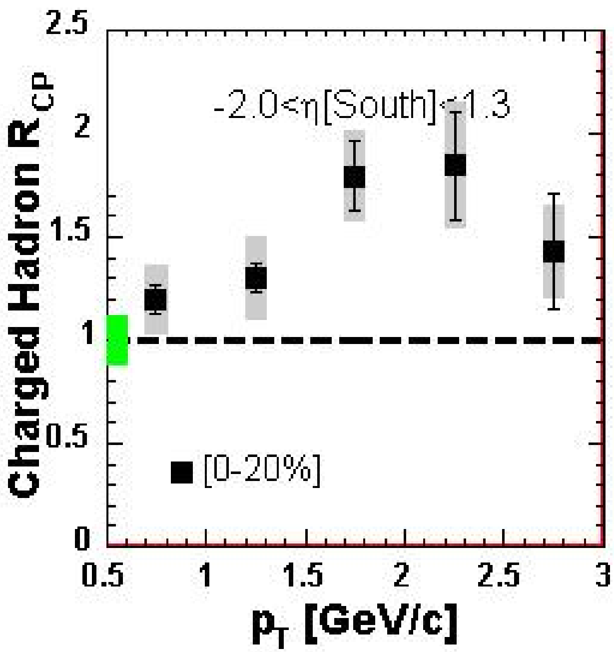


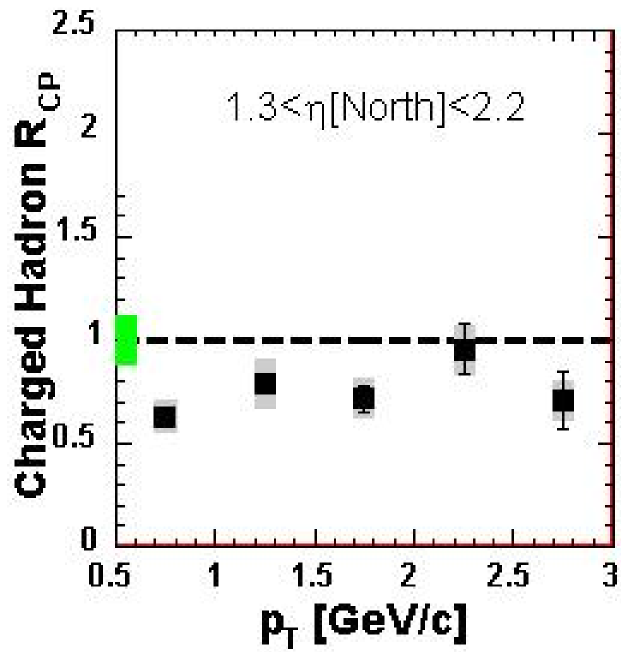



d
Au
Charged Hadron R_{CP}
$1<p_T<3$ GeV/c
Central Arm
[20-40%]
η
Phenix Preliminary
-2.0<η[South]<1.3
[20-40%]
p_T [GeV/c]
1.3<η[North]<2.2
p_T [GeV/c]



Phenix Preliminary

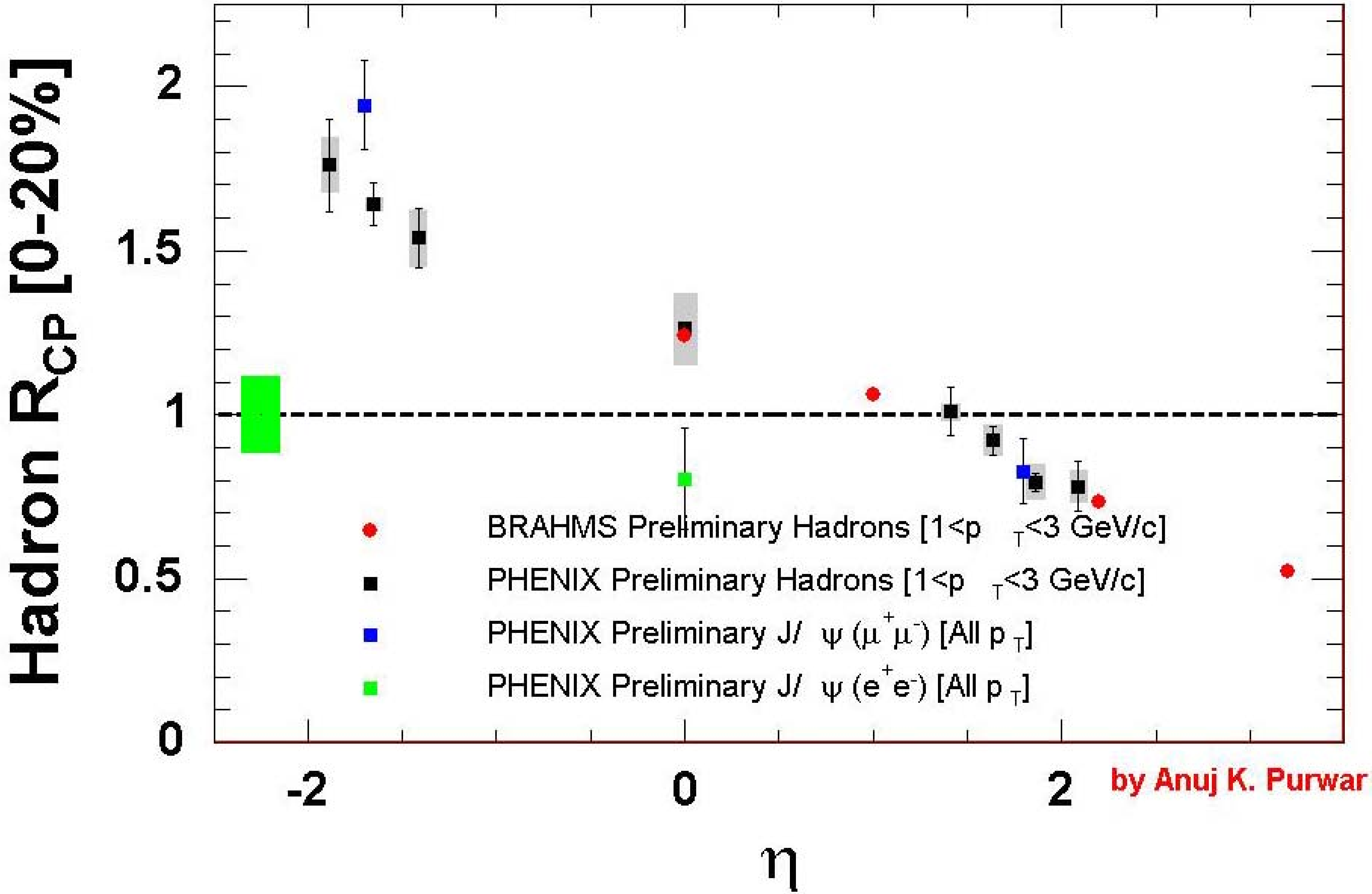




R_{CP} is suppressed at forward rapidities

- Suppression in North Arm (small-x of Au).
- Enhancement in South Arm (large-x of Au).
- Almost linear increase from $\eta=2.2$ in South to $\eta=2.4$ in the North.
- Suppression (and enhancement) is maximum for 0-20% centrality and decreases for less central collisions.

R_{CP} comparison plot



Summary: Part II

- R_{CP} suppressed at forward rapidities: qualitatively consistent with shadowing/saturation.
- Enhancement at backward rapidity is not understood in terms of CGC. Perhaps due to:
  - rapidity exchange: Consistent with linear behaviour of R_{CP} but not expected to be large at RHIC energies.
  - anti-shadowing?

Future Directions

- Measure "prompt" muons from charm decays and measure R_{CP}.
- eRHIC: proposed electron beam accelerator for e-A (and polarized protons).
  - Gluon PDFs: Color Glass Condensate Calculations vs. Conventional pQCD predict very large differences at small-x.
  - Parton propagation through nuclei: which can lead to p_T broadening.