Measurement of beam energy dependent nuclear modification factors at STAR

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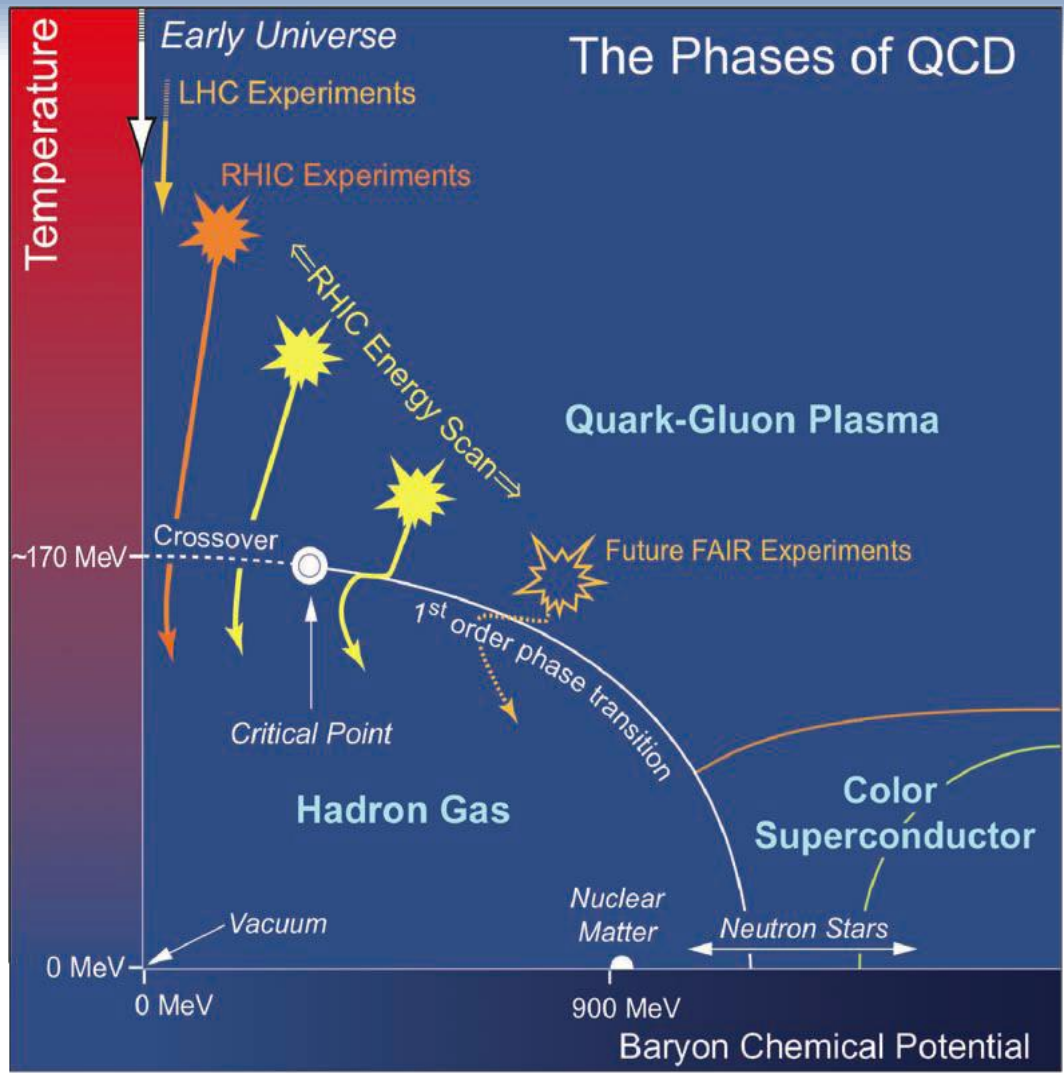
Outline

- The RHIC Beam Energy Scan (BES)
- Nuclear modification factors
  - High Energy Results
  - Results from the BES
- Model Comparisons
- Alternative methods to measure quenching

Beam Energy Scan

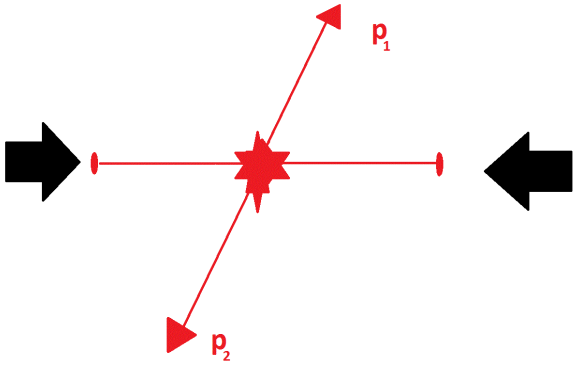
- Search for the critical point
- Search for a first order phase transition
- Look for the turn off of key QGP signatures
  - nuclear modification factor
  - dihadron correlations
  - …



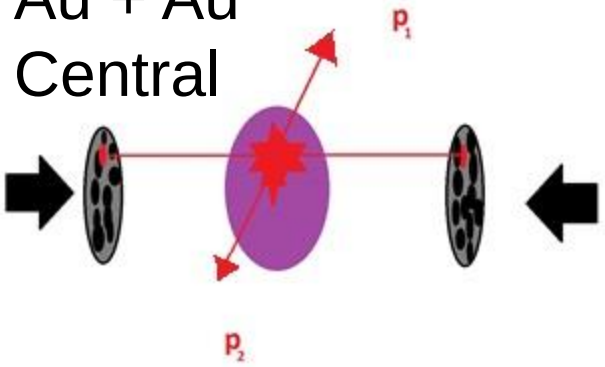
Nuclear Modification Factor

hard scatterings produce early high p_T probes

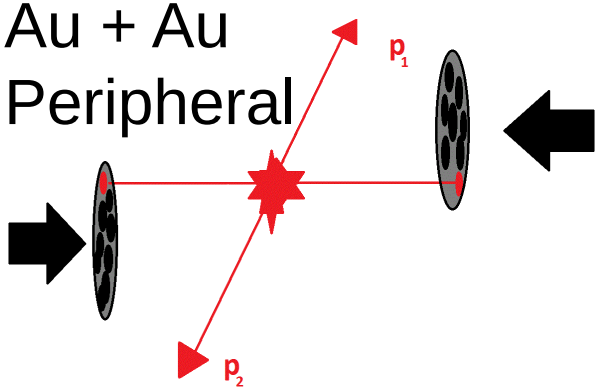
p + p



Au + Au
Central



Au + Au
Peripheral

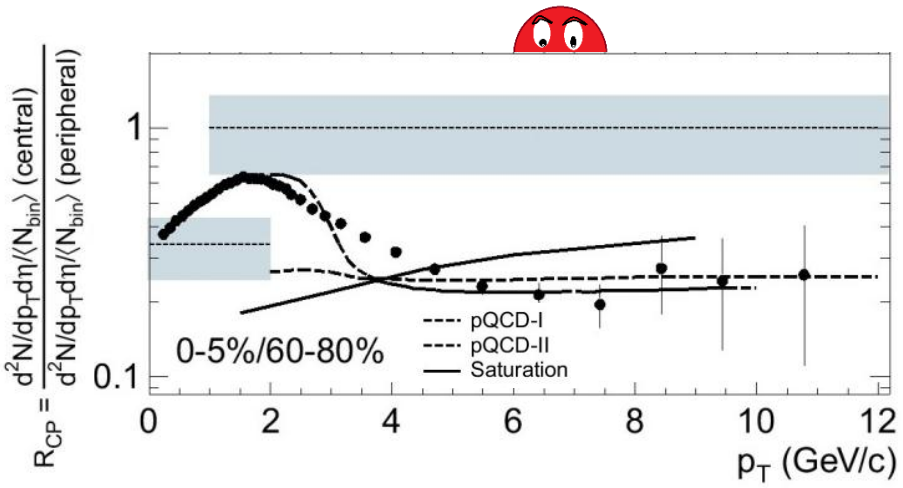


$$R_{CP} = \frac{(N_{bin})_P}{(N_{bin})_C} \times \frac{\left(\frac{d^2N}{p_T dp_T d\eta}\right)_C}{\left(\frac{d^2N}{p_T dp_T d\eta}\right)_P}$$

N_{part} ≡ number of participating nucleons

N_{bin} ≡ number of binary collisions (from Glauber)

Suppression of high p_T



- high p_T charged hadrons are suppressed
- cold nuclear matter effect?
  - ➢ Check d + Au collisions

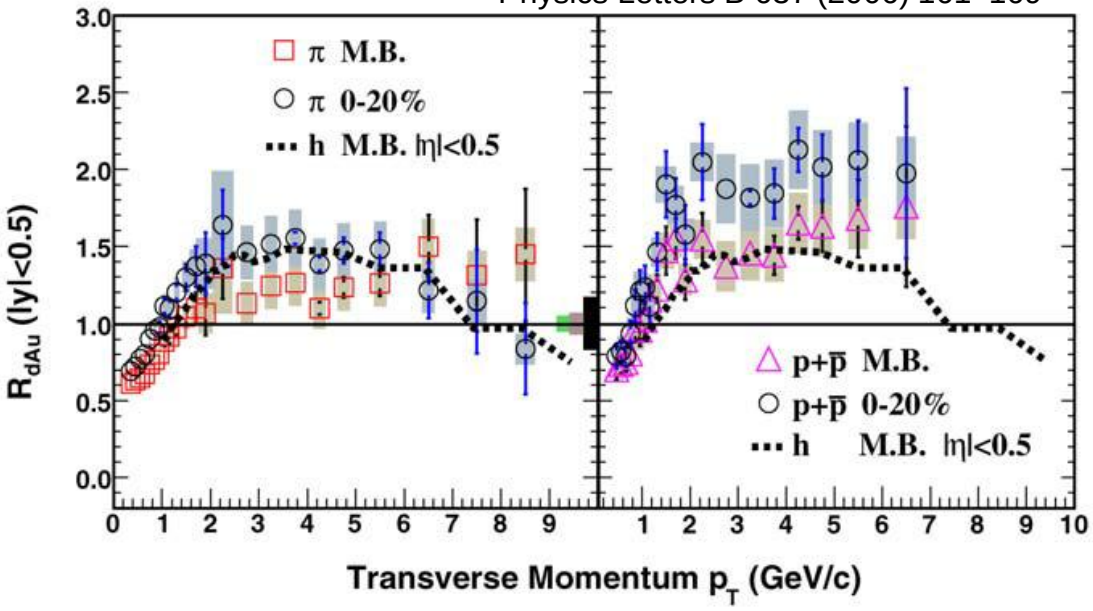
'Suppression' ≡ $R_{CP} < 1$

'Quenching' ≡ loss of energy for high momentum particles

Phys. Rev. Lett. 91, 172302 (2003)

Cronin Effect

Physics Letters B 637 (2006) 161–169



- Not Suppressed… Enhanced
- Protons are more enhanced than pions
  → maybe pions are better probes?

Competing Effects

- We would expect unmodified R_{CP} to equal 1 (at high p_T)
- Quenching leads to suppression
- The Cronin Effect leads to enhancement
- What we measure has contributions from both

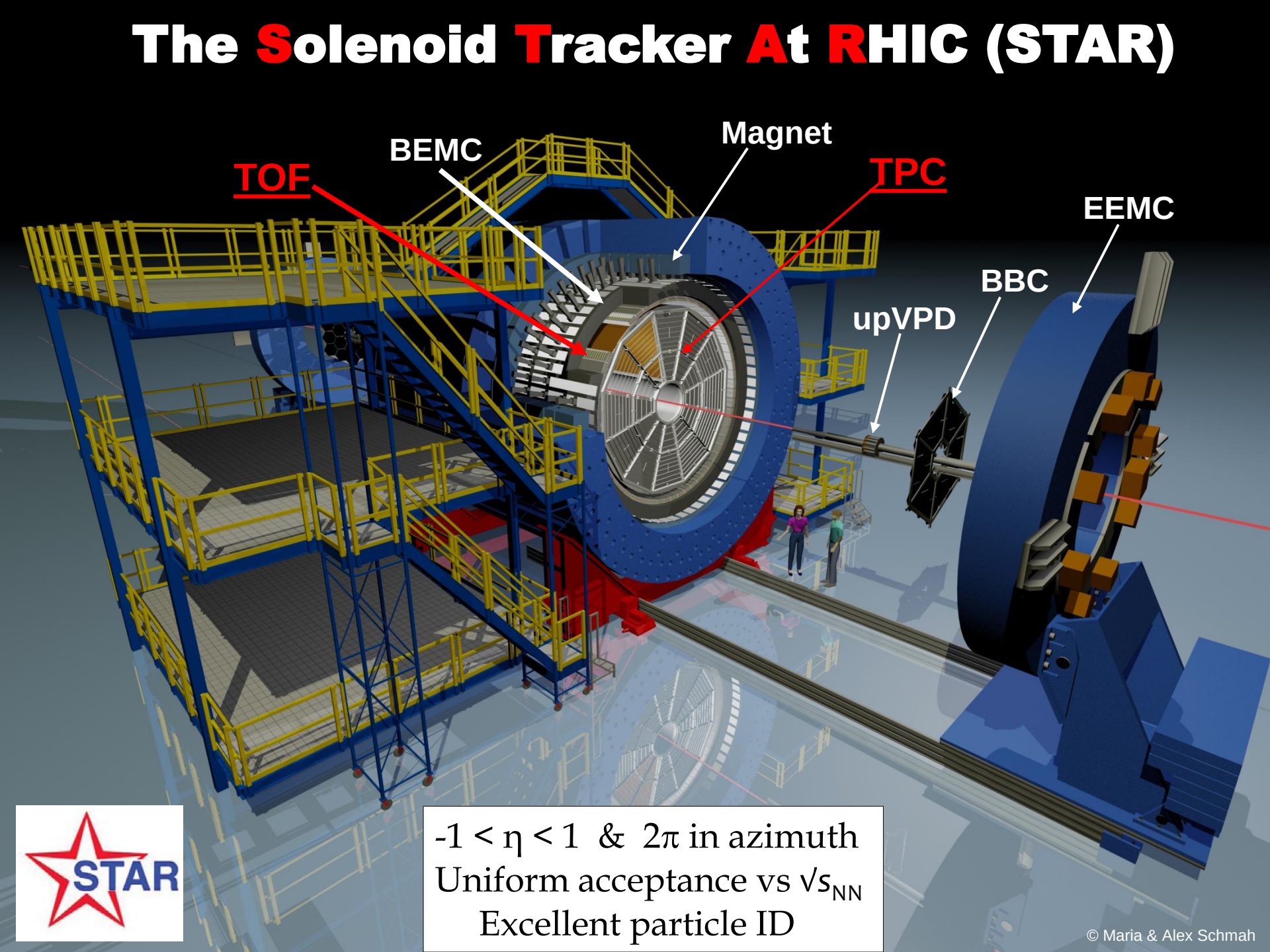
→ An $R_{CP} > 1$ can still have quenching

→ An $R_{CP} < 1$ can still have enhancement

Expectations for the BES

- Suppression is observed at $\sqrt{s_{NN}}$ = 200GeV and is attributed to a QGP
- We expect a smaller and shorter lived QGP at lower beam energies → less quenching as $\sqrt{s_{NN}}$ decreases

The Solenoid Tracker At RHIC (STAR)



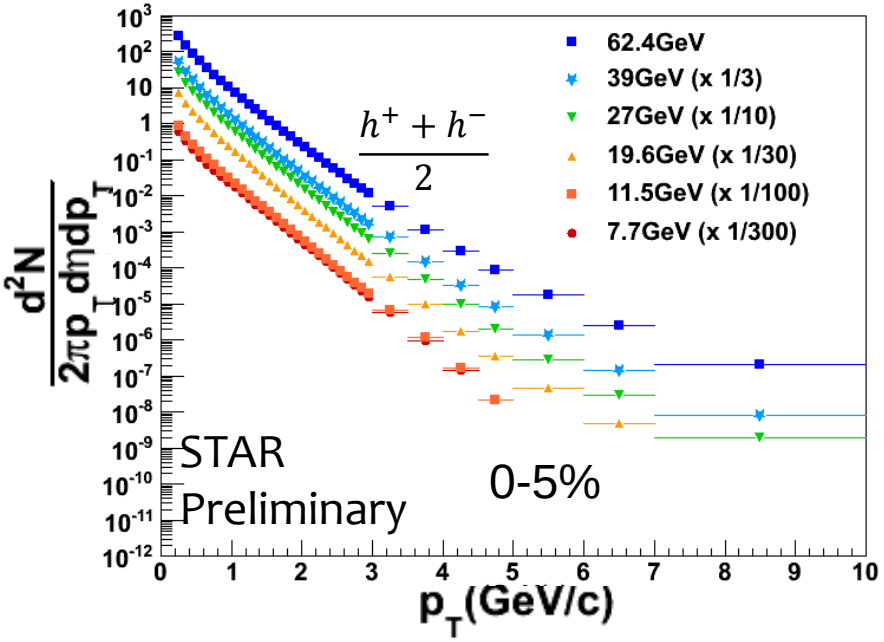
$-1 < \eta < 1$ & 2π in azimuth
Uniform acceptance vs $\sqrt{s_{NN}}$
Excellent particle ID

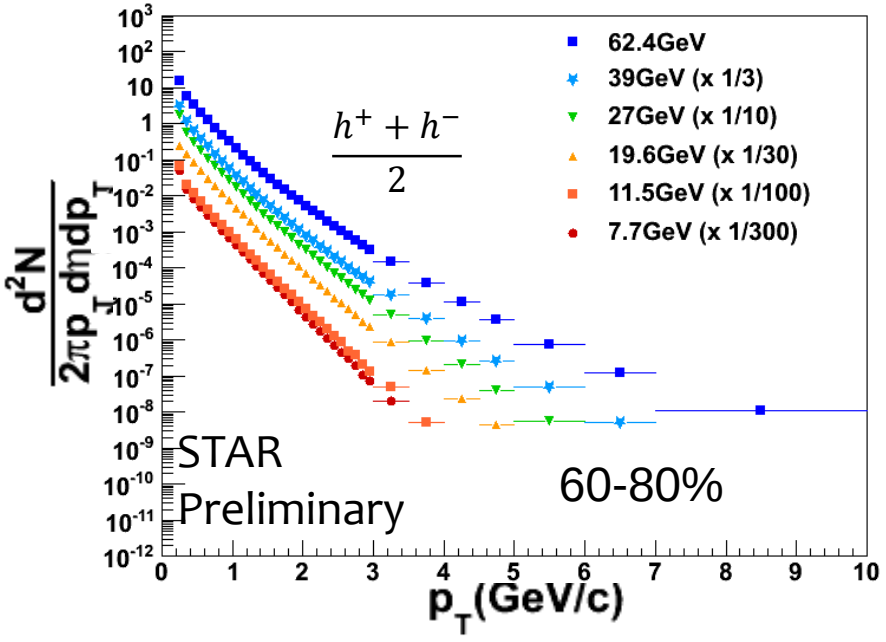
Data

- These data are from phase 1 of the BES at RHIC
- Starting in 2015 phase 2 will provide additional statistics and energies for $\sqrt{s_{NN}} < 20\text{GeV}$

$\sqrt{s_{NN}}$ (GeV)	Year	N_{Ev} MB
7.7	2010	3.7M
11.5	2010	7.3M
19.6	2011	33M
27	2011	64M
39	2010	116M
62.4	2010	62M
200	2003	4M

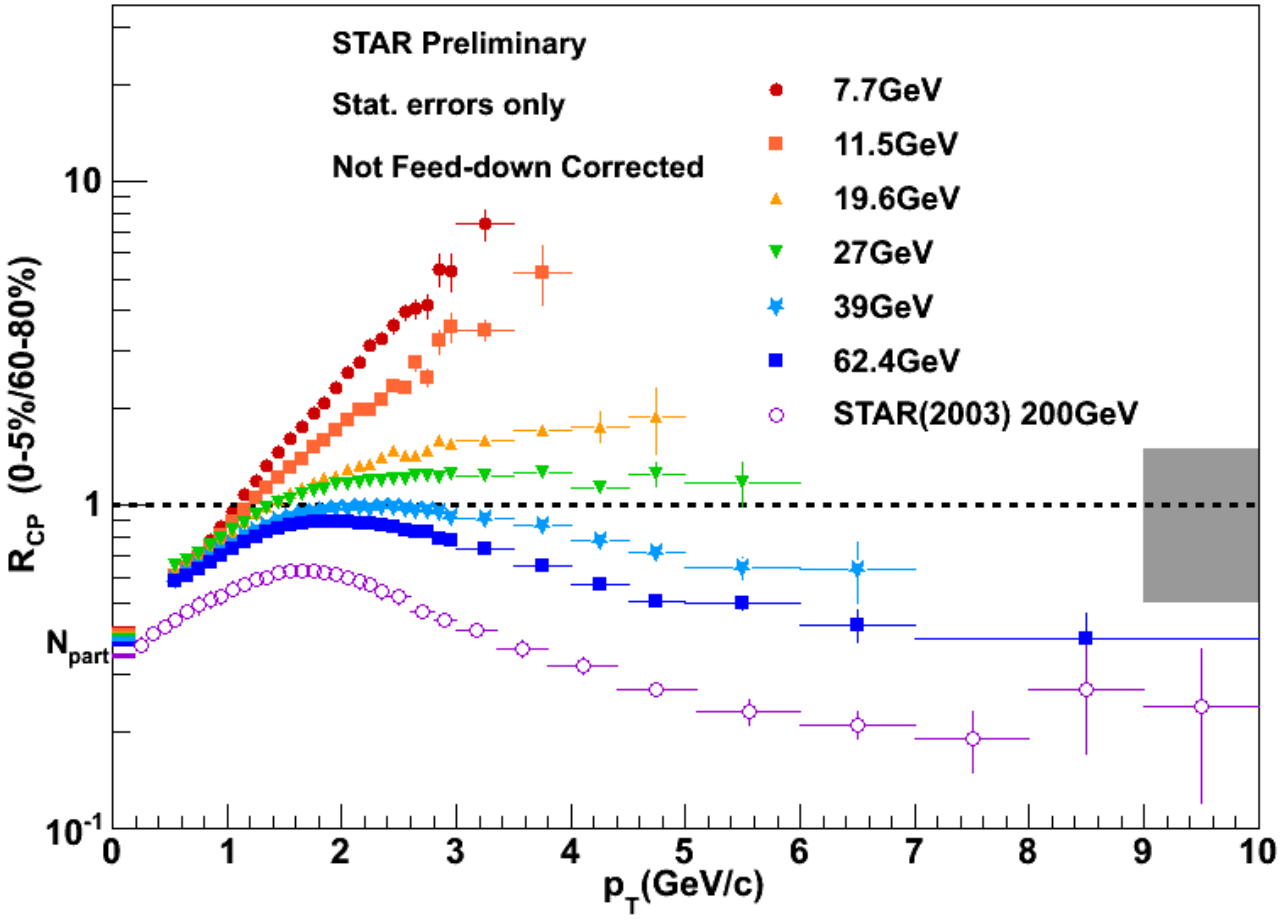
Spectra





- Peripheral spectra shows stronger dependence on beam energy

R_{CP}



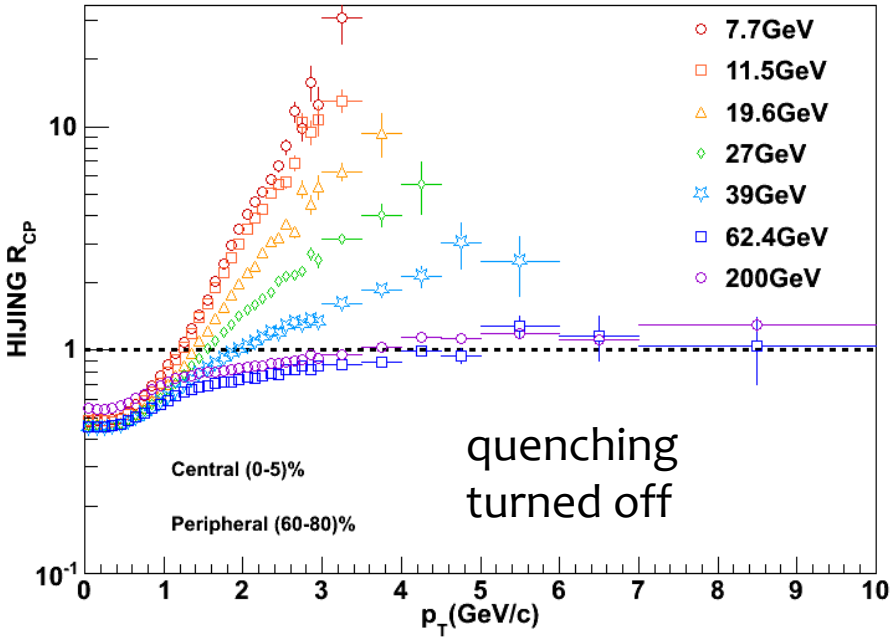
- Suppression turns off below 39GeV
- The Cronin Effect dominates lower beam energies
- It is not clear where quenching turns off

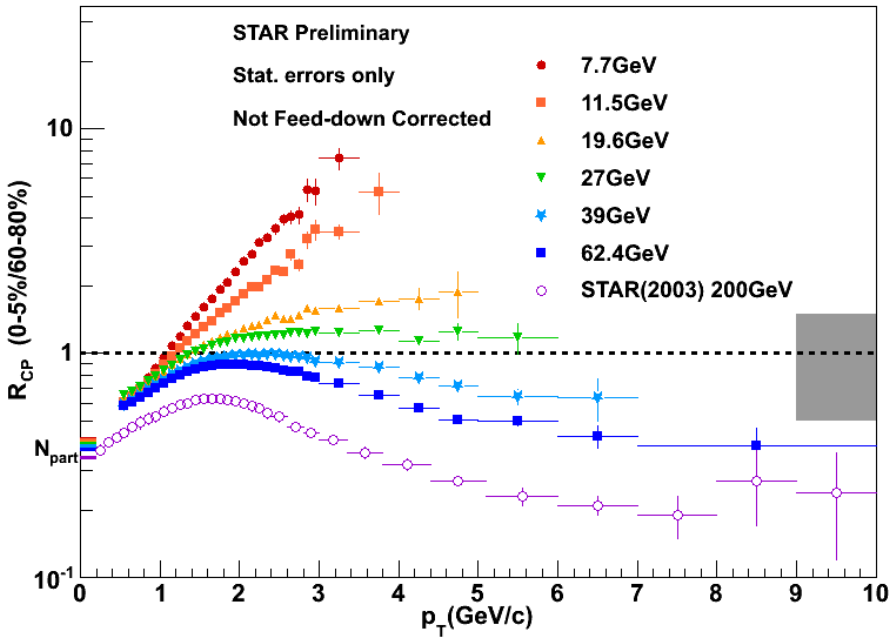
To Measure Quenching

This motivates alternative methods to measure quenching

1. triggered dihadron correlations
2. species dependence through identified R_{CP}
3. comparison to models
4. variation from patterns found by scaling

HIJING





HIJING version 1.35 with jet quenching turned off

- Similar beam energy dependence and Cronin Enhancement
- Looking into other HIJING tunes as well as AMPT

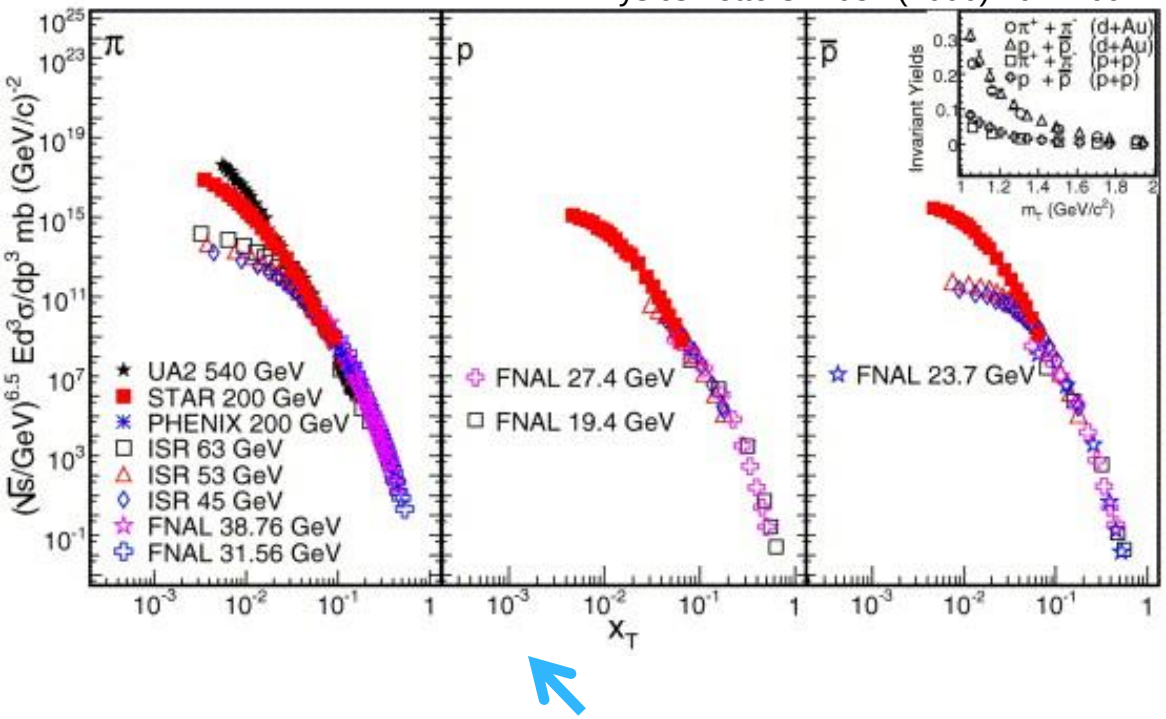
Alternative Scaling

- It can be expected that the proper scaling would reveal trends independent of $\sqrt{s_{NN}}$ in the high p_T regime
- x_T scaling was not enough on its own

$$x_T = \frac{2p_T}{\sqrt{s_{NN}}}$$

- The y-axis was also scaled by $(\sqrt{s_{NN}}/\text{GeV})^{6.5}$

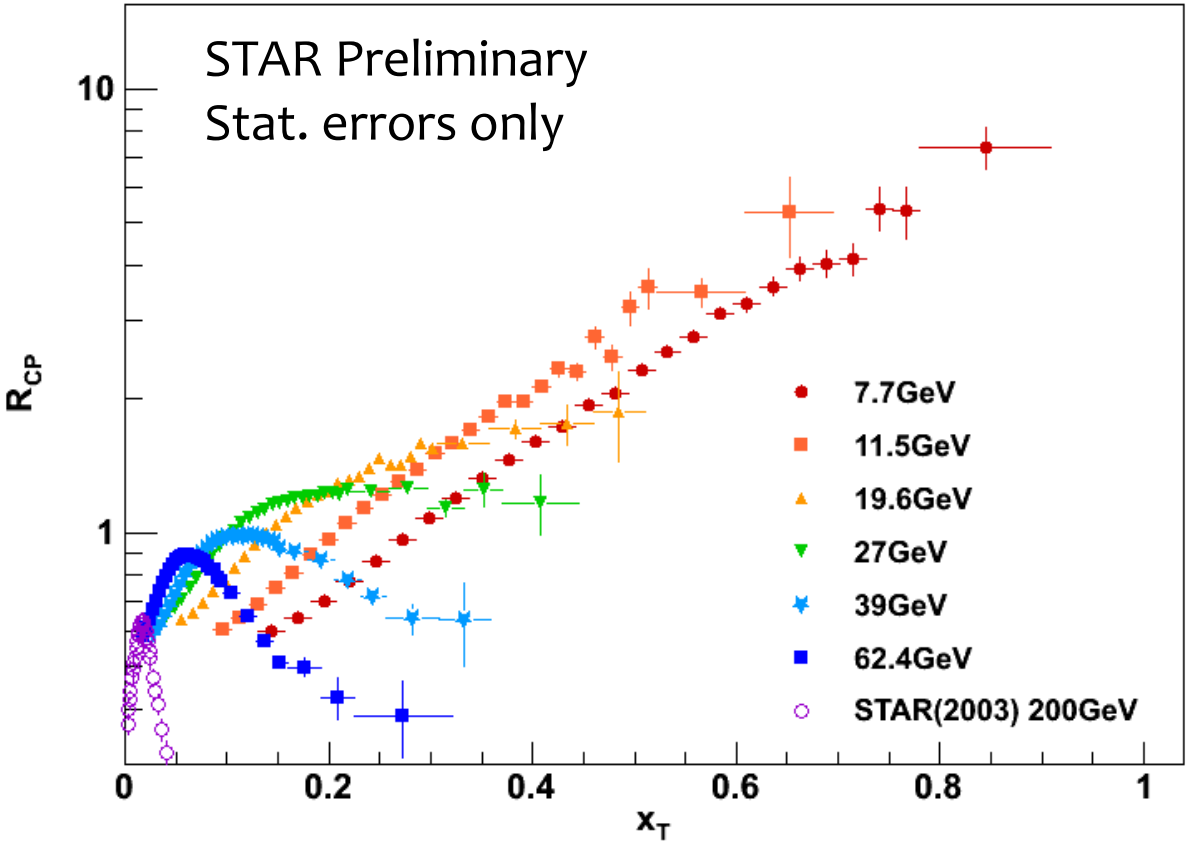
Physics Letters B 637 (2006) 161–169



These are simply differently scaled spectra from p+p collisions

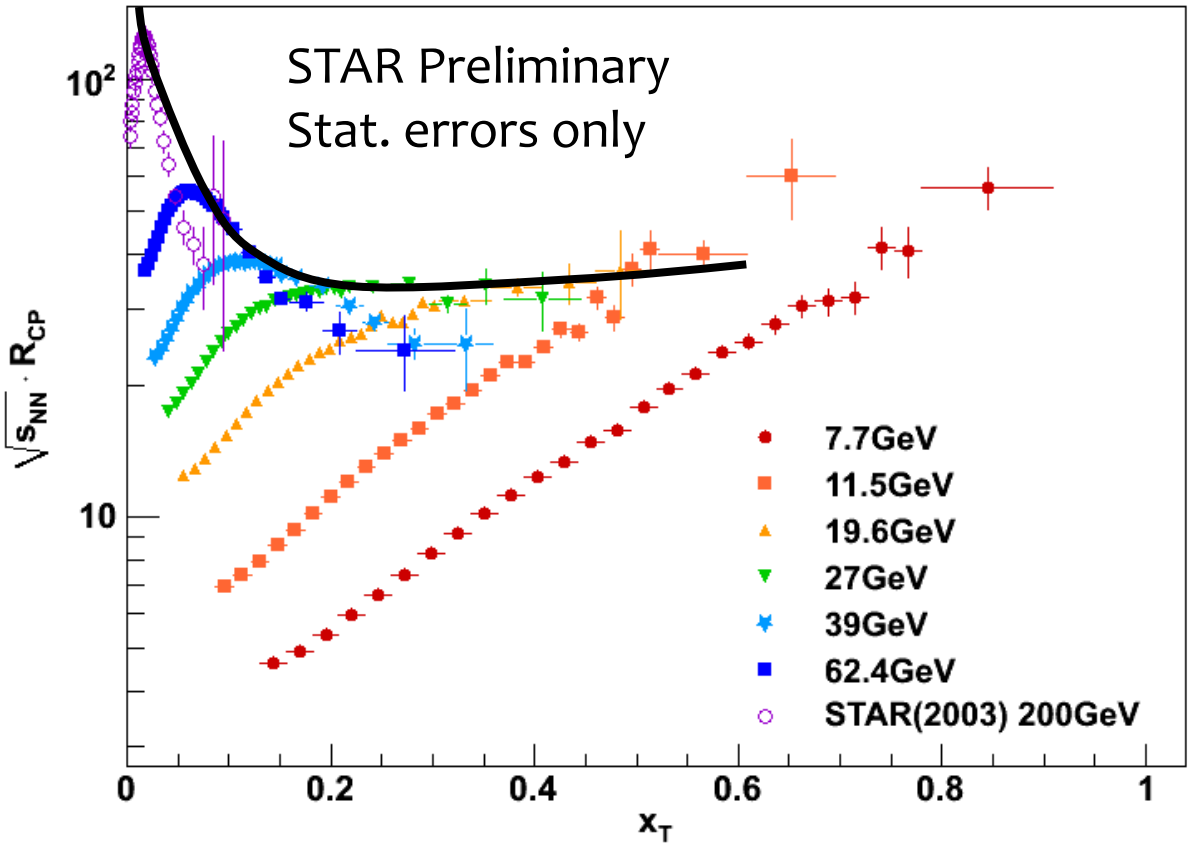
- There may be centrality dependence to the exponent (6.5)

x_T scaling



- No beam energy independent trends emerge from x_T scaling alone
- If the scale on the y-axis has centrality dependence then we would want to scale the these results by $(\sqrt{s_{NN}}/\text{GeV})^n$

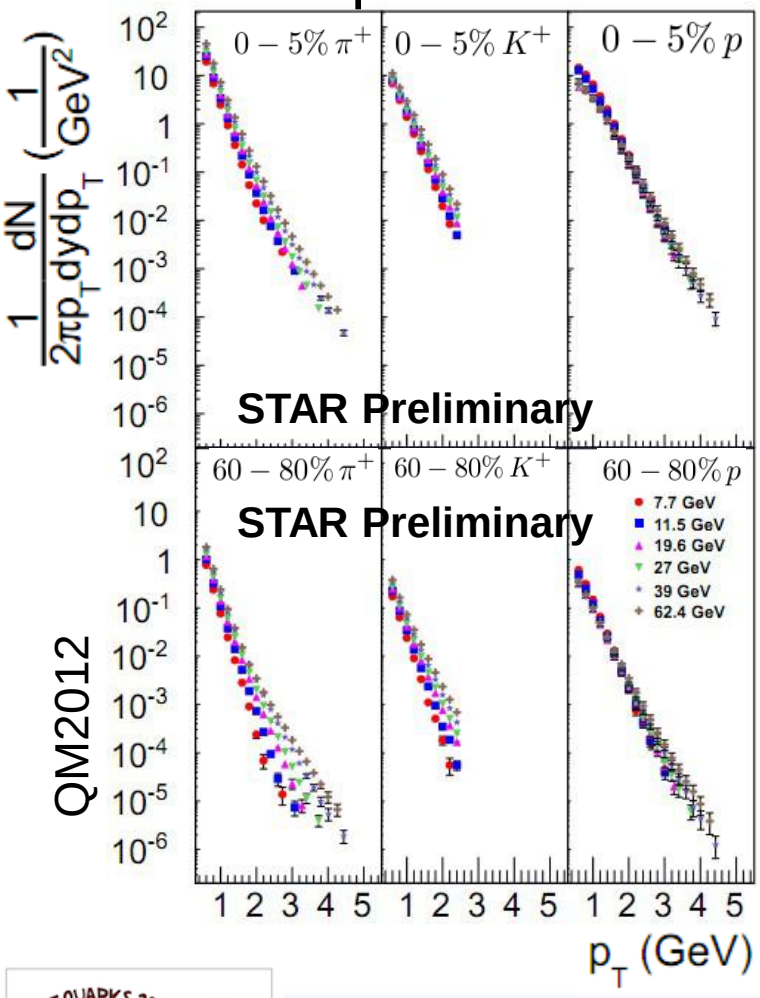
Scaling the y-axis



- Also scaling the y-axis by $\sqrt{s_{NN}}$ (n=1) a possible trend emerges
- The trend is what appears to be an asymptotic behavior in the high p_T regime
- $\sqrt{s_{NN}} \geq 39$GeV dips below the curve at high p_T (consistent with quenching)

PID Spectra

Positive particles

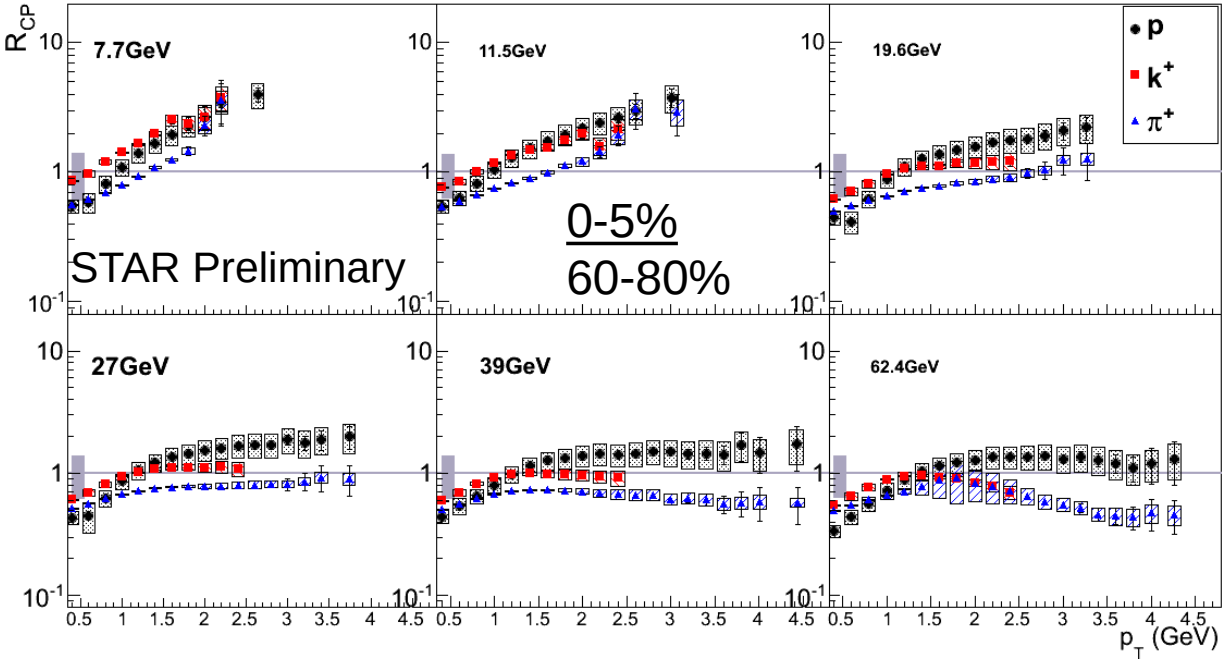


- Again, the peripheral collisions have stronger beam energy dependence
- Also note that pions have a stronger beam energy dependence

PID R_{CP}

Positive particles

QM2012

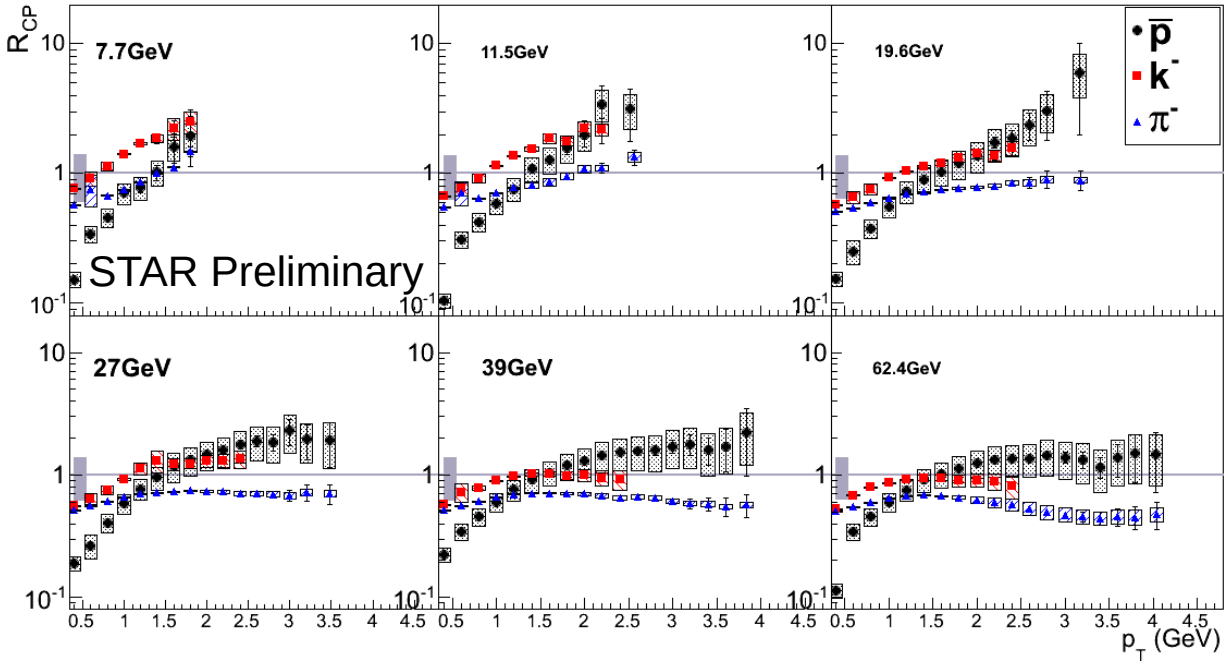


- Protons are enhanced relative to pions, similar to measurements in d + Au at $\sqrt{s_{NN}}$ = 200GeV
- Pion suppression turns off at low energies (but still have some Cronin enhancement)

PID R_{CP}

Negative particles

QM2012

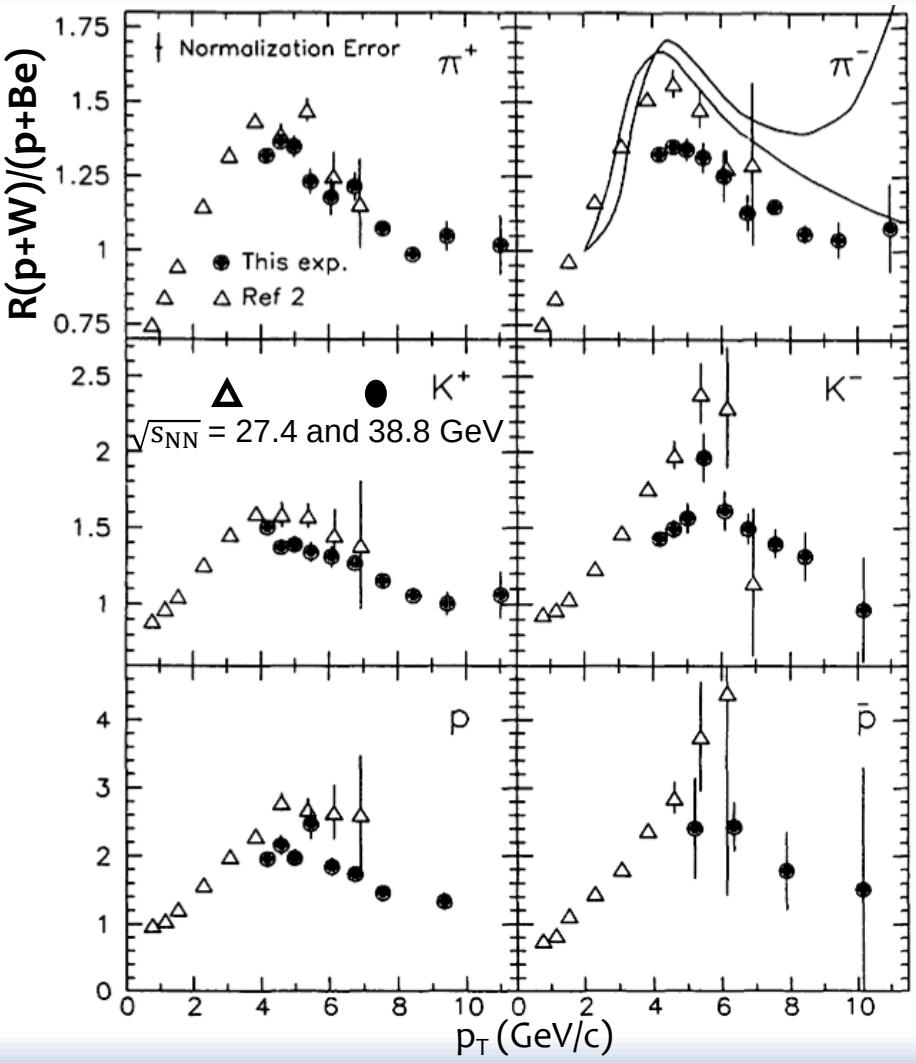


- Behavior is similar to positive particles
- Anti-protons are suppressed relative to protons at low p_T (consistent with annihilation)

Data that would help

- Cronin's data already showed beam energy dependence in the Cronin Effect
- running p + Au or d + Au for each energy would allow further study of this dependence

PRL 68, 452 (1992) Straub *et al.*



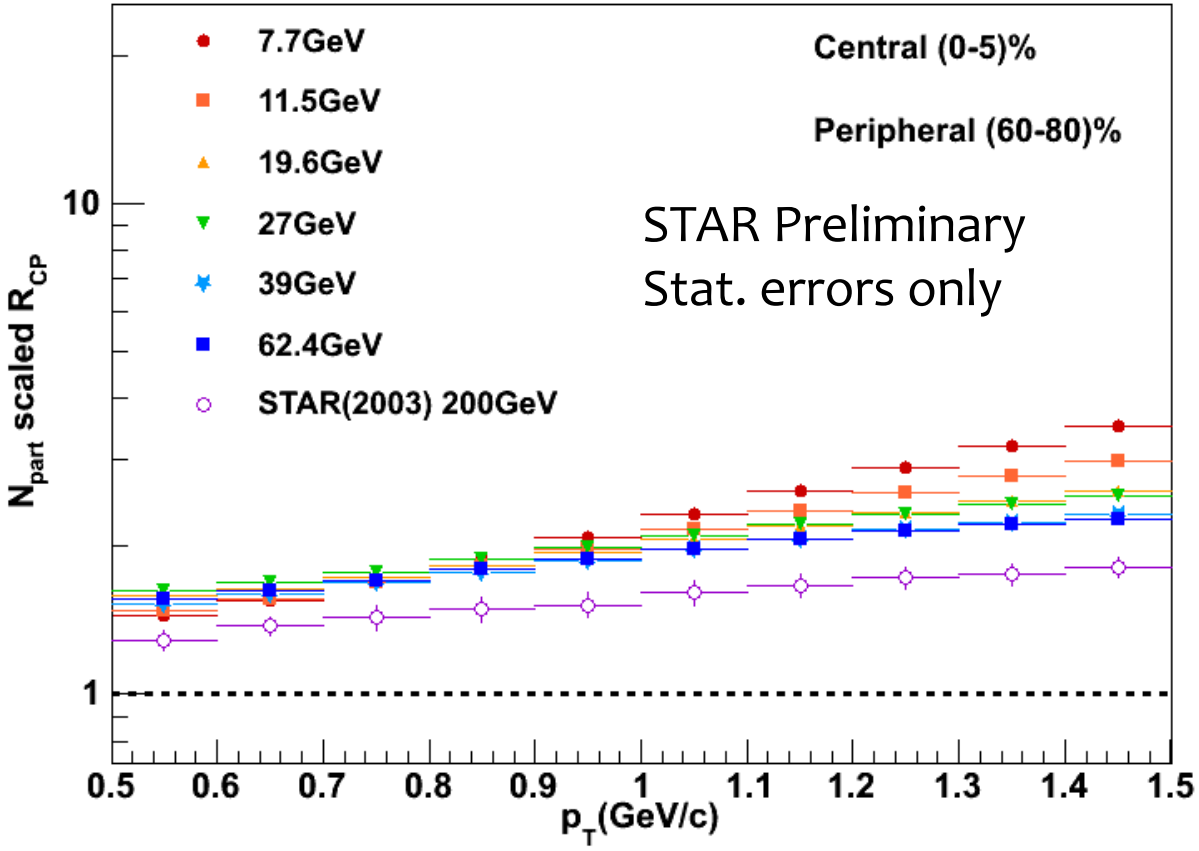
Conclusions

- Charged R_{CP} is suppressed for 200, 62, and 39GeV data-sets
- Efforts are being made to measure quenching
- Clear energy ordering is observed
- The Cronin Effect dominates the lower beam energies
- Scaling might demonstrate beam energy independent trends and quenching could emerge as deviation from these trends
- A complimentary study of identified R_{CP} shows the species dependence for the Cronin Effect

Questions???

Backups

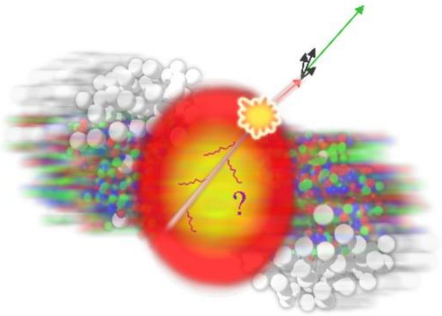
N_{part} Scaling



- Soft physics regime
- Weak energy dependence

Dihadron Correlations

- Di-jets produced in heavy ion collisions traverse the medium
- Triggering on high p_T particles we look at the distribution of correlated particles
- At $\sqrt{s_{NN}}$ = 200GeV we see quenching of the away-side



Phys. Rev. Lett. **91** (2003) 072304