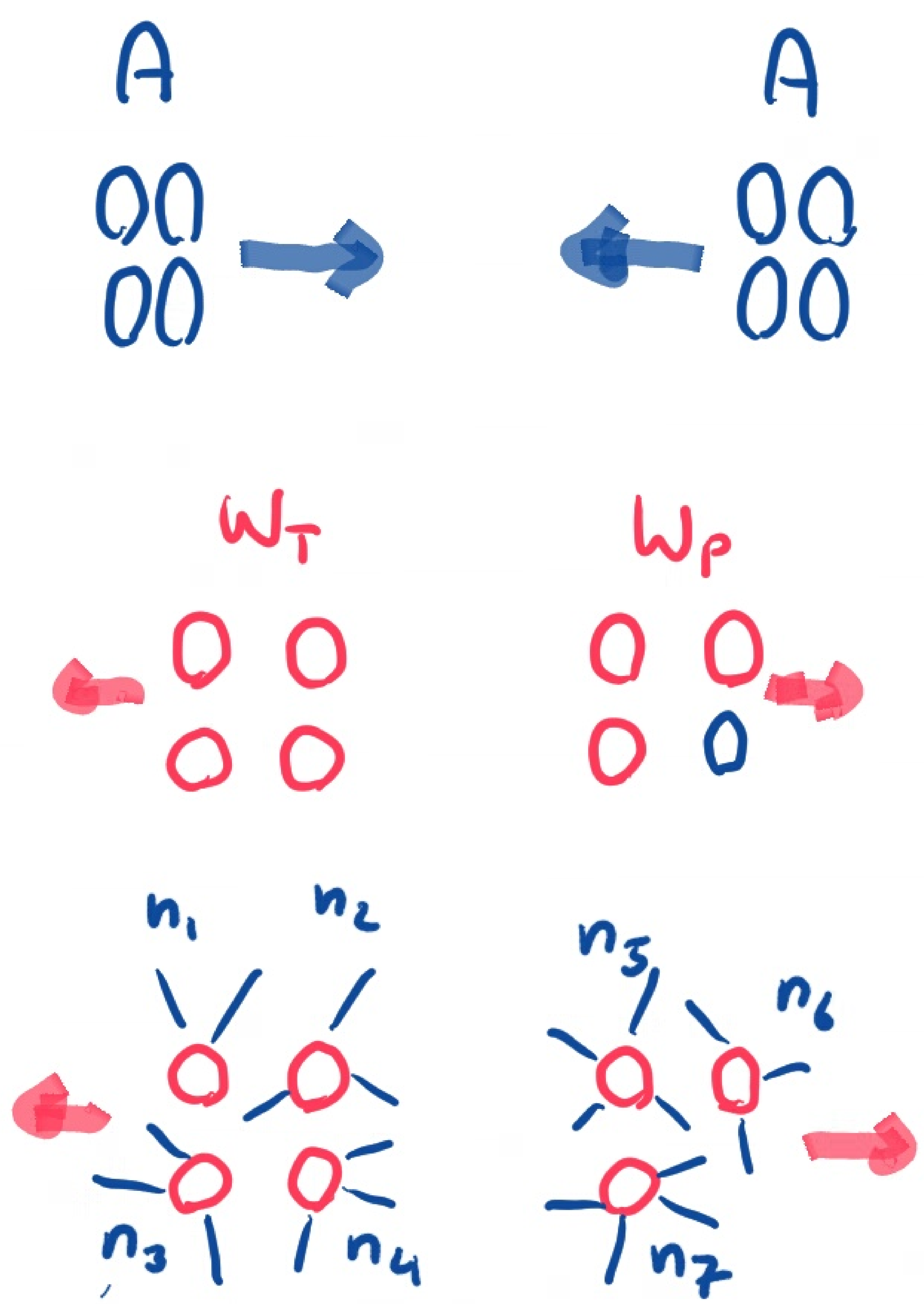
# FLUCTUATIONS AND CORRELATIONS FROM NA61/SHINE

M. GAZDZICKI, FRANKFURT, KIELCE
FOR THE NA61/SHINE COLLABORATION

- REMOVING VOLUME FLUCTUATIONS
  NA61/SHINE TRICKS
- EXPLOITING CONSERVATION LAWS
  PERCOLATION THRESHOLD ?
- SEARCH FOR CRITICAL POINT
  NO EVIDENCE SO FAR

# REMOVING VOLUME FLUCTUATIONS

REFERENCE MODEL: WOUNDED NUCLEON MODEL:



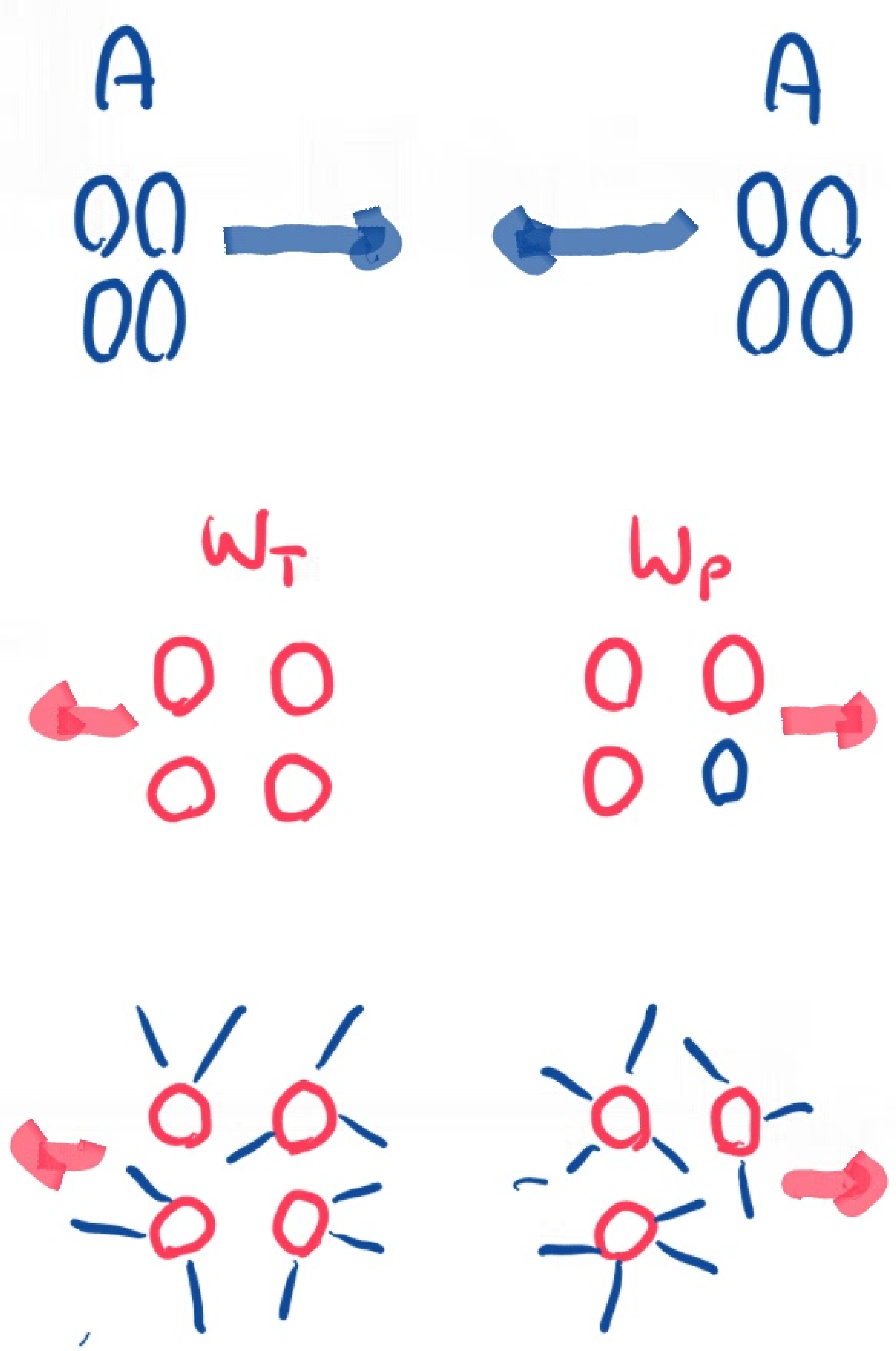

$N = \sum n_i$

NUMBERS OF PROJECTILE ($W_P$) AND TARGET ($W_T$) NUCLEONS THAT INTERACTED INELASTICALLY (WOUNDED NUCLEONS) ARE CALCULATED ASSUMING STRAIGHT LINE TRAJECTORIES ($W = W_P + W_T$).

WOUNDED NUCLEONS IN $A_P + A_T$ COLLISIONS HAVE PROPERTIES THE SAME AS WOUNDED NUCLEONS IN N+N ($\approx$ p+p) INTERACTIONS AT THE SAME $\sqrt{s_{NN}}$.

BIALAS, BLESZYNSKI, CZYZ

# MULTIPLICITY FLUCTUATIONS IN WNM:




LET $W$ VARY ACCORDING TO $P(W)$

$$Var[N] = \langle (N - \langle N \rangle)^2 \rangle =$$

$$= Var[n]\, \langle W \rangle + \langle n \rangle^2\, Var[W]$$

DEPENDS ON $\langle W \rangle$ AND $Var[W]$

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SIMILAR RELATIONS ARE VALID FOR STATISTICAL MODELS IN IDEAL BOLTZMANN GAS WITHIN GCE (WOUNDED NUCLEONS → VOLUME ELEMENTS, $v$, $W = V/v$)

# MULTIPLICITY FLUCTUATIONS IN WNM:

$$\omega[N] = \underbrace{\omega[N]_W}_{\text{WANTED}} + \underbrace{\langle N\rangle/\langle W\rangle \cdot \omega[W]}_{\text{UNWANTED}}$$

$\omega[A] \equiv Var[A]/\langle A\rangle$

$\omega[A]_W \equiv \omega[A]$ AT FIXED W

## TWO METHODS TO REMOVE THE UNWANTED TERM:

(I) SELECT EVENTS WITH $W = \text{CONST} \Rightarrow \omega(W) = 0$

$\Rightarrow$ SELECTION USING PROJECTILE SPECTATORS

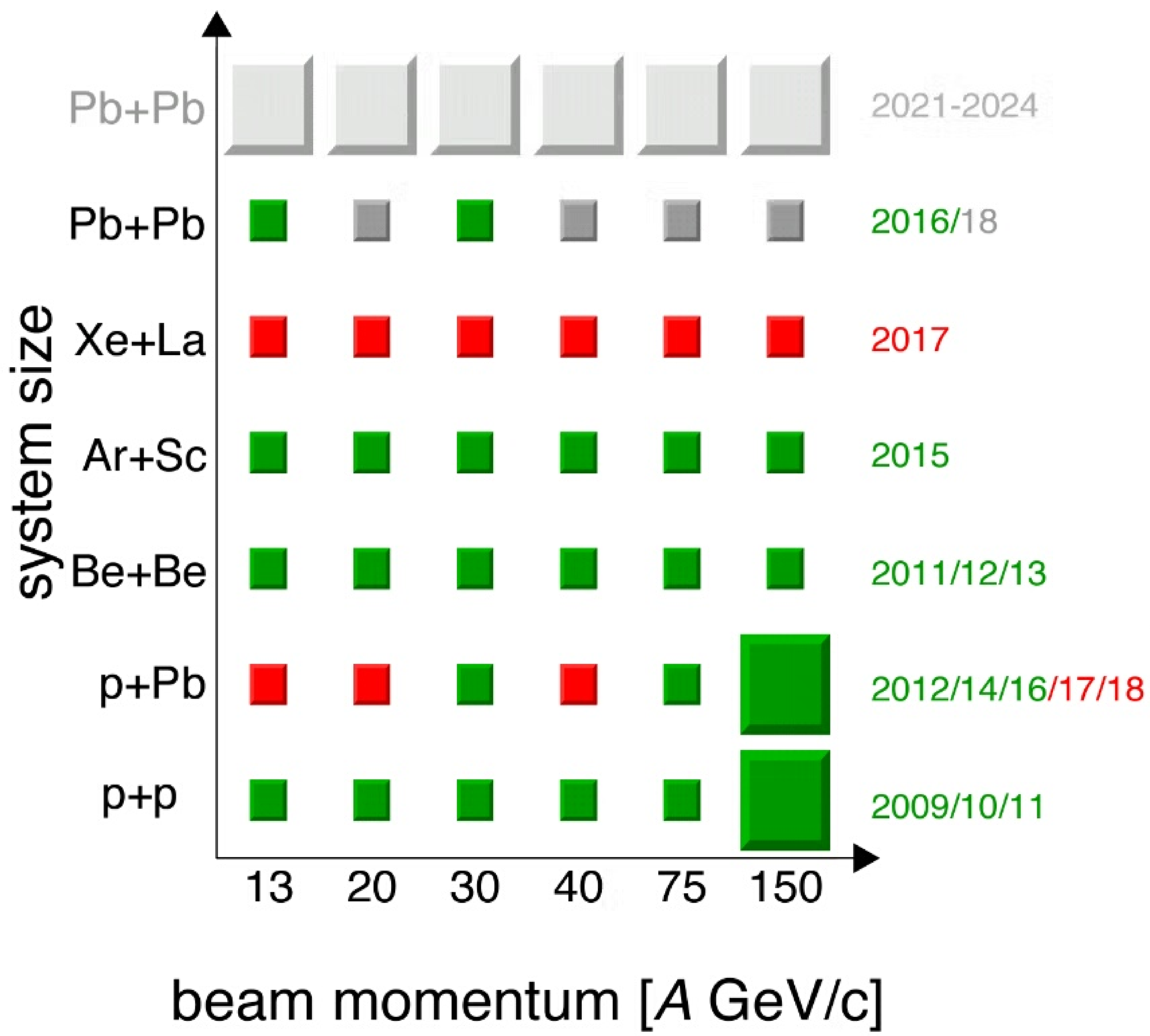
(II) DEFINE FLUCTUATION QUANTITIES TO BE INDEPENDENT OF $P(W)$

$\Rightarrow$ STRONGLY INTENSIVE QUANTITIES

⑤

# NA61/SHINE SELECTION OF VIOLENT EVENTS

COLLISIONS OF SIMILAR SIZE NUCLEI

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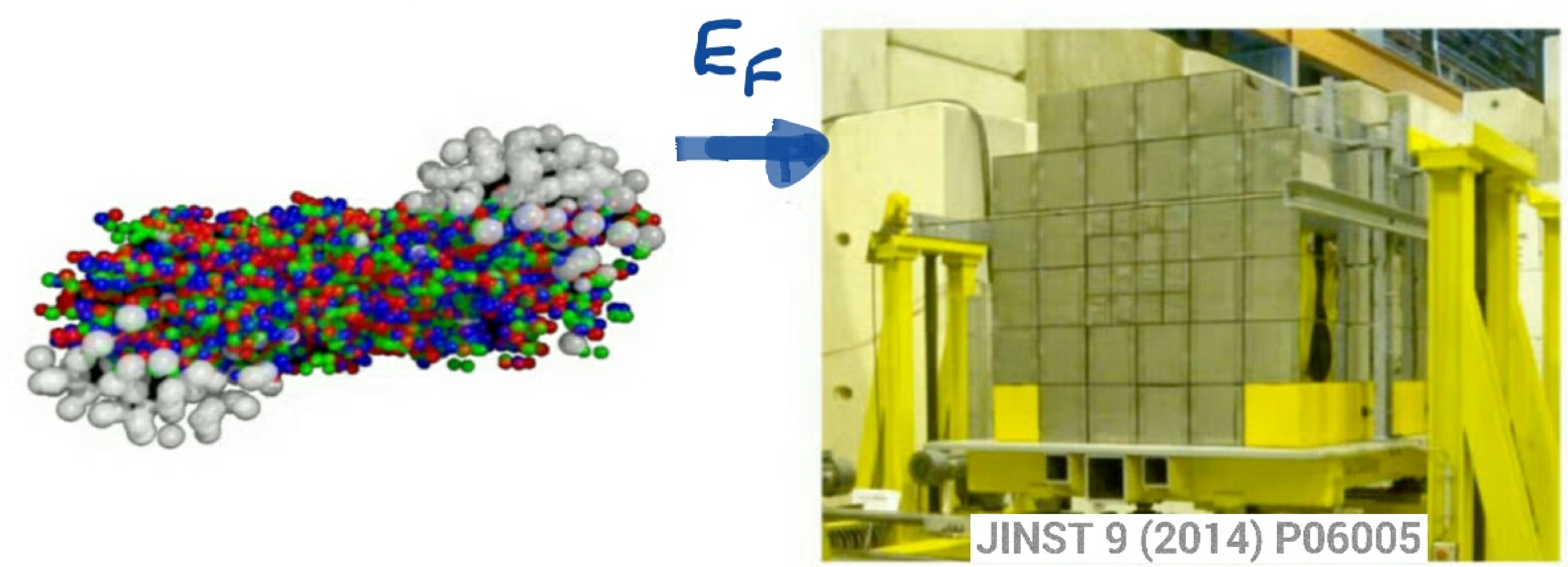
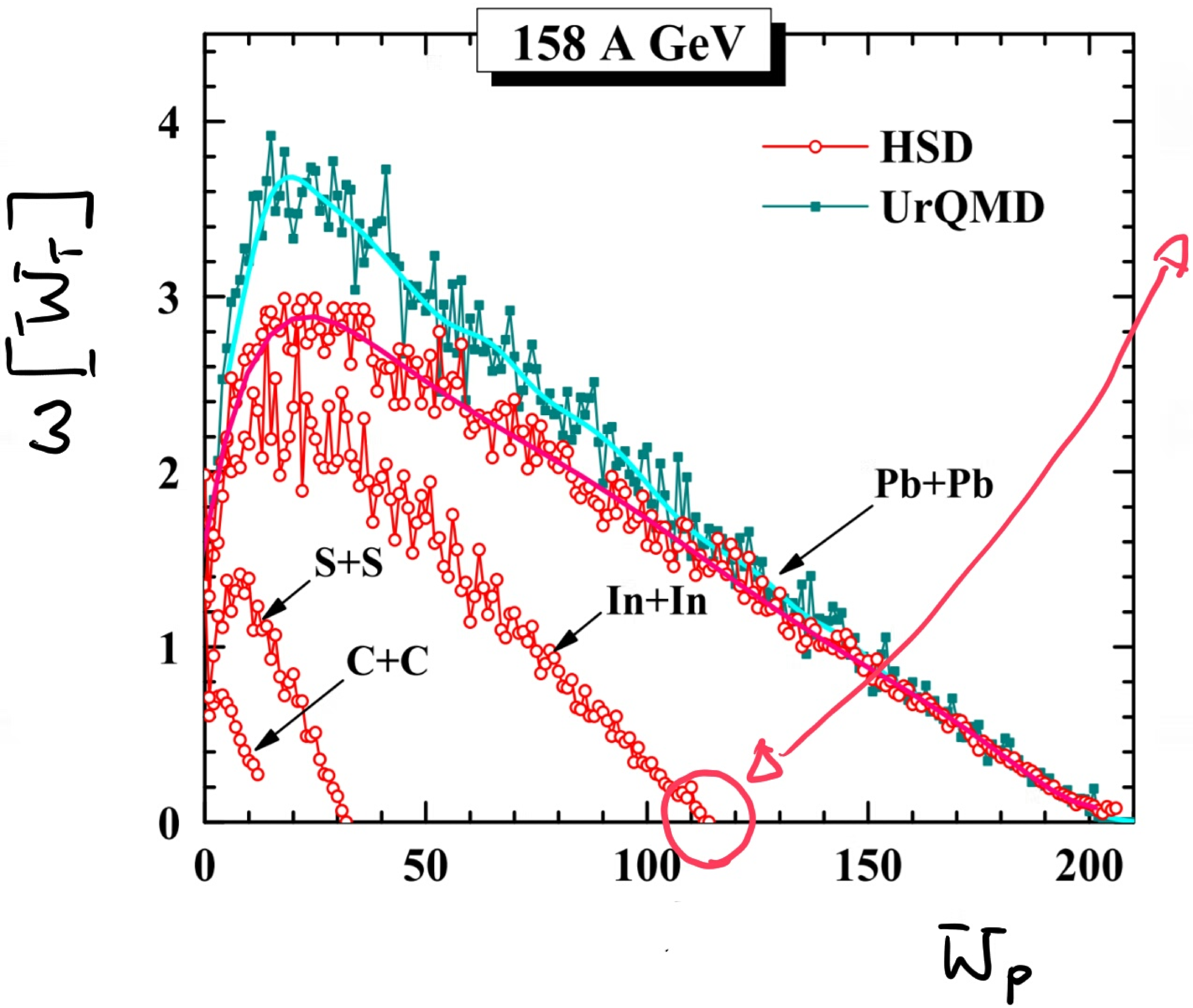
SELECTION OF EVENTS WITH SMALL NUMBER OF PROJECTILE SPECTATORS




COST AND TIME EXPENSIVE BUT REWARDING PROCEDURE

# NA61/SHINE SELECTION OF VIOLENT EVENTS




EXAMPLE FOR In+In (Xe+La):

FOR $\bar{W}_P \approx A$ (113) $\omega[\bar{W}_T] \approx 0$
AND $W_T \approx A$

$\Downarrow$

$\omega[\bar{W} = \bar{W}_P + \bar{W}_T] \approx 0$

$$\omega[N] = \underbrace{\omega[N]_W}_{P} + \cancel{\langle N\rangle/\langle W\rangle \cdot \omega[W]}$$

WANTED

~~UNWANTED~~

KANCHAKOVSKI, LUNGWITZ, GORENSTEIN BRATKOUSKAYA

# STRONGLY INTENSIVE QUANTITIES

FLUCTUATION MEASURES THAT ARE INDEPENDENT OF $P(\overline{W})$ WITHIN WNM (IB-GCE)

FOR EXAMPLE:

$$\Omega[N, E_P] \equiv \omega[N] - \frac{\langle N \cdot E_P \rangle - \langle N \rangle \langle E_P \rangle}{\langle E_P \rangle} \approx \omega[N]_W = $$

$$= \omega[n]$$

WHERE $E_P = E_{BEAM} - E_F$

$\langle N \cdot E_P \rangle_W \approx \langle N \rangle_W \langle E_P \rangle_W$

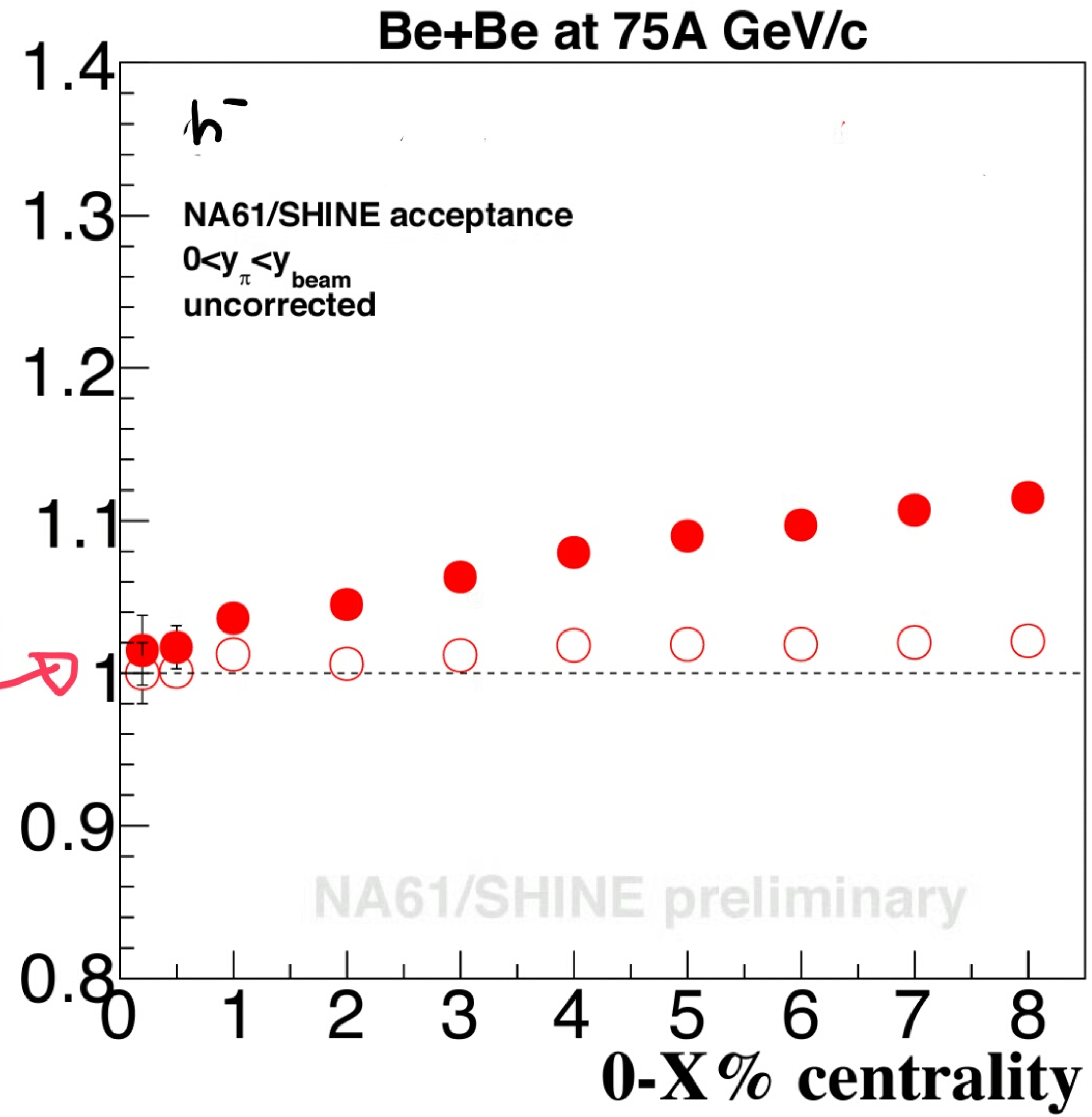
$\langle E_P \rangle_W \sim \overline{W}$

VIOLENT A+A COLLISIONS

MG, MROWCZYNSKI
MG, GORENSTEIN
SANGELINE

# REMOVING VOLUME FLUCTUATIONS: EXPERIMENTAL CROSS-CHECK

ω[N] FOR MOST VIOLENT COLLISIONS




STRONGLY INTENSIVE $\Omega[N, E_P]$

## EXPLOITING CONSERVATION LAWS

THE MOST EFFICIENT DESCRIPTION OF BULK PROPERTIES OF HADRON PRODUCTION IN HIGH ENERGY COLLISIONS IS GIVEN BY STATISTICAL / HYDRODYNAMICAL MODELS.

CONSIDER CONSERVATION LAWS WITHIN STATISTICAL MODELS.

FOR SIMPLICITY CONSIDER ONLY MATERIAL CONSERVATION LAWS (CONSERVED CHARGES: $Q, B, S, \ldots$)

$$\Downarrow$$

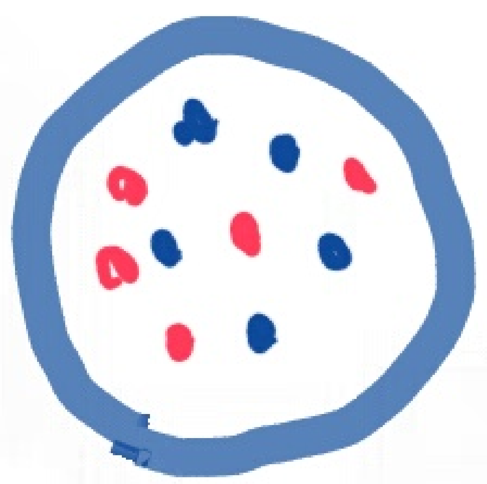
MODEL HADRON PRODUCTION AS DUE TO CREATION OF CLUSTERS OF VOLUME $V_c$ FILLED WITH IDEAL IDEAL BOLTZMANN GAS AT TEMPERATURE $T$ CONSIDERED WITHIN CANONICAL ENSEMBLE:

$$\text{IB-CE}(V_c, T)$$

# CLUSTER-VOLUME DEPENDENCE OF $\langle N \rangle$ AND $\omega[N]$

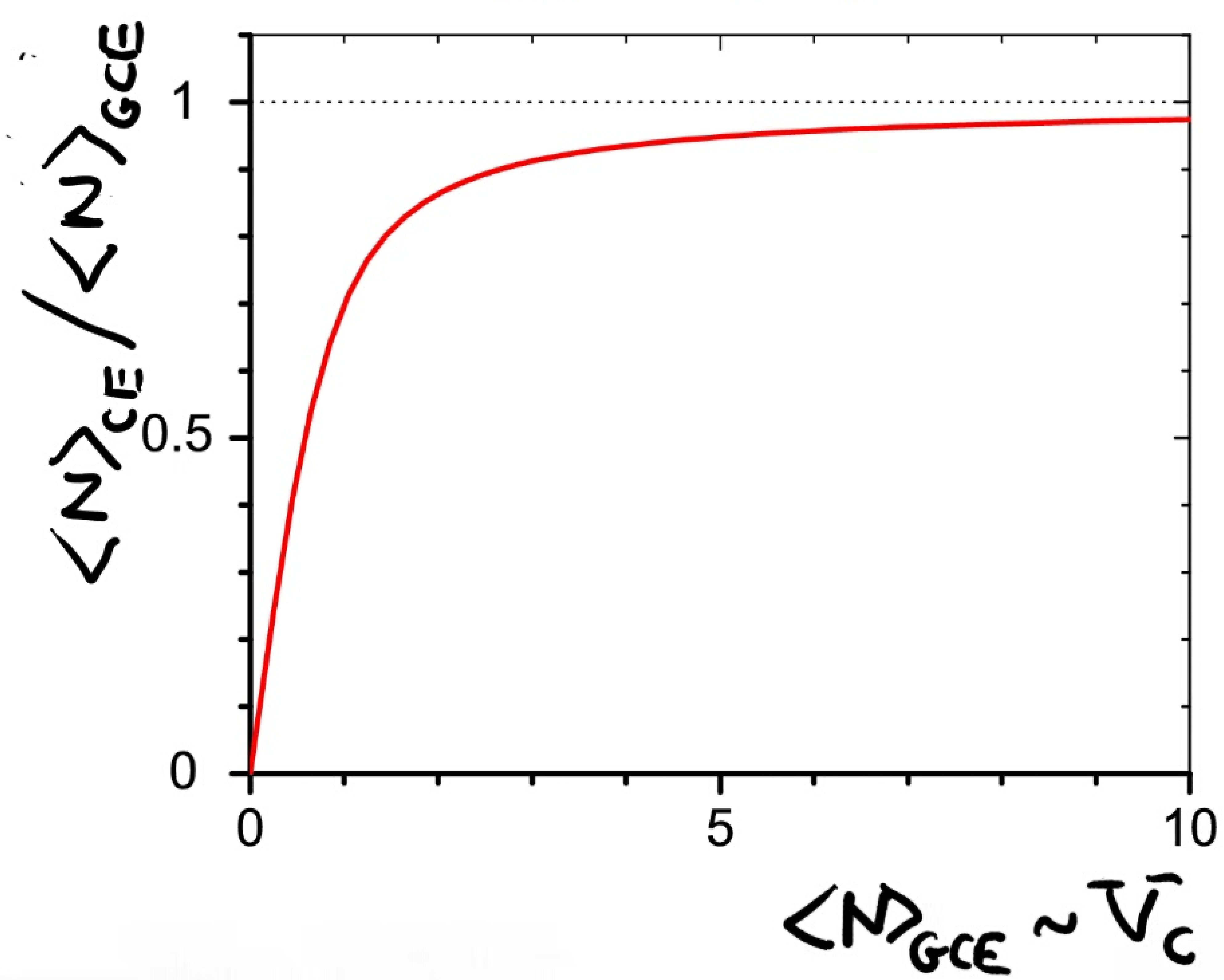
$V_c, T$

$Q=0$



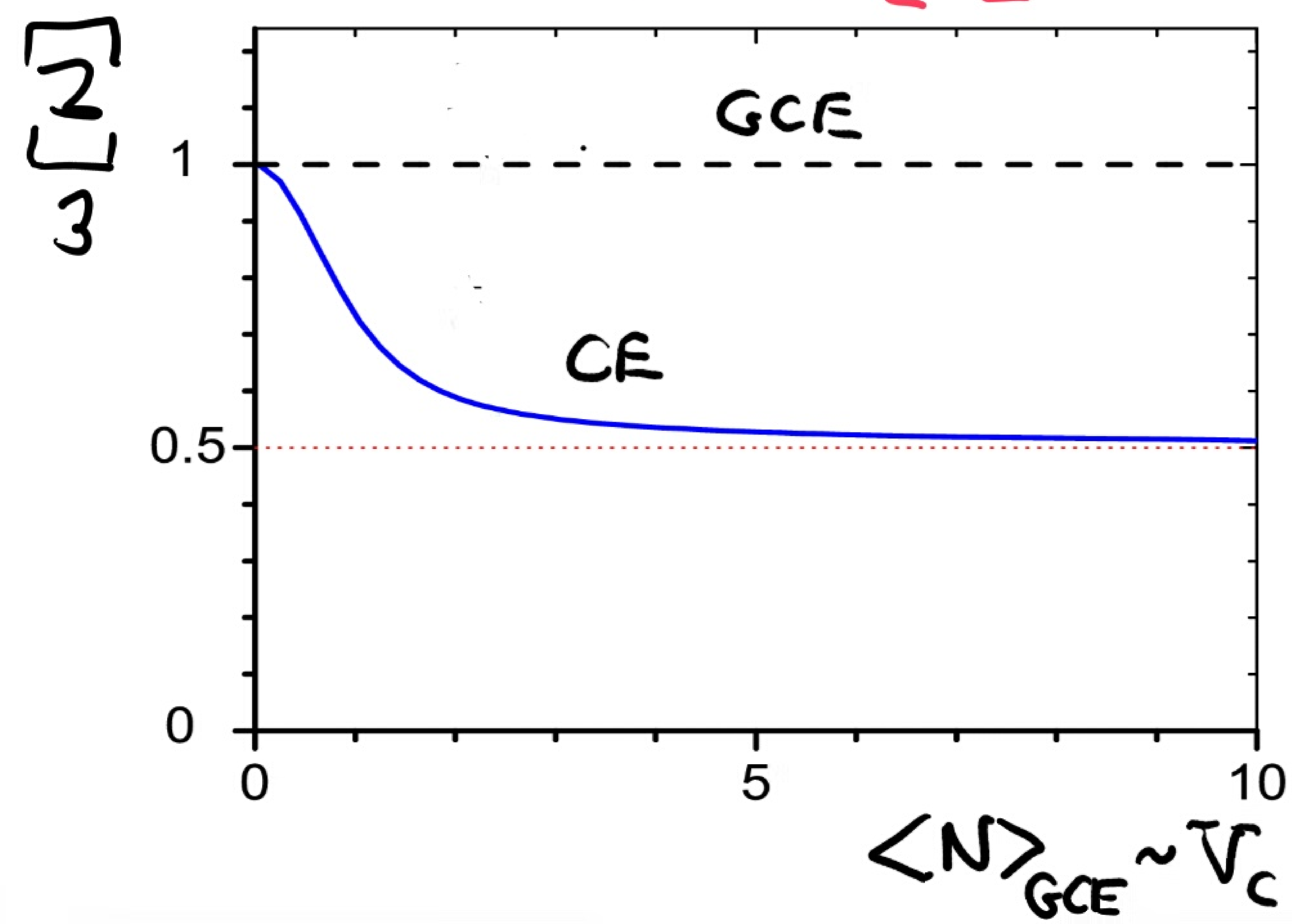
IB-CE: CORRELATIONS BETWEEN PARTICLES ARE ONLY DUE TO MATERIAL CONSERVATION LAWS.

"CANONICAL SUPPRESSION" OF $\langle N \rangle$




DANOS, RAFELSKI

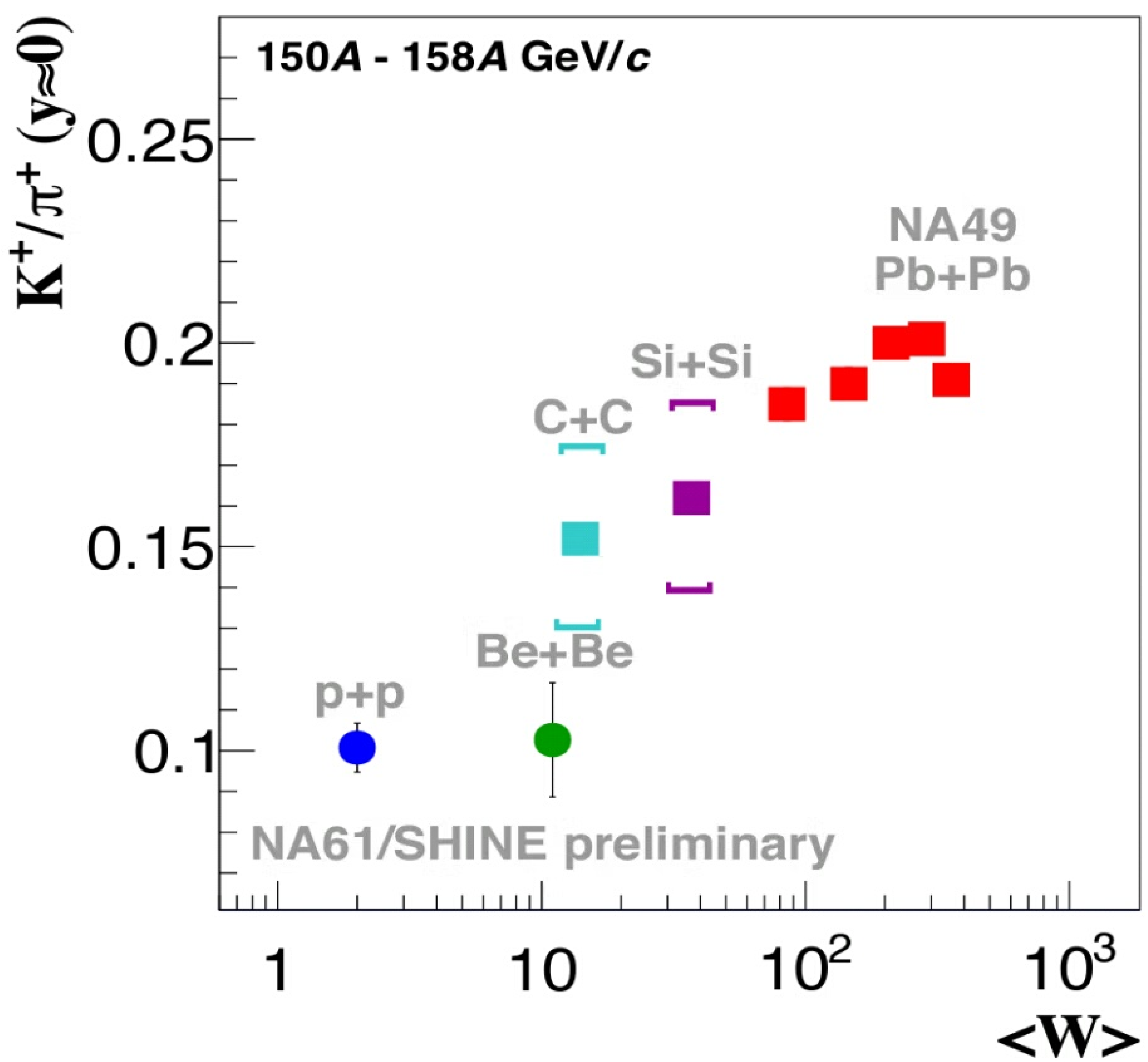
"CANONICAL ENHANCEMENT" OF $\omega[N]$



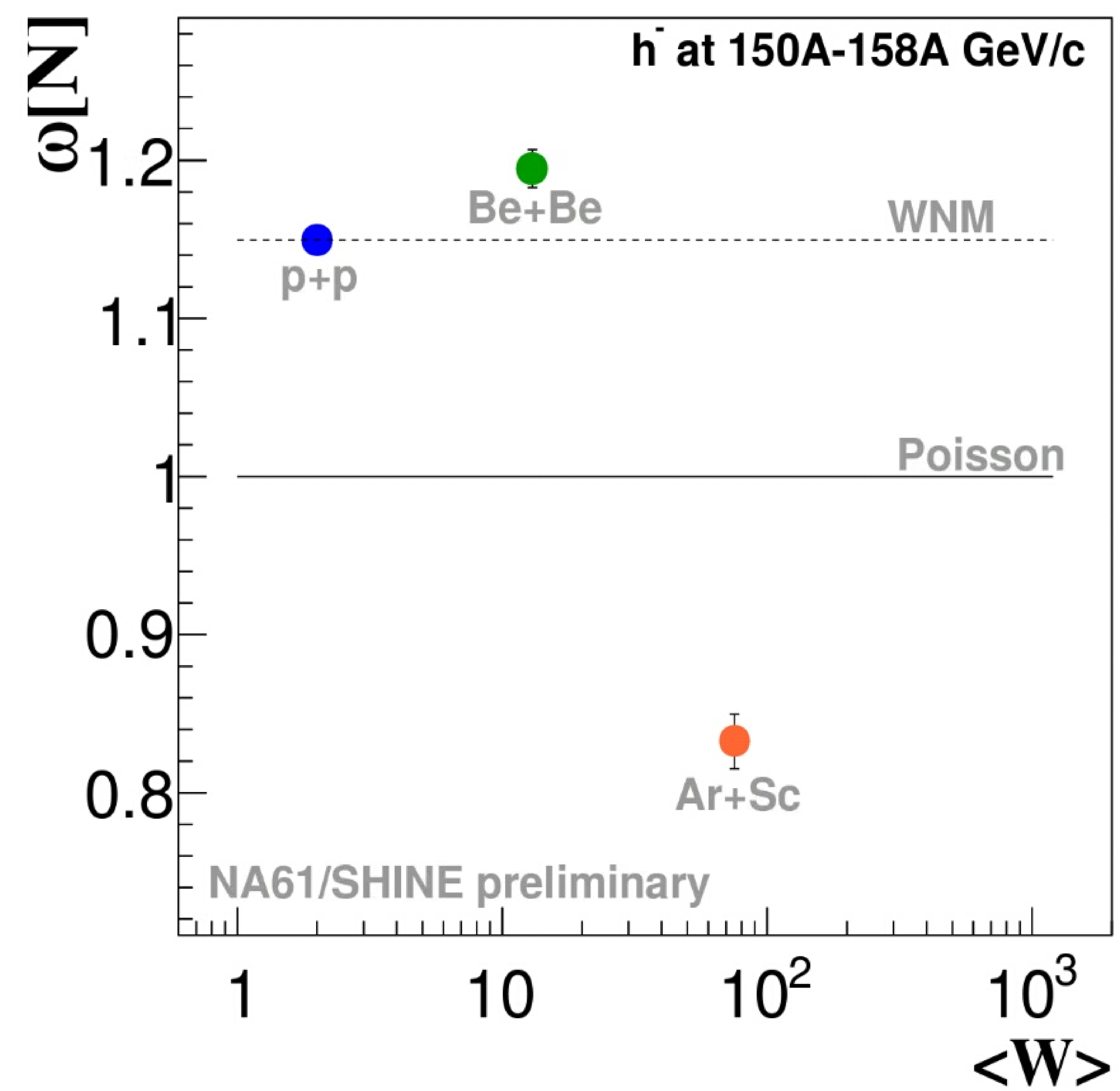

BEGUN, MG, GORENSTEIN, ZOZULYA

# RAPID CHANGES IN SYSTEM SIZE DEPENDENCE

## MEAN MULTIPLICITY RATIO

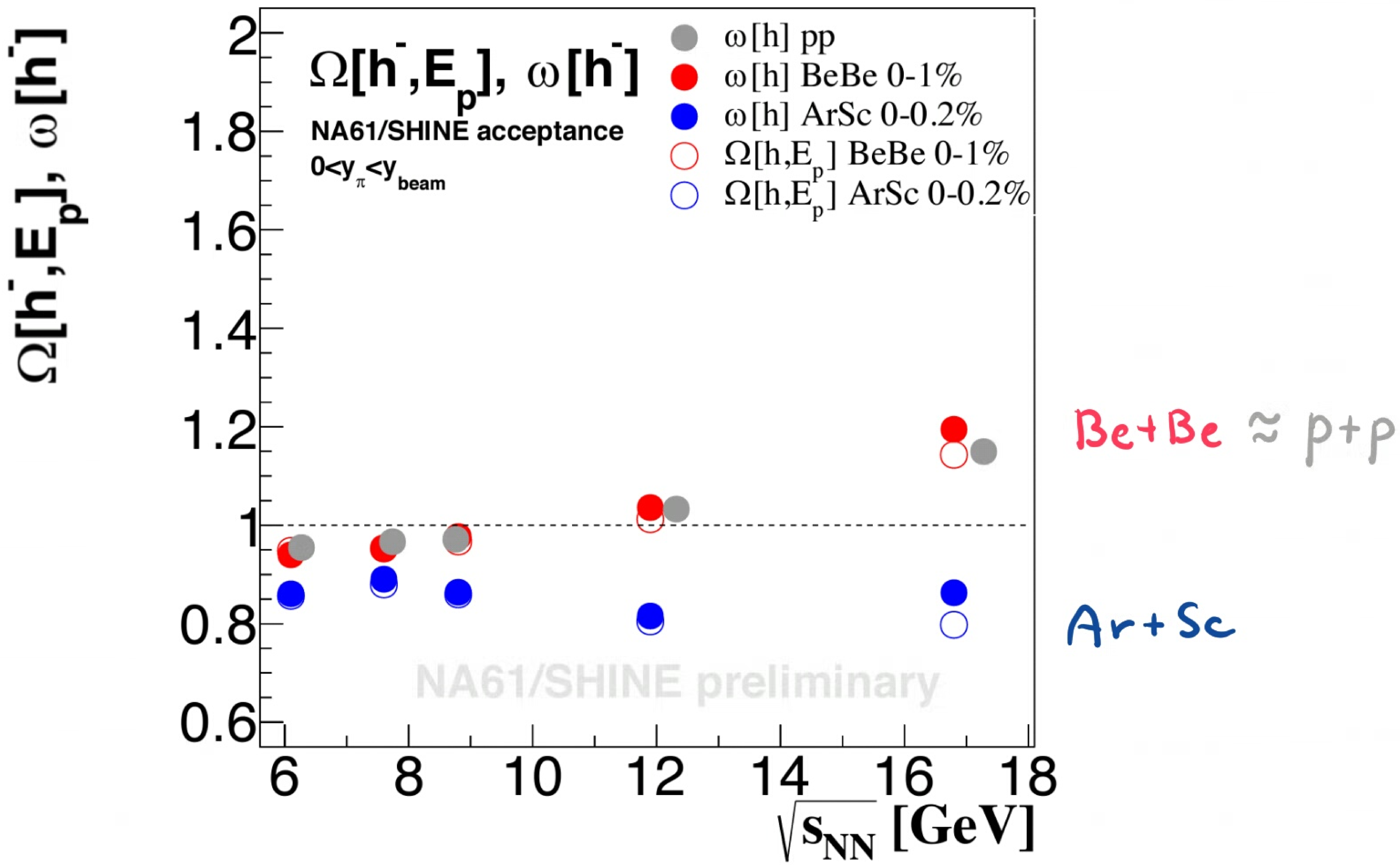



## MULTIPLICITY FLUCTUATIONS




DATA: CLUSTER VOLUME ≈ CONST FROM p+p TO Be+Be
THEN RAPIDLY INCREASES ?

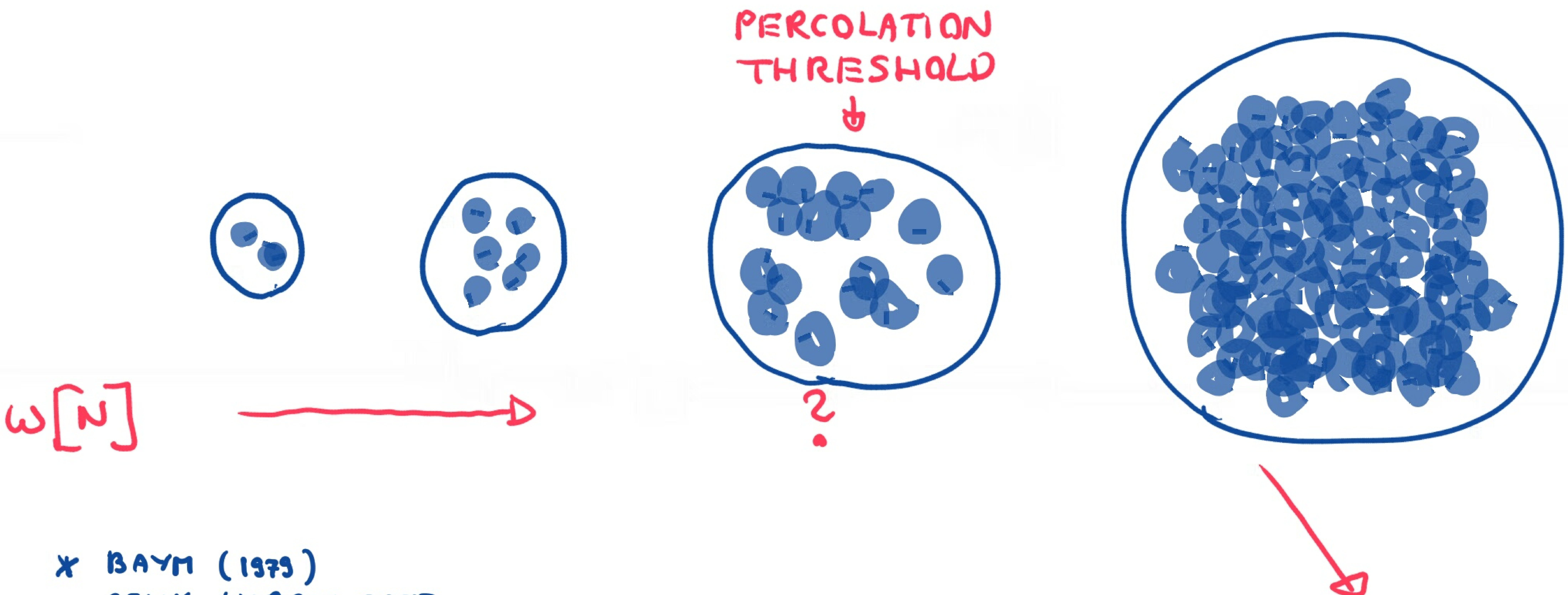
# RAPID CHANGES IN SYSTEM SIZE DEPENDENCE




DATA: CLUSTER VOLUME ≈ CONST FROM p+p TO Be+Be THEN RAPIDLY INCREASES AT ALL ANALYZED COLLISION ENERGIES

# PERCOLATION OF ELEMENTARY CLUSTERS

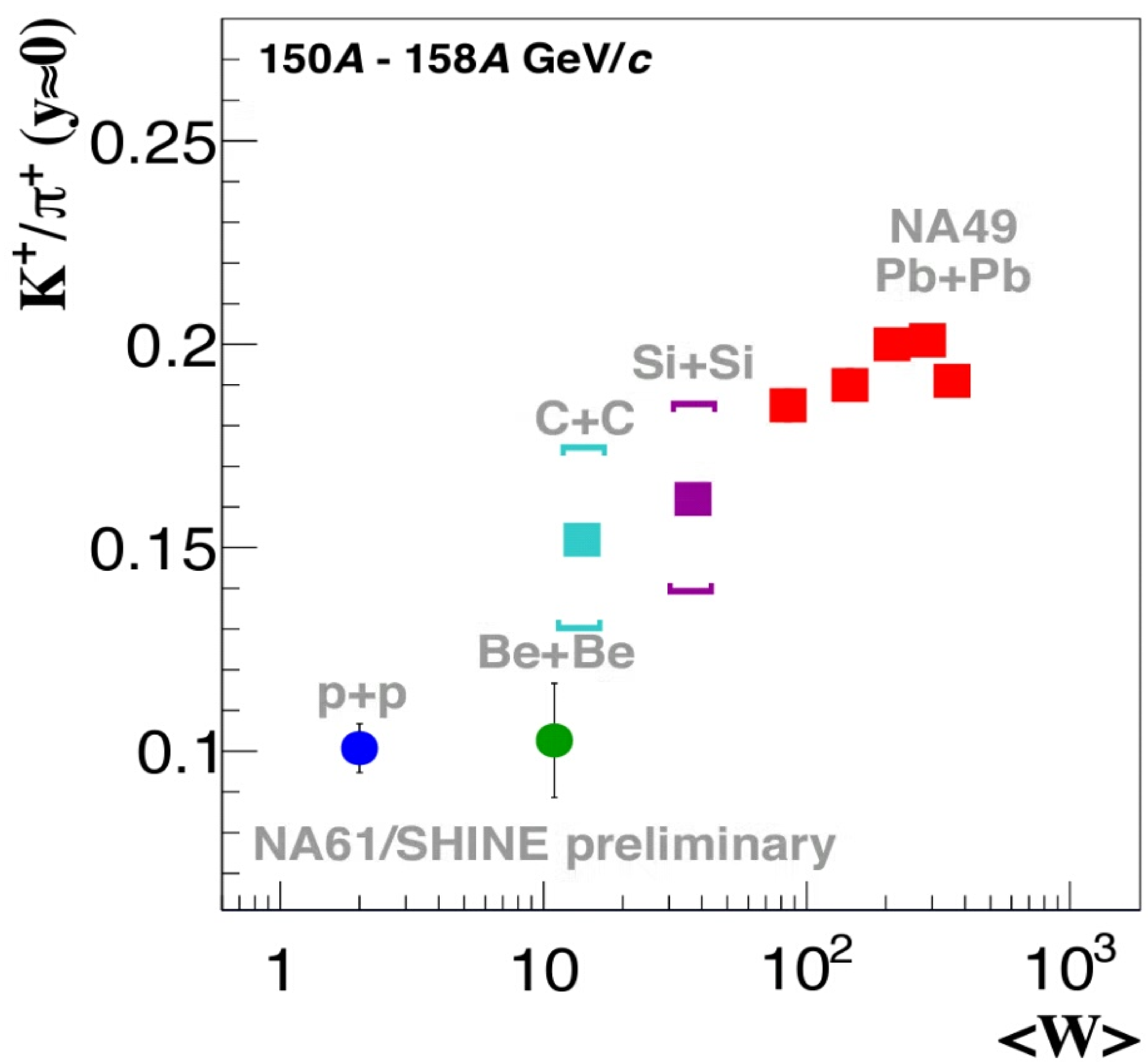
ONE EXPECTS* THAT WITH INCREASING SIZE OF COLLIDING NUCLEI DENSITY OF ELEMENTARY CLUSTERS (STRINGS, PARTONS, ...) INCREASES. AT HIGH ENOUGH DENSITY THEY WILL START TO OVERLAP FORMING LARGE CLUSTERS.



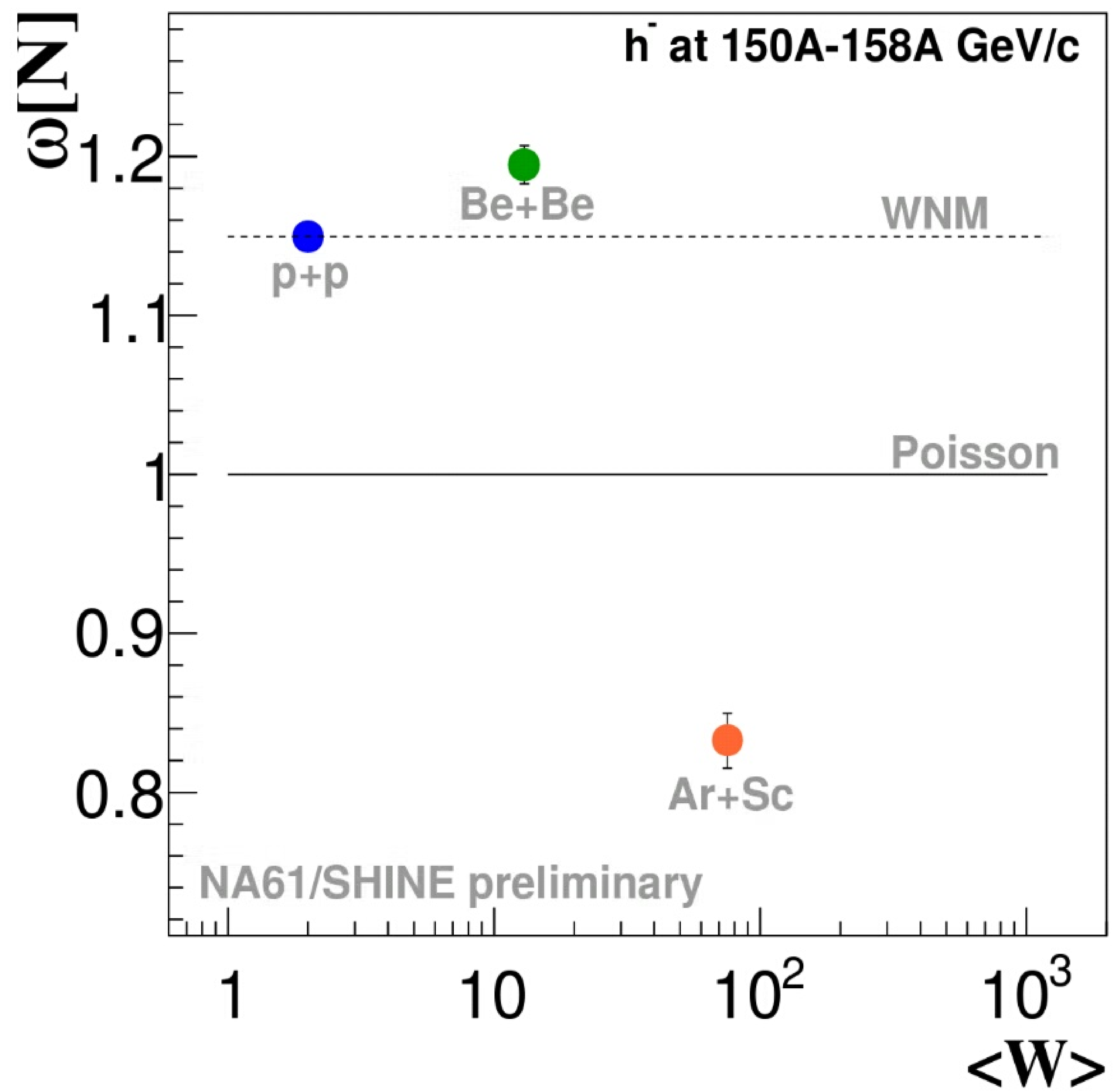

* BAYM (1979)
CELIK, KARSCH, SATZ
ARMESTO, BRAUN, FERRIORO, PAJARES
BRAUN, PAJARES
DIGAL, FORTUNATO, PETRECZKY, SATZ

# EVIDENCE FOR PERCOLATION THRESHOLD?

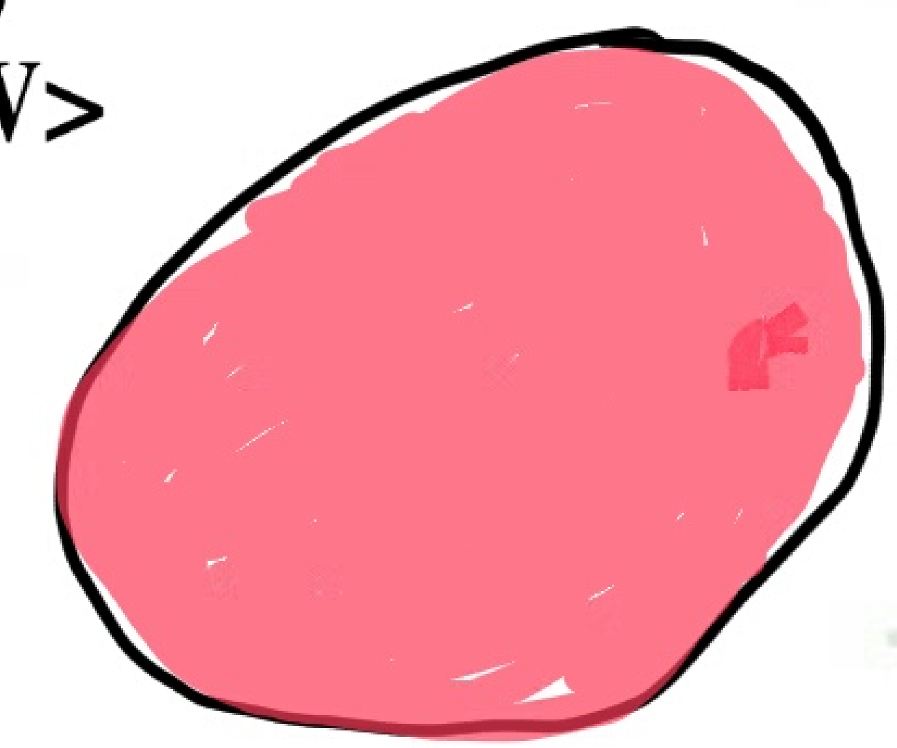
## MEAN MULTIPLICITY RATIO




## MULTIPLICITY FLUCTUATIONS




PERCOLATION THRESHOLD?



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... OR THRESHOLD FOR CREATION OF "BLACK-HOLE"-LIKE OBJECTS ("TRAPPED SURFACE")

arXiv:0902.1508v2 [hep-th] 18 Feb 2009

# Grazing Collisions of Gravitational Shock Waves and Entropy Production in Heavy Ion Collision

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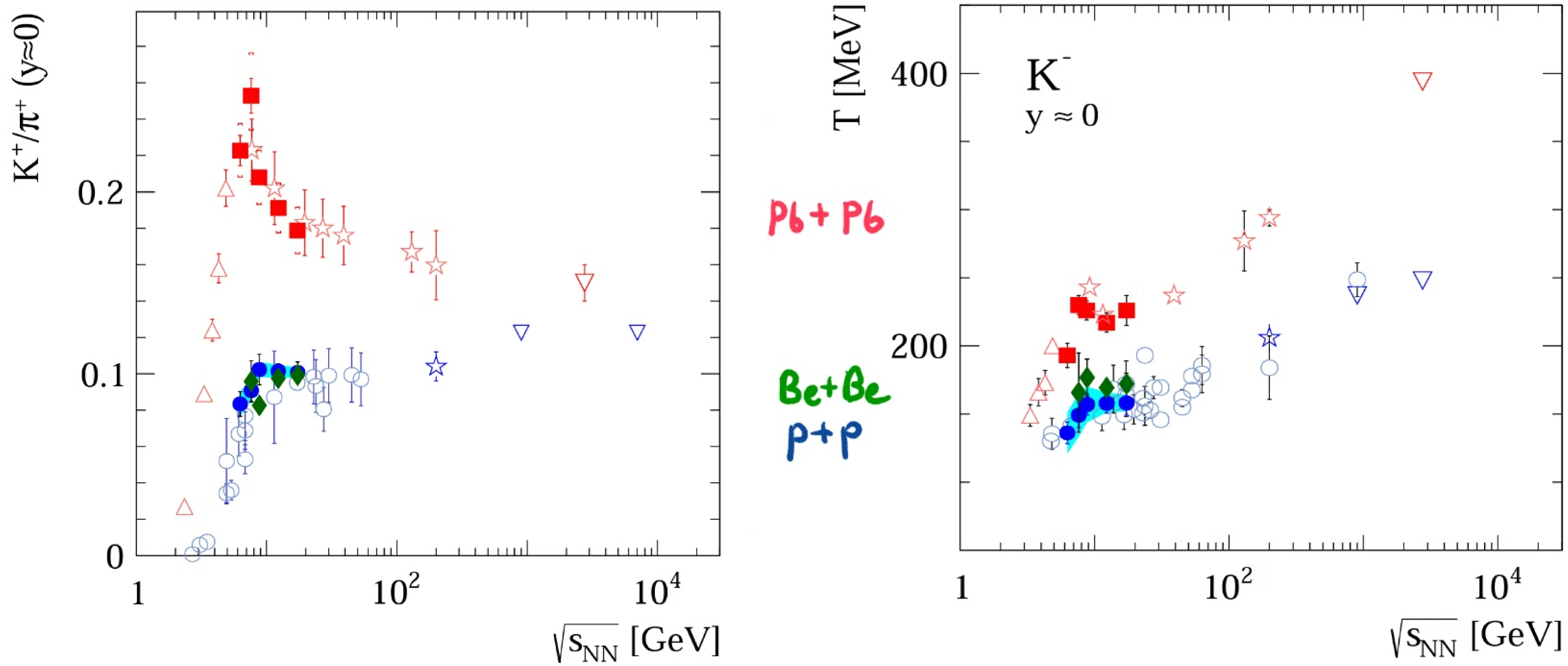
*Department of Physics and Astronomy, SUNY Stony-Brook, NY 11794*

**Abstract**

AdS/CFT correspondence is now widely used for study of strongly coupled plasmas, such as produced in ultrarelativistic heavy ion collisions at RHIC. While properties of equilibrated plasma and small deviations from equilibrium are by now reasonably well understood, its initial formation and thermal equilibration is much more challenging issue which remains to be studied. In the dual gravity language, these problems are related to formation of bulk black holes, and trapped surfaces we study in this work is a way to estimate the properties (temperature and entropy) of such black hole. Extending the work by Gubser et al, we find numerically trapped surfaces for non-central collision of shock waves with different energies. We observe a critical impact parameter, beyond which the trapped surface does not exist: and we argue that there are experimental indications for similar critical impact parameter in real collisions. We also present a simple solvable example of shock wave collision: wall-on-wall collision. The applicability of this approach to heavy ion collision is critically discussed.

# "OLD" RESULTS ON ENERGY DEPENDENCE






EVIDENCE FOR RAPID CHANGES IN COLLISION ENERGY DEPENDENCE OF HADRON PRODUCTION PROPERTIES IN p+p INTERACTIONS

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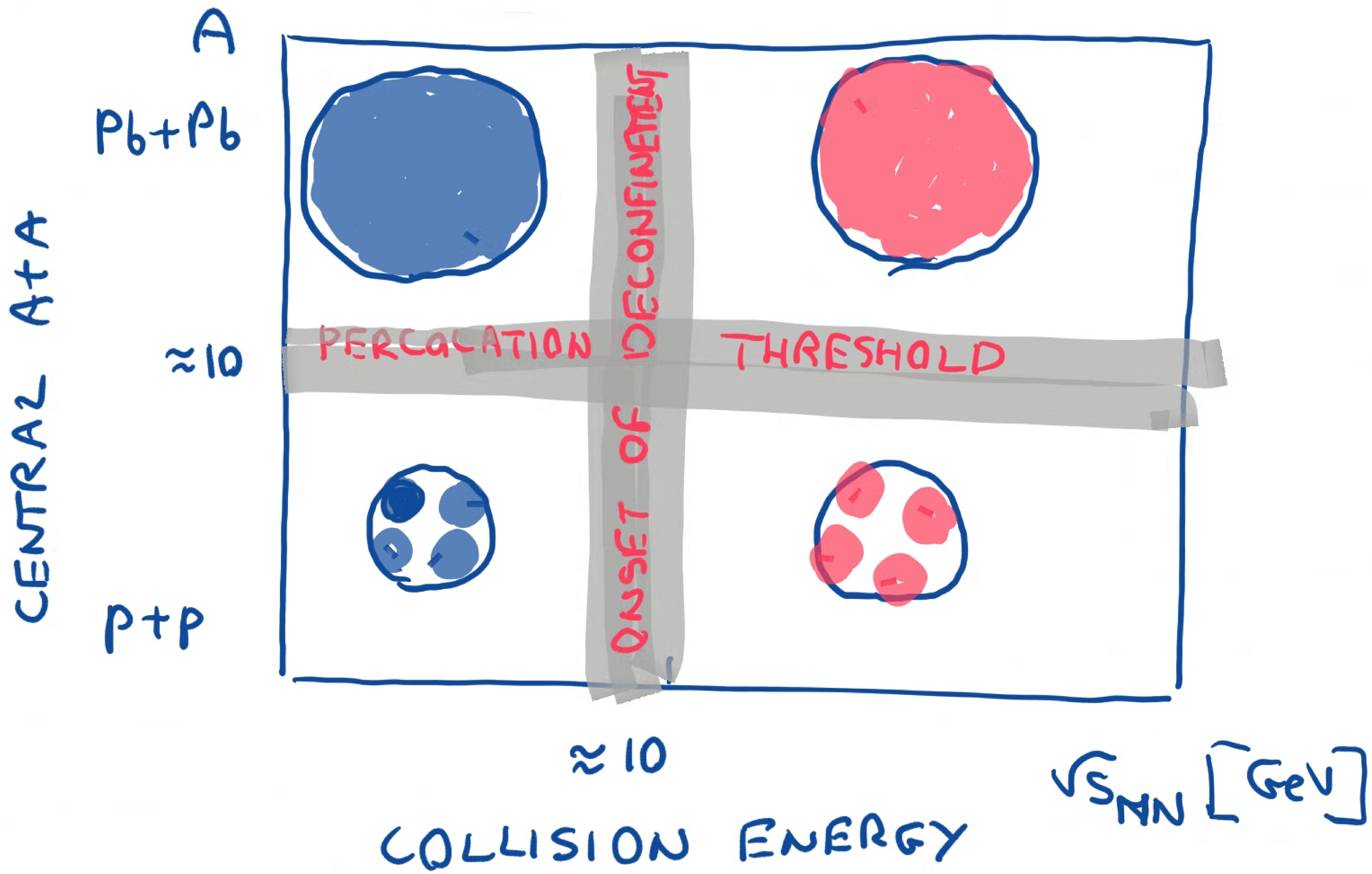
NA49 HORN AND STEP IN Pb+Pb →
EVIDENCE FOR ONSET OF DECONFINEMENT IN Pb+Pb AND p+p

IN SUMMARY, RESULTS SUGGESTS
TWO THRESHOLDS AND
FOUR DOMAINS IN (SYSTEM-SIZE) – $\sqrt{s_{NN}}$ PLANE



# SEARCH FOR CRITICAL POINT

## FLUCTUATIONS VS $\sqrt{s_{NN}}$ AND A

USE QUANTITIES INSENSITIVE TO VOLUME FLUCTUATIONS AND MATERIAL CONSERVATION LAWS:

$\Downarrow$

STRONGLY INTENSIVE QUANTITIES WITH A PROPER SELECTION OF EXTENSIVE QUANTITIES:

$$\Sigma[N, P_T] \equiv C^{-1}\left[\langle P_T\rangle\, \omega[N] + \langle N\rangle \cdot \omega[P_T] - 2\left(\langle N \cdot P_T\rangle - \langle N\rangle\langle P_T\rangle\right)\right]$$

$$\Delta[N, P_T] \equiv C^{-1}\left[\langle P_T\rangle\, \omega[N] - \langle N\rangle \cdot \omega[P_T]\right]$$

WITH $C \equiv \langle N\rangle \cdot \omega[P_T]$, $\quad P_T = \sum_{i}^{N} p_T^i$

$\rightarrow$ IB-GCE WITH $V \updownarrow$

$\Sigma[N, P_T] = \Delta[N, P_T] = 1$

# CONSERVATION LAWS AND CRITICAL POINT

WITIN IB-CE (MATERIAL CONSERVAION) WITH VOLUME FLUCTUATIONS:

$$\Sigma[N, P_T] = 1 \qquad \Delta[N, P_T] = 1$$

IB-CE:

$$f_N(\bar{p}_1, \bar{p}_2, \dots \bar{p}_N) = f(\bar{p}_1) f(\bar{p}_2) \dots f(\bar{p}_N)$$

AND THUS ARE EQUAL TO $\Sigma[N, P_T]$, $\Delta[N, P_T]$ IN IB-GCE. THEY ARE INDEPENDENT OF MATERIAL CONSERVATION LAWS.

HOPE** THAT CRITICAL POINT WILL CORRELATE PARTICLES IN MOMENTUM SPACE $\left( f_N(\bar{p}_1, \bar{p}_2, \dots \bar{p}_N) \neq f(\bar{p}_1) f(\bar{p}_2) \dots f(\bar{p}_N) \right)$ AND THUS IT WILL LEAD TO ANOMALIES IN DEPENDENCE OF $\Sigma$ AND $\Delta$ ON $\sqrt{s_{NN}}$ AND A.

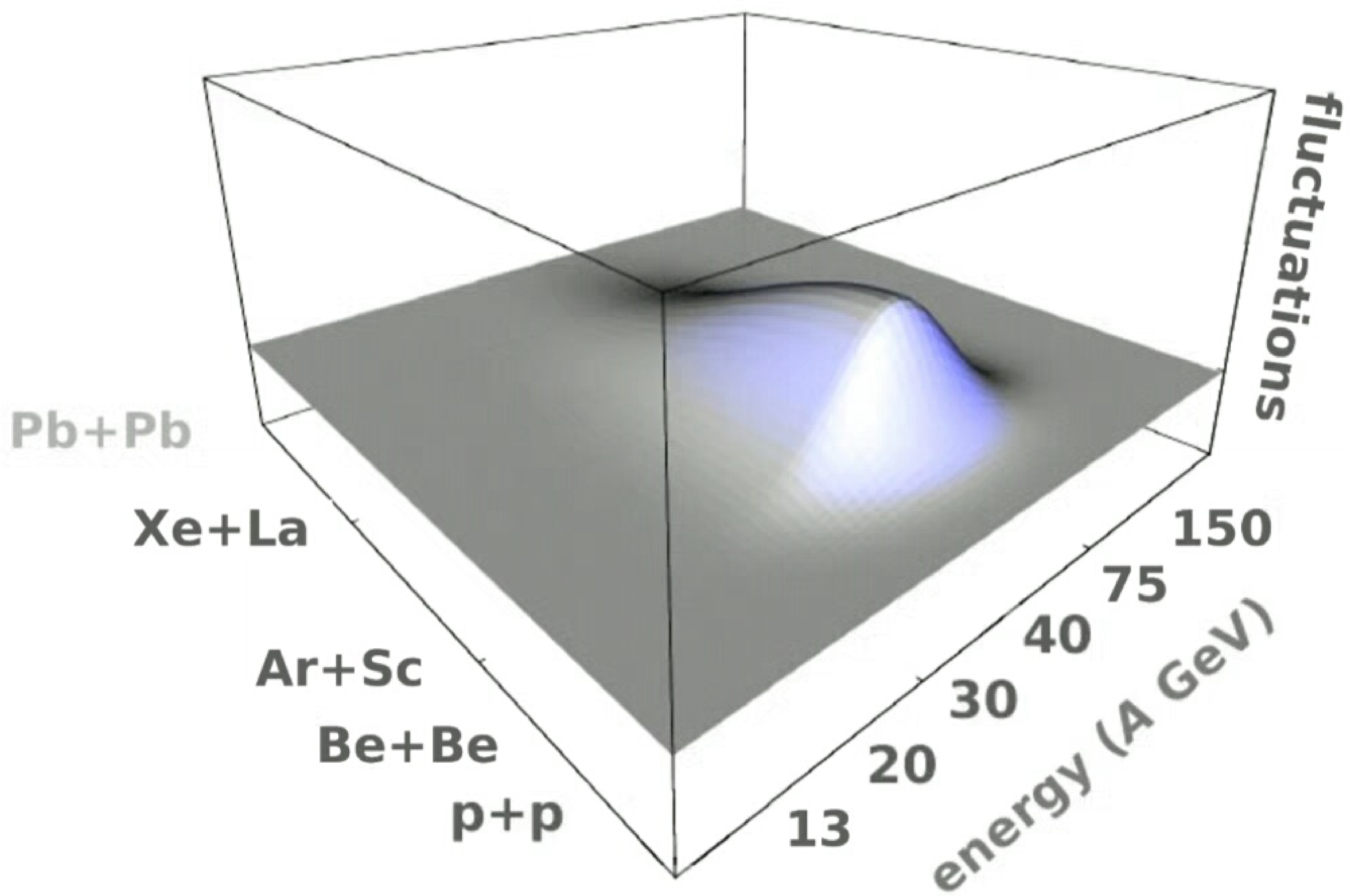
* MG, GORENSTEIN, MACKOWIAK

** BIALAS, HWA
STEPHANOV, RAJAGOPAL, SHURYAK

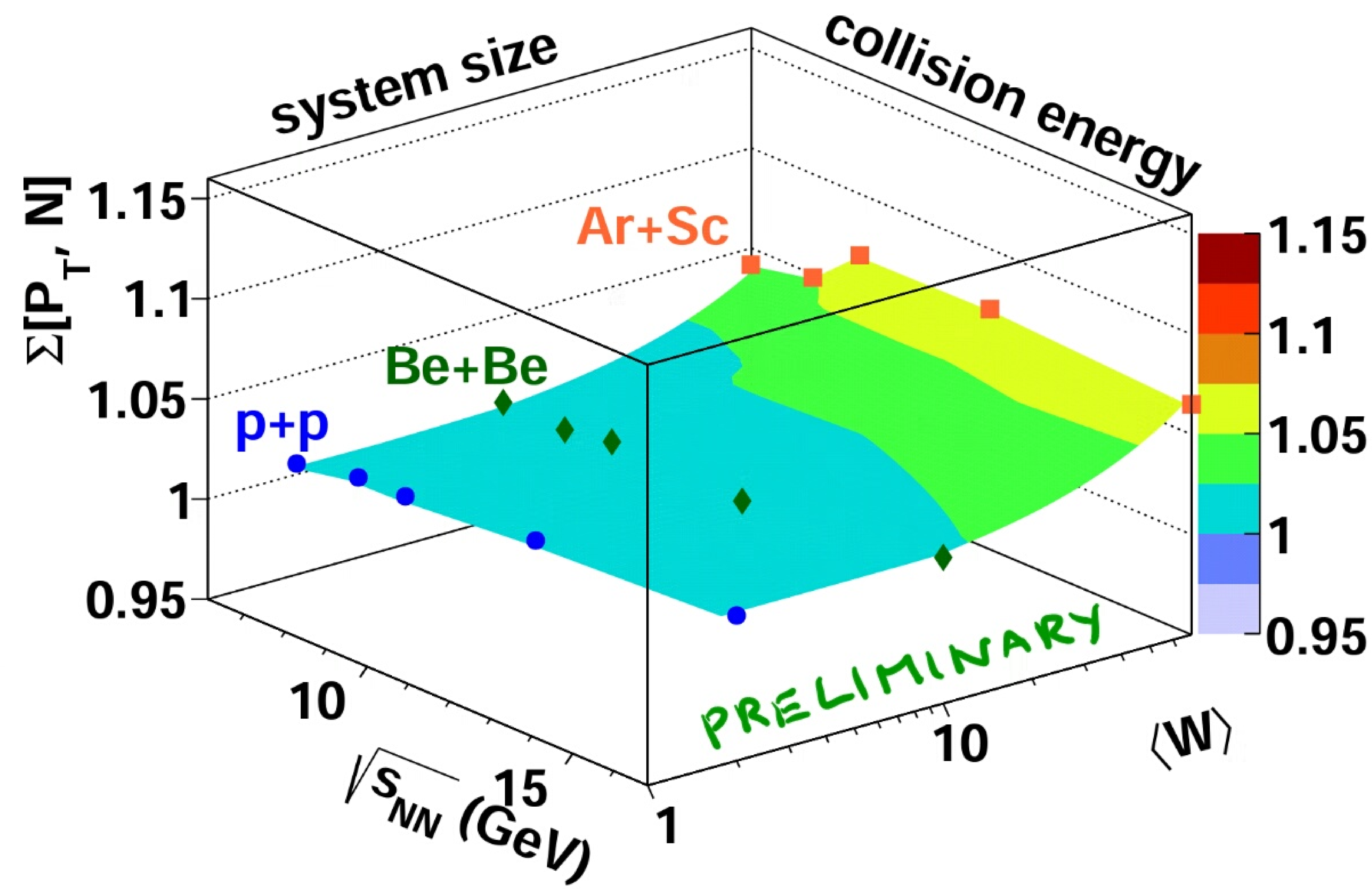
# SEARCH FOR CRITICAL POINT: FLUCTUATIONS VS $\sqrt{s_{NN}}$ AND A

NEGATIVELY CHARGED PIONS

CP ⇒ "FLUCTUATION HILL"




NA61/SHINE DATA




NO INDICATION FOR CRITICAL POINT SO FAR

# SEARCH FOR CRITICAL POINT : FLUCTUATIONS VS M
## "INTERMITTENCY ANALYSIS"

SECOND ORDER PHASE TRANSITION → SCALE INVARIANCE → CHARACTERISTIC DEPENDENCE OF FLUCTUATIONS ON SIZE $\delta$ OF SUBDIVISION INTERVALS OF MOMENTUM SPACE $\Delta$

$M = \Delta/\delta$ – NUMBER OF INTERVALS

$$F_2(M) \equiv \sum_{i=1}^{M} \langle N_i (N_i - 1) \rangle \Big/ \sum_{i=1}^{M} \langle N_i \rangle^2$$

WHERE $N_i$ – PARTICLE NUMBER IN BIN $i$,
$\langle .. \rangle$ – AVERAGING OVER EVENTS

AT THE CRITICAL POINT POWER LAW DEPENDENCE IS EXPECTED

$$F_2(M) = F_2(\Delta) \cdot M^{\phi_2}$$

WOSIEK (1988)
BIALAS, PESZANSKI
SATZ
ANTONIOU, DIAKONOS, KAPOYANIS

# SEARCH FOR CRITICAL POINT : FLUCTUATIONS VS M

NOTE THAT $F_2(M)$ IS SENSITIVE TO BATH VOLUME FLUCTUATIONS AND MATERIAL CONSERVATION LAWS

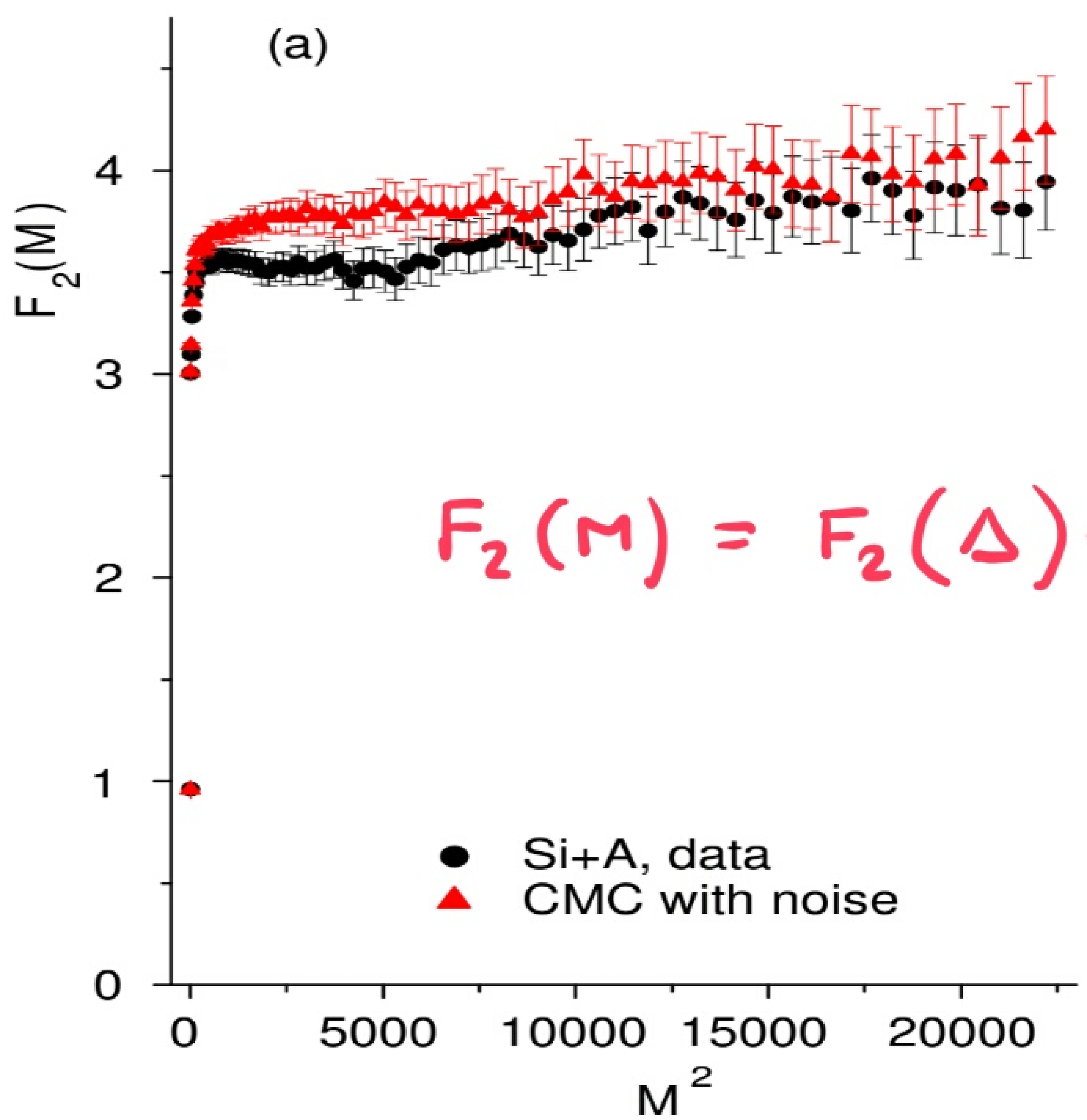
HOPE (CHECKED BY MONTE CARLO) THAT FOR SUFFICIENTLY SMALL $\delta$ (LARGE M) THE CP FLUCTUATIONS WILL DOMINATE.

AN IMPROVEMENT OF THE METHOD WOULD HELP IN FUTURE SEARCHES

# SEARCH FOR CRITICAL POINT : FLUCTUATIONS VS M
# PROTONS



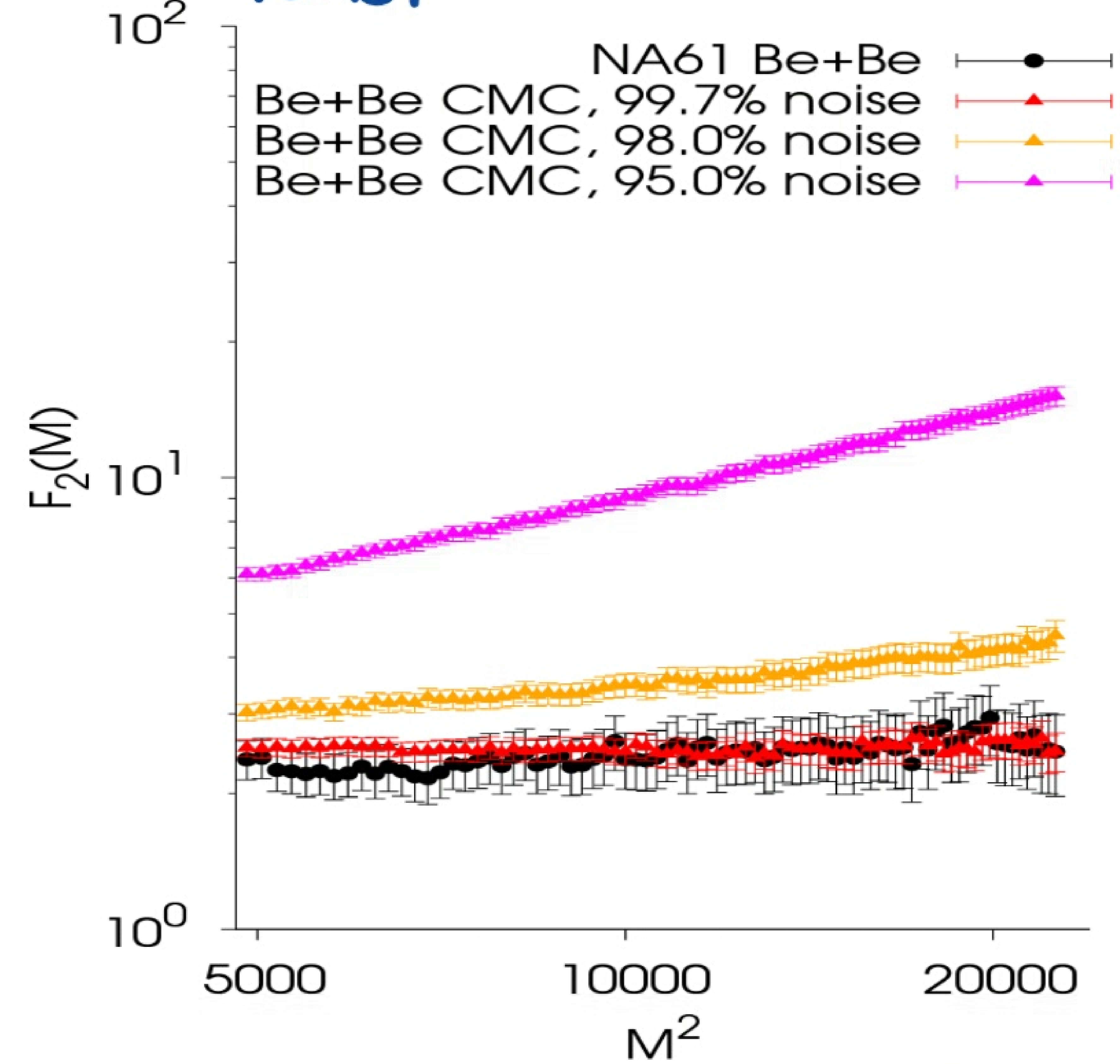
Si+A AT 158A GEV/c
NA49




$$F_2(M) = F_2(\Delta) \cdot M^{\phi_2}$$

NA49: RESULTS CONSISTENT WITH ≈ 1 % OF "CRITICAL" PROTONS , $\phi_2 \approx 1$

Be+Be at 150A GEV/c
NA61




UPPER LIMIT OF "CRITICAL" PROTONS ≈ 0.3%

# FLUCTUATIONS AND CORRELATIONS FROM NA61/SHINE

- REMOVING VOLUME FLUCTUATIONS
  - EVENT SELECTION USING PROJECTILE SPECTATORS
  - STRONGLY INTENSIVE QUANTITIES
- EXPLOITING CONSERVATION LAWS
  - EVIDENCE OF PERCOLATION THRESHOLD
- SEARCH FOR CRITICAL POINT
  - NO EVIDENCE SO FAR

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MORE ON THIS FROM NA61/SHINE:

- INTERMITTENCY : NIKOS DAVIS
- CORRELATIONS : BARTEK MAKSIAK

# NA61/SHINE Collaboration

- Azerbaijan
  - National Nuclear Research Center, Baku
- Bulgaria
  - University of Sofia, Sofia
- Croatia
  - IRB, Zagreb
- France
  - LPNHE, Paris
- Germany
  - KIT, Karlsruhe
  - Fachhochschule Frankfurt, Frankfurt
  - University of Frankfurt, Frankfurt
- Greece
  - University of Athens, Athens
- Hungary
  - Wigner RCP, Budapest
- Japan
  - KEK Tsukuba, Tsukuba
- Norway
  - University of Bergen, Bergen
- Poland
  - UJK, Kielce
  - NCBJ, Warsaw
  - University of Warsaw, Warsaw
  - WUT, Warsaw
  - Jagiellonian University, Kraków
  - IFJ PAN, Kraków
  - AGH, Kraków
  - University of Silesia, Katowice
  - University of Wrocław, Wrocław
- Russia
  - INR Moscow, Moscow
  - JINR Dubna, Dubna
  - SPBU, St.Petersburg
  - MEPhI, Moscow
- Serbia
  - University of Belgrade, Belgrade
- Switzerland
  - ETH Zürich, Zürich
  - University of Bern, Bern
  - University of Geneva, Geneva
- USA
  - University of Colorado Boulder, Boulder
  - LANL, Los Alamos
  - University of Pittsburgh, Pittsburgh
  - FNAL, Batavia
  - University of Hawaii, Manoa

**$\sim$150 physicists from $\sim$30 institutes**

DATA VS EPOS1.99