Charge-to-neutral multiplicity fluctuation in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

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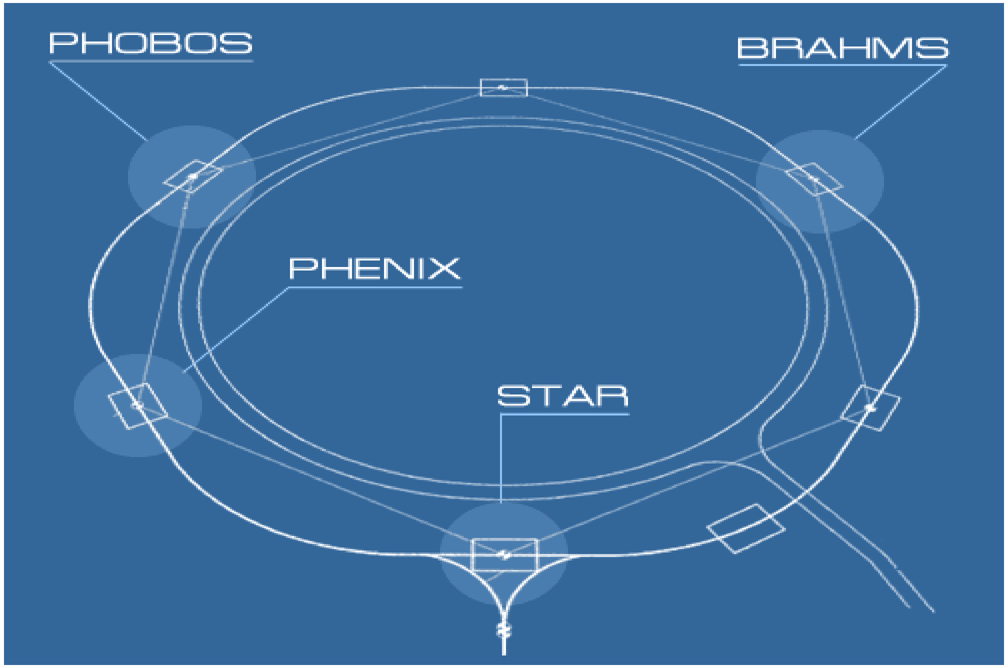


DAE HEP Symposium 2010, Jaipur, India

Motivation & Outline

- Event-by-event charge-to-neutral multiplicity fluctuation at forward rapidity in Au+Au collision at $\sqrt{s_{NN}}$ =200 GeV
- Study of centrality dependence of the dynamical fluctuation of charge-to-neutral multiplicity.

Motivation

- Addressing Isospin fluctuation of pions.

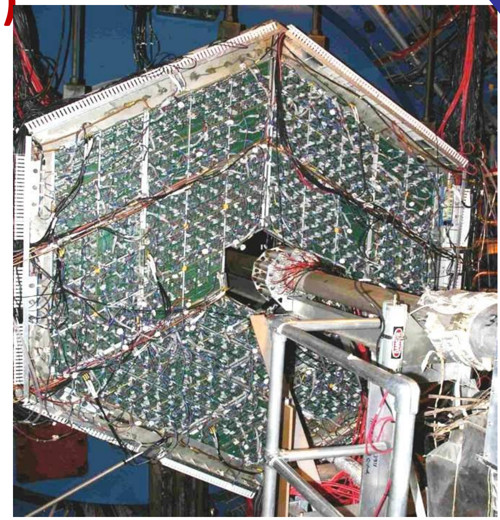
-Signals of anomalous fluctuation in the relative pion production of different Isospin due to formation of domains of "Disoriented Chiral Condensate" (DCC). [1][2][3][4][5]

This analysis includes:

- Event-by-event measurement of charge and photon multiplicity in common coverage of FTPC and PMD.
- Identification of a robust observable sensitive to small signal of dynamical Isospin fluctuation.
- Comparison with HIJING and mixed event.
- Comparison with DCC inspired model.

◆ Measurement

STAR PMD



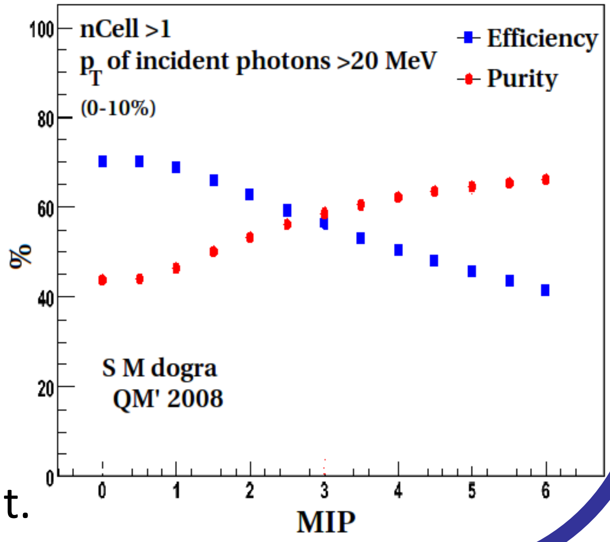
Photon Multiplicity Detector (PMD) **(for photon detection)**

- Two planes : Veto + Pre-shower
- Each plane :array of 41472 hexagonal shaped cells
- Each cell : gas proportional counter
- Cell cross-section : 1.0 cm^2
- Cell depth : 0.8 cm
- Gas mix : Ar + CO_2 (70 : 30)
- Cathode Voltage 1400 V
- Distance from vertex : - 539 cm
- Coverage : -2.4 to -3.6 in η with full Φ

Nucl. Instrum. Meth. A 499, 751 (2003)

For photon-hadron Discrimination –

- Cluster ADC > 3 x MIP ADC
- Number of cells in cluster > 1



From previous studies * :

~ 40 % Contamination effect at 3 MIP

-Very weak dependence of fluctuation variables on MIP cut.

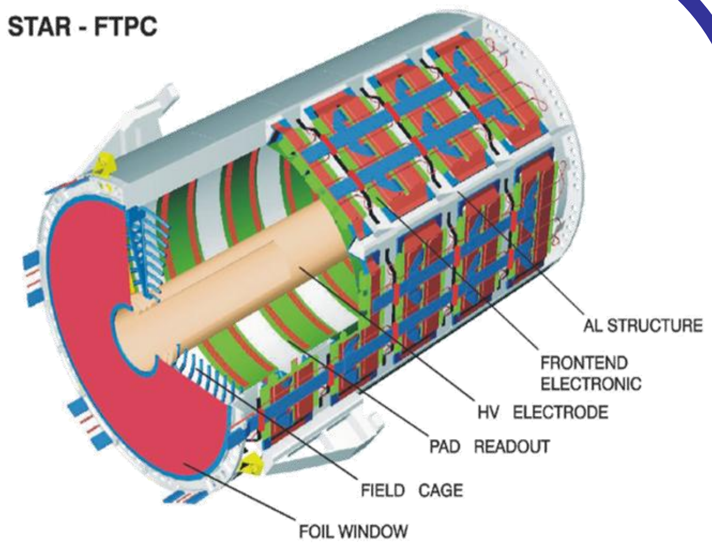
Ref: SM Dogra (STAR Collab.) Jour. of Phys. G 35 (2008) 104094

◆ Measurement

Forward Time Projection Chamber (FTPC):

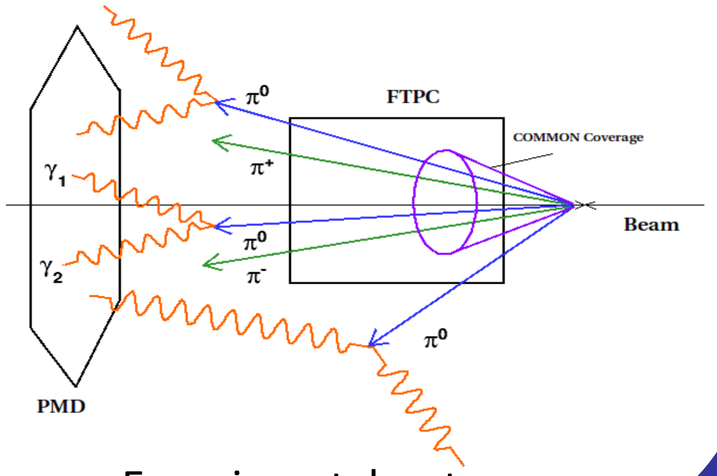
(for charged particle detection):

- Inner and outer radius: 7.73 cm & 30.05 cm
- Chamber length: 120 cm
- Solenoid magnetic field 0.5 T (|| beam)
- Gas mix : Ar + CO_2 (50 : 50)
- drift cathode voltage 10-15 kV.
- Drift Velocity : 0.3-2.0 cm/μs
- Coverage : -2.5 to -4.0 in η with full Φ



For charged track selection –

- Primary Tack : no of fitpoints> 5
- $0.15 < p_T < 1.5$ GeV/c and DCA < 3 cm



Experimental setup

Ref: Nucl. Instrum.Meth A 499, 713 (2003)

Data Details

Data analysis details:

- System: Au+Au collision
- Energy : $\sqrt{s_{NN}}$ = 200 GeV
- Event sample : ~1.8 M events
- Year: 2007
- Analysis : Real and Mixed event
- Common 2d η-Φ contour of PMD & FTPC within $-3.7 < \eta < -2.8$ is selected.
- |Vz|<30 is used for analysis & for event mixing bins of 10 cm are used.
- Centrality selection: From Uncorrected $dN_{ch}/d\eta$ of Time Projection Chamber.
- Event mixing criteria: →Raw (tracks + clusters) kept constant.

Simulation Details

Modeling of anomalous (DCC like) pion production using HIJING

Neutral pion fraction,

$$f = \frac{N_{\pi^0}}{N_{\pi^0} + N_{\pi^\pm}}$$

$$\left.\frac{dP(f)}{df}\right|_{GEN} = \delta\left(f - \frac{1}{3}\right)$$

$$\left.\frac{dP(f)}{df}\right|_{DCC} = \frac{1}{2\sqrt{f}}$$

In this model :

For "x" frac. of HIJING events:

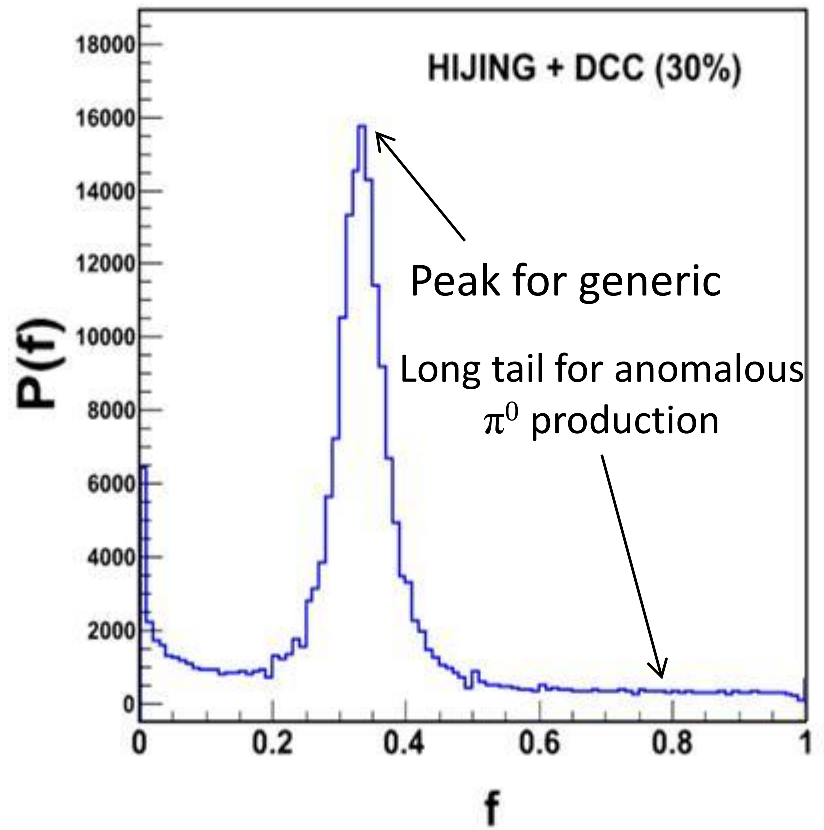
step 1:

Id's of all $\pi+$, $\pi-$, π^0 flipped to follow the $1/(2\sqrt{f})$ distribution. ($\pi^+ \pi^- \leftrightarrow 2\,\pi^0$)

step 2:

-The final π^0s are decayed to 2γ uniformly in their rest frame ($\pi^0 \rightarrow 2\gamma$) ;

→ x is varied for comparison with data.

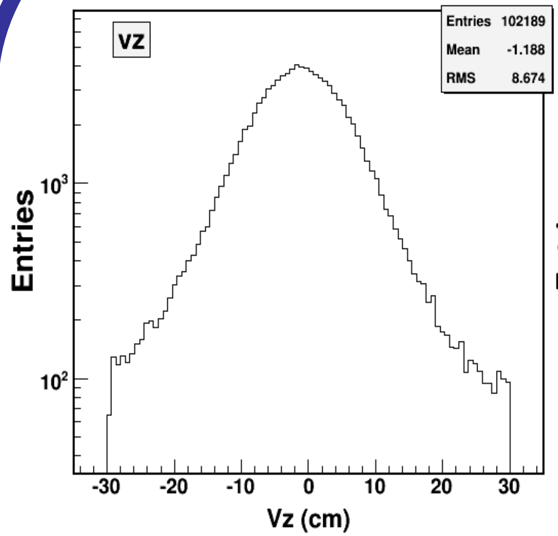


We use exactly same η-Φ coverage contour for both data and simulation

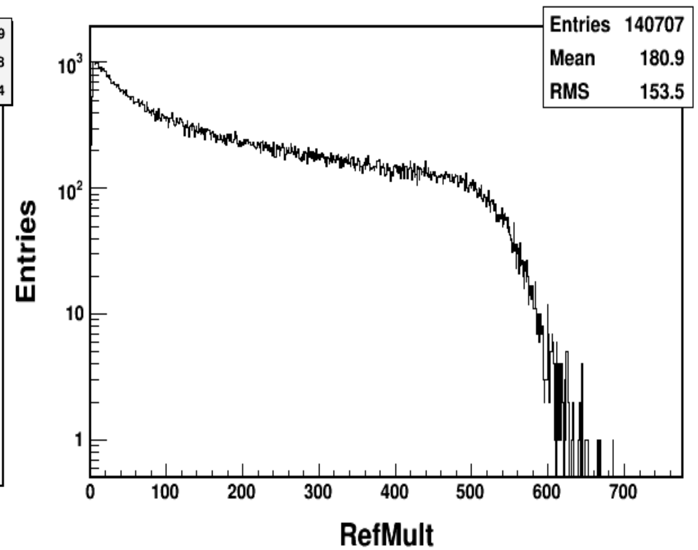
B. K. Nandi et al , Phys.Lett. B449 (1999) 109-113

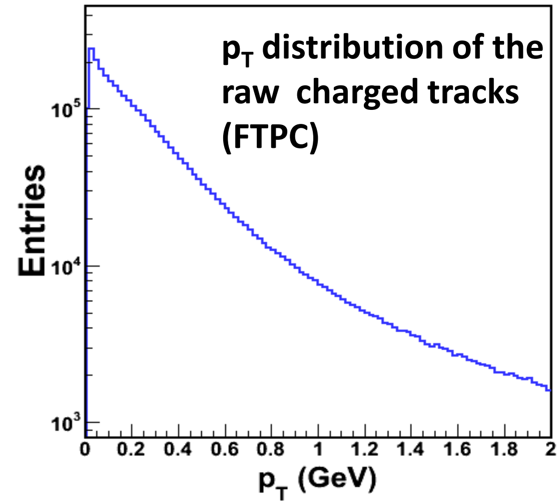
◆ QA Plots

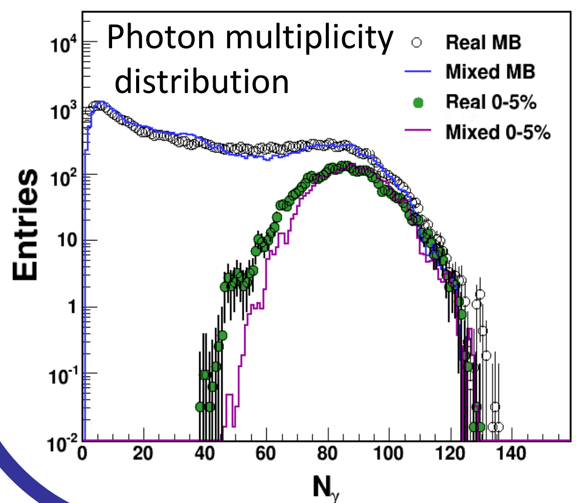
V_z distribution

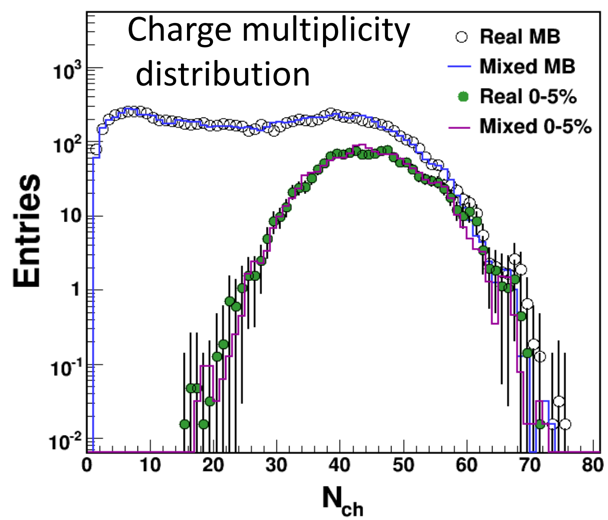


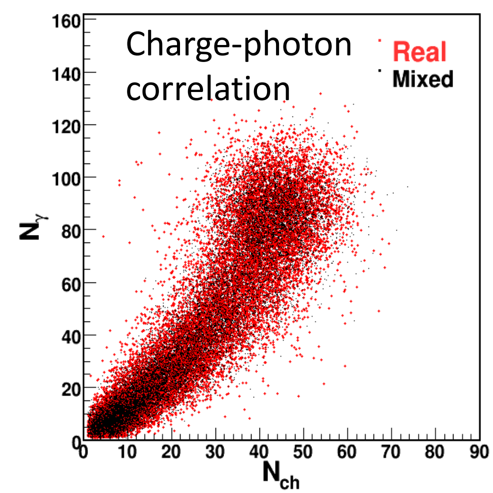
Uncorrected $dN_{ch}/d\eta$ from TPC)









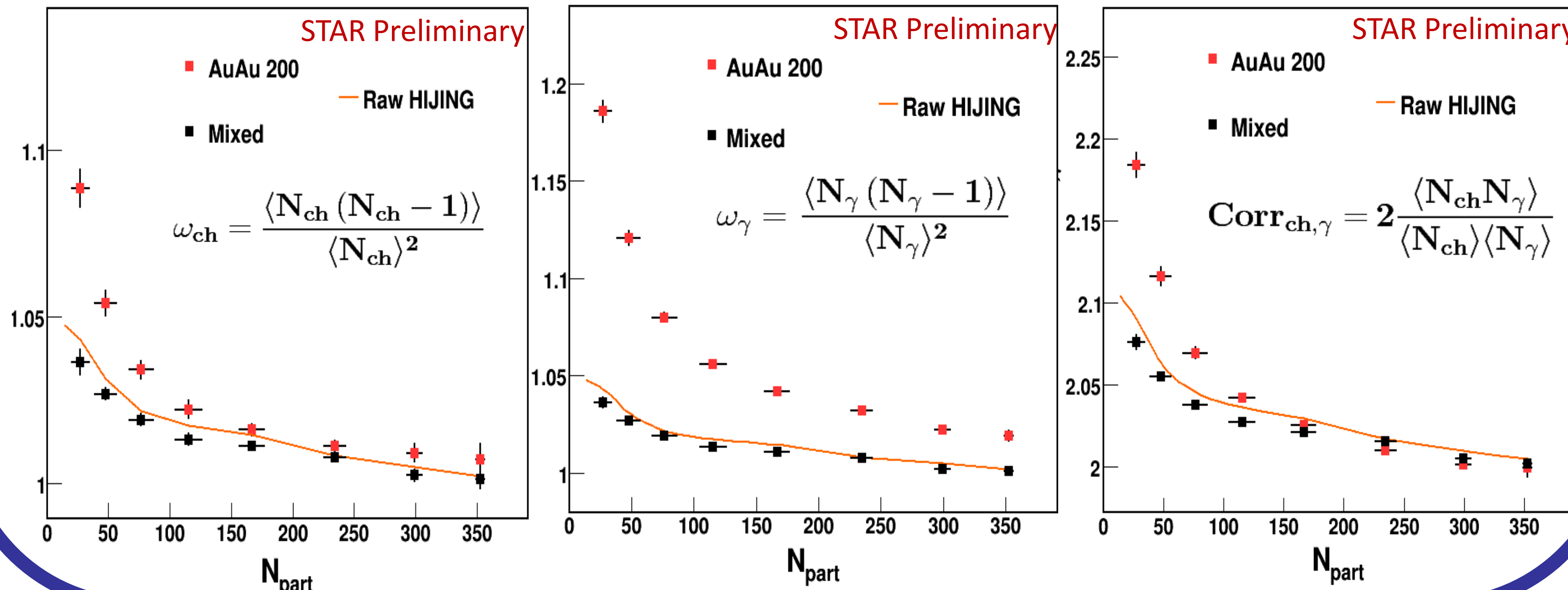


◆ Results and discussions (I)

Fluctuation variable ν_{dyn}(ch-gamma)

$$\nu_{\mathrm{dyn}} = \underbrace{\frac{\langle N_{ch}(N_{ch}-1)\rangle}{\langle N_{ch}\rangle^2}}_{\text{Charge fluctuation}} + \underbrace{\frac{\langle N_{\gamma}(N_{\gamma}-1)\rangle}{\langle N_{\gamma}\rangle^2}}_{\text{Photon fluctuation}} - \underbrace{2\frac{\langle N_{ch}N_{\gamma}\rangle}{\langle N_{ch}\rangle\langle N_{\gamma}\rangle}}_{\text{Correlated fluctuation}}$$

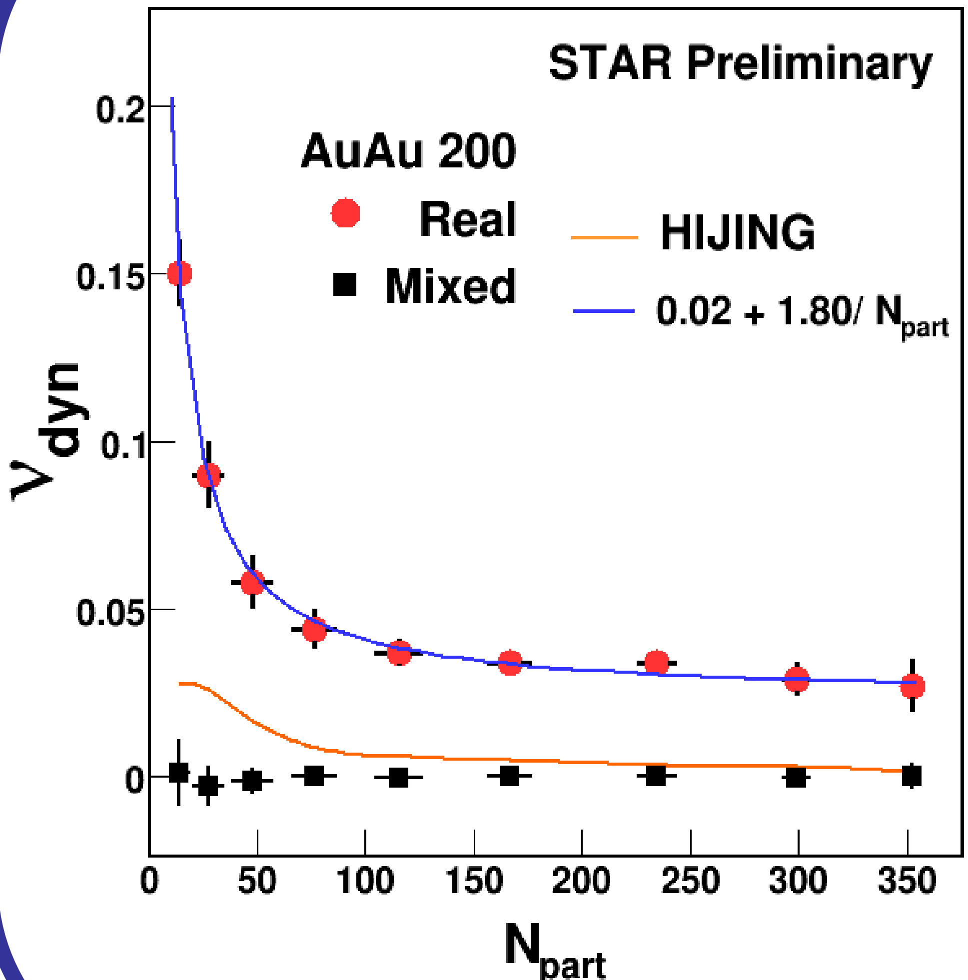
Charge fluctuation | Photon fluctuation | Correlated fluctuation



Ref: Pruneau C, Gavin. S, Voloshin S., Phys Rev. C 66(2002) 044904

Results and discussions (I)

Fluctuation variable ν_{dyn}(ch-γ)



$$\omega_{\gamma} = \frac{\langle f^2 \rangle}{\langle f \rangle^2} + \frac{2\varepsilon_2/(\varepsilon_1 + 2\varepsilon_2)^2}{\langle f \rangle \langle N \rangle}$$

$$\omega_{ch} = \frac{\langle (1-f)^2 \rangle}{\langle 1-f \rangle^2}$$

$$\mathrm{Corr}_{ch,\gamma} = \frac{\langle f(1-f) \rangle}{\langle f \rangle \langle 1-f \rangle}$$

f → π^0 fraction

N → Parent multiplicity

ε_1, ε_2 → Efficiency of detecting 1, 2 γ's from π^0

Choice of ν_{dyn} as fluctuation variable :

- Excludes statistical (Poissonian) fluctuation.
- ω_{ch} → No eff. dependence w.r.to signals of π^+, π^-
- ω_{γ} → Has explicit efficiency dependence w.r.to dynamical signals from π^0 ($\pi^0 \rightarrow 2\gamma$)
- Corr → No explicit efficiency dependence.

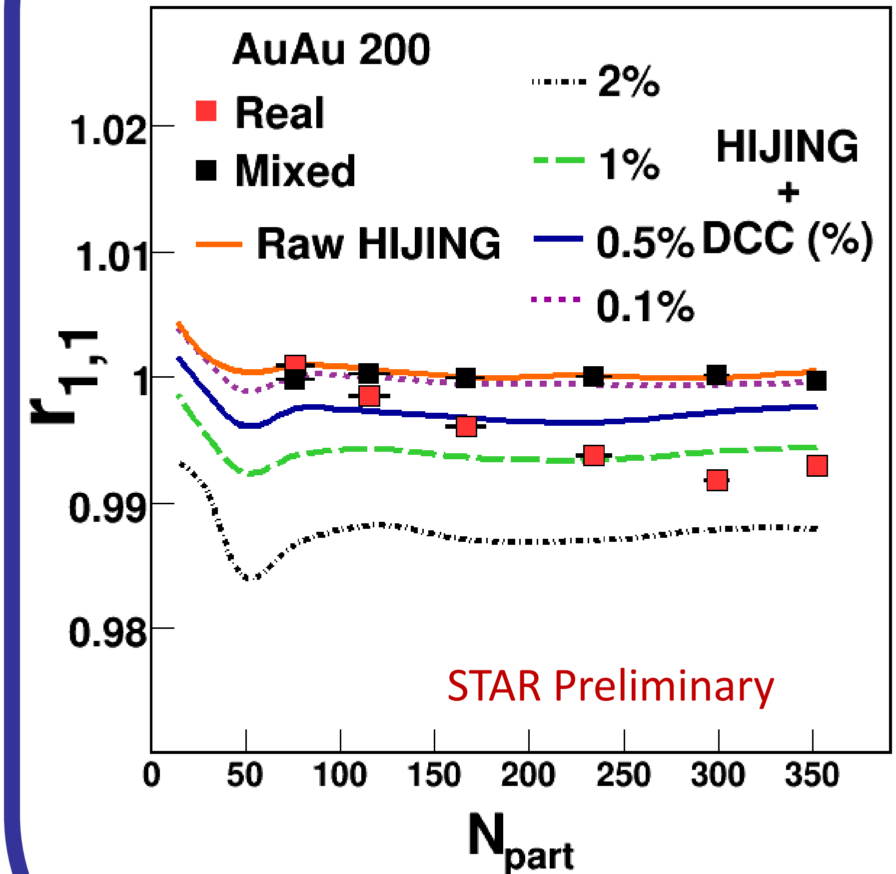
Observation:

- A function of the form A+B/ N_{part} seems to give very good fit to N_{part} dependence of ν_{dyn} .
- ν_{dyn} (ch-γ) is positive and higher than values predicted from both RAW- HIJING and Mixed Event. (Error bars are statistical only)

Ref: Pruneau C, Gavin. S, Voloshin S., Phys Rev. C 66(2002) 044904

Results and discussions (II)

Robust variables $r_{m,1}$



$$r_{m,1} = 1/(m+1) \rightarrow \mathrm{DCC}$$
$$= 1.0 \quad \rightarrow \mathrm{GEN}$$

Choice of $r_{m,1}$ as fluctuation variable:

- Removes explicit efficiency & centrality dependence.
- Sensitive to small anti-correlation signal.
- $r_{m,1}$ is not immune to contamination.
- Lower $r_{m,1}$ → More anti-correlation.

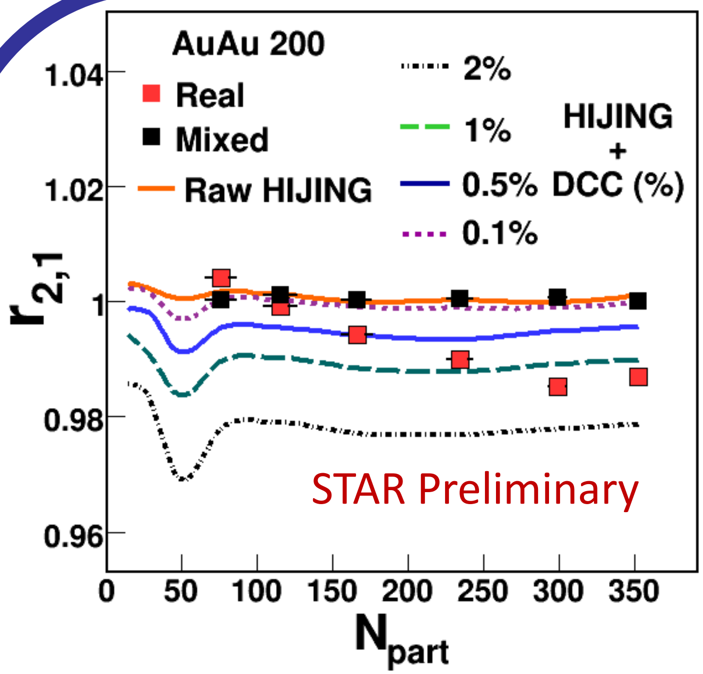
$$r_{1,1} = \frac{\langle N_{ch} N_\gamma \rangle \langle N_{ch} \rangle}{\langle N_{ch}(N_{ch}-1)\rangle \langle N_\gamma \rangle}$$

$$r_{2,1} = \frac{\langle N_{ch}(N_{ch}-1) N_\gamma \rangle \langle N_{ch} \rangle}{\langle N_{ch}(N_{ch}-1)(N_{ch}-2)\rangle \langle N_\gamma \rangle}$$

$$r_{3,1} = \frac{\langle N_{ch}(N_{ch}-1)(N_{ch}-2) N_\gamma \rangle \langle N_{ch} \rangle}{\langle N_{ch}(N_{ch}-1)(N_{ch}-2)(N_{ch}-3)\rangle \langle N_\gamma \rangle}$$

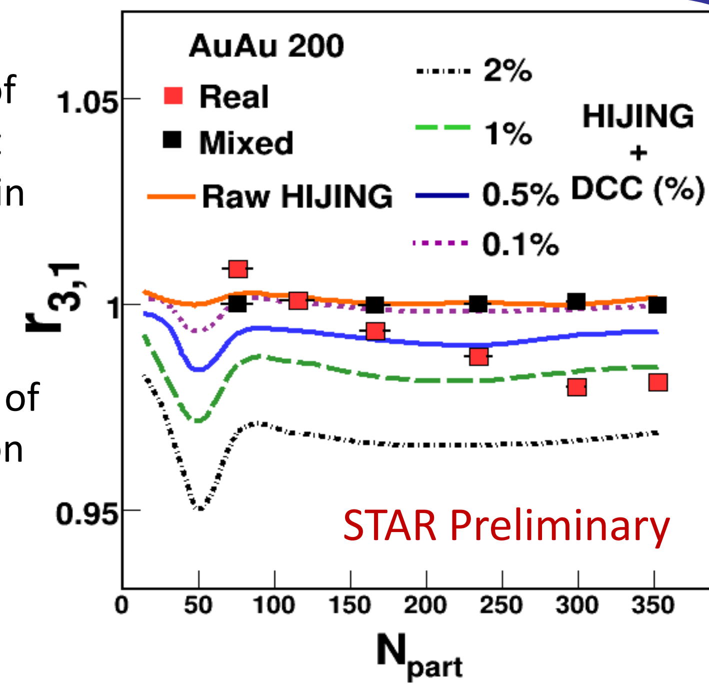
Ref: MiniMax Collaboration, Phys Rev D,55,5667,(1997)

◆ Results and discussions (II)



Fraction "x" of DCC like event mixed shown in terms of % in figures;

x → measure of anti-correlation signal



$$r_{1,1} = \frac{\langle n_{ch} n_{\gamma} \rangle \langle n_{ch} \rangle}{\langle n_{ch}(n_{ch}-1)\rangle \langle n_{\gamma} \rangle}$$

$$= \frac{\langle f(1-f)\rangle \langle (1-f)\rangle}{\langle (1-f)^2 \rangle \langle f \rangle}$$

→ No efficiency dependence

- **Observation:**

1. $r_{m,1}$ → Mixed event & Raw HIJING → Flat w.r.to N_{part}
2. Data have centrality dependence → decreases with N_{part}
3. Model + HIJING → ~Flat for high N_{part} & decreases with "x"
   (Error bars → only statistical & within marker size)

Summary

- Fluctuation of charge-to-neutral multiplicity ratio at forward rapidity :
  - Centrality dependence of variables ν_{dyn} and $r_{m,1}$ have been studied.
  - Data compared to Raw HIJING, mixed event and simple DCC-like model.
  - Mixed event is close to Raw HIJING.
- ν_{dyn} :
  - for data shows centrality dependence of the form $A + B / N_{part}$.
  - close to Poissonian limit for Mixed event and Raw HIJING towards higher centrality.
  - for data lies above Poissonian limit , Raw HIJING and Mixed event.
  - individual terms approach towards respective Poissonian limit for higher centrality.
- Robust observables $r_{m,1}$:
  - Mixed event and Raw HIJING has weak centrality dependence and their values very close to theoretical generic values corresponding to zero anti-correlation.
  - Simple DCC model on HIJING shows trend & sensitivity to signals of anti-correlation.
  - Data values are close to 1% deviation from generic values in central event.
  - 1% value should be viewed w.r.to the simplicity of the model, contamination in photon signal and other detector effects.
  - Systematic error analysis, study of contamination effect on $r_{m,1}$ along with GEANT simulation towards putting a upper limit of observed signal (DCC –like) is going on.

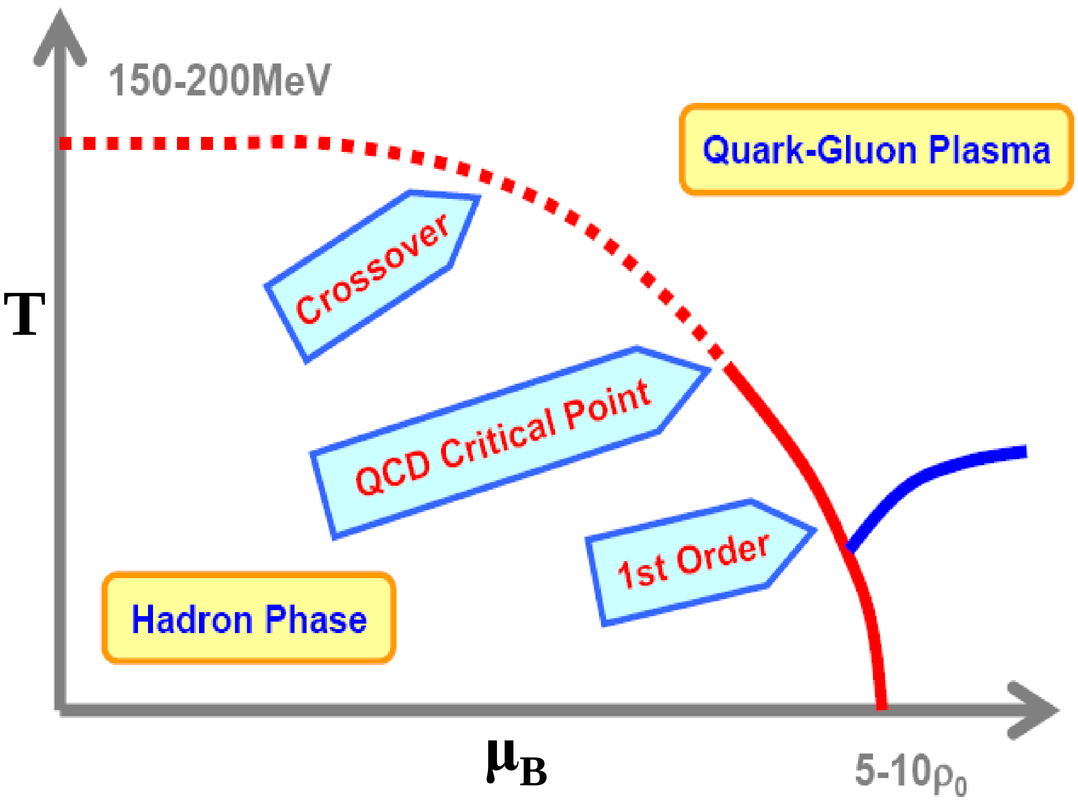
References

[1] J. D. Bjorken et al, SLAC preprint SLAC-PUB-619
[2] Krishna Rajagopal et al, Nucl.Phys.B404:577-589,1993
[3] B. Mohanty et al, Phys.Rept.414:263-358,2005
[4] WA98 Collb), M.M. Aggarwal, et al., Phys Rev.C67(2009)
[5] MINIMAX Collaboration, Phys. Rev. D61 (2000) 032003

Thank You

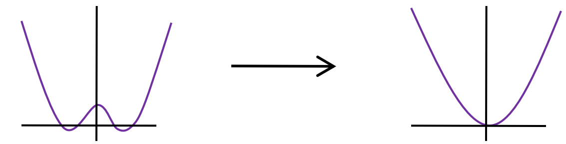
Backup slides

So Called –QCD phase Diagram



Chiral Phase Transition

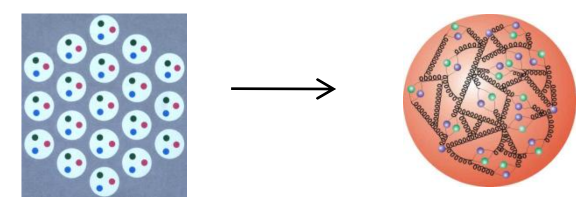
$\langle \bar{\psi}\psi \rangle$ Chiral Condensate



$\neq 0$ $= 0$

Deconfinement Transition

$W \sim \exp[-f_q / T]$ Polyakov Loop



$= 0$ $\neq 0$

Ref: Kenji Fukushima QM'08

Disoriented Chiral Condensate

A space-time region where vacuum is misaligned with :

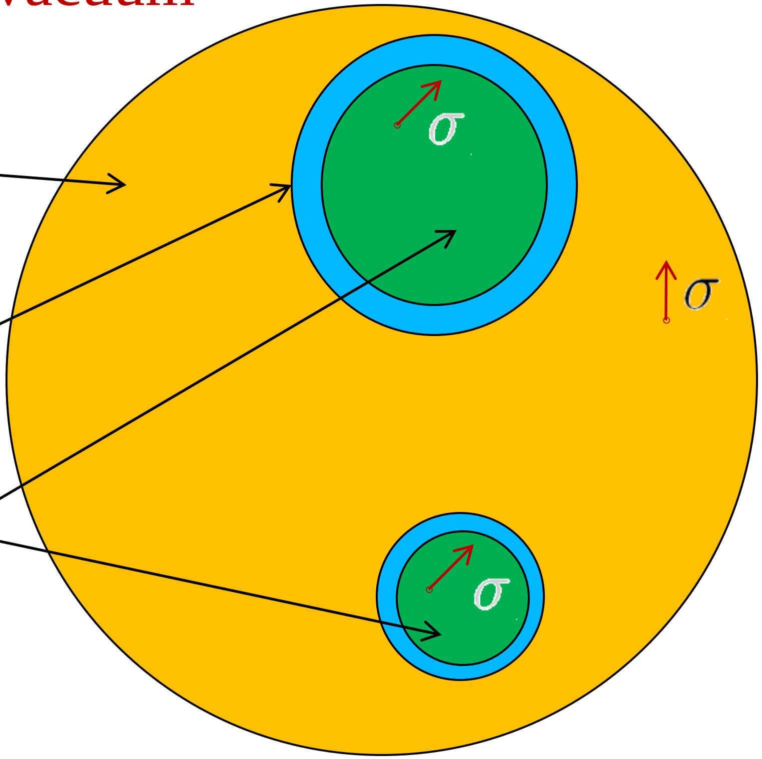
A non-vanishing pion condensate

Protected by a hot shell from the normal vacuum

Normal Vacuum $\langle \pi_i \rangle = 0, \ \langle \sigma \rangle \neq 0$

Hot Shell

Meta-stable Domains $\langle \pi_i \rangle \neq 0, \ \langle \sigma \rangle \neq 0$



rapid cooling-like quenching

"Baked Alaska" scenario

Ref: J.D. Bjorken et al, SLAC preprint SLAC-PUB-6109

Likelihood of DCC Formation :

Prediction based on spherical expansion of a hot medium described by the linear sigma model:

Central collision of PbPb at SPS energies :

$$\text{Probability(“ observable” DCC)} \lesssim 10^{-3}$$

Ref: A Krzywicki and J Serreau, Phys.Lett.B448:257-264,1999

Data from SPS WA98 experiment :

$$\text{DCC-like fluctuations} \sim 3 \times 10^{-3}$$

Ref: (WA98 Collb), M.M. Aggarwal, et al., Phys Rev.C 67(2009)

$\mu_{RHIC} < \mu_{SPS}$ provides faster cooling time |dT/dt| suggests that RHIC collisions provide more favorable condition for DCC production than SPS collisions.

Ref: Krishna Rajagopal, Nucl.Phys.A680:211-220,2000.

Inclusion of Detector Efficiencies :

Treating observing and not-observing a particle as "decay" modes of a particle, we can apply the cluster decay theorem by replacing z_{ch} by the generating function

$$g_{ch}(z_{ch}) = (1-\varepsilon_{ch}) + \varepsilon_{ch} z_{ch}$$

and z_0 by the generating function

Ref [1]

$$g_0(z_\gamma) = \varepsilon_0 + \varepsilon_1 z_\gamma + \varepsilon_2 z_\gamma^2$$

where ε_{ch} is the probability of detecting a charged particle by FTPC, and ε_0, ε_1 and ε_2 are probabilities of detecting 0, 1 and 2 photons by PMD, respectively.

Then we can calculate factorial moments with detector efficiency folded in (next page).

Ref[1] (J. Pumplin PRD 50 6811 (1994))

Generalized form of moments

$$f_{i,j}\left(n_{ch}n_{\gamma}\right) = \left\langle \frac{n_{ch}!\,n_{\gamma}!}{\left(n_{ch}-i\right)!\left(n_{\gamma}-j\right)!} \right\rangle = \left(\frac{\partial^{i,j} G(z_{ch}, z_{\gamma})}{\partial z^{i}{}_{ch}\,\partial z^{j}{}_{\gamma}} \right)$$

Final form of generation function :

$$G(z_{ch}, z_{\gamma}) = \int_0^1 df\ p(f) \sum_N P(N)\left[f\ g_0(z_{\gamma}) + \left(1-f\right) g_{ch}(z_{ch}) \right]^N$$

Various moment with efficiency folded:

f_{10}= $$\langle n_{ch} \rangle = \frac{\partial G}{\partial Z_{ch}}\Big|_{z_{ch}=z_{\gamma}=1} = \langle 1-f \rangle \varepsilon_{ch} \langle N \rangle$$

f_{01}= $$\langle n_{\gamma} \rangle = \frac{\partial G}{\partial Z_{\gamma}}\Big|_{z_{ch}=z_{\gamma}=1} = \langle f \rangle (\varepsilon_1 + 2\varepsilon_2) \langle N \rangle$$

f_{20}= $$\langle n_{ch}(n_{ch}-1) \rangle = \frac{\partial^2 G}{\partial Z^2{}_{ch}}\Big|_{z_{ch}=z_{\gamma}=1} = \left\langle (1-f)^2 \right\rangle \varepsilon_{ch}^2 \langle N(N-1) \rangle$$

f_{11}= $$\langle n_{ch} n_{\gamma} \rangle = \frac{\partial}{\partial Z_{ch}}\left(\frac{\partial G}{\partial Z_{\gamma}} \right)\Big|_{z_{ch}=z_{\gamma}=1} = \langle f(1-f) \rangle (\varepsilon_1 + 2\varepsilon_2) \varepsilon_{ch} \langle N(N-1) \rangle$$

f_{02}= $$\langle n_{\gamma}(n_{\gamma}-1) \rangle = \frac{\partial^2 G}{\partial Z^2{}_{\gamma}}\Big|_{z_{ch}=z_{\gamma}=1} = \langle f^2 \rangle (\varepsilon_1 + 2\varepsilon_2)^2 \langle N(N-1) \rangle + 2\varepsilon_2 \langle f \rangle \langle N \rangle$$