ON TRANSITIONS IN HIGH ENERGY NUCLEAR COLLISIONS

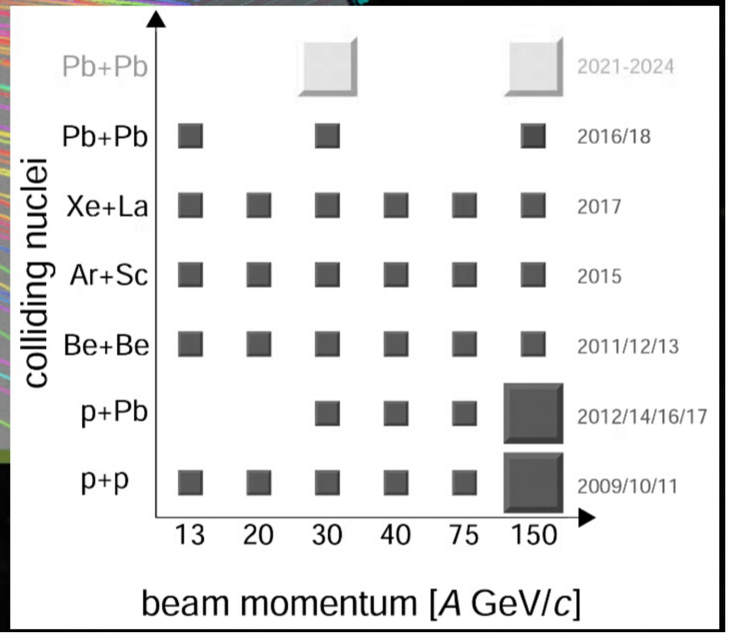
NEWS FROM NA61/SHINE AT CERN SPS

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

- VOCABULARY
- ONSET OF FIREBALL
- ONSET OF DECONFINEMENT
- SEARCH FOR CRITICAL POINT

MEASURMENTS OF HADRON PRODUCTION PROPERTIES FOR

- NEUTRINO BEAMS (J-PARC, FERMILAB)
- COSMIC RAY EXPS. (PAO, AMS, ...)
- STRONG INTERACTIONS (HEAVY IONS, ...)



STRONGLY INTERACTING MATTER (SIM)

≡ MAXIMUM ENTROPY STATE OF ISOLATED SYSTEM OF STRONGLY INTERACTING PARTICLES
(ALL MICROSTATES HAVE EQUAL PROBABILITY TO APPEAR)

FOR FIXED $E, B_1, \ldots$ AND LARGE V

SIM IN HM PHASE IF ENTROPY (HM) > ENTROPY (QGP)

SIM IN QGP PHASE IF ENTROPY (QGP) > ENTROPY (HM)

QGP - QUARK-GLUON PLASMA
HM - HADRONIC MATTER

LARGE CLUSTER OF SIM

CLUSTER OF SIM WITH VOLUME SUFFICIENTLY LARGE TO MAKE INTENSIVE QUANTIES* (E.G. $\langle N \rangle / V$, $Var[N]/\langle N \rangle$) VOLUME INDEPENDENT

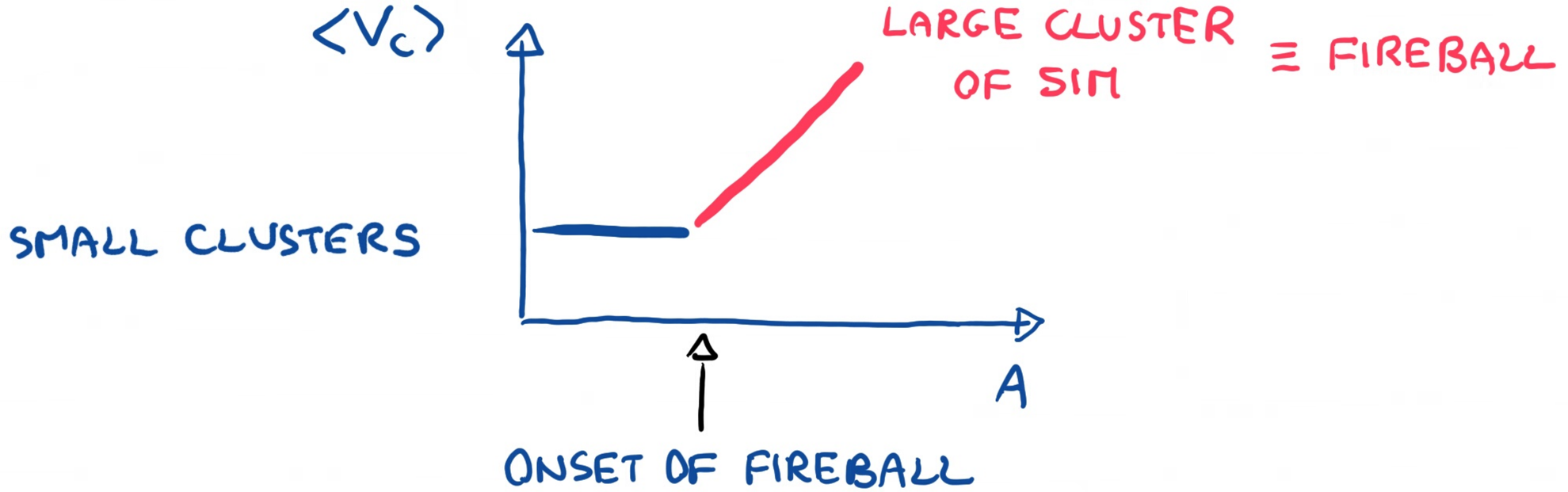
* INTENSIVE QUANTITIES - QUANTITIES WHICH ARE VOLUME INDEPENDENT IN GCE

STATISTICAL MODEL OF THE EARLY STAGE (SMES)

MAIN ASSUPTION: CLUSTERS OF SIM ARE CREATED AT THE EARLY STAGE OF COLLISIONS

ONSET OF FIREBALL

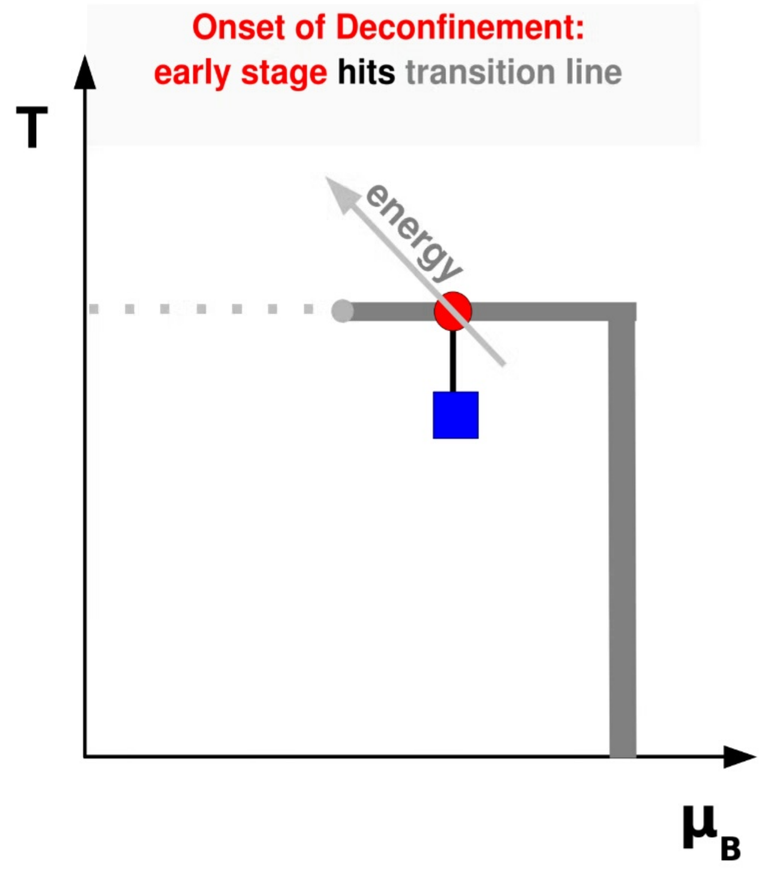
≡ BEGINNIG OF CREATION OF LARGE CLUSTERS OF STRONGLY INTERACTING MATTER (SIM) IN NUCLEUS-NUCLEUS (A+A) COLLISIONS WITH INCREASING NUCLEAR MASS NUMBER (A)

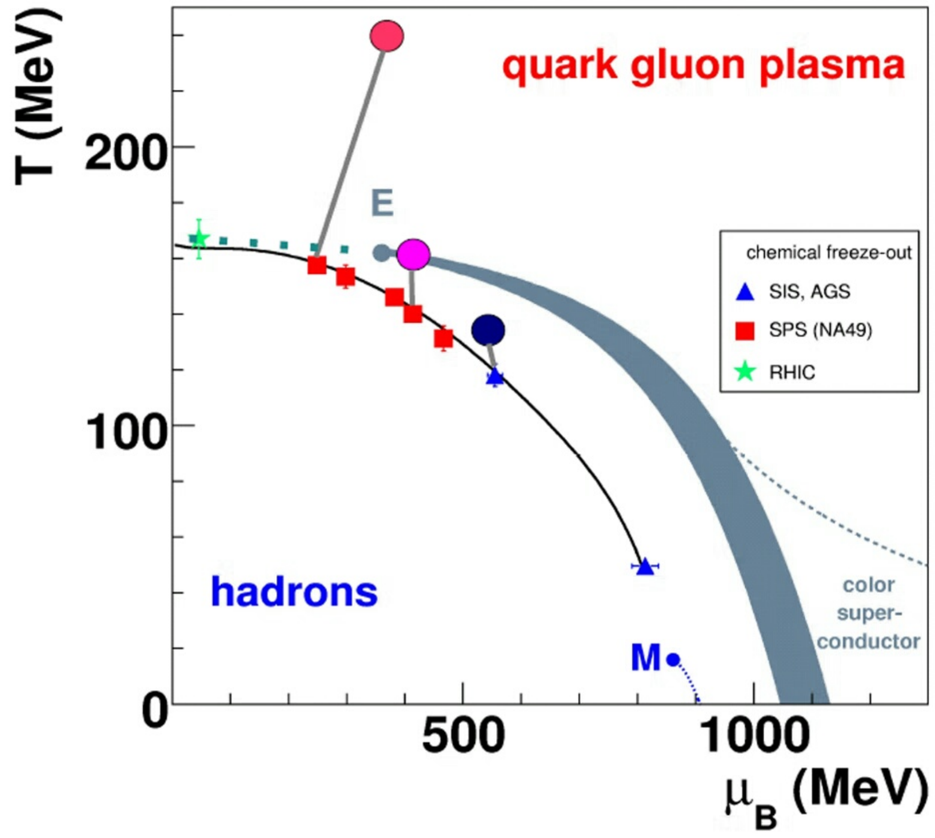


<Vc> - MEAN CLUSTER VOLUME

ONSET OF DECONFINEMENT

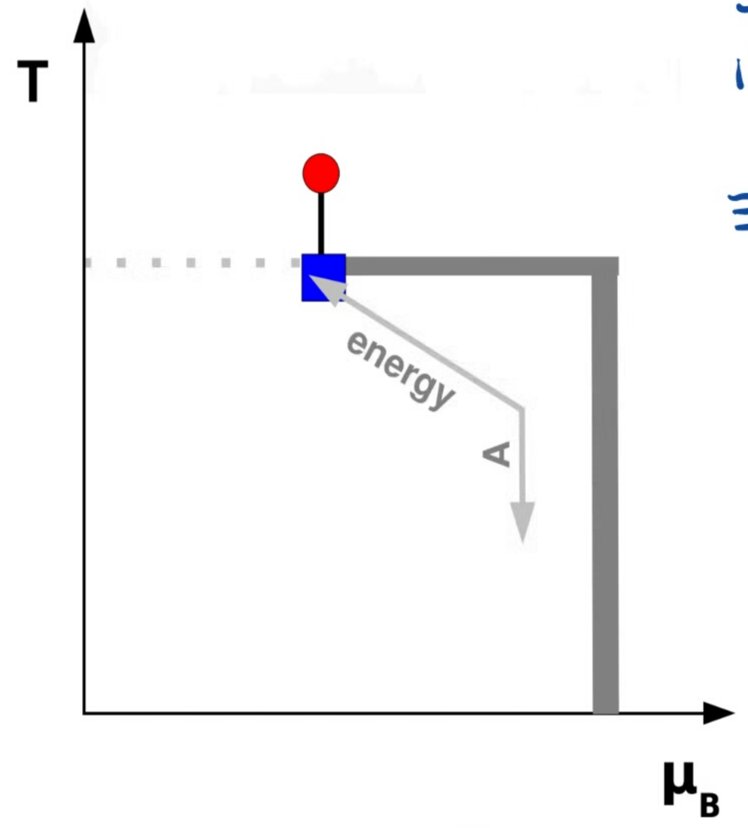
≅ BEGINING OF CREATION OF QUARK-GLUON PLASMA IN NUCLEUS-NUCLEUS COLLISIONS WITH INCREASING COLLISION ENERGY ($\sqrt{s_{NN}}$)





CRITICAL POINT OF SIM

≡ HYPOTHETICAL END POINT OF FIRST ORDER TRANSITION LINE THAT HAS PROPERTIES OF SECOND ORDER TRANSITION

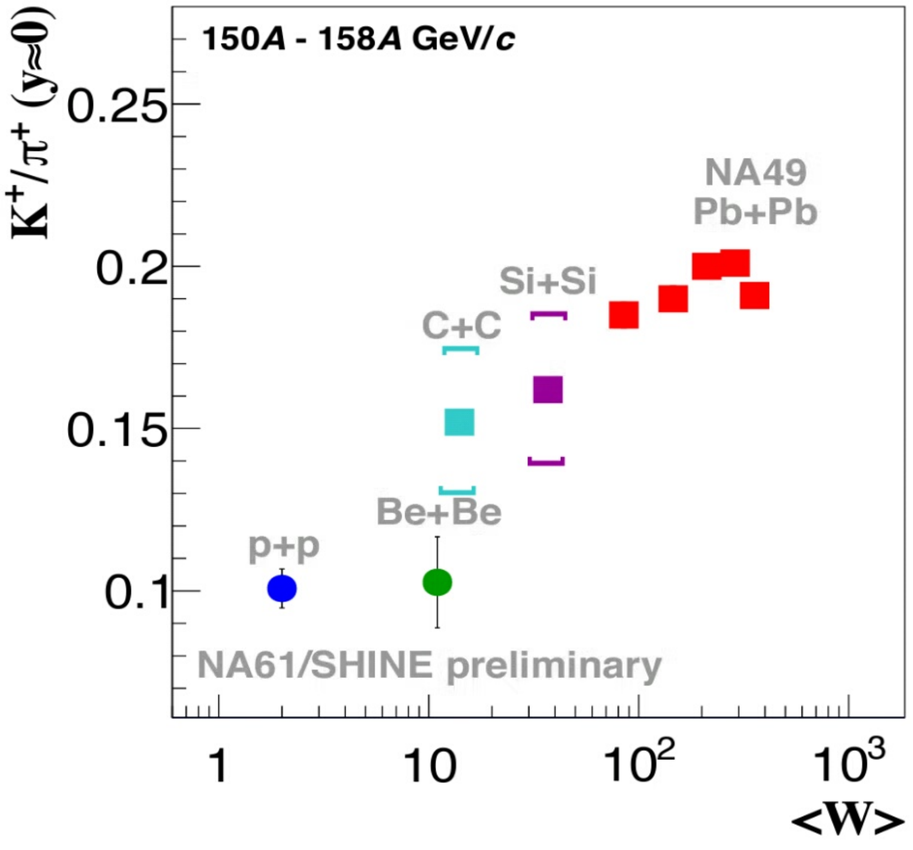


SEARCH FOR CRITICAL POINT (CP) OF SIM IN A+A COLLISIONS

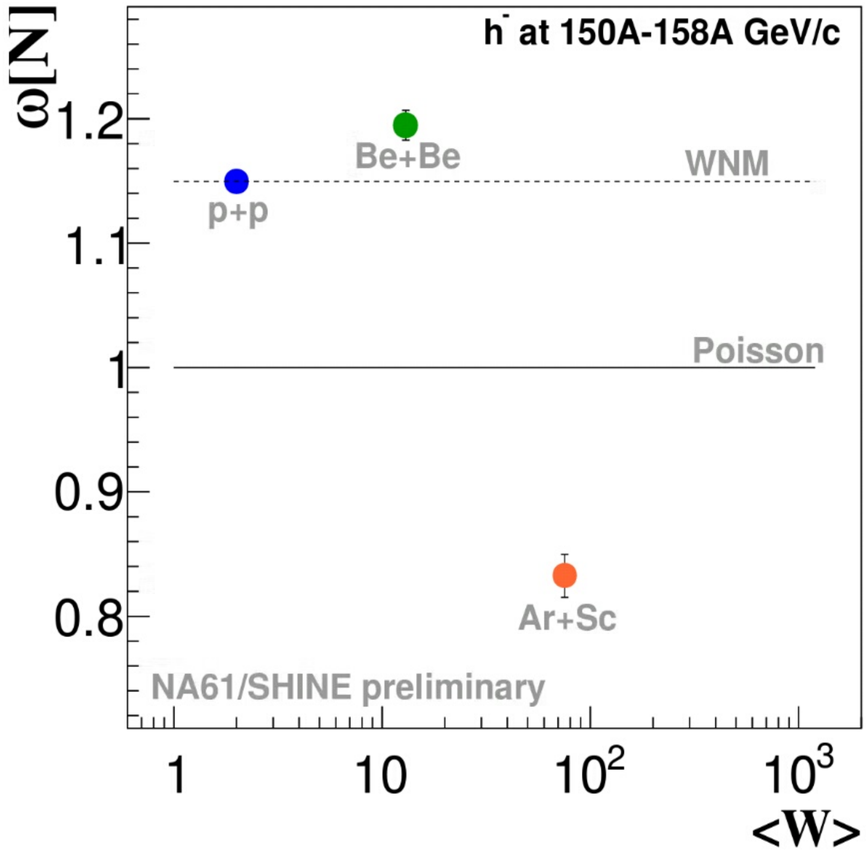
≡ SCAN IN $\sqrt{s_{NN}}$ AND A TO POSITION FREEZE-OUT POINT CLOSE TO CP

ONSET OF FIREBALL

MEAN MULTIPLICITY RATIO (STRONGLY INTENSIVE)



MULTIPLICITY FLUCTUATIONS (INTENSIVE)

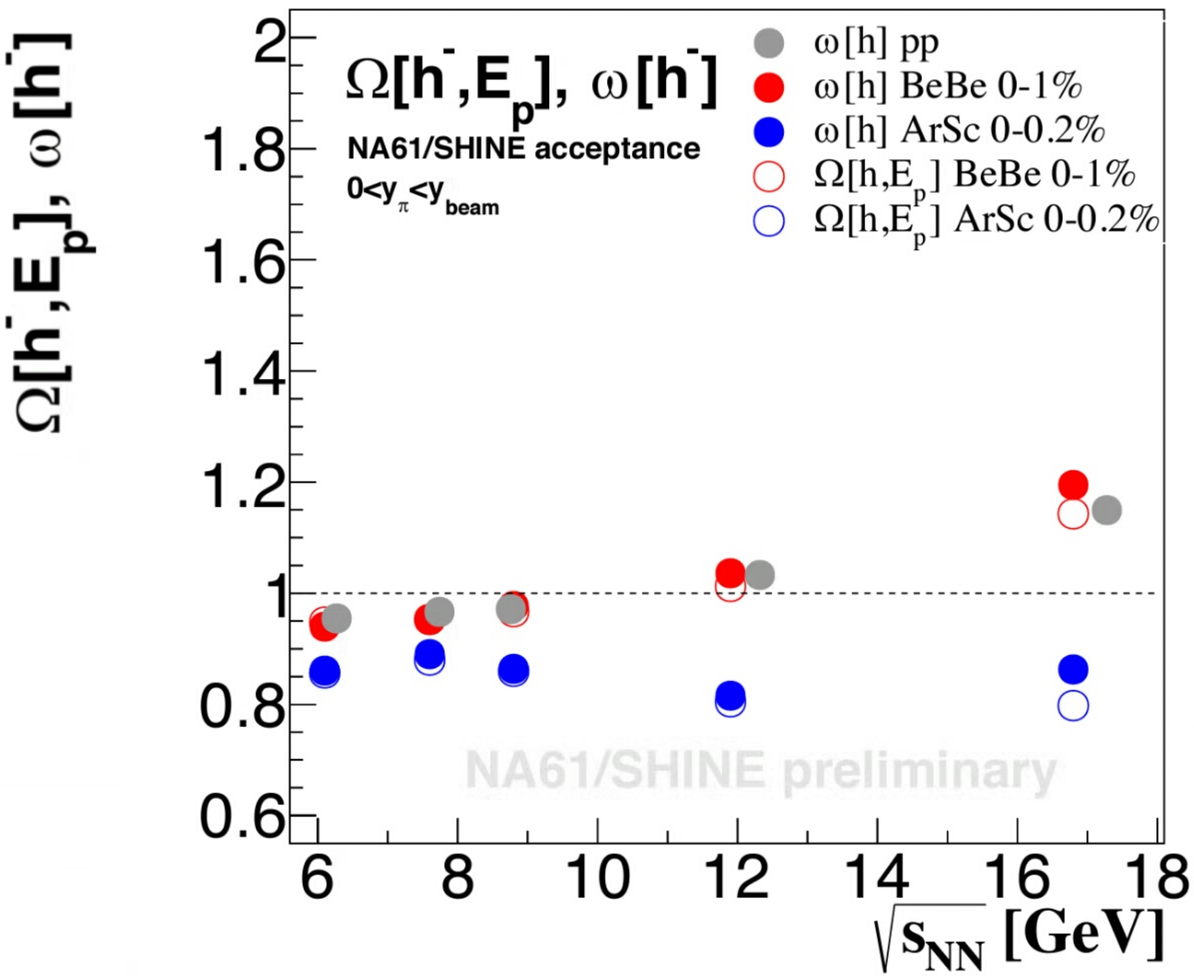


$\omega[N] \equiv \mathrm{Var}[N]/\langle N \rangle$

↑ ONSET OF FIREBALL? ↑

(NUMBER OF WOUNDED NUCLEONS)

MULTIPLICITY FLUCTUATIONS



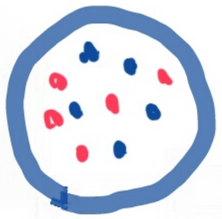
Be+Be ≈ p+p

Ar+Sc

RAPID CHANGE OF A-DEPENDENCE AT A ≈ 10
OBSERVED AT ALL SPS COLLISION ENERGIES

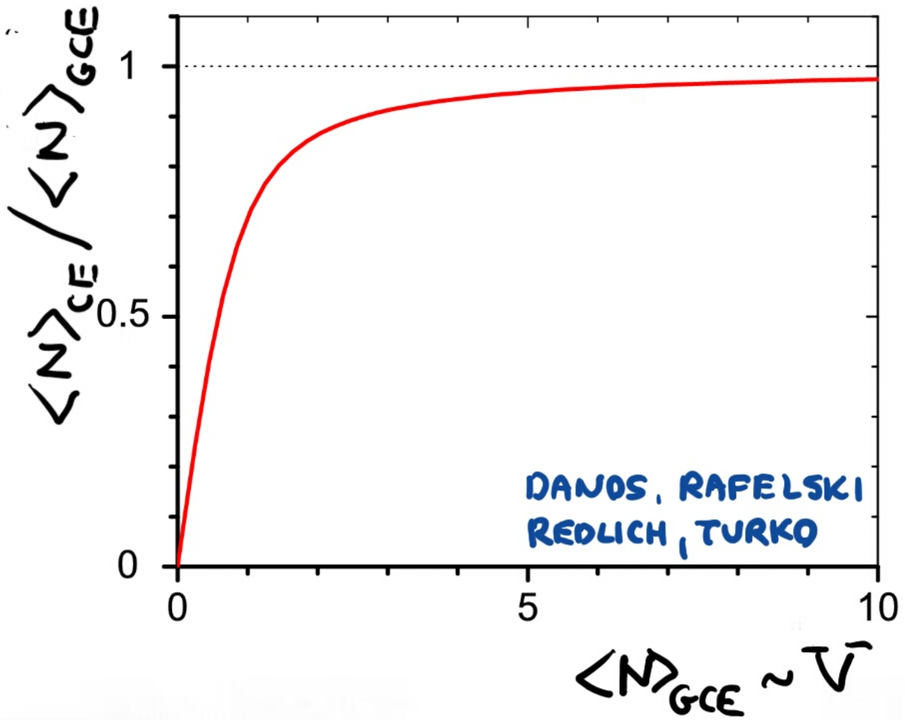
VOLUME DEPENDENCE OF $\langle N \rangle$ AND $\omega[N]$

V, T
$Q = 0$

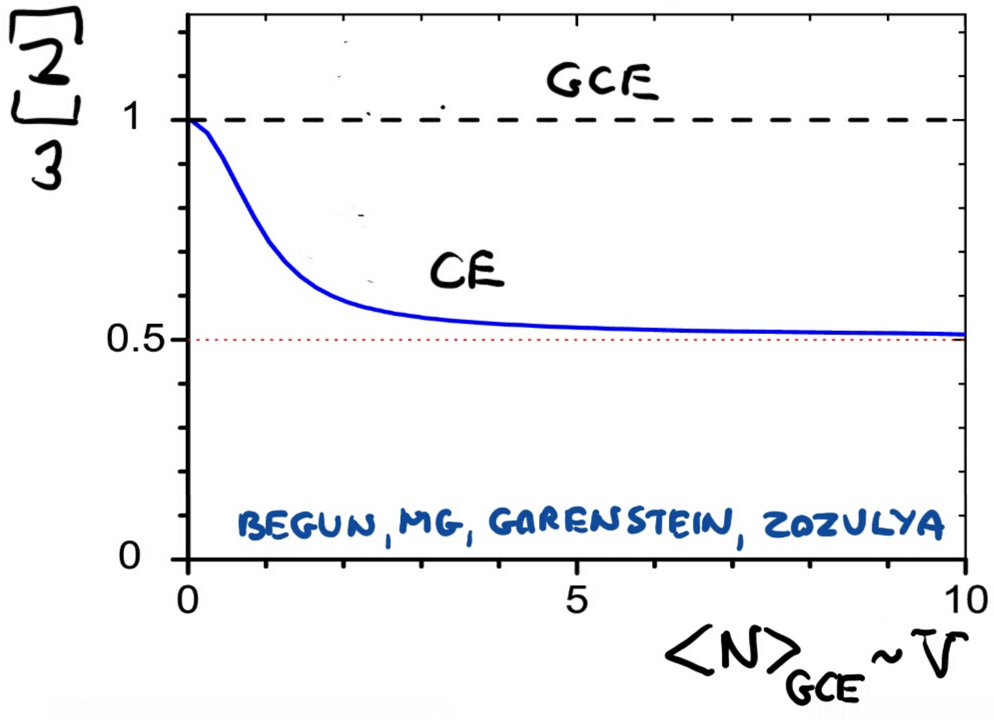


IDEAL BOLTZMANN (IB) GAS WITHIN CANONICAL ENSEMBLE (CE) → NON-TRIVIAL DEPENDENCE OF $\langle N \rangle$ AND $\omega[N]$ ON V

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

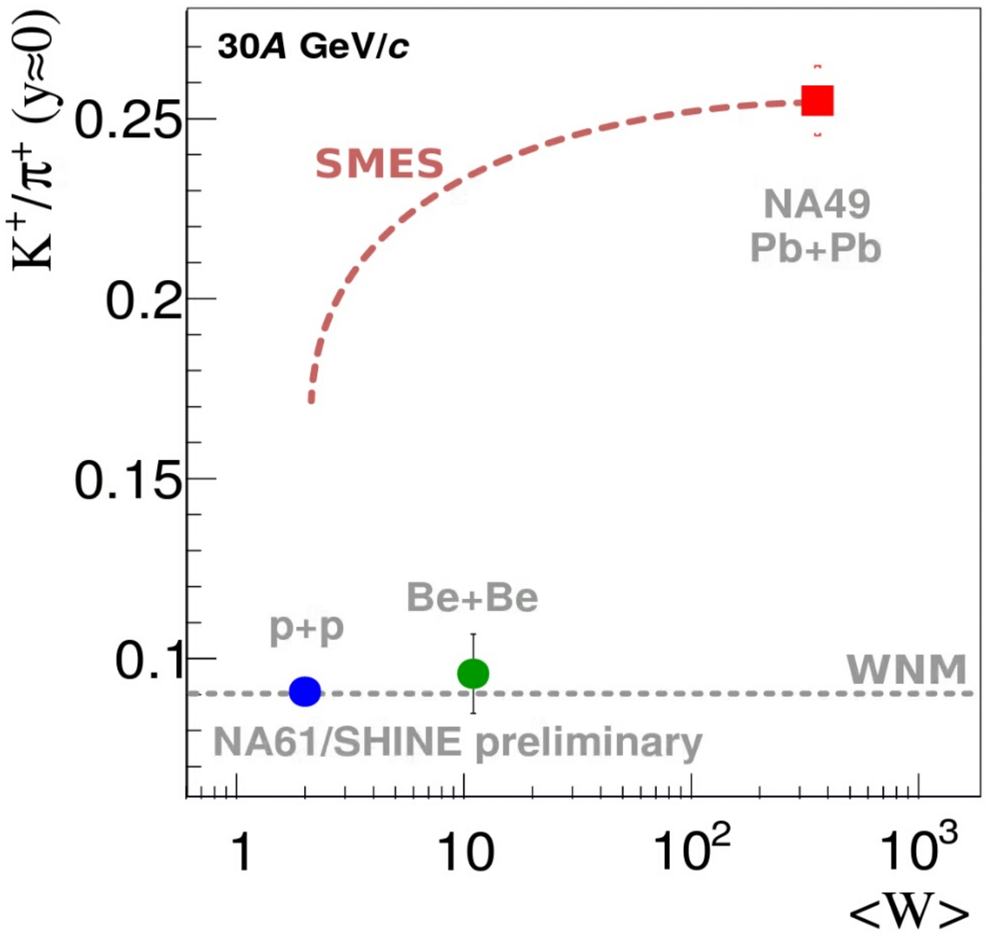


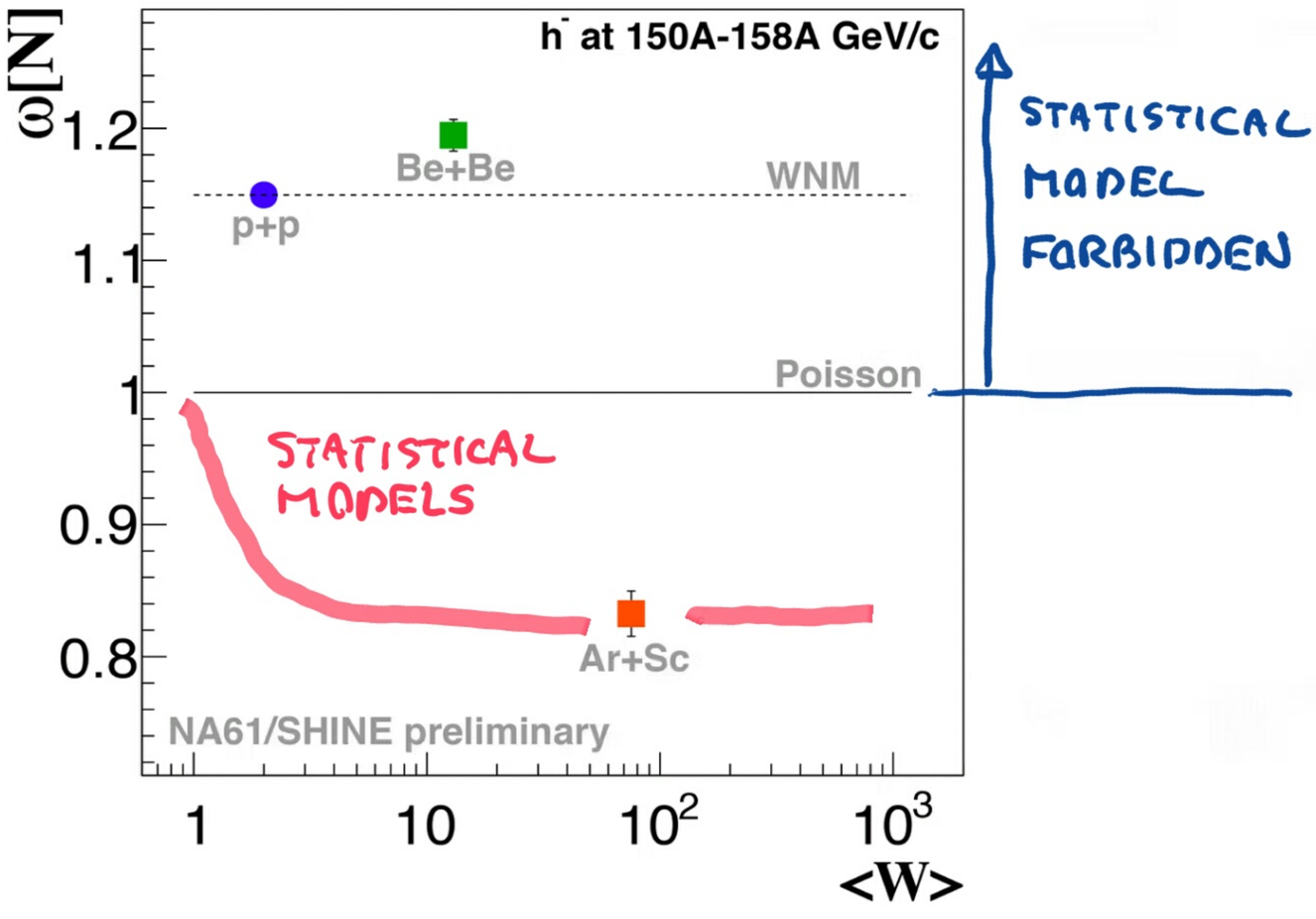
"CANONICAL ENHANCEMENT" OF $\omega[N]$



FAR INSUFFICIENT TO REPRODUCE DATA

p+p AND Be+Be SUPPERPOSITION OF "NON-STATISTICAL CLUSTERS"

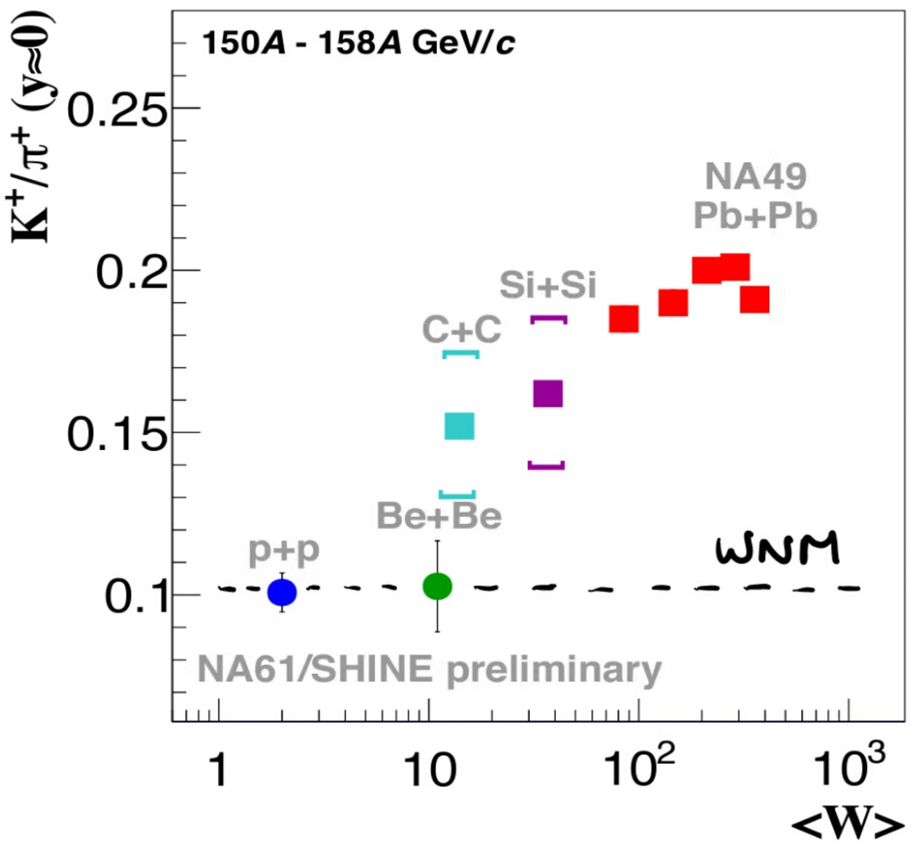




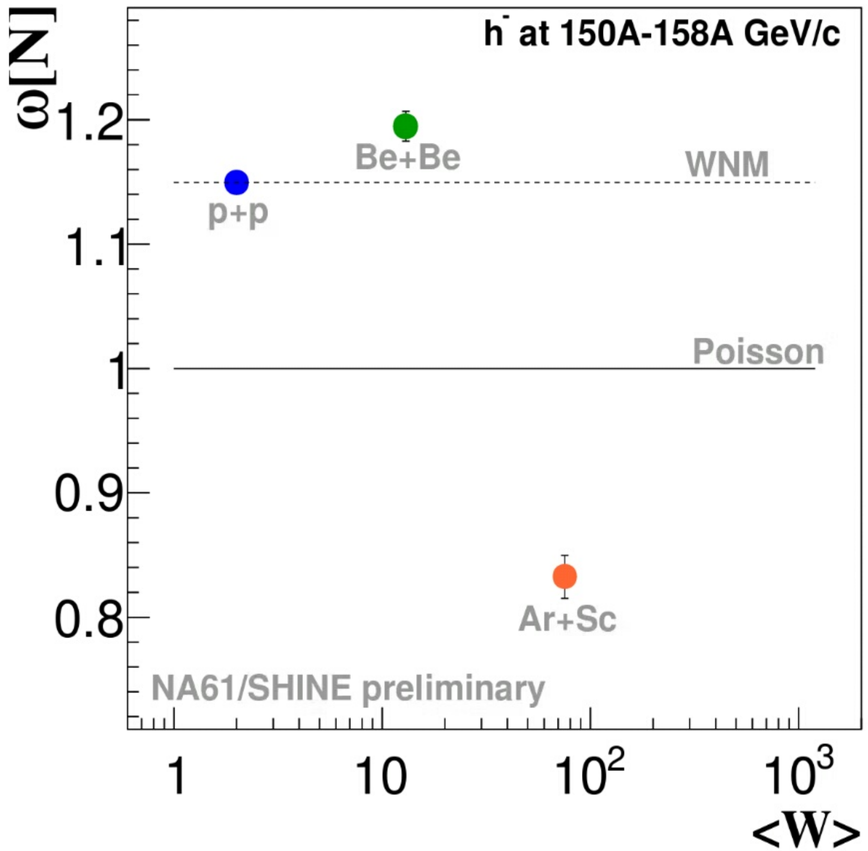
Ar+Sc AND Pb+Pb ≈ LARGE VOLUME CLUSTER OF SIM ?

NA61/SHINE INDICATION FOR ONSET OF FIREBALL

MEAN MULTIPLICITY RATIO



MULTIPLICITY FLUCTUATIONS



↑ ONSET OF FIREBALL ↑

ON INTERPRETATION OF ONSET OF FIREBALL: PERCOLATION APPROACH

WITH INCREASING A DENSITY OF CLUSTERS (STRINGS, PARTONS, ...) INCREASES. THUS PROBABILITY TO OVERLAP MANY ELEMENTARY CLUSTERS MAY RAPIDLY INCREASE WITH A → PERCOLATION MODELS.

THIS APPROACH DOES NOT EXPLAIN EQUILIBRIUM PROPERTIES OF LARGE CLUSTERS

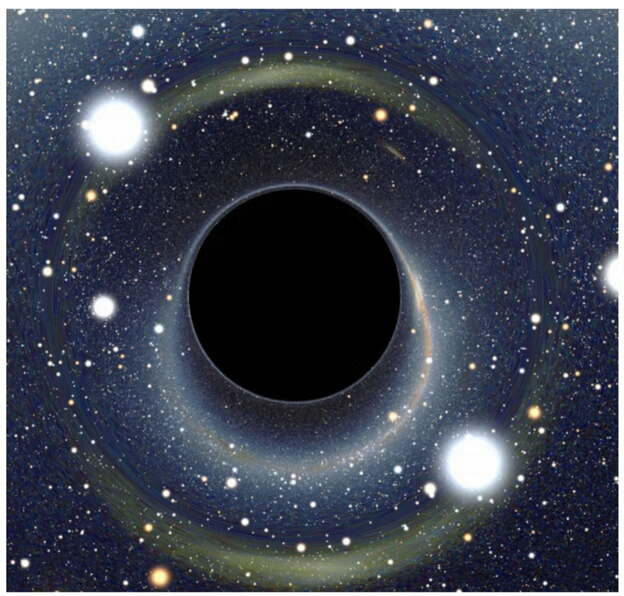
BAYM, PHYSICA A96 (79) 131
CELIK, KARSCH, SATZ PL B97 (80) 128
BRAUN, PAJARES, NP B390 (93) 542
ARMESTO, BRAUN, FERREIRO, PAJARES, PRL 77 (96) 3736
CUNQUEIRO, FERREIRO, MORAL, PAJARES PRC75 (05) 024907

ON INTERPRETATION OF ONSET OF FIREBALL: AdS/CFT CORRESPONDENCE

MALDACENA, INT. J. THEOR. PHYS. 38 (1999) 1113

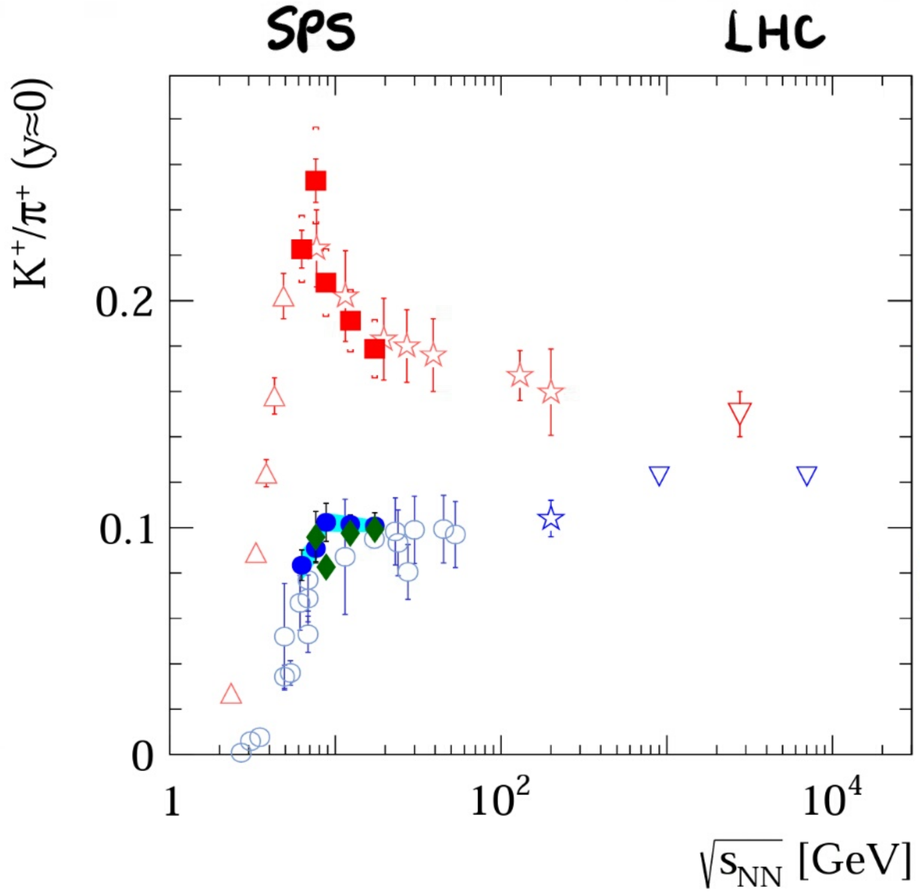
AdS (GRAVITY): FORMATION OF A BLACK HOLE HORIZON (INFORMATION TRAPPING SURFECE) TAKES PLACE WHEN CRITICAL VALUES OF MODEL PARAMETERS ARE REACHED.

CFT (QCD): ONLY STARTING FROM A SUFFICIENTLY LARGE NUCLEAR MASS NUMBER THE FORMATION OF THE TRAPPING SURFACE IN A+A COLLISIONS IS POSSIBLE → ONSET OF FIREBALL



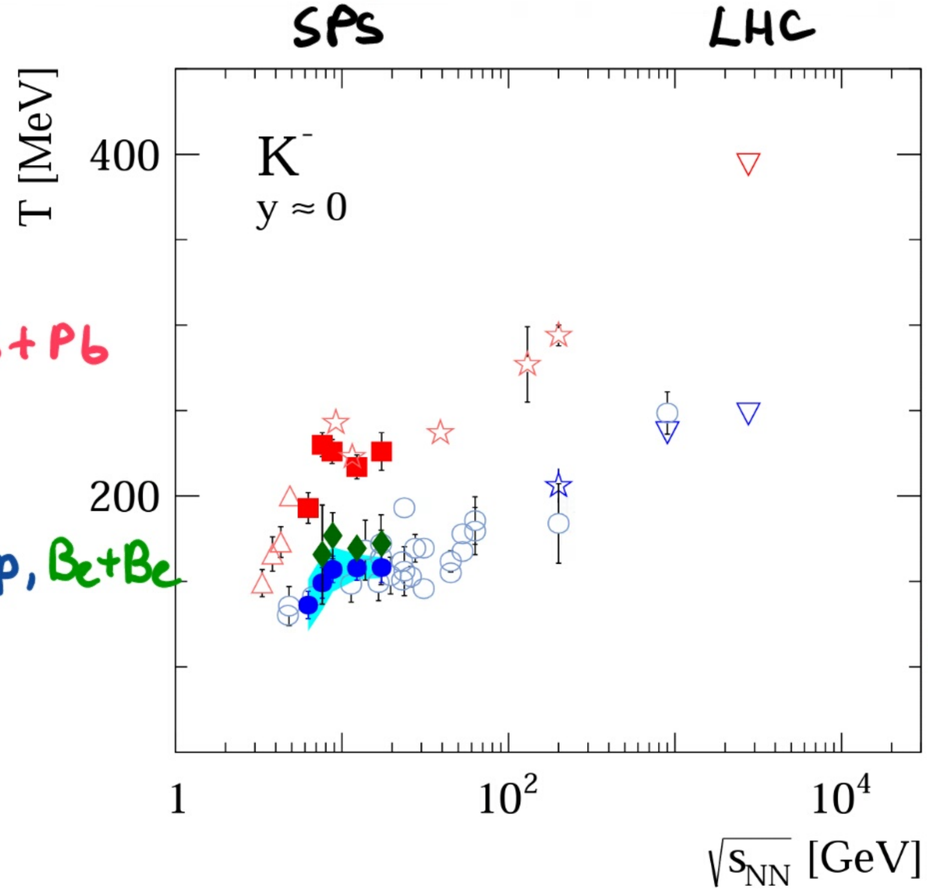
SHURYAK, PROG. PART. NUCL. PHYS. 62 (2009) 48
LIN, SHURYAK PR D79 (2009) 124015

ONSET OF DECONFINEMENT



Pb+Pb

PHP, Be+Be

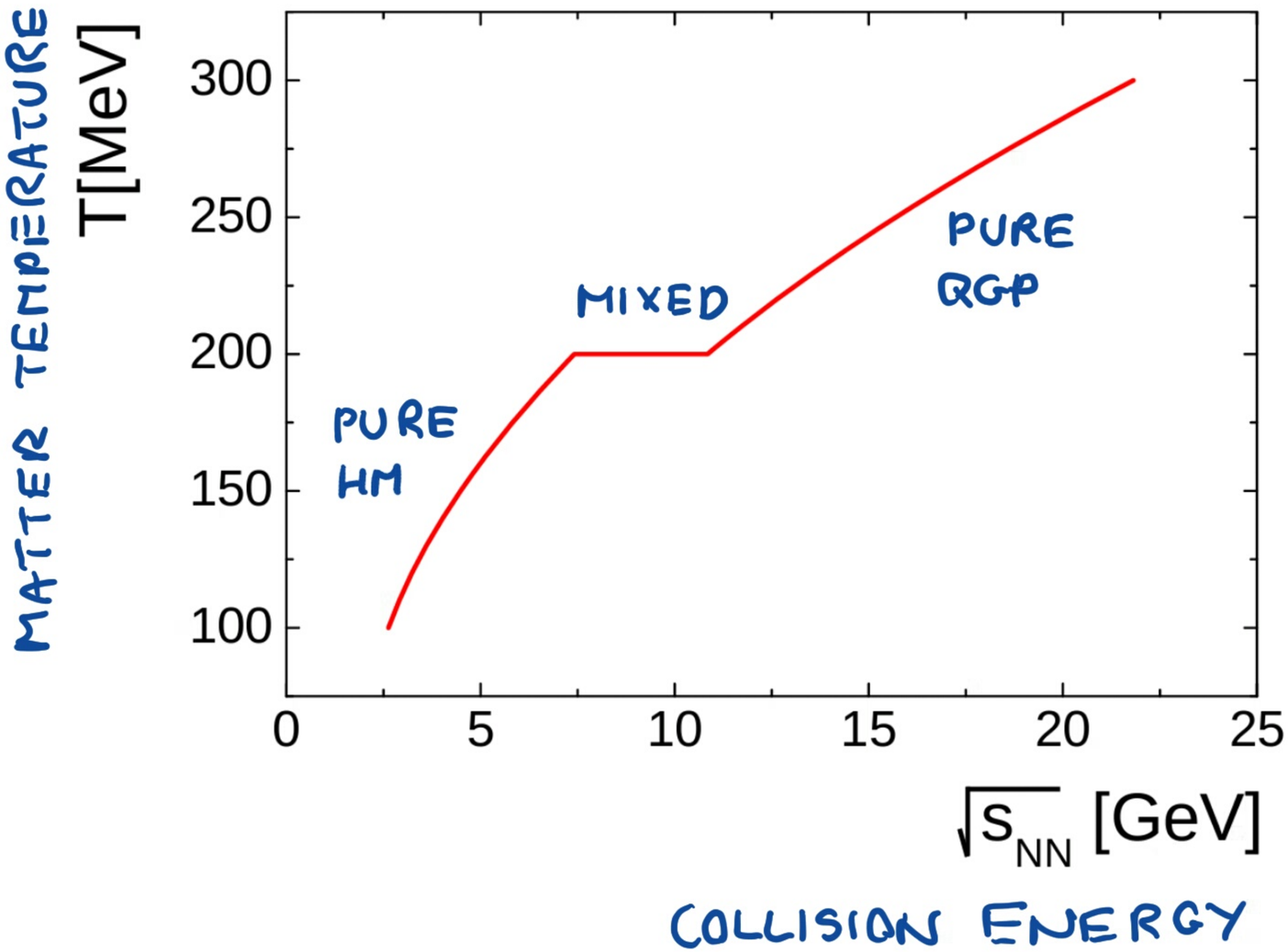


FIREBALL

SMALL CLUSTERS

RAPID CHANGE OF $\sqrt{s_{NN}}$ - DEPENDECE AT $\sqrt{s_{NN}} \approx 10$ GEV
OBSERVED FOR BOTH, FIREBALL AND SMALL CLUSTERS

ONSET OF DECONFINEMENT IN SMES

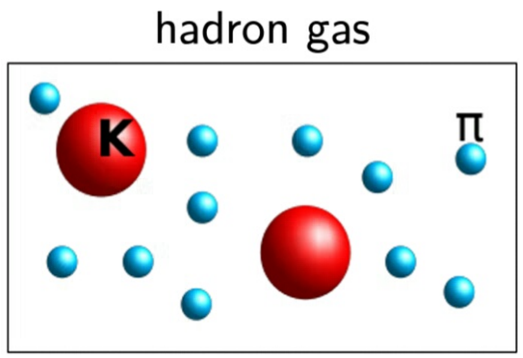


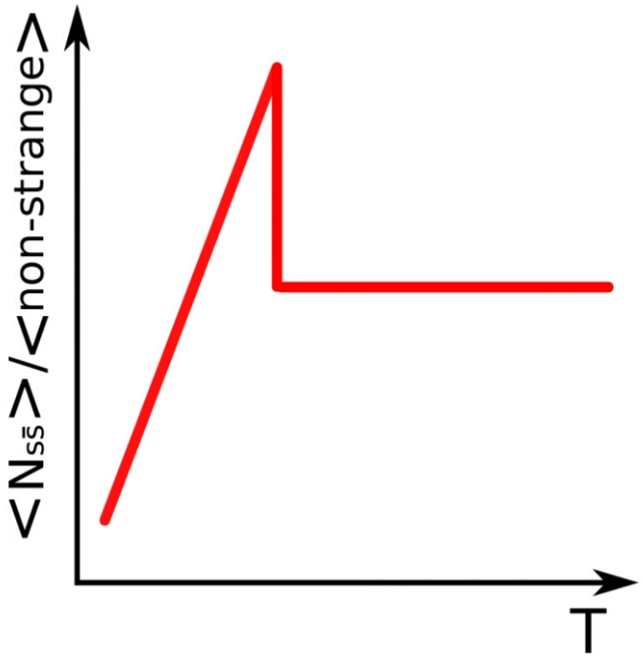
ONSET OF DECONFINEMENT IN SMES

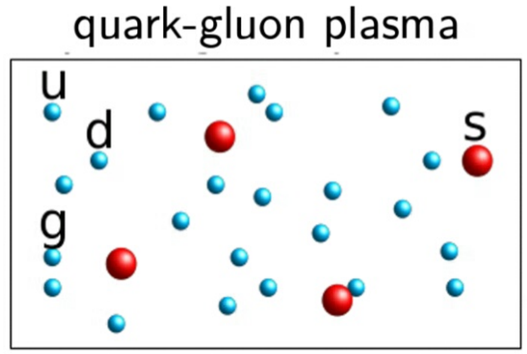
$M_K \approx 500$ MeV

$T_c \approx 150$ MeV

$M_s \approx 100$ MeV ($\approx 10^{-29}$ kg)







$$\frac{\langle K \rangle}{\langle \pi \rangle} \propto \frac{M T^{3/2}}{T^3} \cdot e^{-M/T}$$

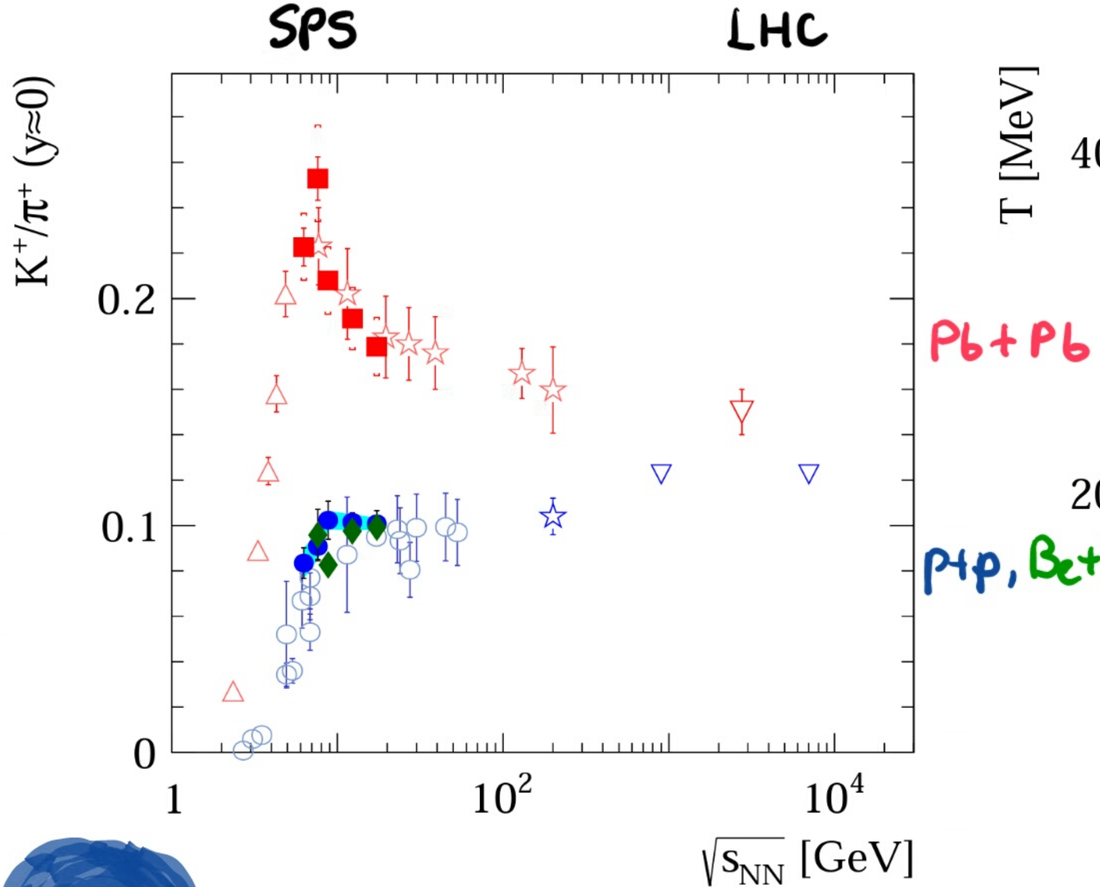
$$\frac{\langle s \rangle}{\langle u+d+g \rangle} \propto \frac{T^3}{T^3} = const(T)$$

$$\langle n \rangle = \frac{g \cdot V}{(2\pi)^3} \int d^3p \, \frac{1}{e^{E/T} \pm 1}$$

$$\approx g \cdot V \frac{2\pi^2}{4 \cdot 45} T^3 \quad \text{FOR } M \ll T$$

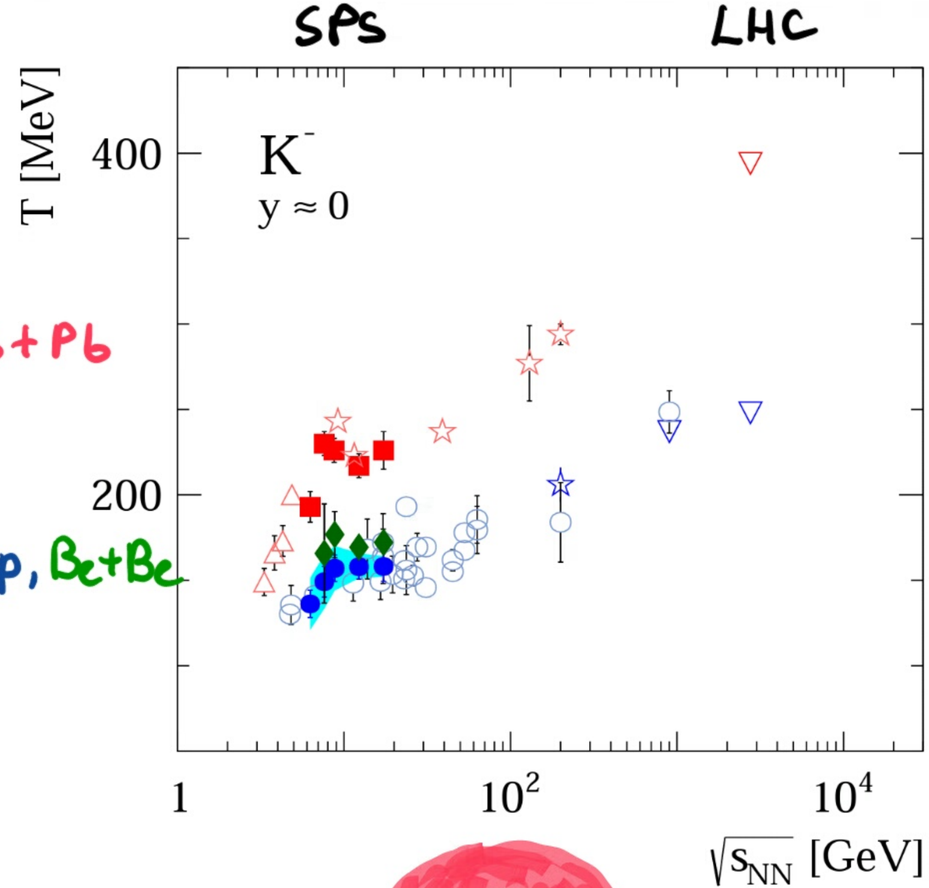
$$\approx g \cdot V \left(\frac{M \cdot T}{2\pi}\right)^{3/2} e^{-M/T} \quad \text{FOR } M \gg T$$

EVIDENCE FOR ONSET OF DECONFINEMENT IN Pb+Pb (FIREBALL)



Pb+Pb

p+p, Be+Be



FIREBALL

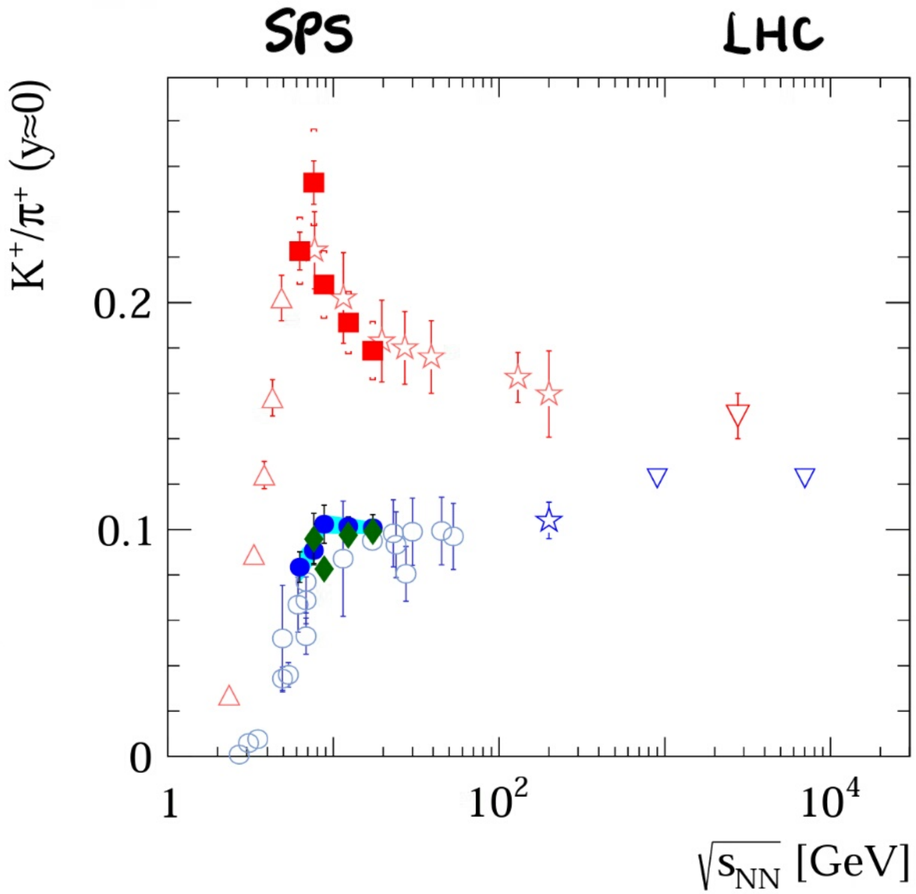
SMALL CLUSTERS

↑ ONSET OF DECONFINEMENT ↑

Pb+Pb CLOSE TO EQUILIBRIUM

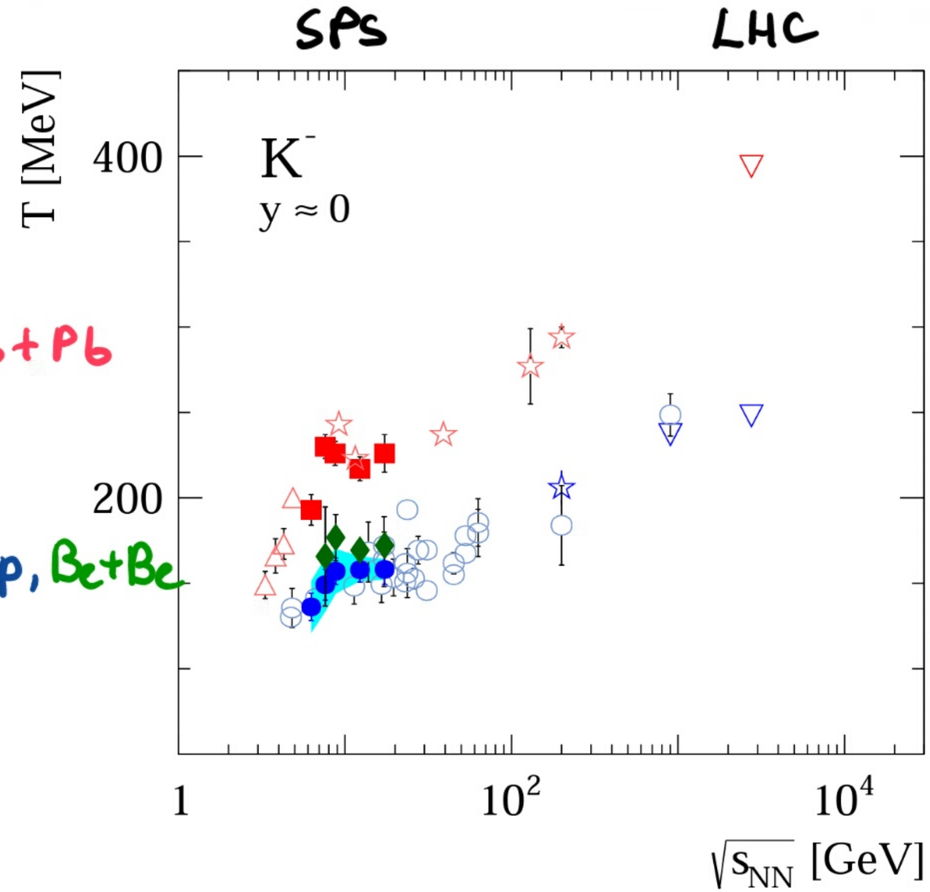
EVIDENCE FOR ONSET OF DECONFINEMENT

CHALLENGE TO UNDERSTAND p+p AND Be+Be DATA



Pb+Pb

p+p, Be+Be



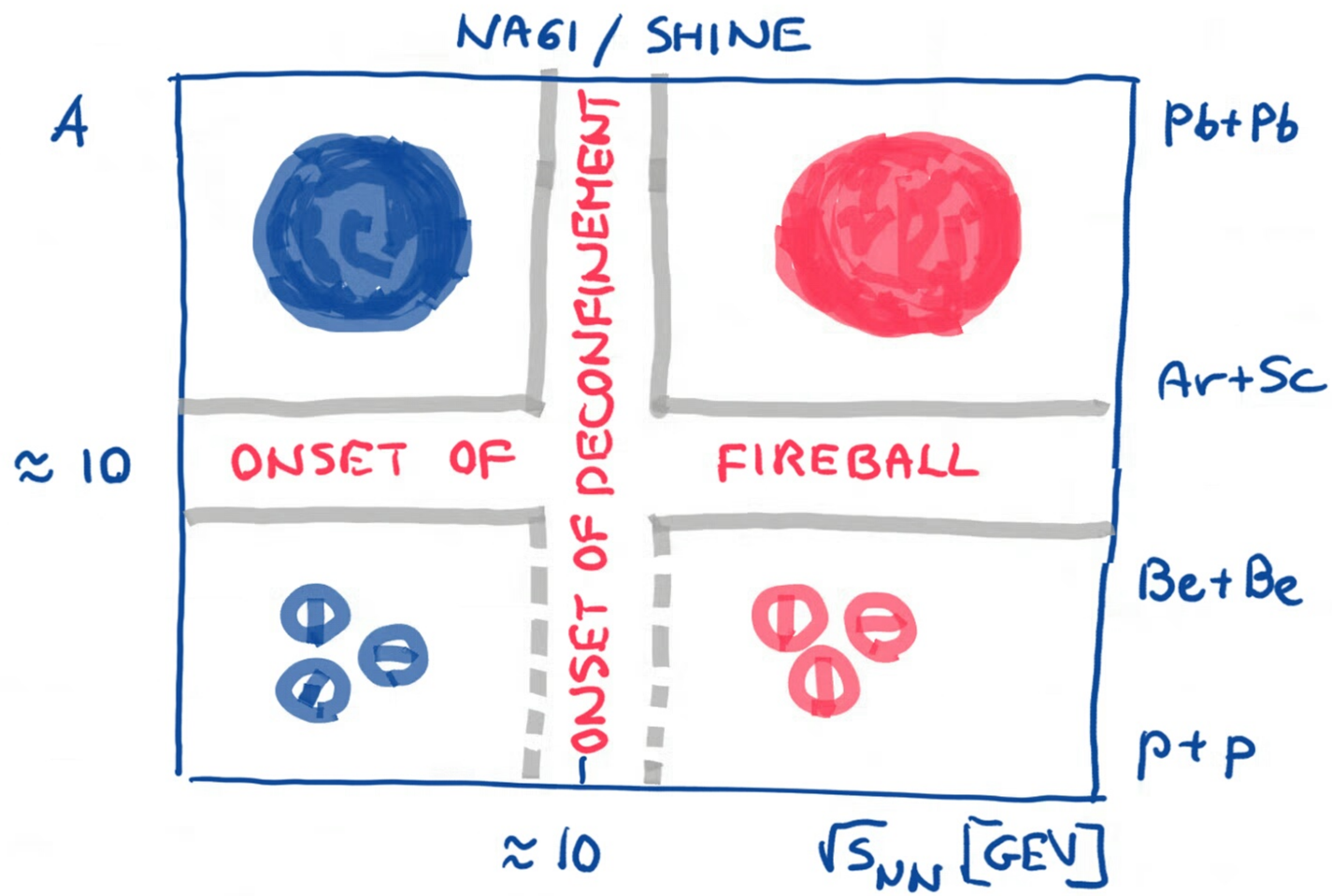
FIREBALL

SMALL CLUSTERS

↑ ONSET OF DECONFINEMENT ? ↑

p+p, Be+Be FAR FROM EQUILIBRIUM

RESULTS ON ONSET OF FIREBALL AND ONSET OF DECONFINEMENT SUGGEST FOUR DOMAINS IN A - $\sqrt{s_{NN}}$ PLANE



SEARCH FOR CRITICAL POINT

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

USE QUANTITIES INSENSITIVE TO VOLUME FLUCTUATIONS AND MATERIAL CONSERVATION LAWS:

⇓

STRONGLY INTENSIVE QUANTITIES WITH 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 $C \equiv \langle N\rangle \cdot \omega[P_T]$, $\quad P_T = \sum_1^N p_T^i$

MG, MROWCZYNSKI
MG, GORENSTEIN
SANGELINE

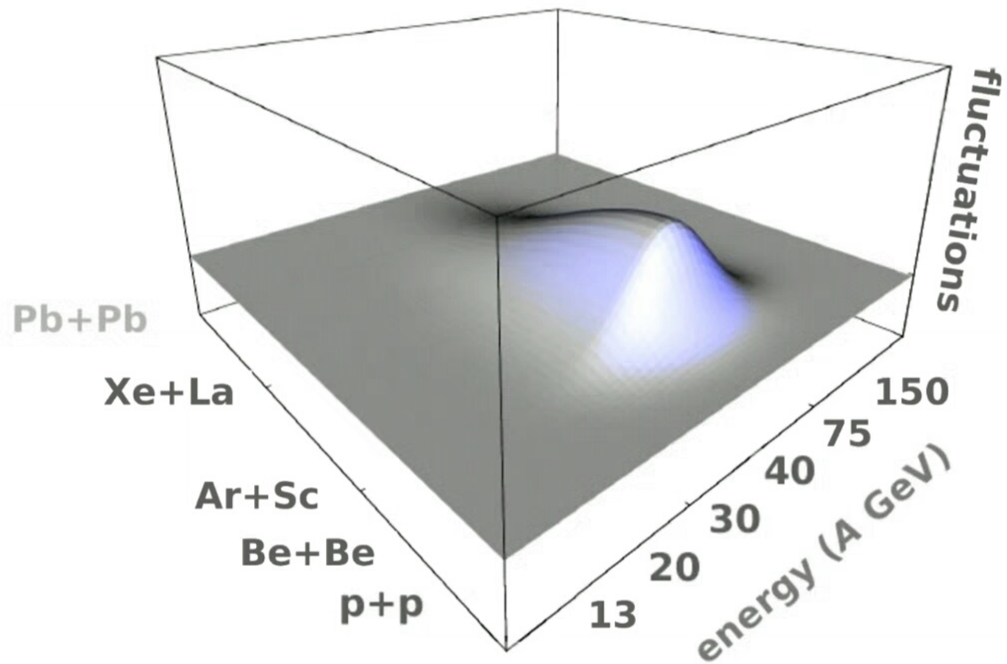
IB-GCE AND
IB-CE WITH V FLUCTUATIONS

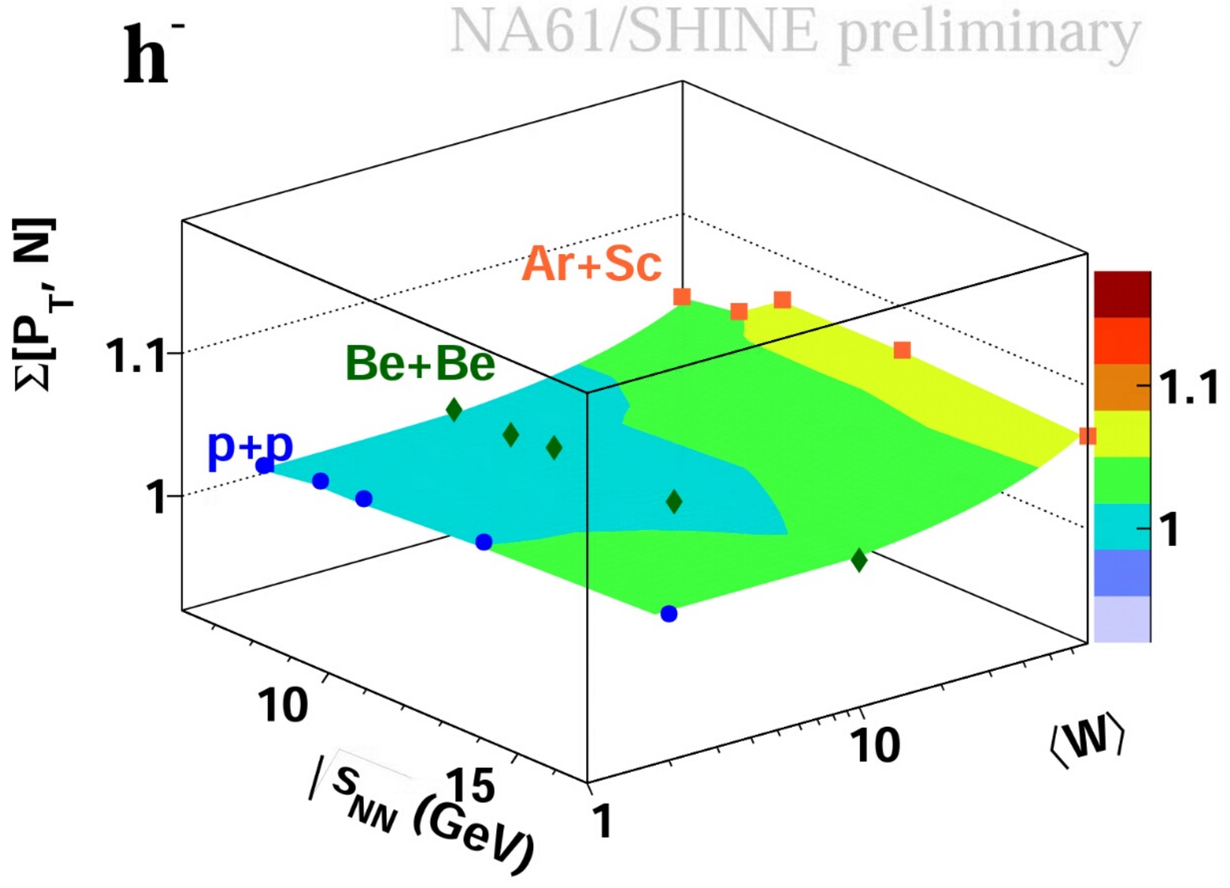
⇓

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

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

CP ⇒ "FLUCTUATION HILL"





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 δ OF SUBDIVISION INTERVALS OF MOMENTUM SPACE Δ
$M = \Delta/\delta$ – 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

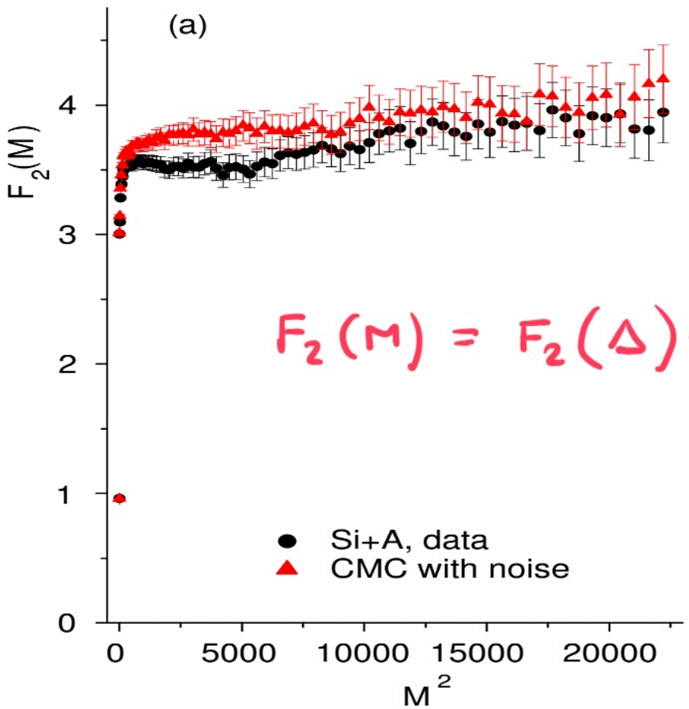
AT CRITICAL PAINT POWER LAW DEPENDENCE IS EXPECTED

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

WOSIEK (1988)
BIALAS, PESZANSKI
SAT2
ANTONIDU, DIAKONOS, KAPOYANIS

SEARCH FOR CRITICAL POINT : FLUCTUATIONS VS M PROTONS

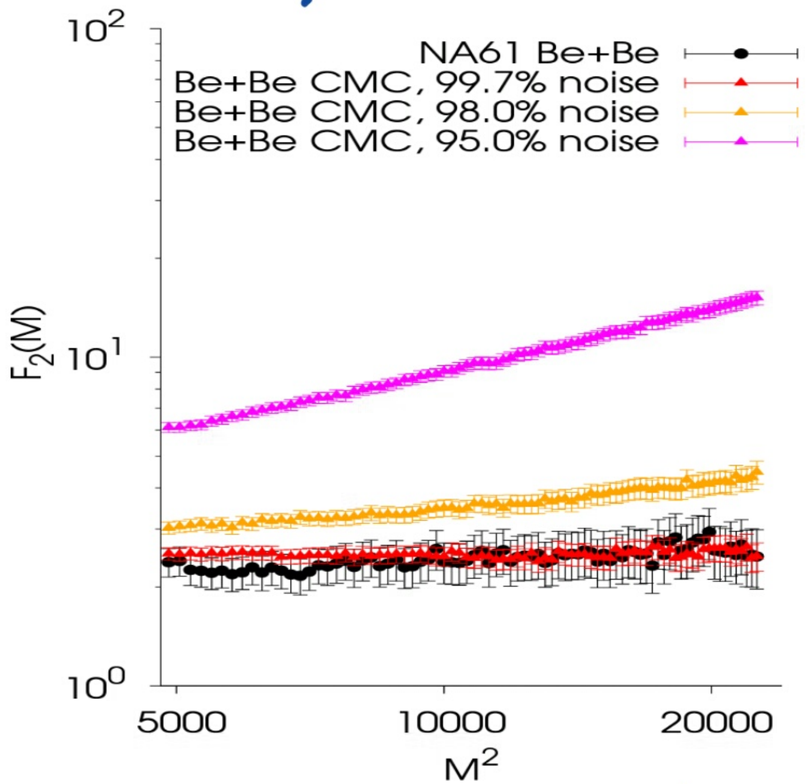
Si+A AT 158A GEV/c NA49



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

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

Be+Be AT 150A GEV/c NA61/SHINE



UPPER LIMIT OF "CRITICAL" PROTONS ≈ 0.3%

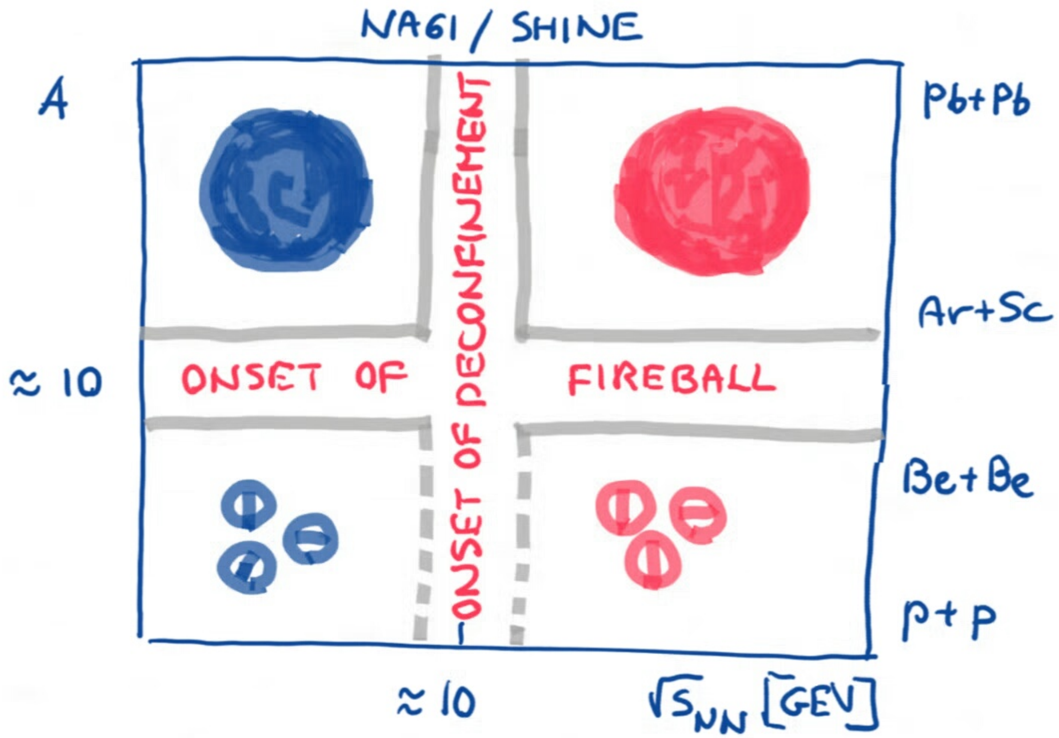
SUMMARY

- INDICATION FOR ONSET OF FIREBALL
  → MORE DATA ON COLLISIONS OF LIGHT NUCLEI MAY BE NEEDED

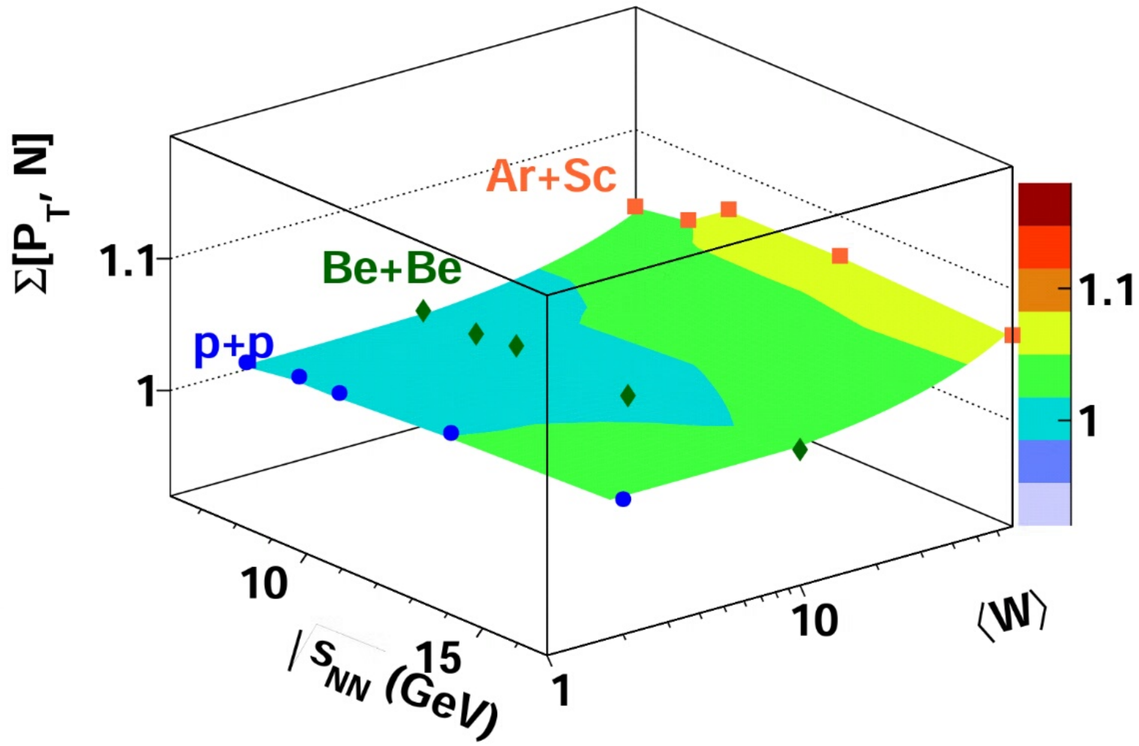
- EVIDENCE FOR ONSET OF DECONFINEMENT IN Pb+Pb
  → CHALLANGE TO UNDERSTAND p+p, Be+Be

- NO EVIDENCE FOR CRITICAL POINT SO FAR
  → ANALYSIS IN PROGRESS

ONSETS

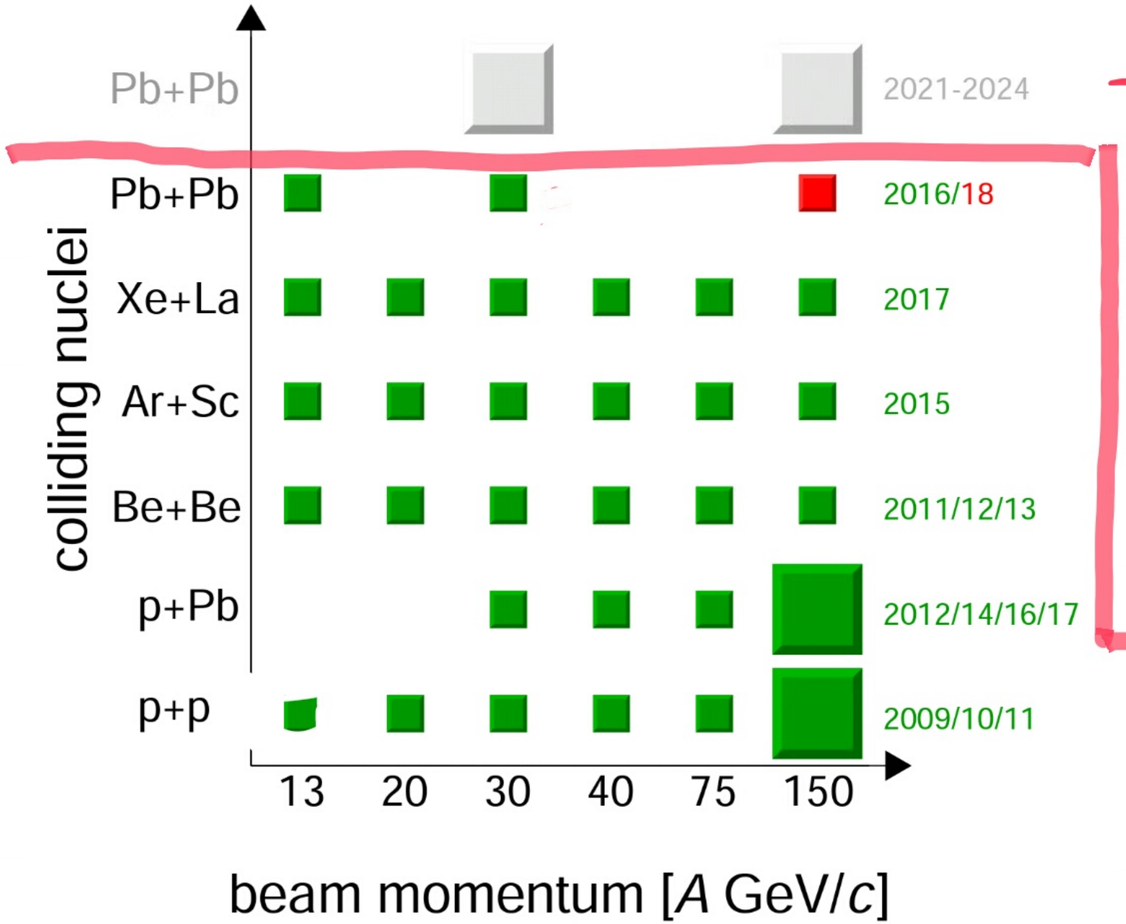


CRITICAL POINT



ADDITIONAL SLIDES

FUTURE PLANS



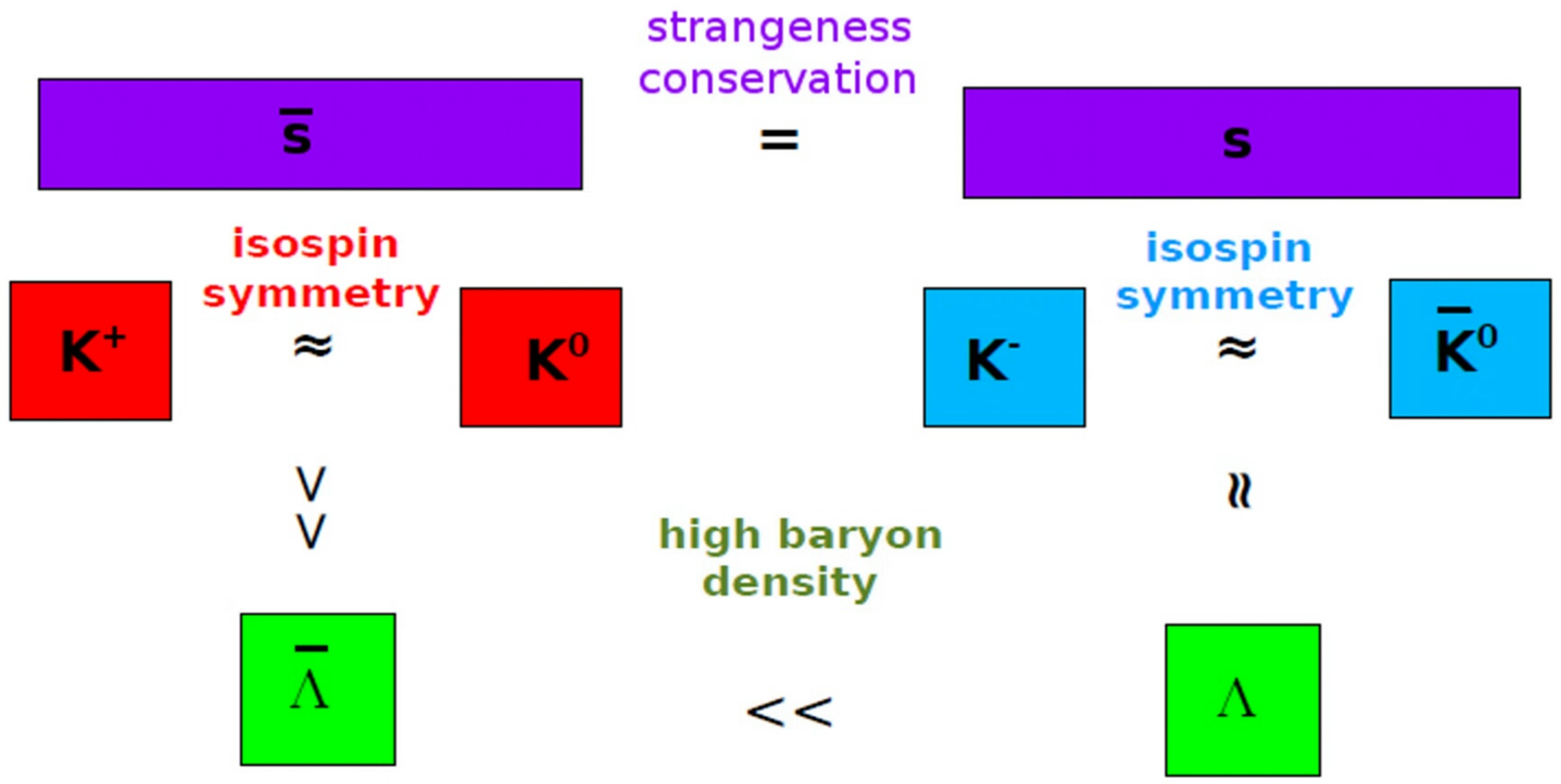
→ OPEN CHARM FOR ONSET OF DECONFINEMENT

ALSO ENERGY SCAN WITH WITH COLLISIONS OF LIGHT IONS (E.G. C+C, Mg+Mg) MAY BE NEEDED FOR ONSET OF FIREBALL

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
  - University of Geneva, Geneva
- USA
  - University of Colorado Boulder, Boulder
  - University of Pittsburgh, Pittsburgh
  - FNAL, Batavia
  - University of Hawaii, Manoa

∼150 physicists from ∼30 institutes



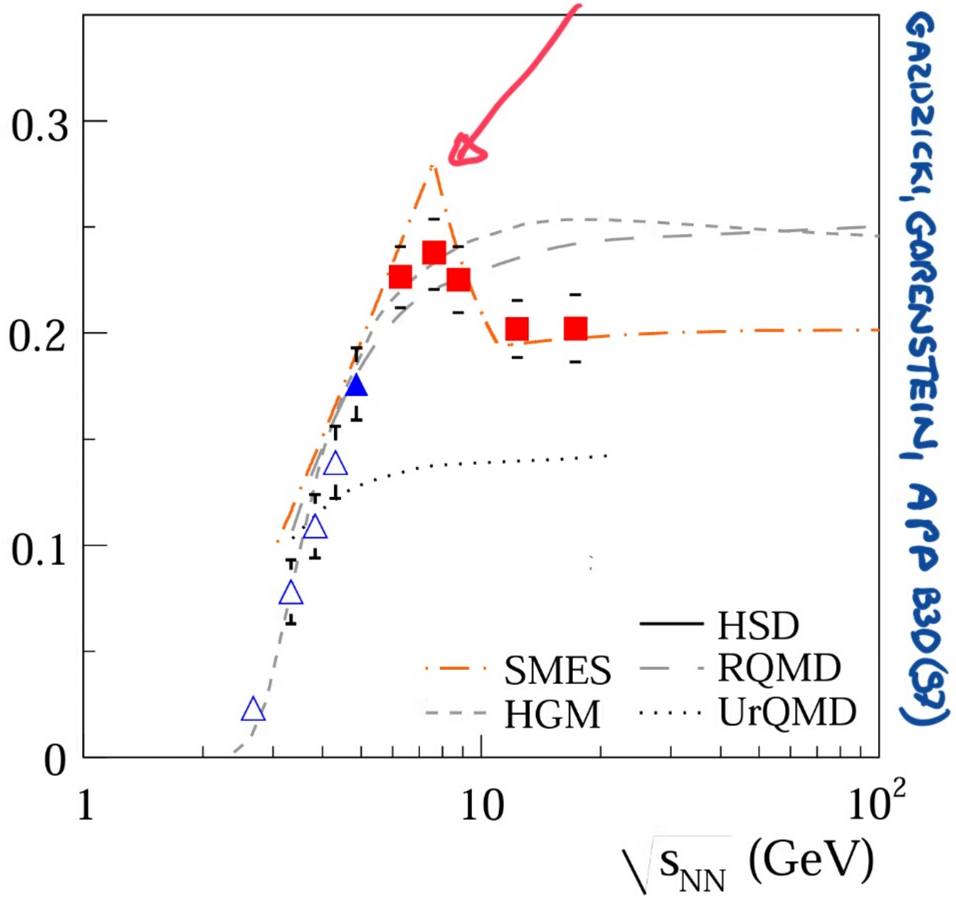
sensitive to strangeness content only

sensitive to strangeness content and baryon density

$E_s \equiv \frac{\langle K+\bar{K}\rangle + \langle \Lambda \rangle}{\langle \pi \rangle}$

ONSET OF DECONFINEMENT IN MODELS

STATISTICAL: SMES



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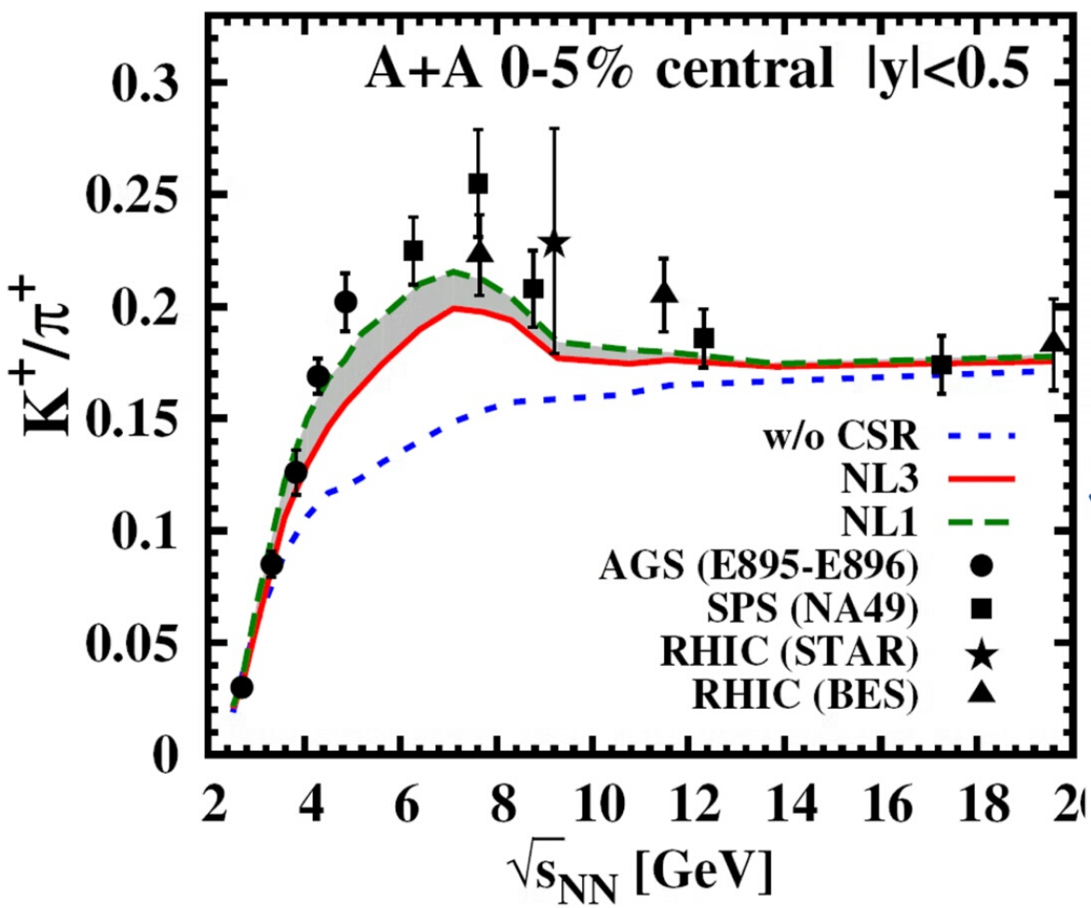
DYNAMICAL: pHSD



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STATISTICAL AND DYNAMICAL MODELS WITH CHIRAL SYMMETRY RESTORATION AND DECONFINEMENT FIT Pb+Pb DATA
(BUT BOTH FAIL TO REPRODUCE SMALL SYSTEMS)