STAR's measurement of long-Range forward backward multiplicity correlations in Heavy Ion central Au-Au collisions at $\sqrt{s} = 200$ GeV.

Is the LRC a signature for partonic matter?

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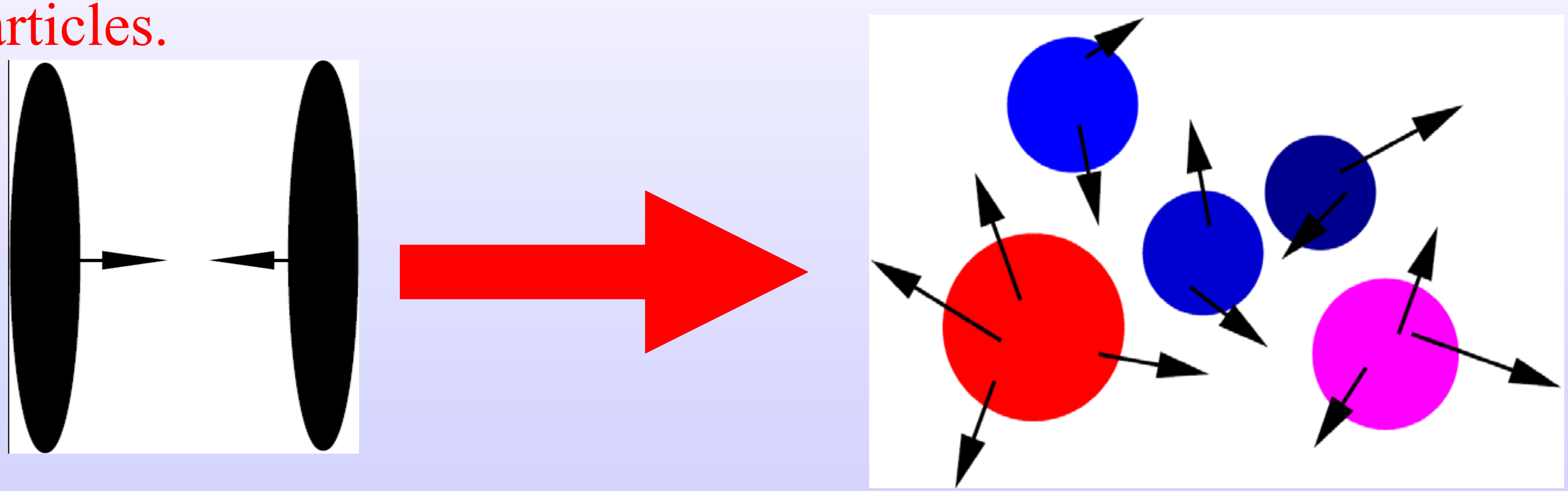
INTRODUCTION

Correlations have always been expected to reflect the features of multiparticle production, including eventual phase transitions.

Simplistic, multipurpose picture of multiparticle production:
first formation of sources, then coherent decay of the sources into particles.



Correlations in rapidity characterize, in principle, the process of formation and decay of such clusters: **how many of them, which size i. e. how many particles do they produce?**

MODEL DEPENDENT ARGUMENT

Multiparticle production at high energies can be described in terms of color strings stretched between the projectile and target. These strings hadronize to produce the observed particles.

The number. of strings grow with energy and the number of participating nucleons. interaction between the strings must be considered.

This problem acquires even more importance considering that, at very high energies, collisions of heavy nuclei at RHIC may produce high density matter.

In this picture collective interactions between strings are required to evolve the system towards a QGP state.

Ref: M. A. Braun and C. Pajares, Nucl. Phys. B390, 542(1993).

M. A. Braun et al., Inter. Jour. Mod. Phys. A14,2689, (1999).

H. Satz, Rep. Prog. Phys., 63, 1511(2000).

N. Armesto et al., Phys. Lett. B527, 92(2002).

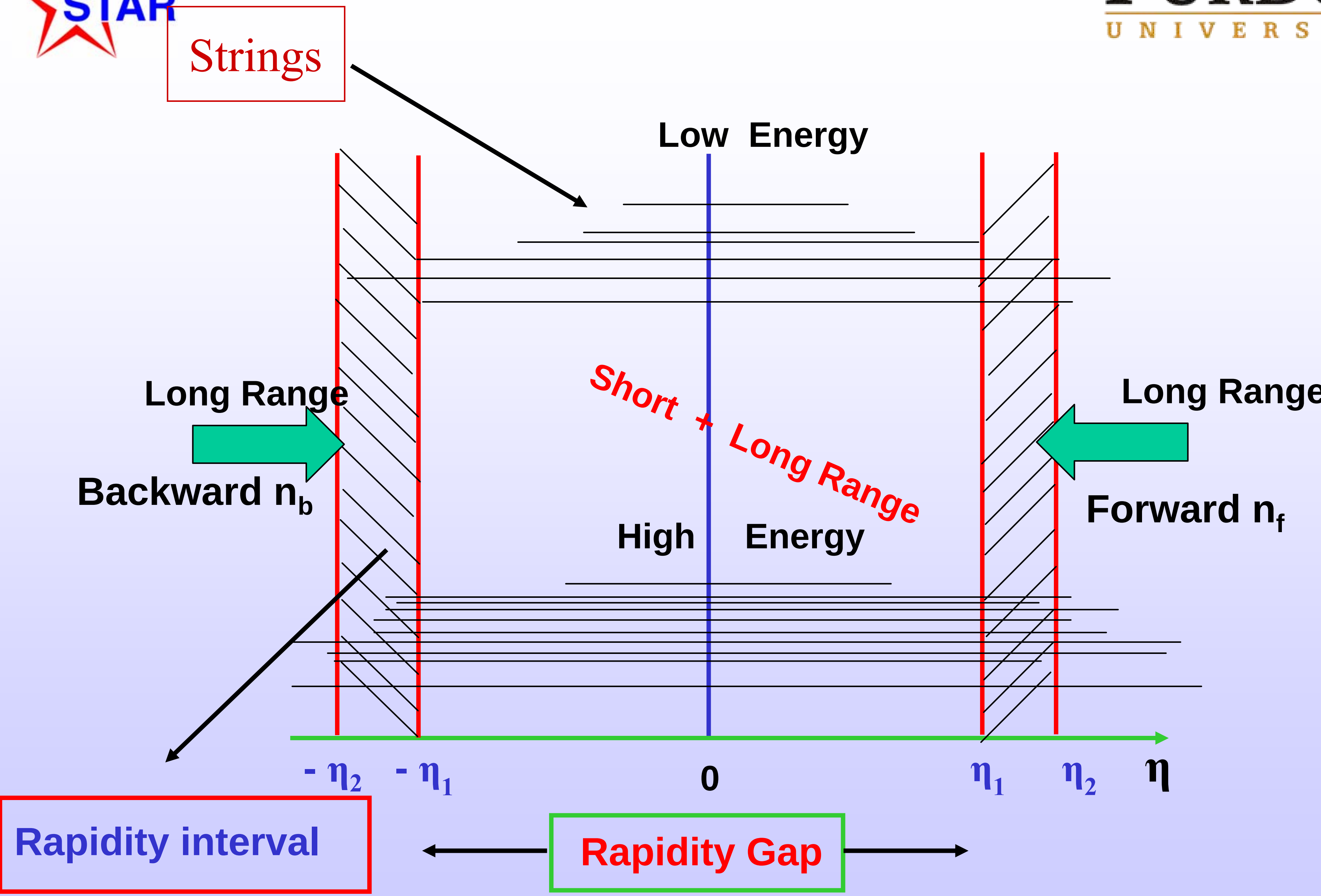
FORWARD-BACKWARD MULTIPLICITY CORRELATIONS

Linear expression relating N_b and N_f (forward and backward multiplicity), "b" is correlation strength. The b coefficient can be expressed as,

N = # of hadrons

$$<N_b>(N_f) = a + bN_f$$

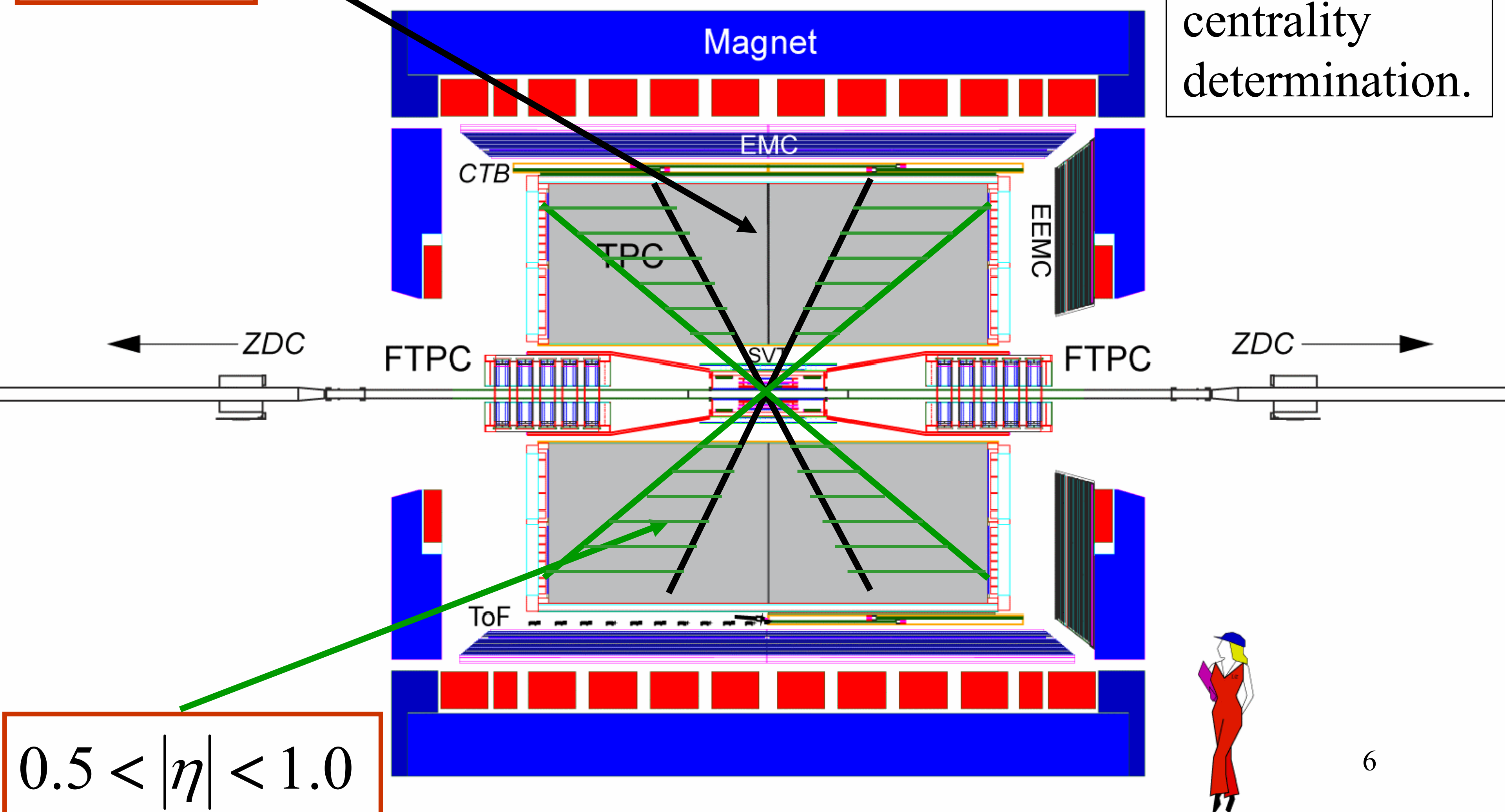
$$b = \frac{<N_f N_b> - <N_f><N_b>}{<N_f^2> - <N_f>^2} = \frac{D_{bf}^2}{D_{ff}^2}$$


Strings
Low Energy
Long Range
Backward n_b
Short + Long Range
Long Range
Forward n_f
High Energy
$-\eta_2$
$-\eta_1$
0
η_1
η_2
η
Rapidity interval
Rapidity Gap

STAR Detector

$|\eta| < 0.5$

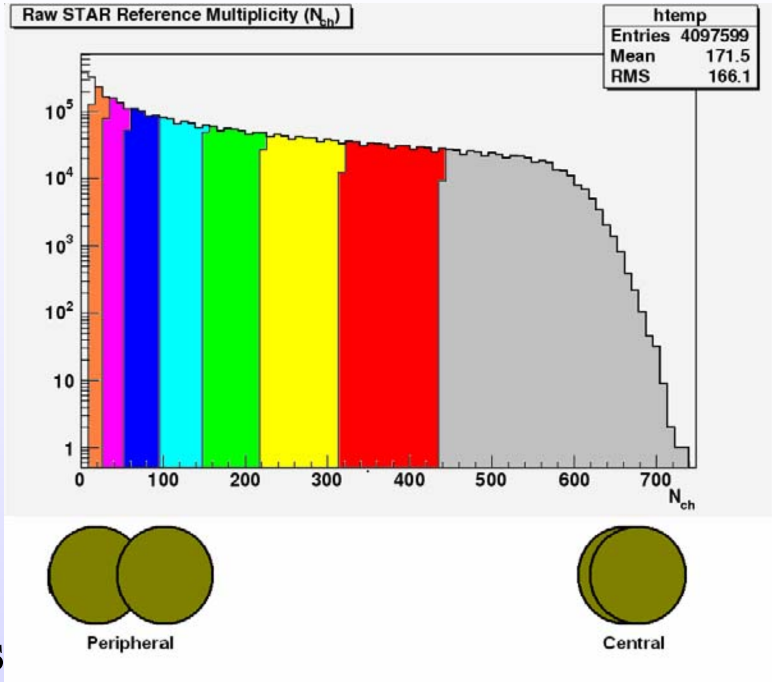
Used for centrality determination.



$0.5 < |\eta| < 1.0$

Analysis

1. **Au+Au, Cu+Cu, and pp MB data.**
2. **For Au+Au, eight centrality bins as defined by STAR charged particle reference multiplicity: 0-10%, 10-20%, …, 70-80% fewer for Cu+Cu).**
   - **$|\eta| < 0.5$ (for intervals w/ $|\eta| > 0.5$) or $0.5 < |\eta| < 1.0$ (for intervals w/ $|\eta| < 0.5$ or $|\eta| < 0.3 + 0.6 < |\eta| < 0.8$ (for $\Delta\eta = 1.0$)**
   - **$p_T > 0.15$**
   - **$|v_z| < 30$**



3. **Backward and forward intervals are 0.2 units. Intervals are separated by an increasing gap about midrapidity from $\Delta\eta = 0.2 - 1.8$, measured from bin centers.**
4. **$\Delta\eta$ is measured in an absolute coordinate system, where $\eta = 0$ is fixed at the primary collision vertex.**

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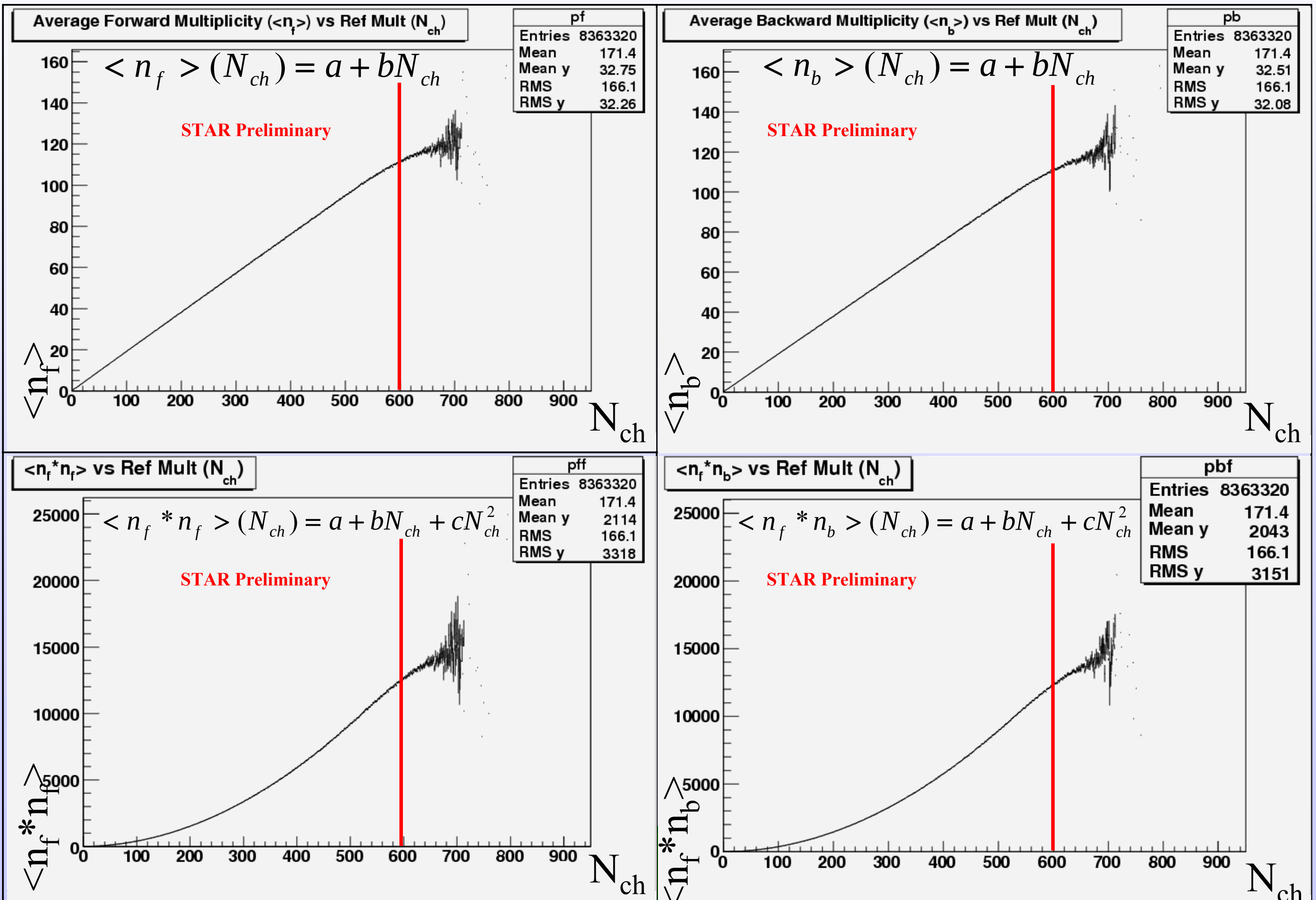
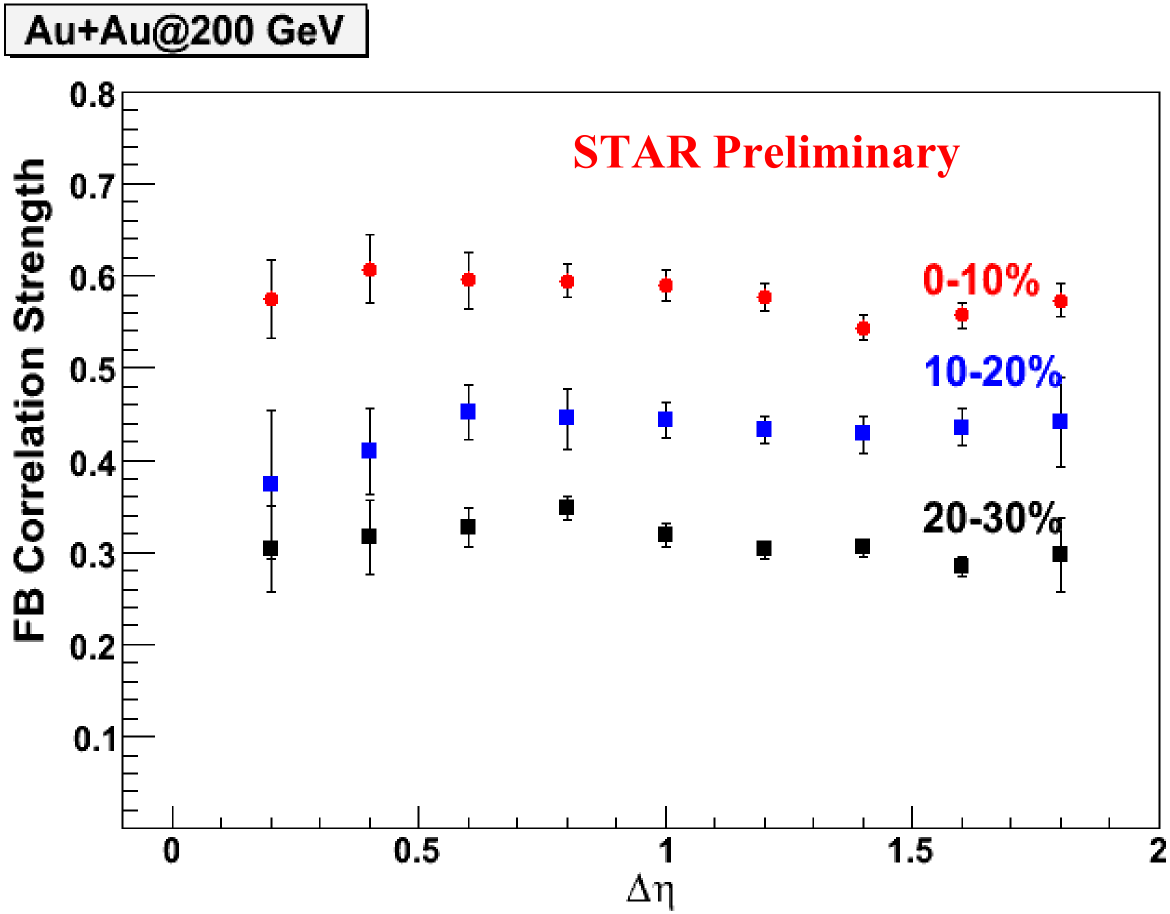
Calculating Dispersion…

- By calculating $<n_f>$, $<n_b>$, $<n_f^2>$, and $<n_f n_b>$ as functions of STAR reference multiplicity.



- Obtained on event-wise basis as function of event multiplicity
- Fitted to obtain the average values.
- Tracking efficiency and acceptance corrections applied in each event.
- Used to calculate, binned by centrality, and normalized by the total number of events in each bin.
- Method removes the dependence of the FB correlation strength on size of centrality bin.

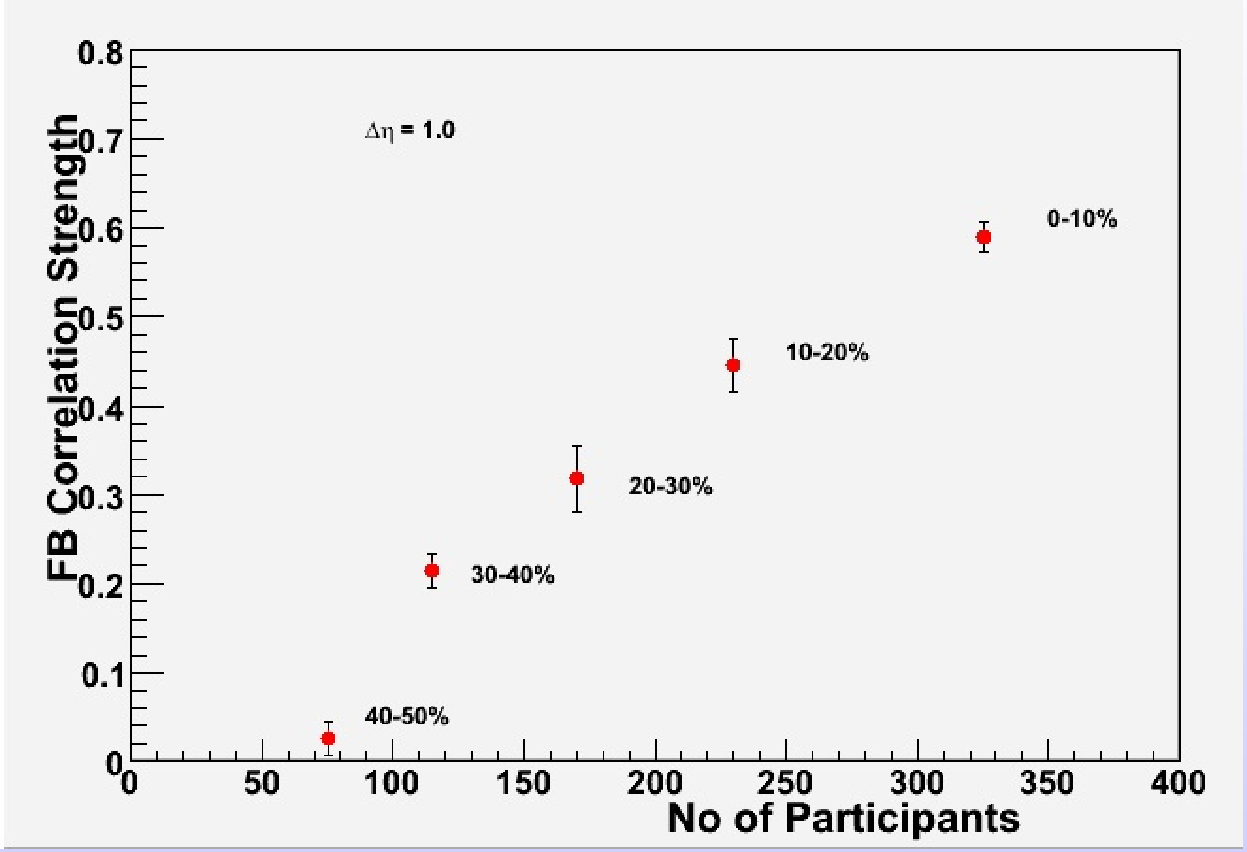


Results corrected for tracking efficiency & detector acceptance.

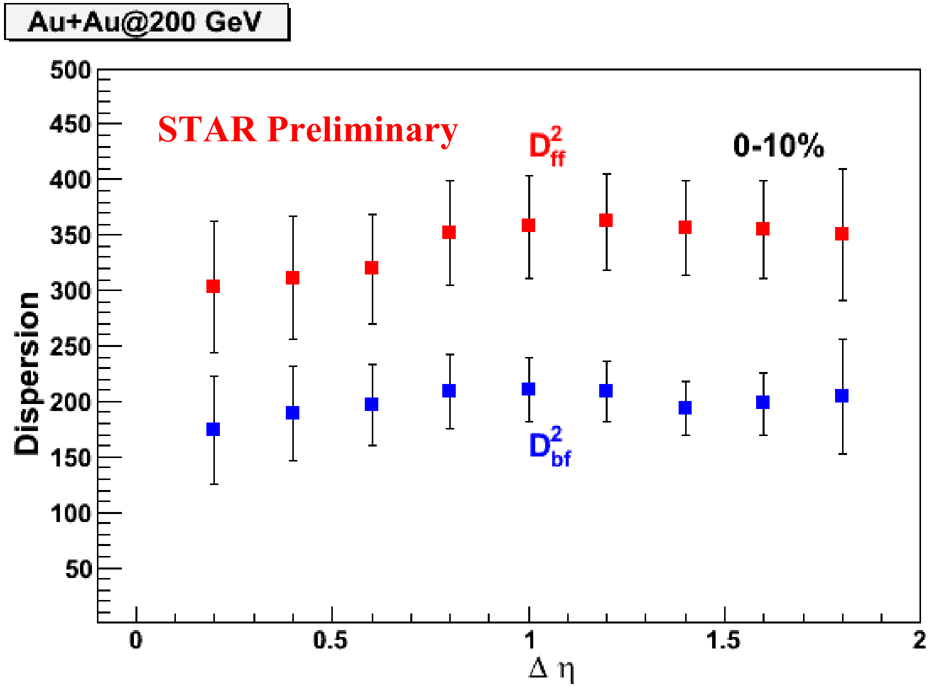
$$b = \frac{\langle n_f n_b \rangle - \langle n_f \rangle \langle n_b \rangle}{\langle n_f^2 \rangle - \langle n_f \rangle^2} = \frac{D_{bf}^2}{D_{ff}^2}$$

LRC b coefficient for $\Delta\eta=1$

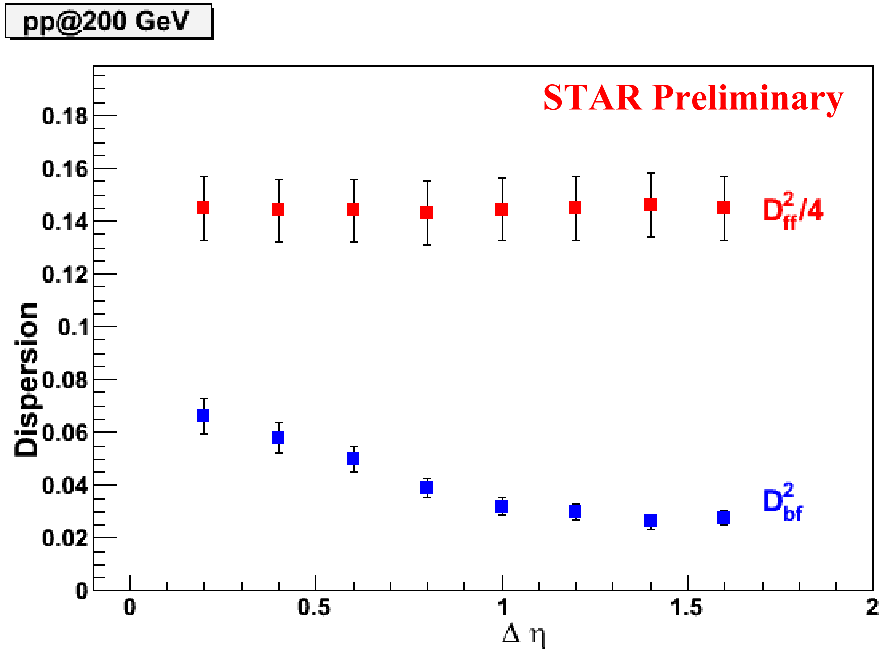
Star Preliminary

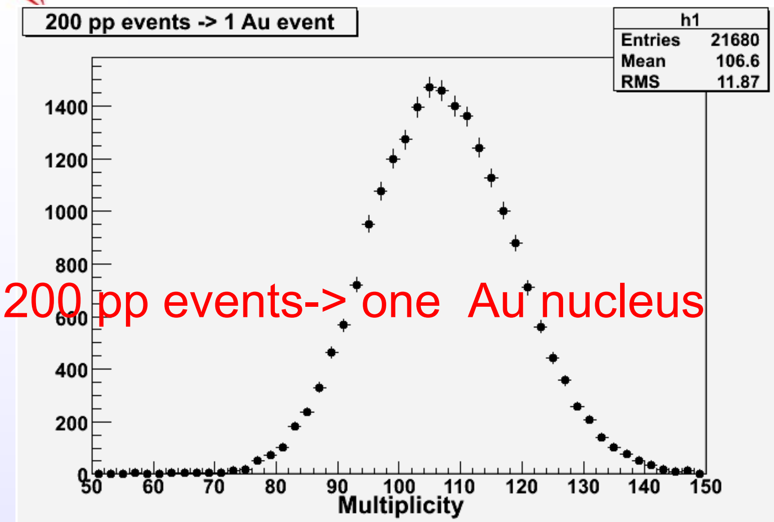


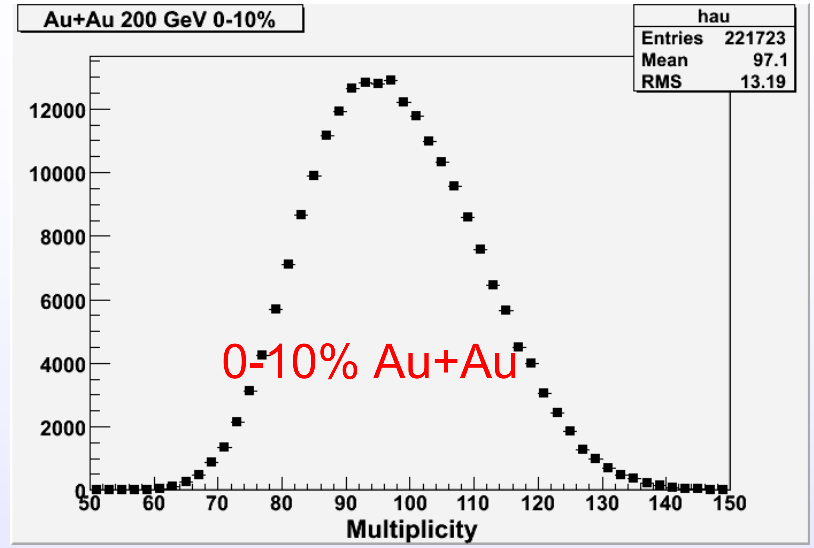
Dispersions, $D_{FF}{}^2$ and $D_{BF}{}^2$

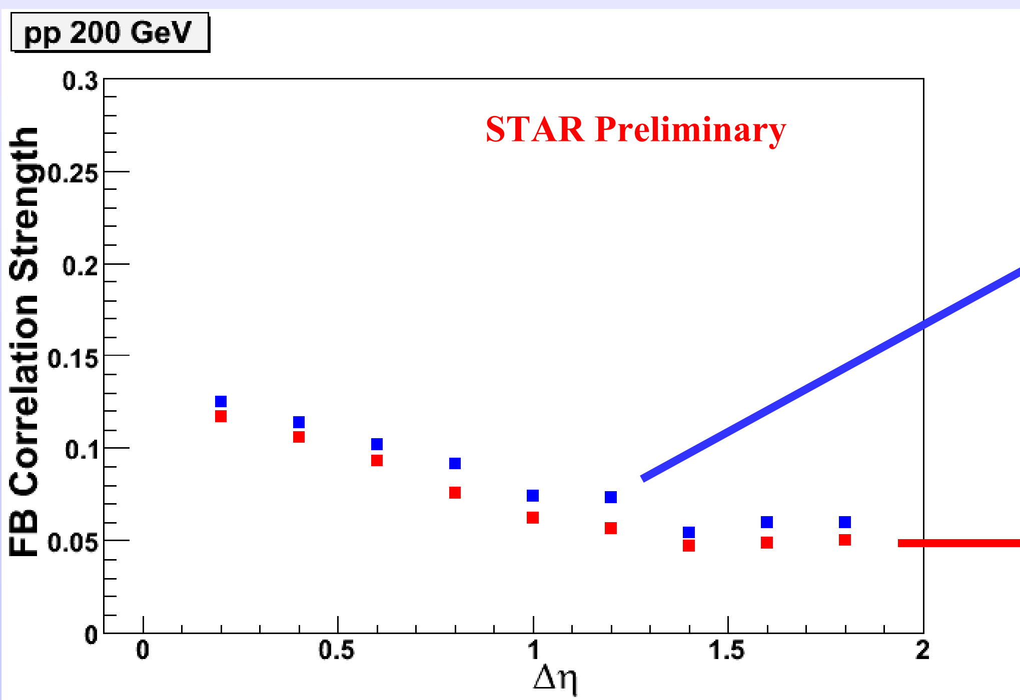


$$b = \frac{<n_f n_b> - <n_f><n_b>}{<n_f^2> - <n_f>^2} = \frac{D_{bf}^2}{D_{ff}^2}$$







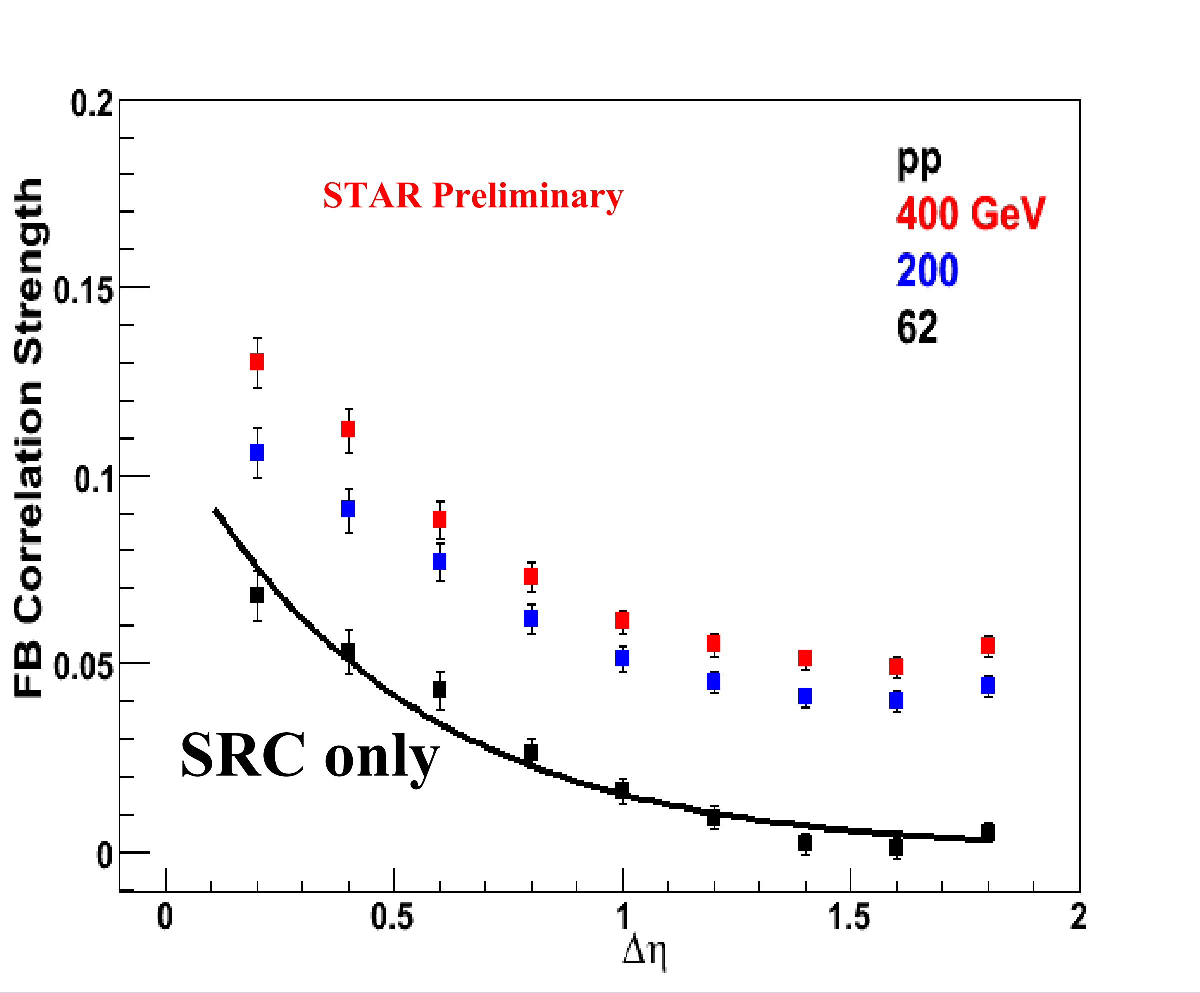


200 pp events to mimic one Au nucleus

pp events

le,WA

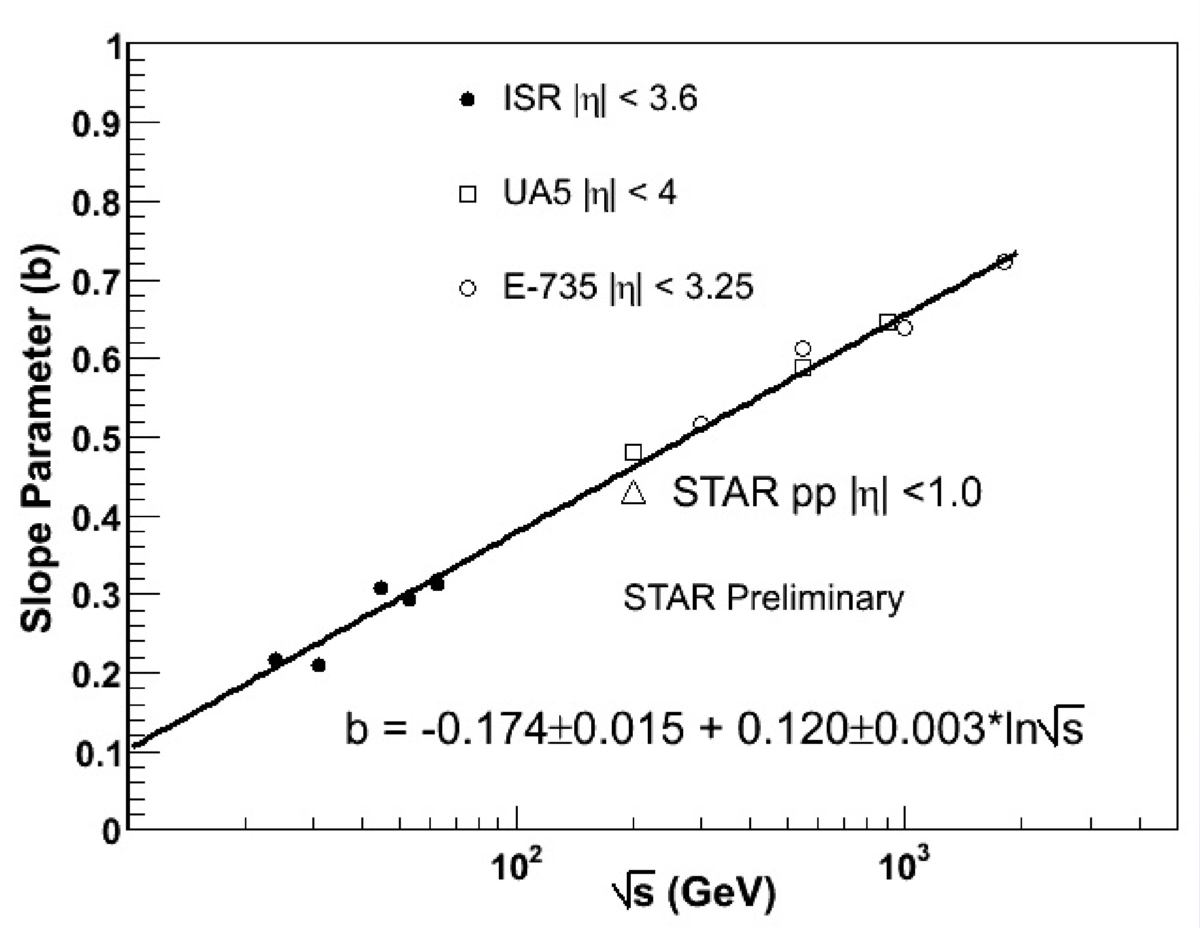
pp at 62, 200 and 400 GeV



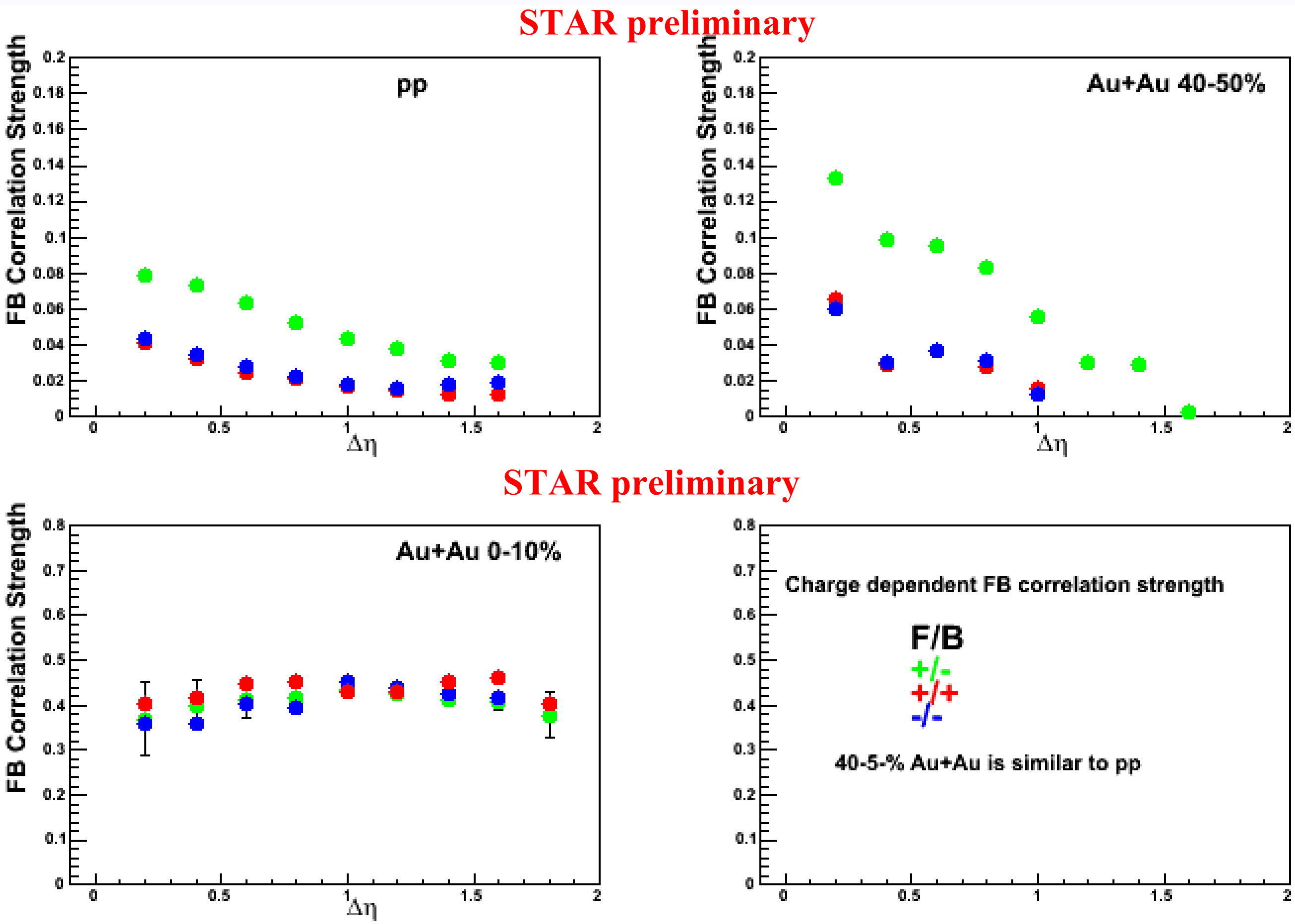
Comparing correlations

1. 200 and 400 GeV in close agreement:
2. 62.4 GeV goes smoothly to $b = 0$. Not even a small LRC.

b coefficient systematics



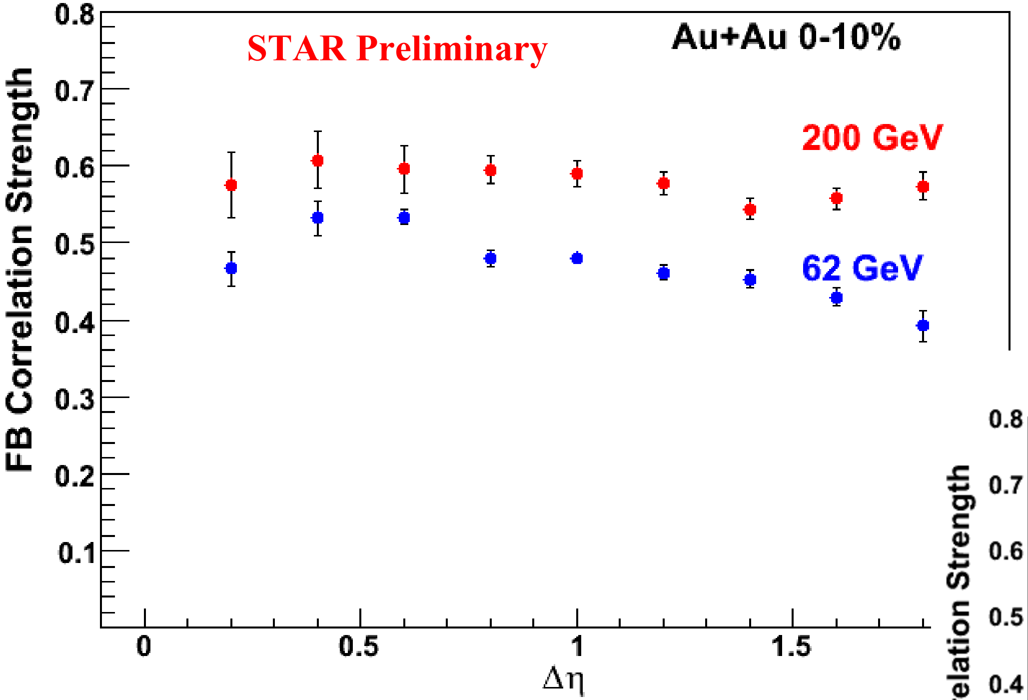
FB Correlations for Like and Unlike Charges

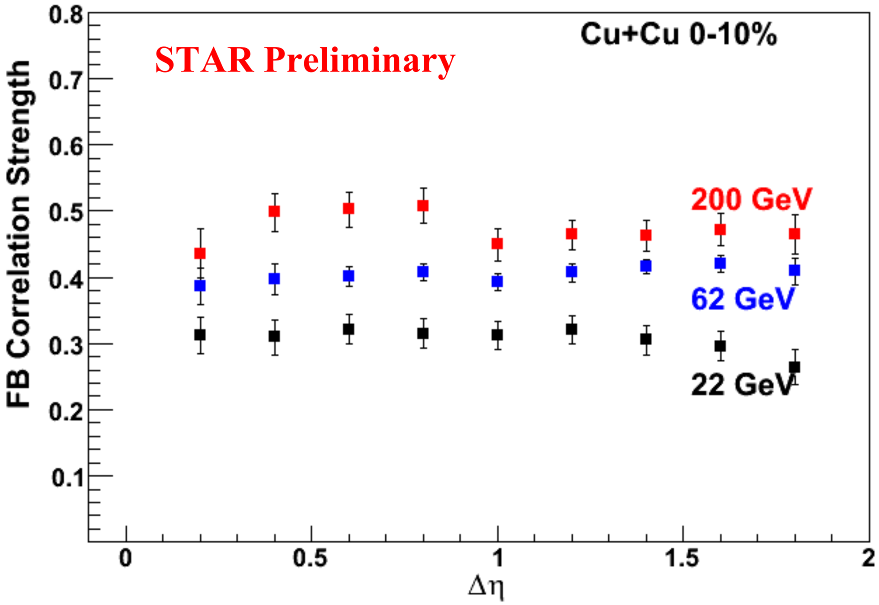


In most central collisions the like and unlike charges have same FB correlation strength.

In pp and 40-50% central Au+Au collisions the FB correlations strength is different for like and unlike charges.

Energy dependence of the b coefficient





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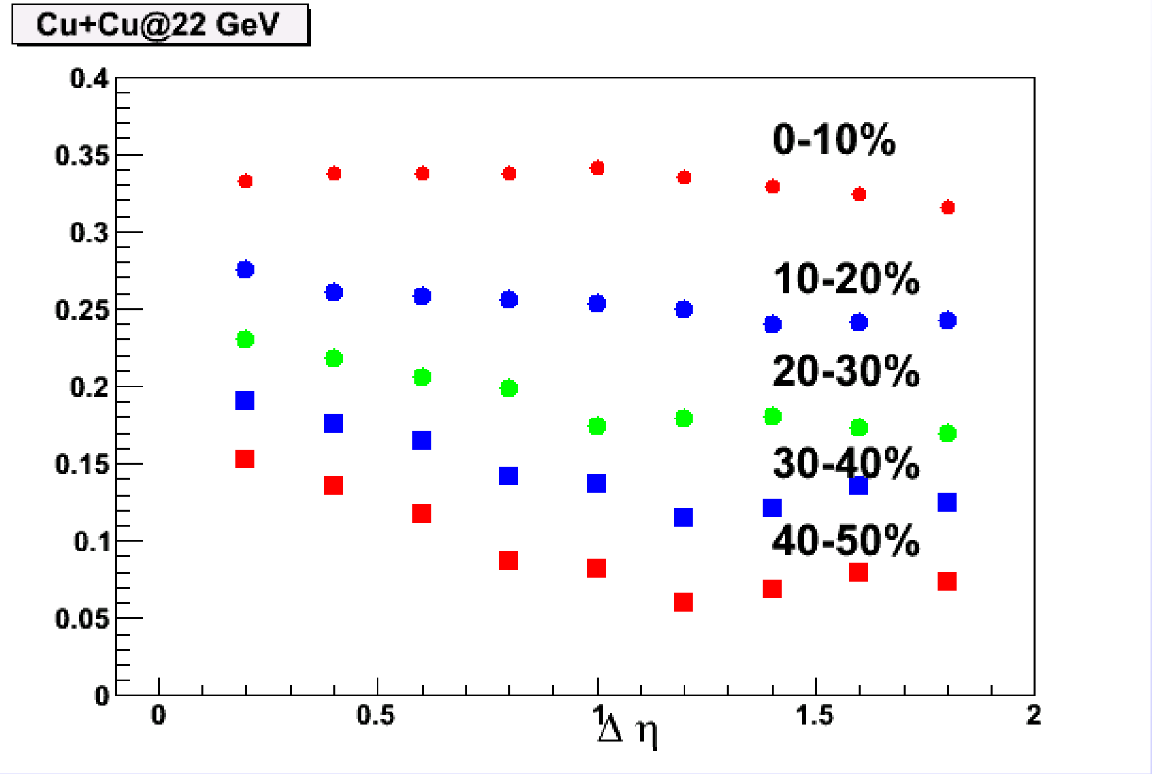

Data Summary

1.Strong long range correlations are observed for central Au+Au at 0 to 10% centrality.

2.Long range correlations decrease with decreasing centrality and vanish at 40 to 50% centrality.

3, Magnitude of the b coefficient for LRC has centrality dependence like the nuclear modification factor R_{AA}.

3. 200 GeV p-p b value agrees with hadron systematics.

4. Charge dependence of b supports a "connected" system in central Au-Au collisions.

5. DPM considerations argue that the long range correlations are due to multiple parton interactions.

6. LRC b~0.3 coefficient seen in central √s =22 GeV Cu-Cu collisions.

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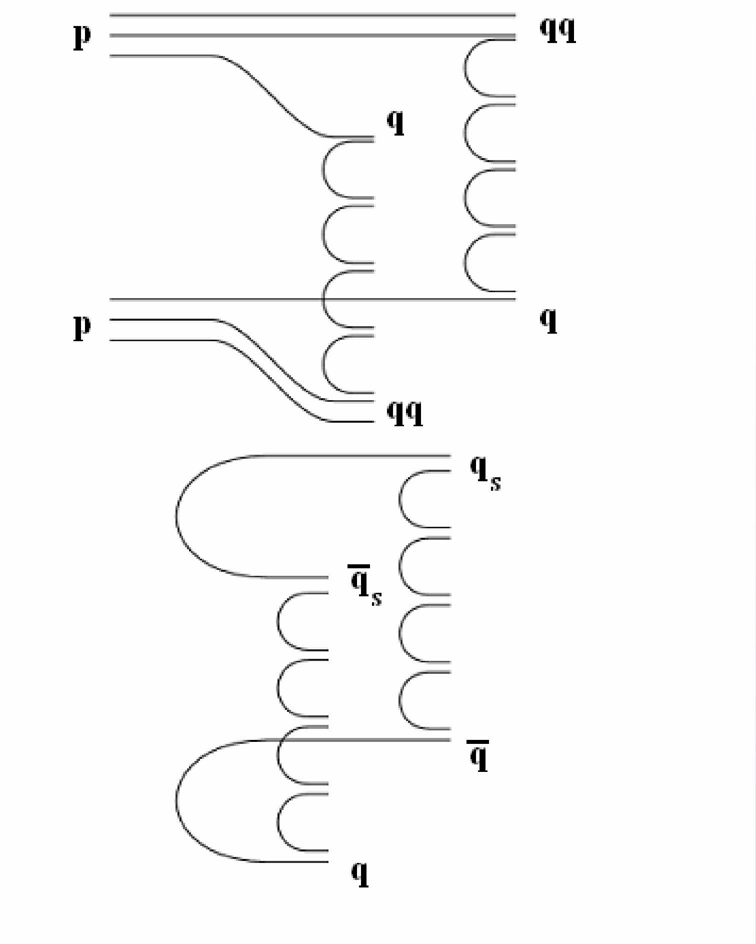
Model Dependent Considerations

1. The Dual Parton Model, motivation for the LRC search.
2. DPM predicted the LRC in high energy nucleus-nucleus collisions from sea quark and gluon contrbutions, to the colored strings, LRC are due to fluctuations in the number of strings.
3. Comparison of DPM and Hijing with Au-Au 0 to10% data at $\sqrt{s}$=200 GeV
4. Color Glass Condensate-Glasma-thermalization ?
5. Fluctuations in the initial singularity and the LRC
6. Partonic Core, Hadronic Carona ?

Color Strings

- At low energies, valence quarks of nucleons form strings that then hadronize → wounded nucleon model.
- At high energies, contribution of sea quarks and gluons becomes dominant.
  - Additional color strings formed.



A long-range correlation is an indication of multiple elementary inelastic collisions .

Interpretation of F-B Multiplicity Correlations in DPM

- DPM assumes short-range correlations confined to individual strings.
- A gap about midrapidity will eliminate effect of short-range correlations (e.g .from clustering, jets, …)
  - Long-range correlations due to superposition of fluctuating number of strings.

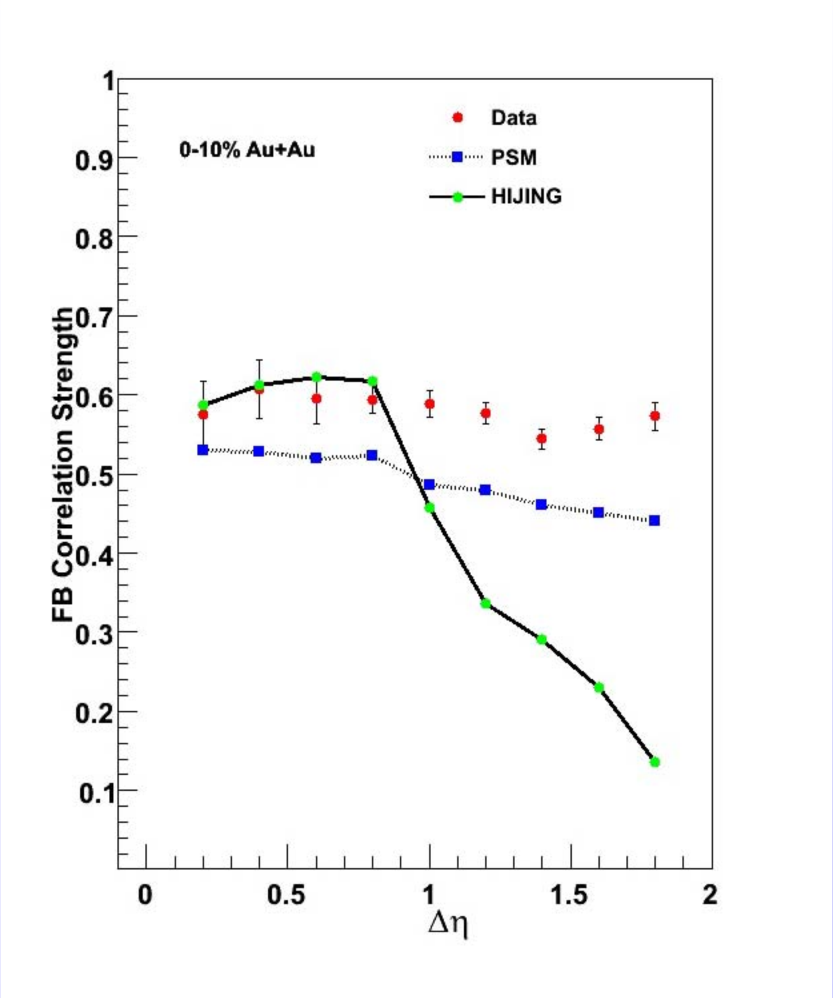
$$\langle N \rangle = \langle n \rangle \langle N_0 \rangle$$

$$\langle n \rangle = \frac{\sum_{n=1}^{\infty} n \sigma_n}{\sum_{n=1}^{\infty} \sigma_n}$$

$$D_{bf}^2 = \langle N_f N_b \rangle - \langle N_f \rangle \langle N_b \rangle =$$
$$\langle n \rangle (\langle N_{0f} N_{0b} \rangle - \langle N_{0f} \rangle \langle N_{0b} \rangle) +$$
$$[(\langle n^2 \rangle - \langle n \rangle^2)] \langle N_{0f} \rangle \langle N_{0b} \rangle$$

Comparison with phenomenological models

STAR Preliminary



HIJING has only SRC

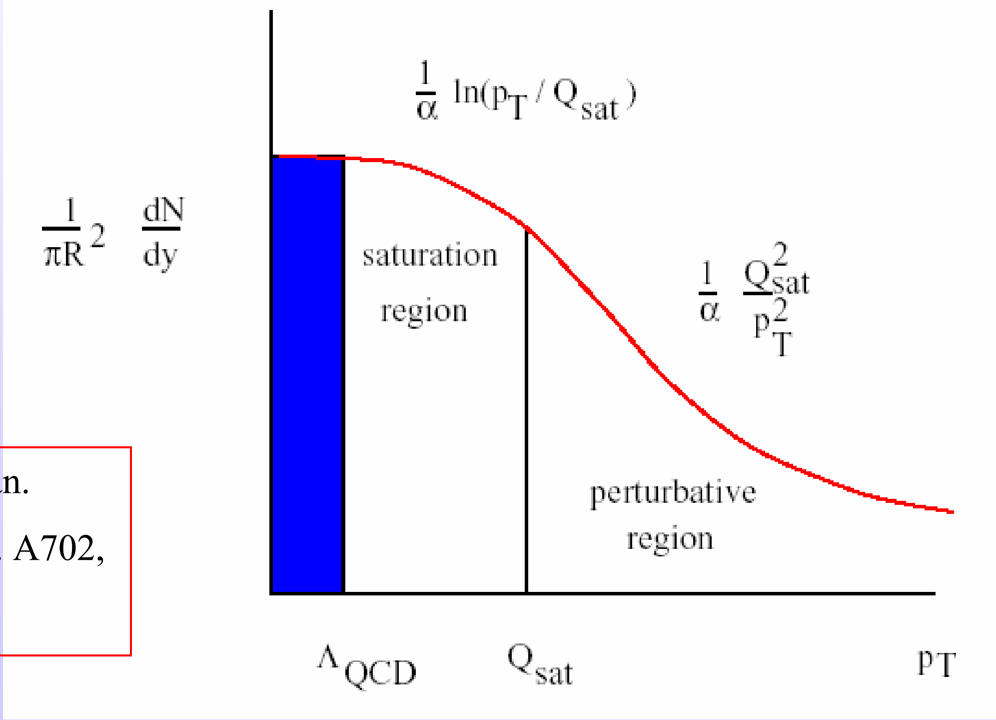
HIJING predicts SRC with a large value of b near midrapidity in agreement with the data.

PSM has both SRC and LRC and is in qualitative agreement with the data

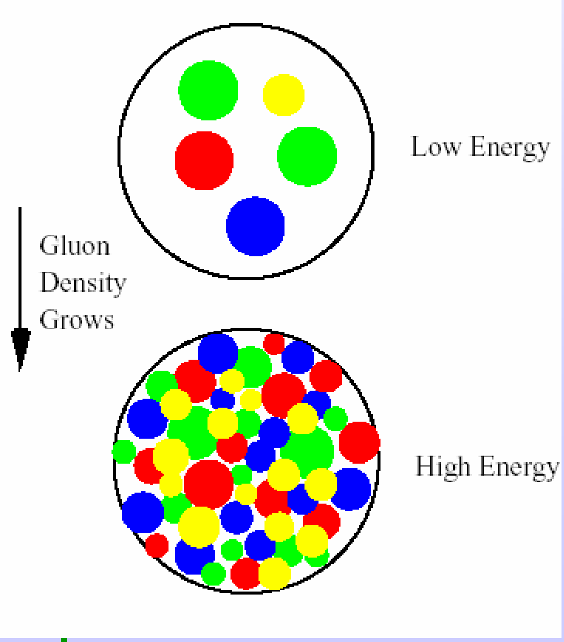
Color Glass Condensate (CGC)

- Description of high density gluonic matter at small-x.

$$x = \frac{p_{constituent}}{p_{hadron}}$$

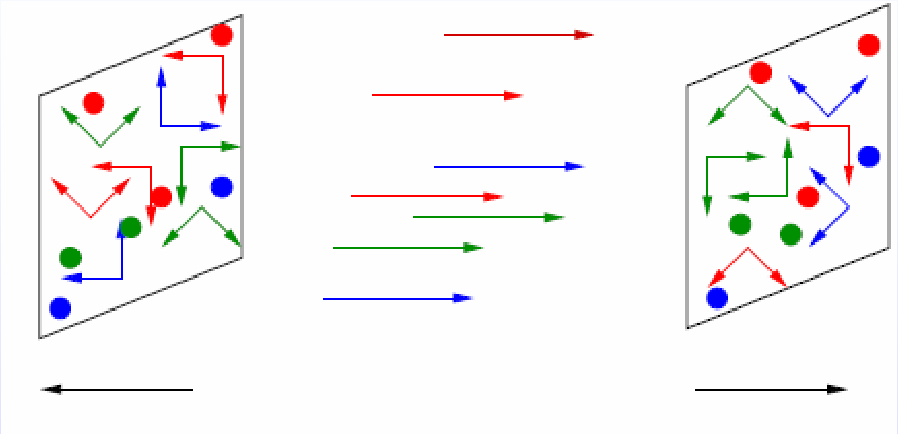


L. McLerran. Nucl. Phys. A702, 49c(2002)



CGC→Glasma

- Longitudinal color fields created in "Glasma".



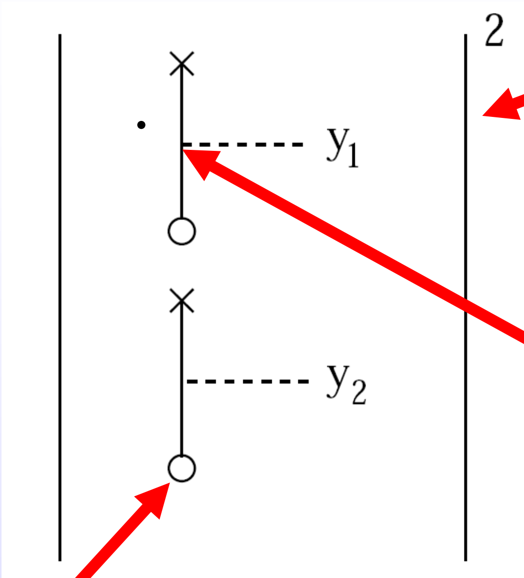
N. Armesto, L. McLerran and C. Pajares , Nucl. Phys . A781, 201(2007)

CGC→Glasma

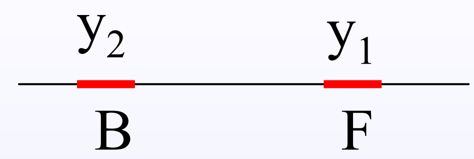
- Longitudinal color fields created in “Glasma”.
  - Similar to strings in DPM.
  - Origin of LRC.
  - Predicts increase of correlation strength with centrality.

N.Armesto, L. McLerran, C. Pajares, hep-ph/0607345

Uncorrelated diagram:



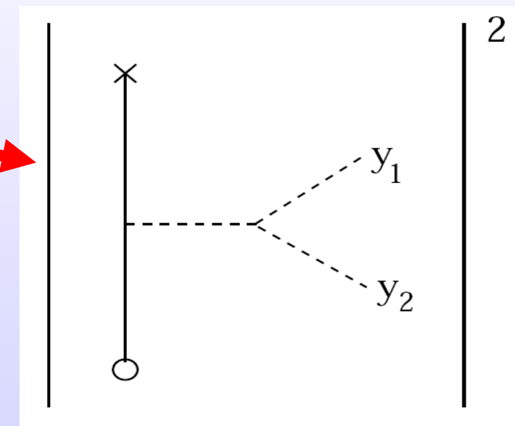
$$\left\langle \left(\frac{dN}{dy}\right)^2 \right\rangle \sim \frac{1}{\alpha_s^2}\pi R^2 Q_{sat}^2 \sim \frac{1}{\alpha_s}\frac{dN}{dy}$$



g

1/g

Correlated diagram:

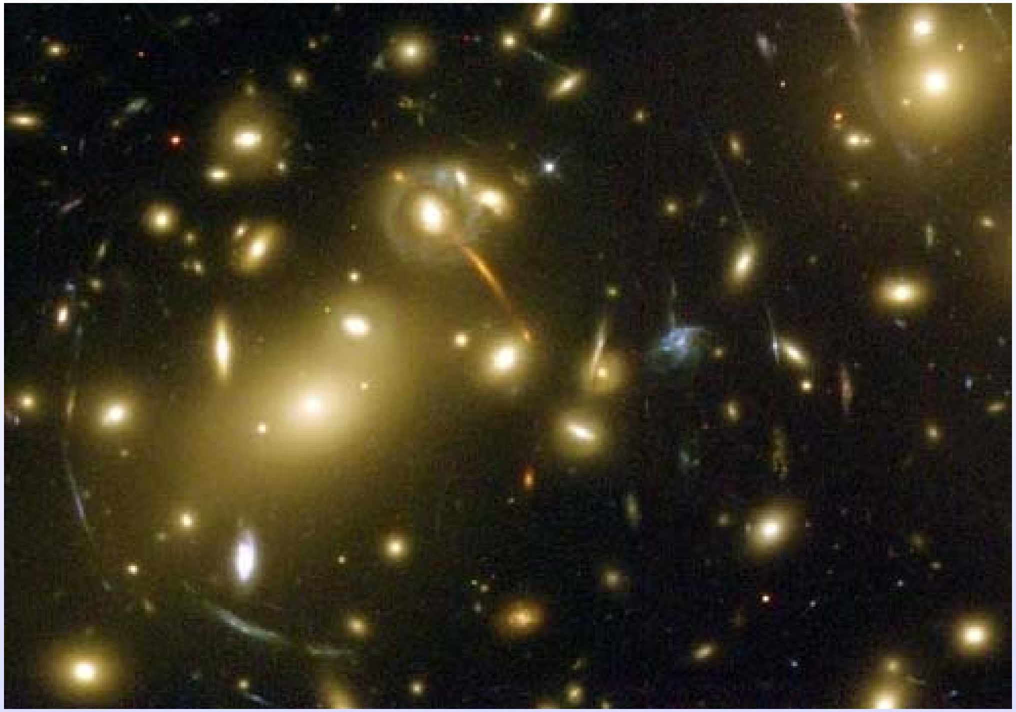


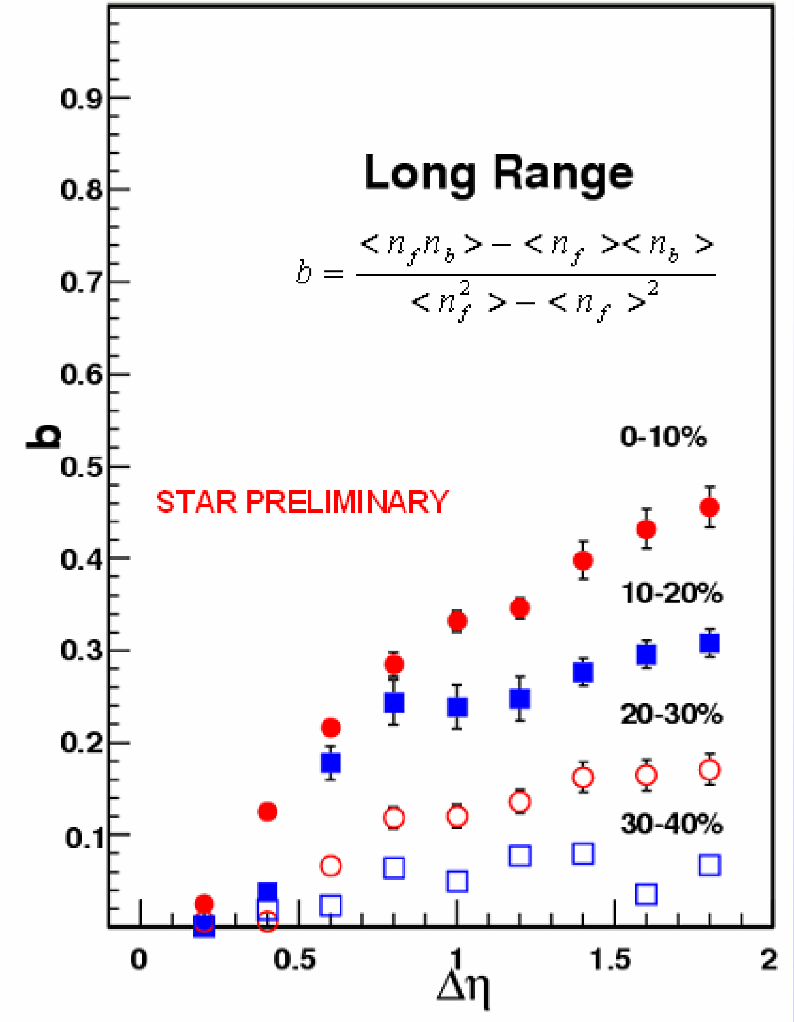
$$\left\langle \frac{dN_{cor}}{dy_1}\frac{dN_{cor}}{dy_2} \right\rangle \sim \pi R^2 Q_{sat}^2 \sim \frac{dN_{cor}}{dy} e^{-\kappa |y_1 - y_2|}$$

- For gluons the long range rapidity correlation increases with energy, centrality and decreases with $|y_1-y_2|$. Baryons -> smaller correlation.

$$\sigma_{FB} = \frac{\langle N_F N_B \rangle - \langle N_F \rangle \langle N_B \rangle}{\langle N^2 \rangle - \langle N \rangle^2} = \frac{1}{1 + c\alpha_s^2}$$

Fluctuations in The Initial Singularity





During inflation: Fluctuations on scale larger than even horizon are made

Late times: Become smaller than even horizon => Seeds for galaxy formation

Fluctuations over many units in rapidity in initial wavefunction

Partonic Core? Hadronic Corona?

An A+A collision can be envisioned as a central core due to multiple partonic interactions, surrounded by a hadronic corona. The LRC is built up during partonic scattering:

- In central collisions, larger volume of the core implies larger LRC.
- In peripheral A+A, smaller (or no) core region) → decrease in correlation strength.

Evidence for a Model Independent Multiparton LRC connection

1. Multiplicity distrbutions in pbar-p collisions from 0.3 to1.8TeV.

2. Breakdown of KNO scaling above $\sqrt{s}$ = 100 GeV.

   KNO-1 shown.

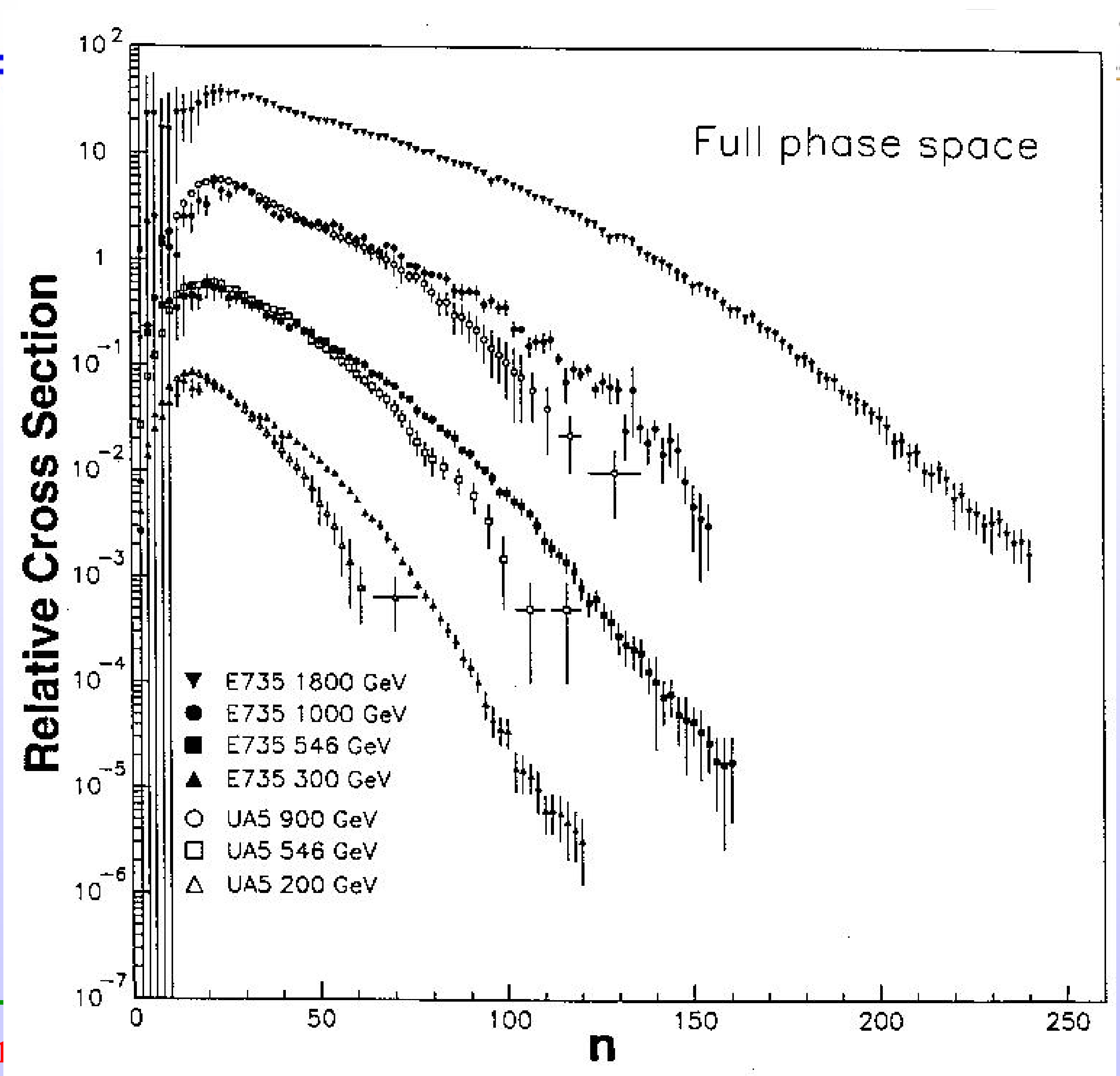
3. Subtract KNO-1, KNO-2 remains and grows with energy

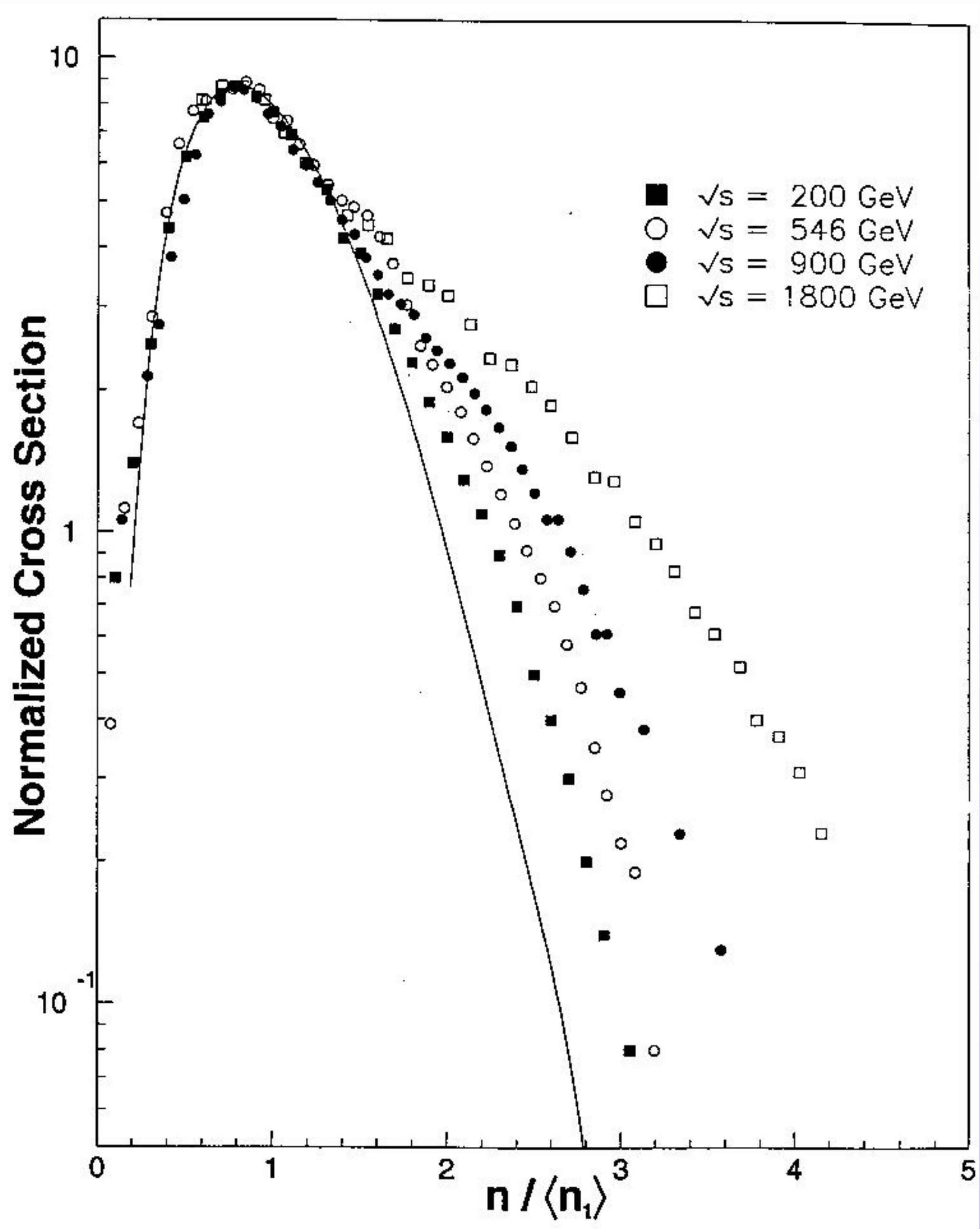
4. Decomposition at 1.8 TeV. W. D. Walker Physical Review D 69, 034007 (2004)

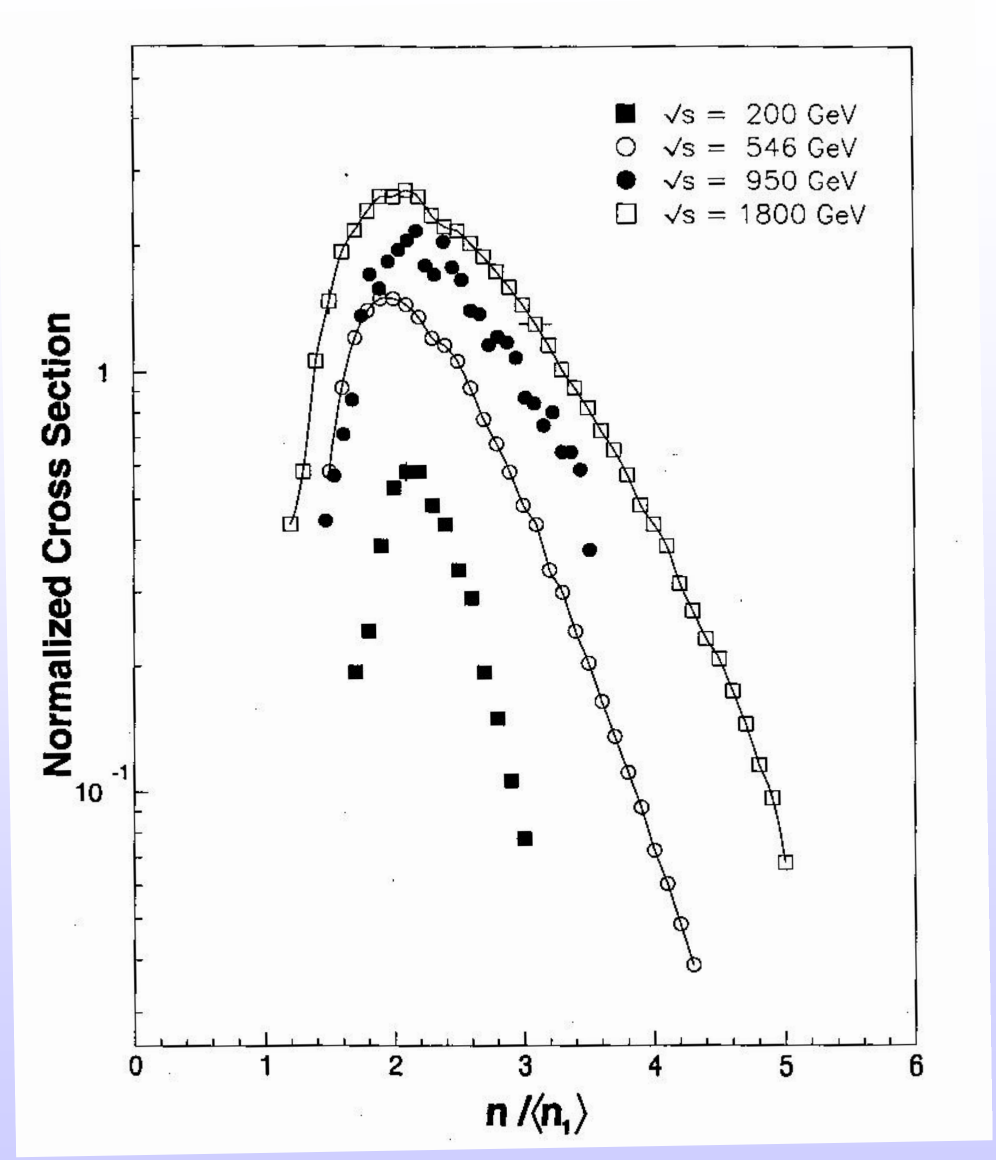
5. Growth of LRC as a function of energy from 0.3 to 1.8 TeV

   E735 collaboration T. Alexopoulos et al Physics Letters B353(1995) 155-160

6. Do > KNO-1 multiparton interactions produce the LRC ?


Relative Cross Section
n
Full phase space
E735 1800 GeV
E735 1000 GeV
E735 546 GeV
E735 300 GeV
UA5 900 GeV
UA5 546 GeV
UA5 200 GeV


Normalized Cross Section
n / ⟨n₁⟩
√s = 200 GeV
√s = 546 GeV
√s = 900 GeV
√s = 1800 GeV
10
1
10⁻¹
0
1
2
3
4
5



√s = 200 GeV
√s = 546 GeV
√s = 950 GeV
√s = 1800 GeV
Normalized Cross Section
1
10^-1
0
1
2
3
4
5
6
n /⟨n1⟩

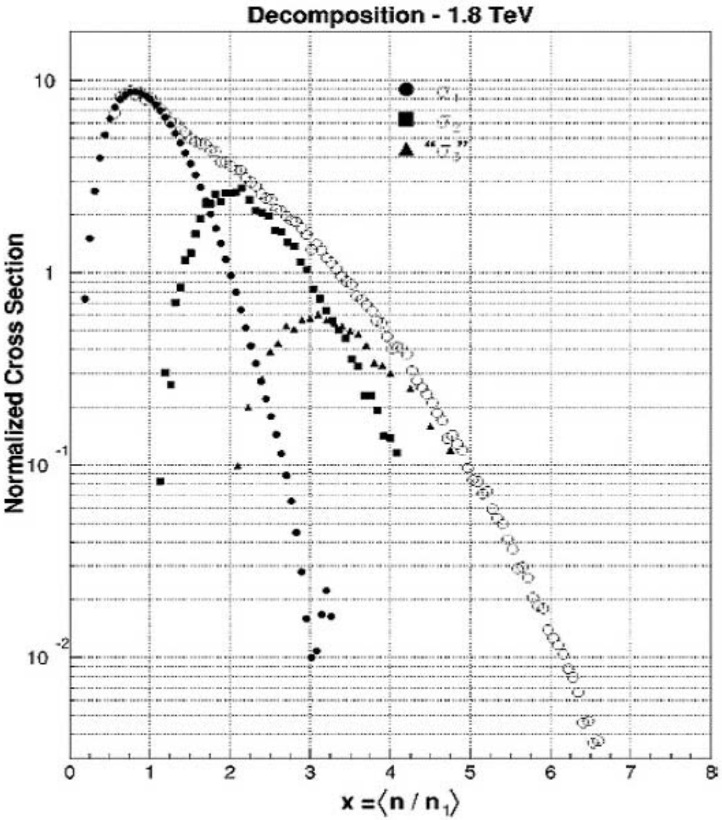
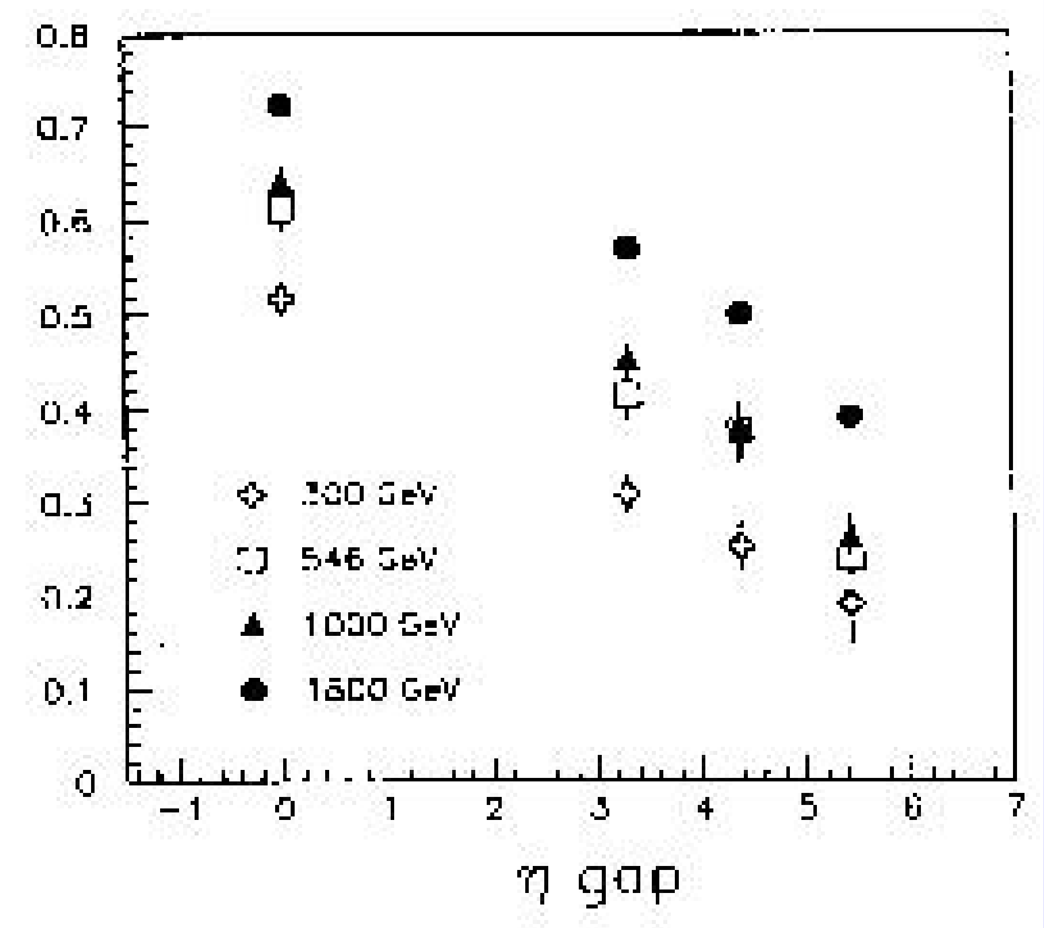
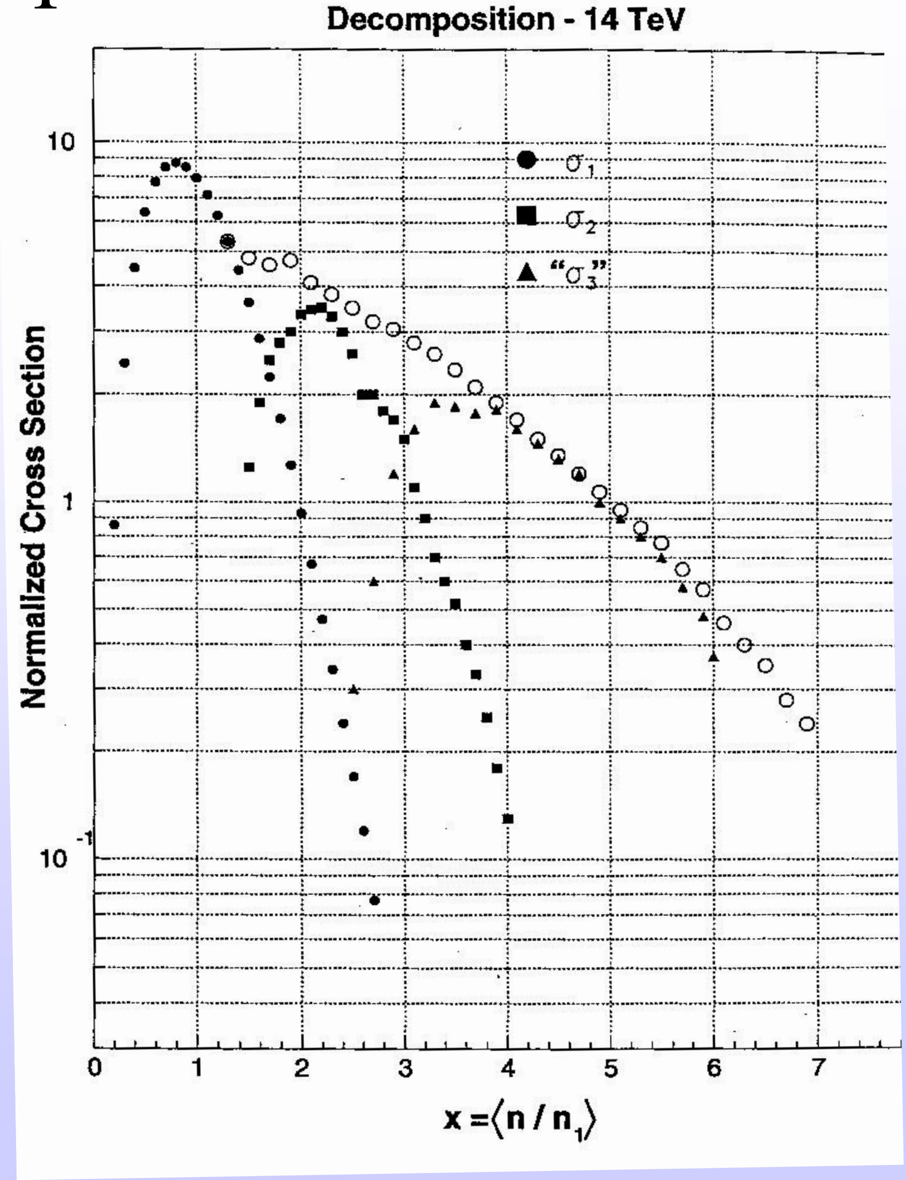


FIG. 5. The decomposition of the multiplicity distribution at $\sqrt{s} = 1800$ GeV. The multiplicity distributions for 1, 2 and 3 parton-parton collisions are shown.

LRC growth versus energy in E-735



p-p collisions at √s=14 TeV



Outlook

1. system size and collision energy dependence

2. Low energy scan to search for the

   tricritical “point”with particle identification

3. FB multiplicity correlations at LHC energies

   with centrality selection.