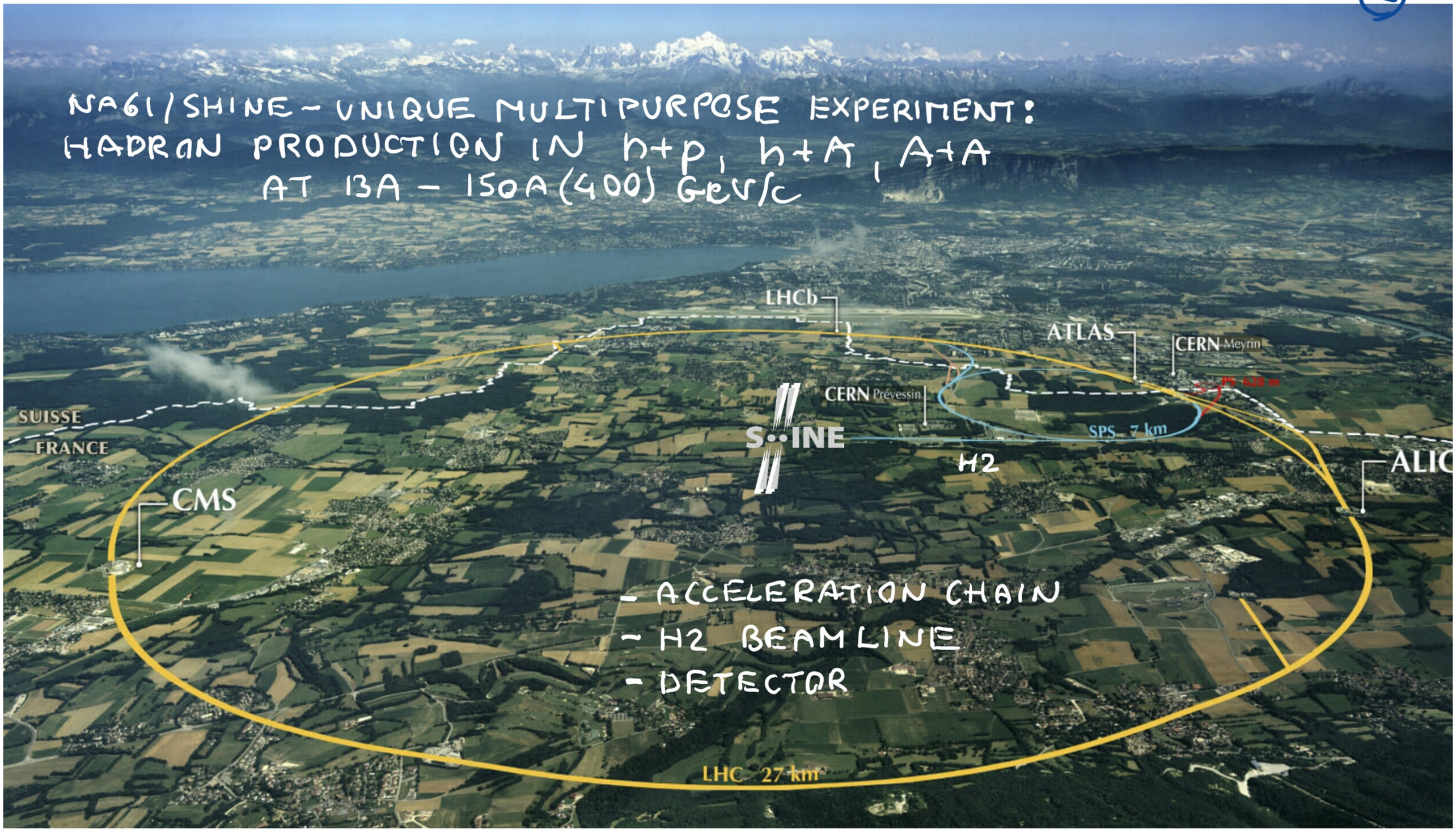
NEWS ON ONSET OF DECONFINEMENT AND CRITICAL POINT OF STRONGLY INTERACTING MATTER FROM NA61/SHINE

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

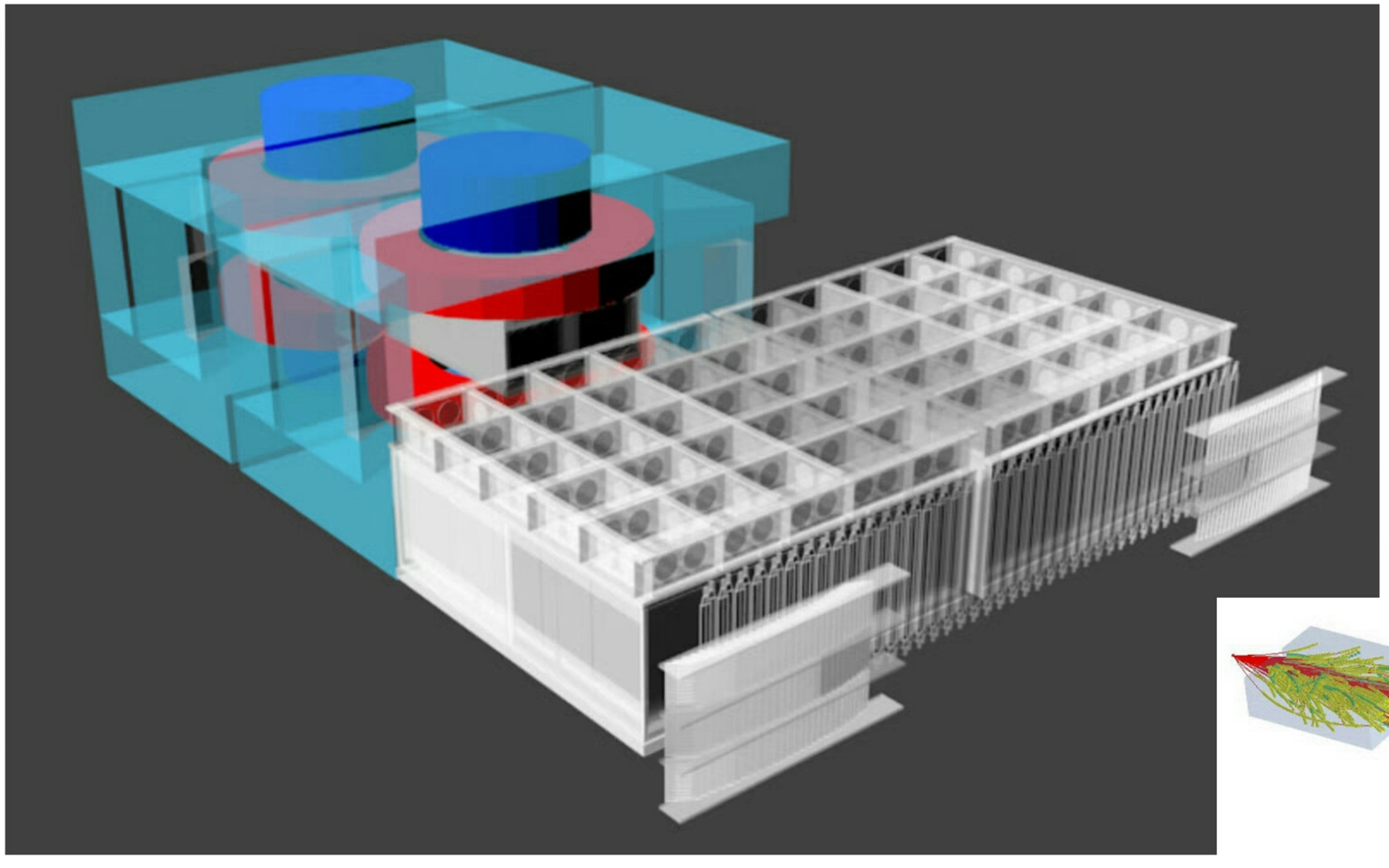
- VOCABULARY
- ONSET OF FIREBALL
- ONSET OF DECONFINEMENT
- SEARCH FOR CRITICAL POINT

VOCABULARY

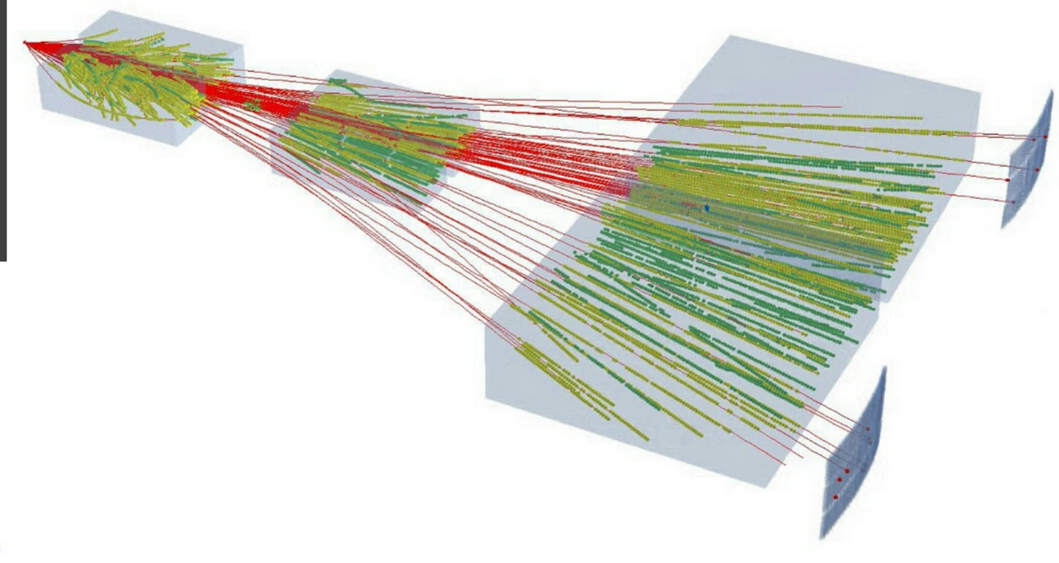
NA61/SHINE



NAGI / SHINE DETECTOR

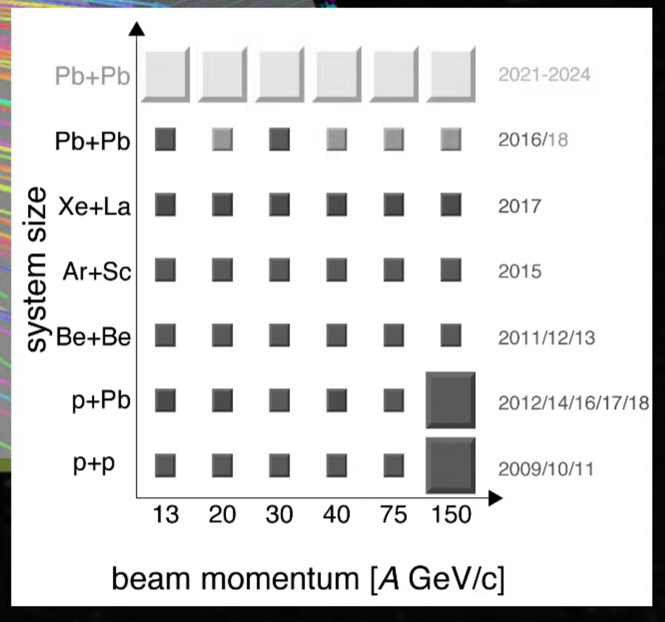


PRECISE MEASUREMENTS OF PROPERTIES OF PRODUCED PARTICLES: ELECTRIC CHARGE, MASS MOMENTUM VECTOR



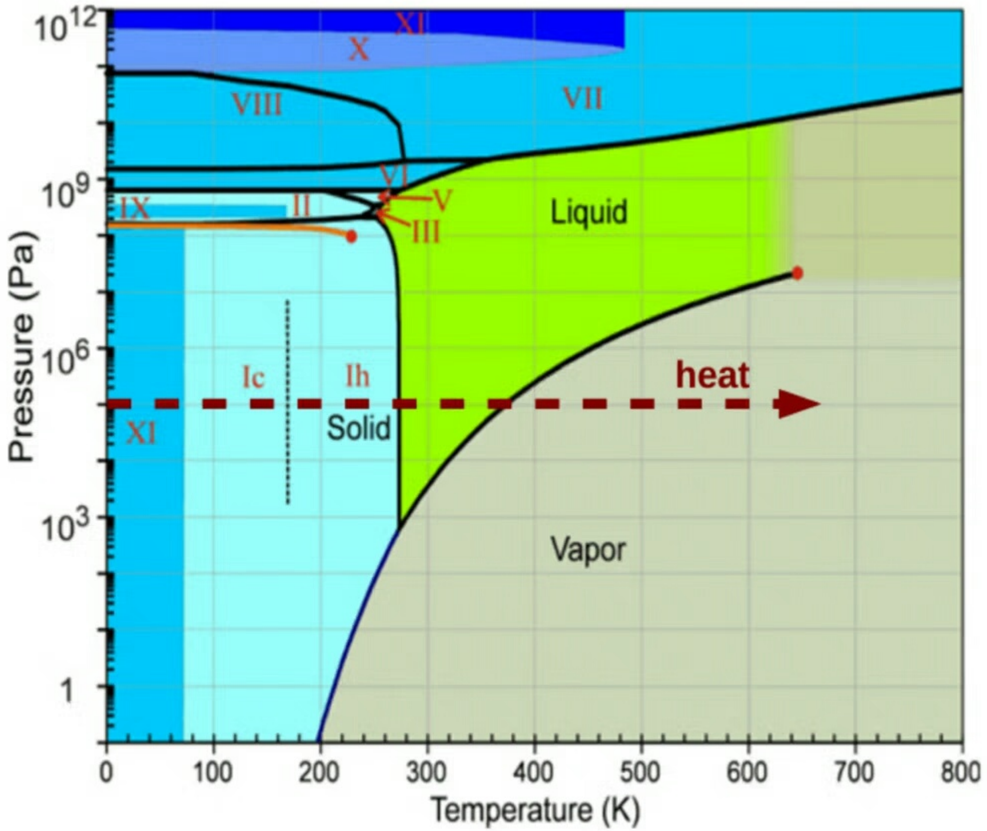
MEASURMENTS OF HADRON PRODUCTION PROPERTIES FOR

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

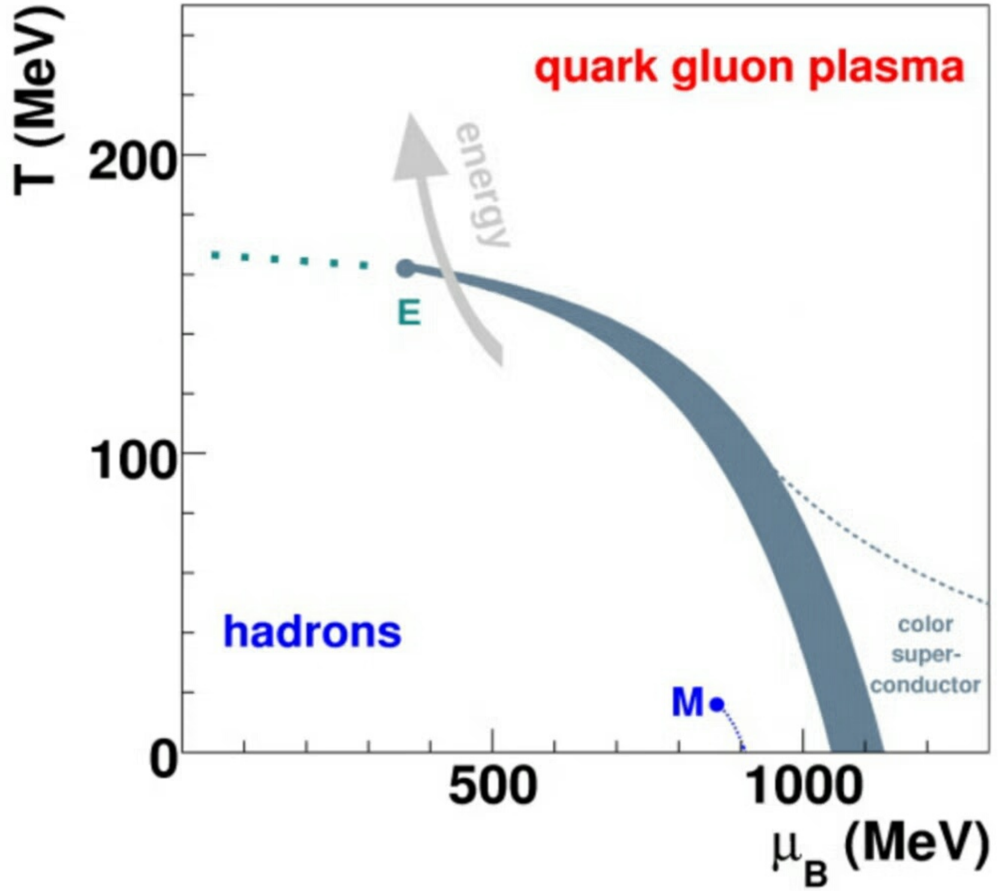


PHASE DIAGRAM

OF WATER



OF STRONGLY INTERACTING MATTER



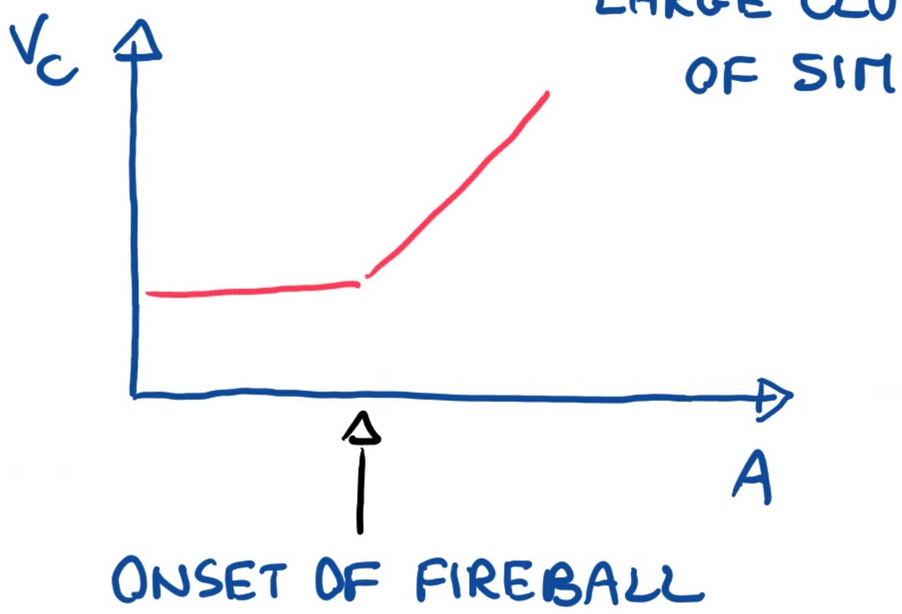
NAGI/SHINE:

→ PHASE TRANSITION VS VOLUME

→ SEARCH FOR CRITICAL POINT

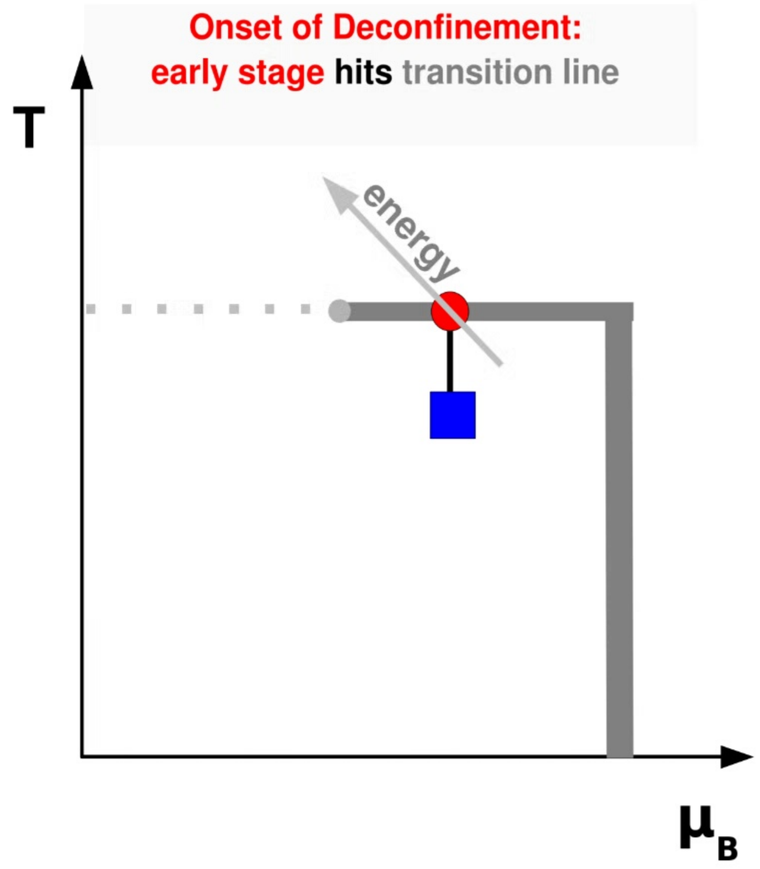
ONSET OF FIREBALL

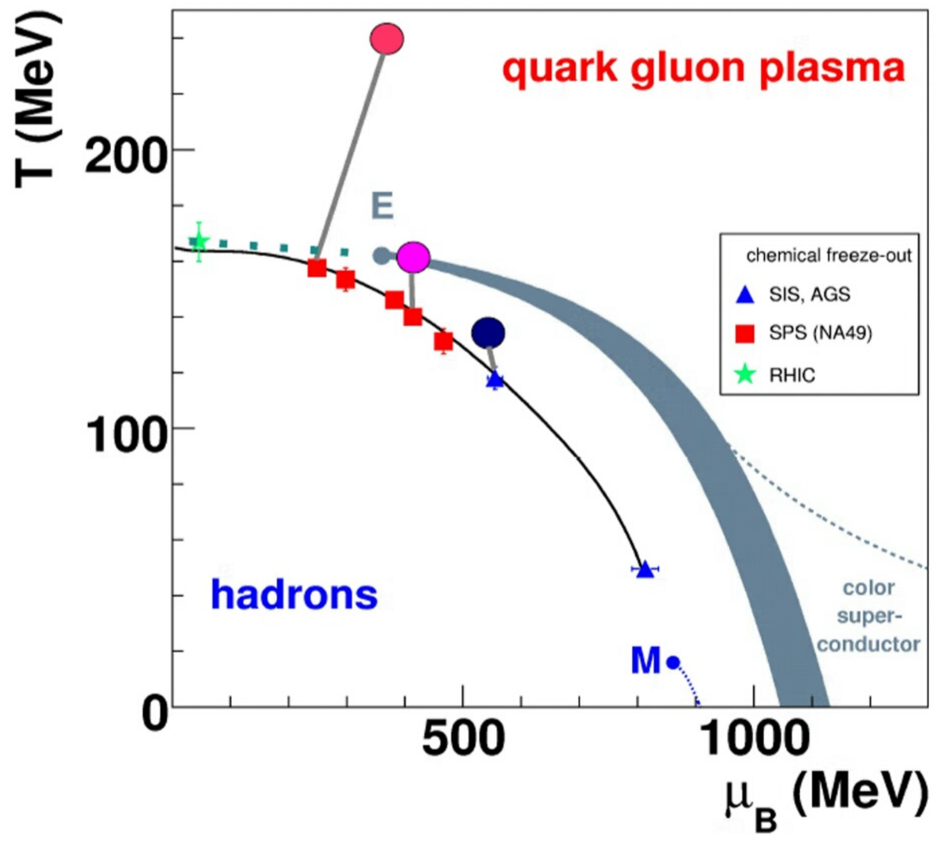
≡ BEGINNIG OF CREATION OF LARGE CLUSTERS OF STRONGLY INTERACTING MATTER (SIM) IN NUCLEUS-NUCLEUS (A+A) COLLISIONS WITH INCREASING NUCLEAR MASS NUMBER (A)



ONSET OF DECONFINEMENT

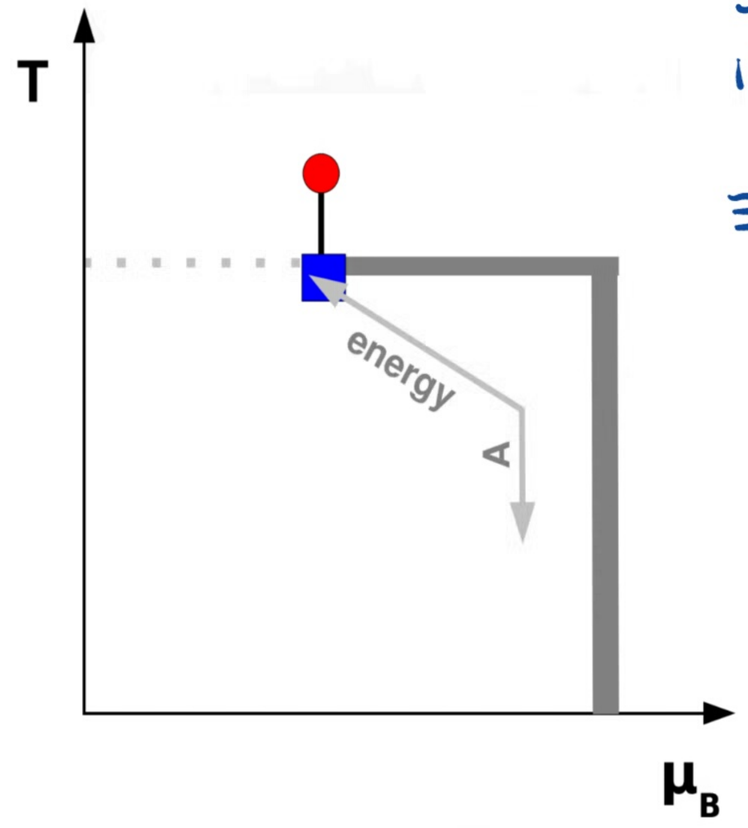
≅ BEGINING OF CREATION OF QUARK-GLUON PLASMA IN NUCLEUS-NUCLEUS COLLISIONS WITH INCREASING COLLISION ENERGY ($\sqrt{s_{NN}}$)





CRITICAL POINT OF SIM

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

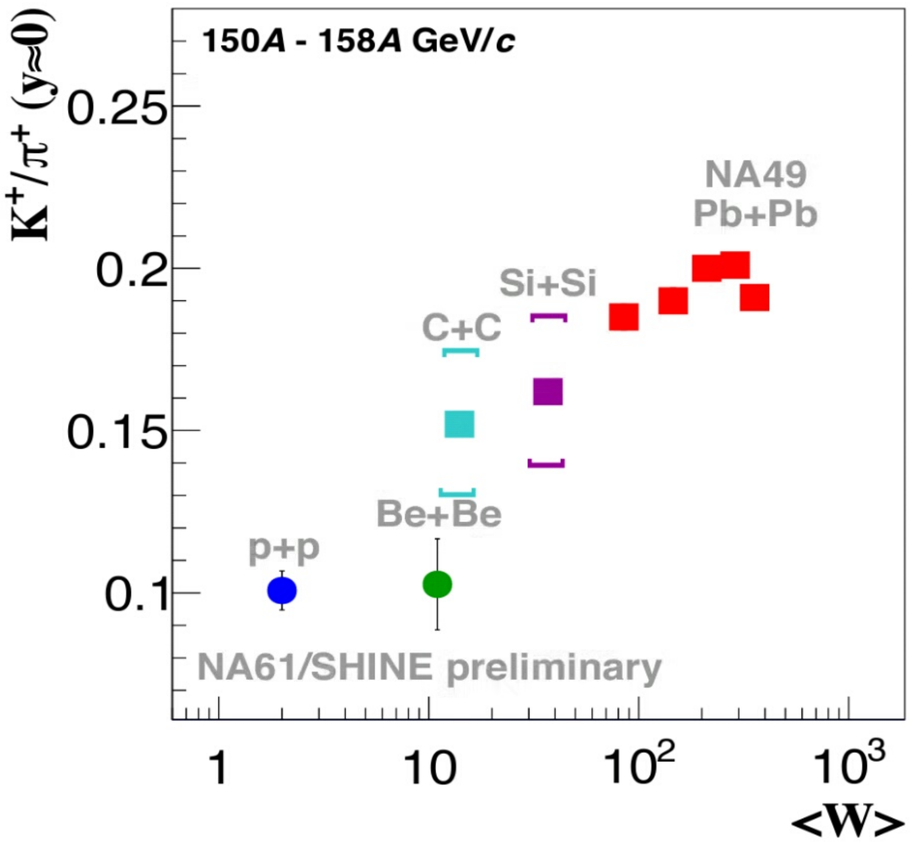


SEARCH FOR CRITICAL POINT (CP) OF SIM IN A+A COLLISIONS

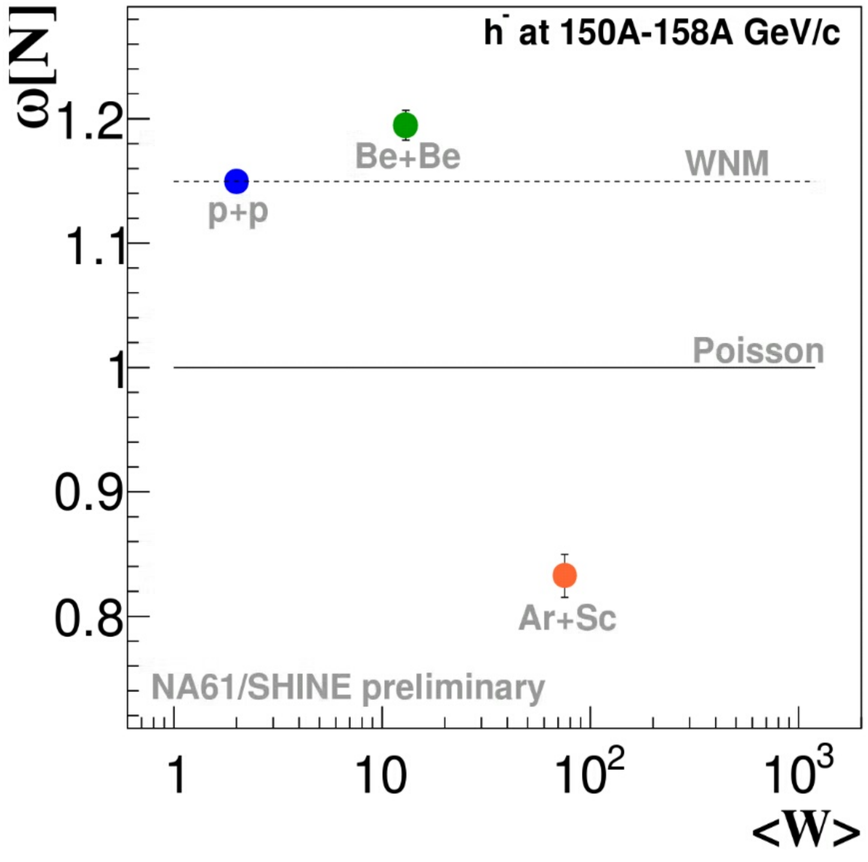
≡ SCAN IN $\sqrt{s_{NN}}$ AND A TO POSITION FREEZE-OUT POINT CLOSE TO CP

ONSET OF FIREBALL

MEAN MULTIPLICITY RATIO



MULTIPLICITY FLUCTUATIONS

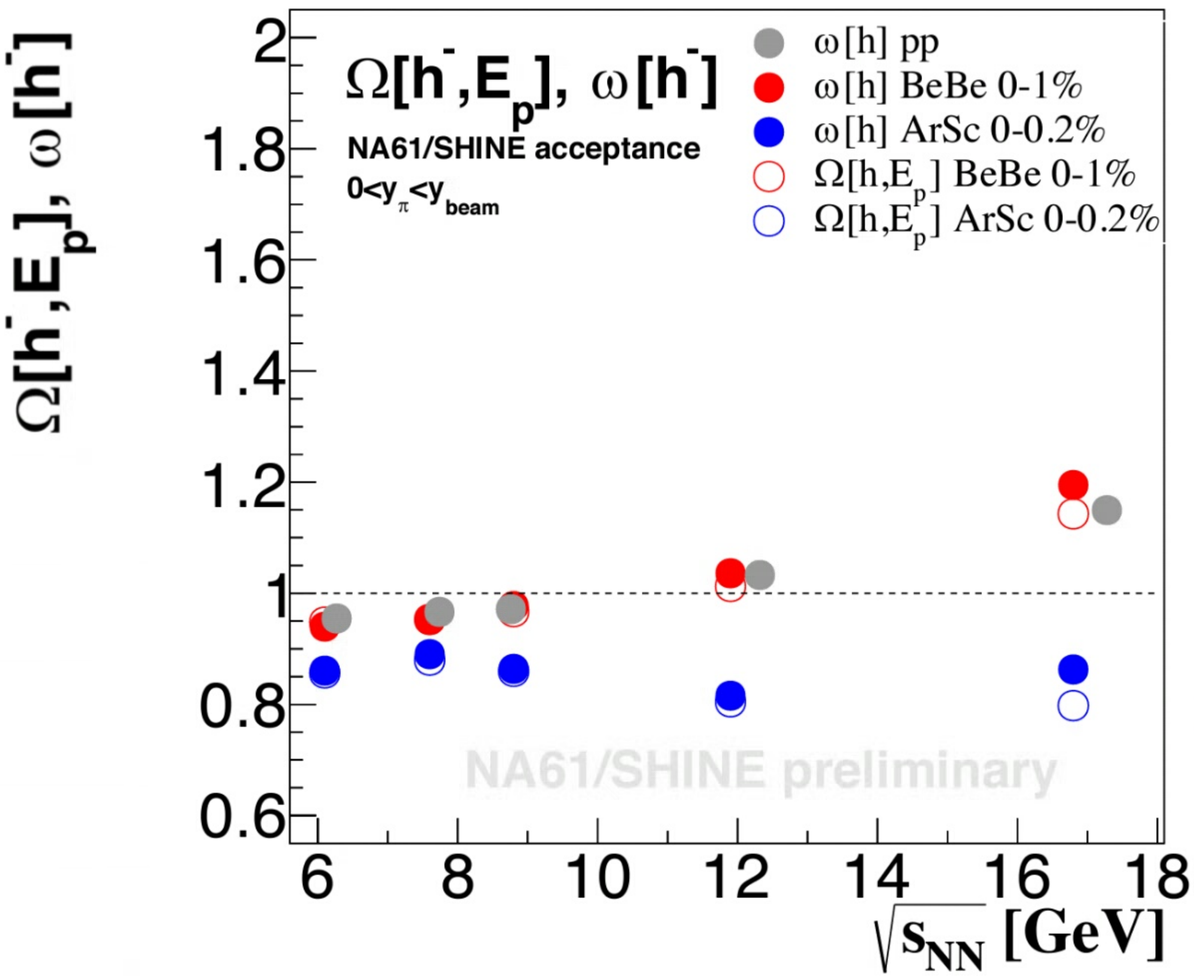


$\omega[N] \equiv \mathrm{Var}[N]/\langle N \rangle$

↑ ONSET OF FIREBALL? ↑

(NUMBER OF WOUNDED NUCLEONS)

MULTIPLICITY FLUCTUATIONS



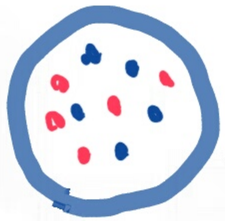
Be+Be ≈ p+p

Ar+Sc

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

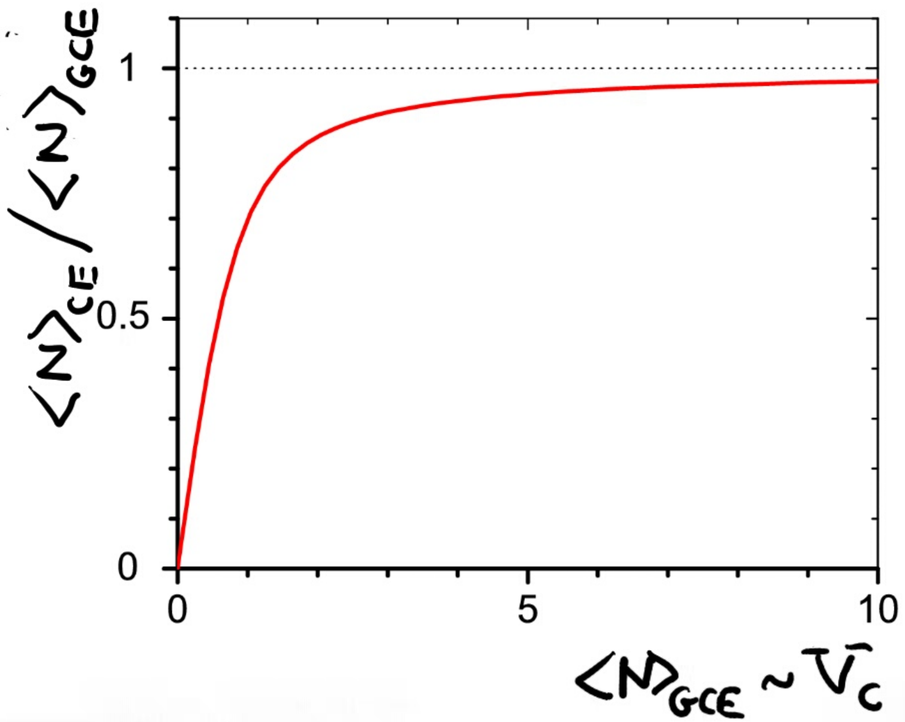
CLUSTER-VOLUME DEPENDENCE OF $\langle N \rangle$ AND $w[N]$

V_c, T
$Q = 0$



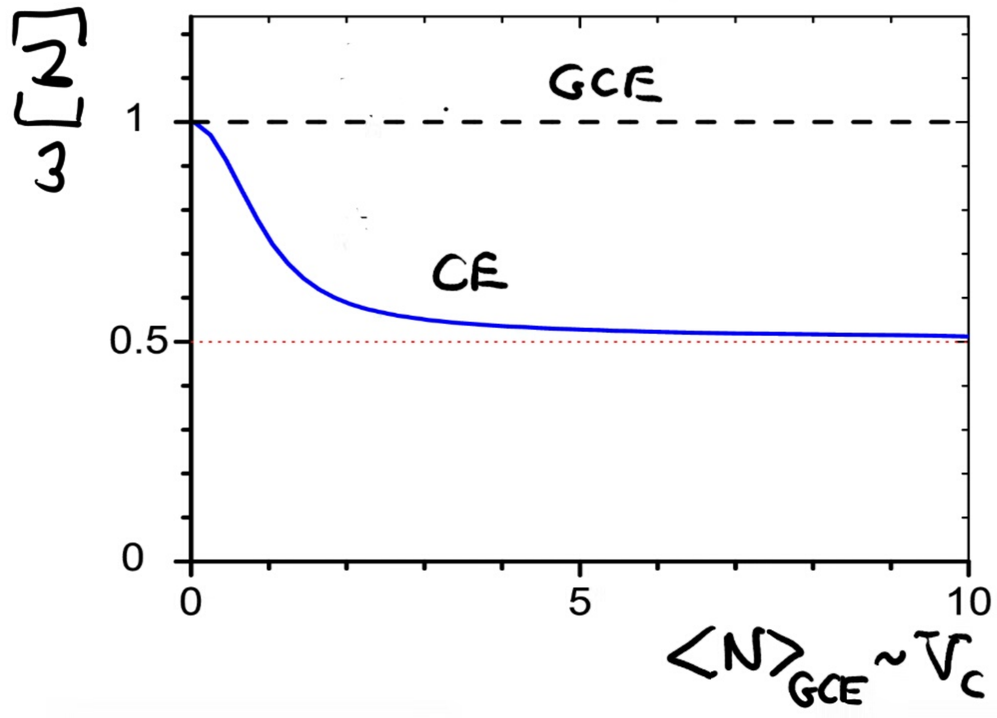
IDEAL BOLTZMANN (IB) GAS WITHIN CANONICAL ENSEMBLE (CE) → NON-TRIVIAL DEPENDENCE OF $\langle N \rangle$ AND $w[N]$ ON V_c

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



DANOS, RAFELSKI

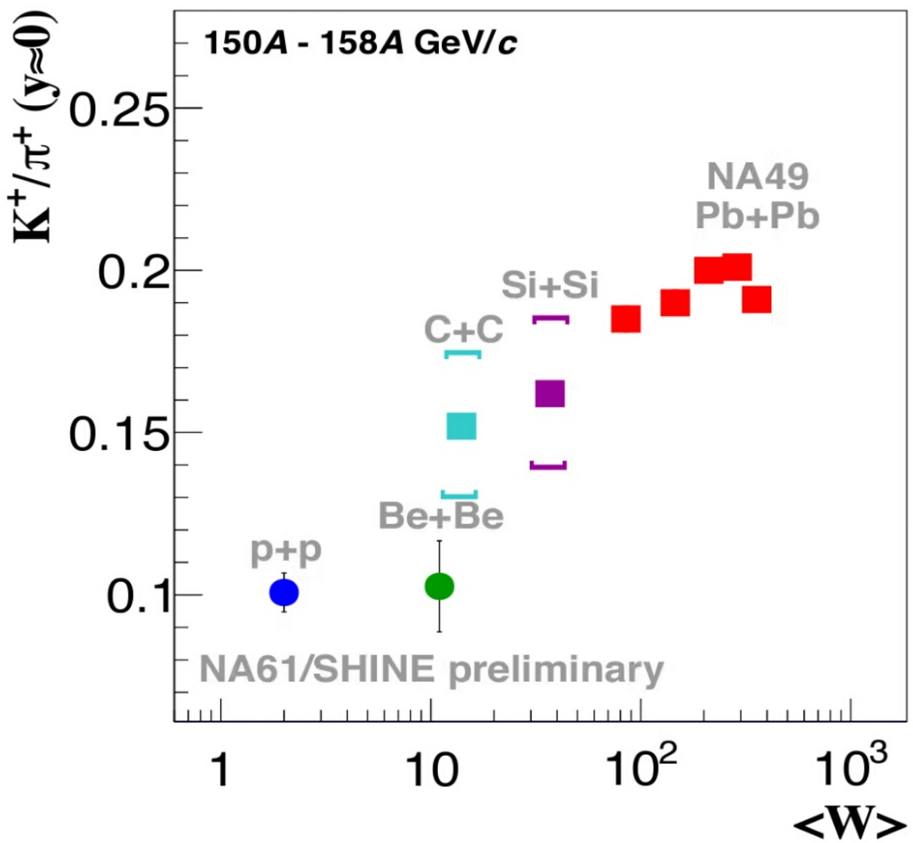
"CANONICAL ENHANCEMENT" OF $w[N]$



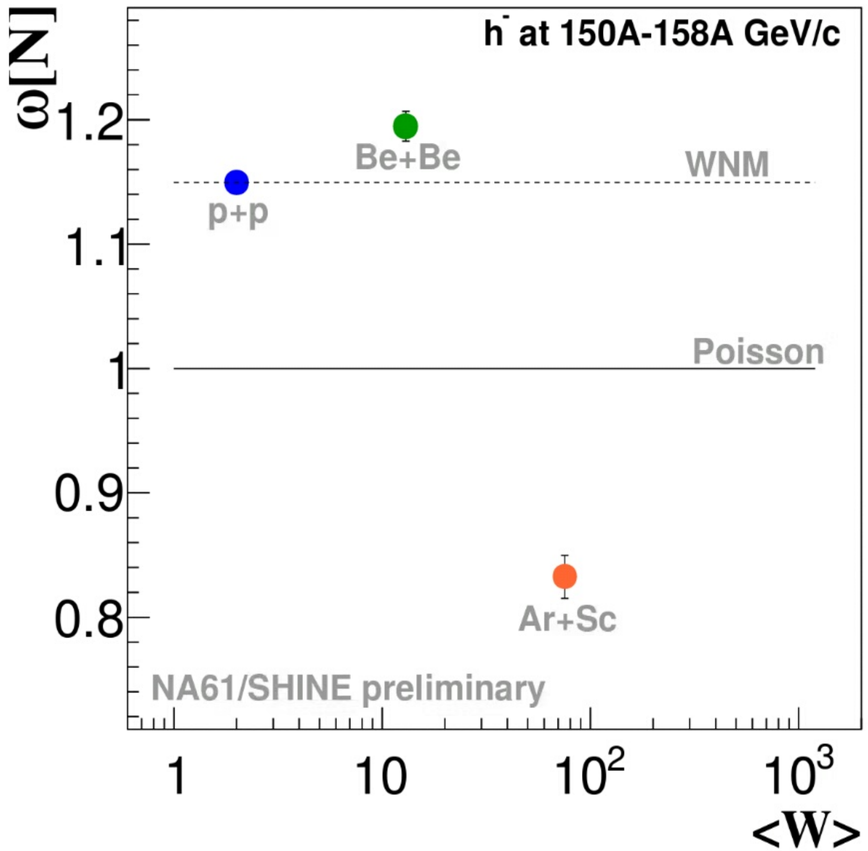
BEGUN, MG, GARENSTEIN, ZOZULYA

NA61/SHINE INDICATION FOR ONSET OF FIREBALL

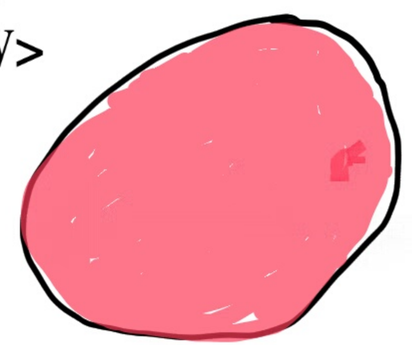
MEAN MULTIPLICITY RATIO



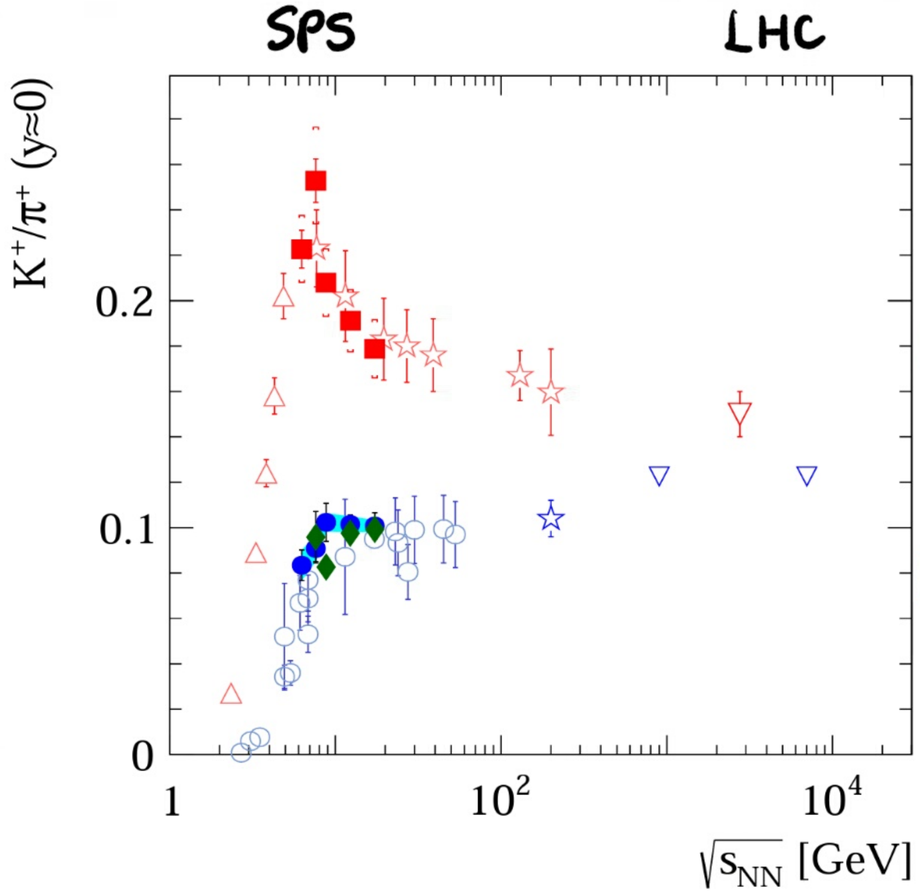
MULTIPLICITY FLUCTUATIONS



↑ ONSET OF FIREBALL ↑

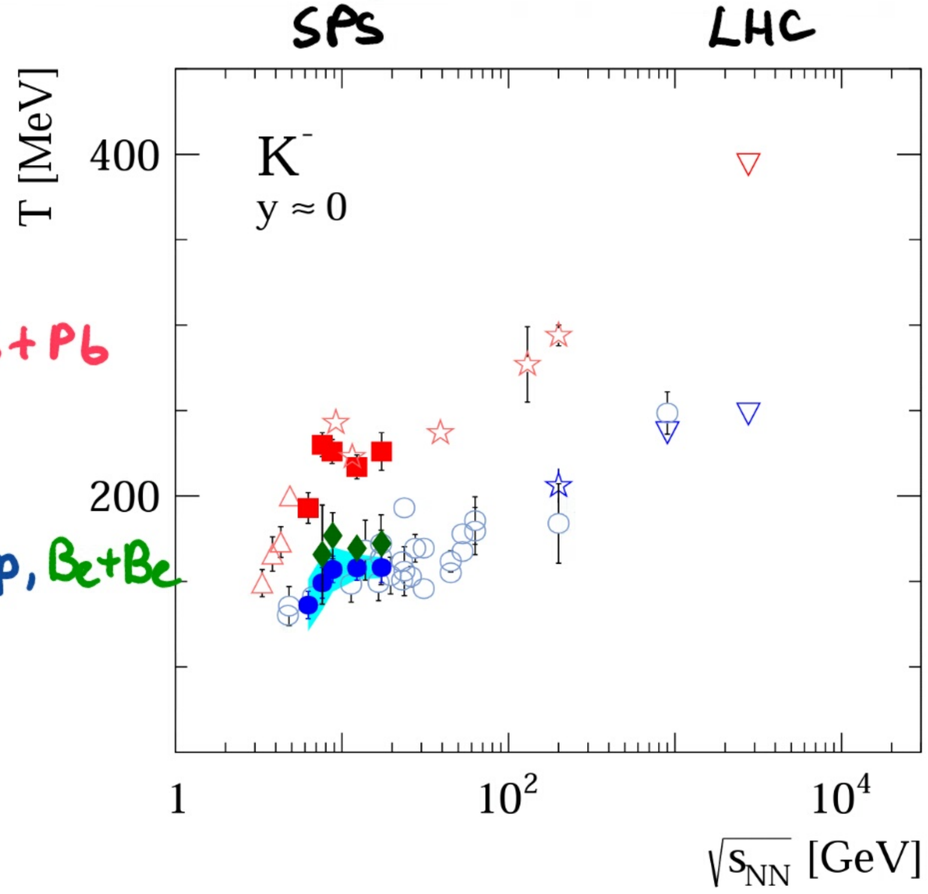


ONSET OF DECONFINEMENT



Pb+Pb

p+p, Be+Be



FIREBALL

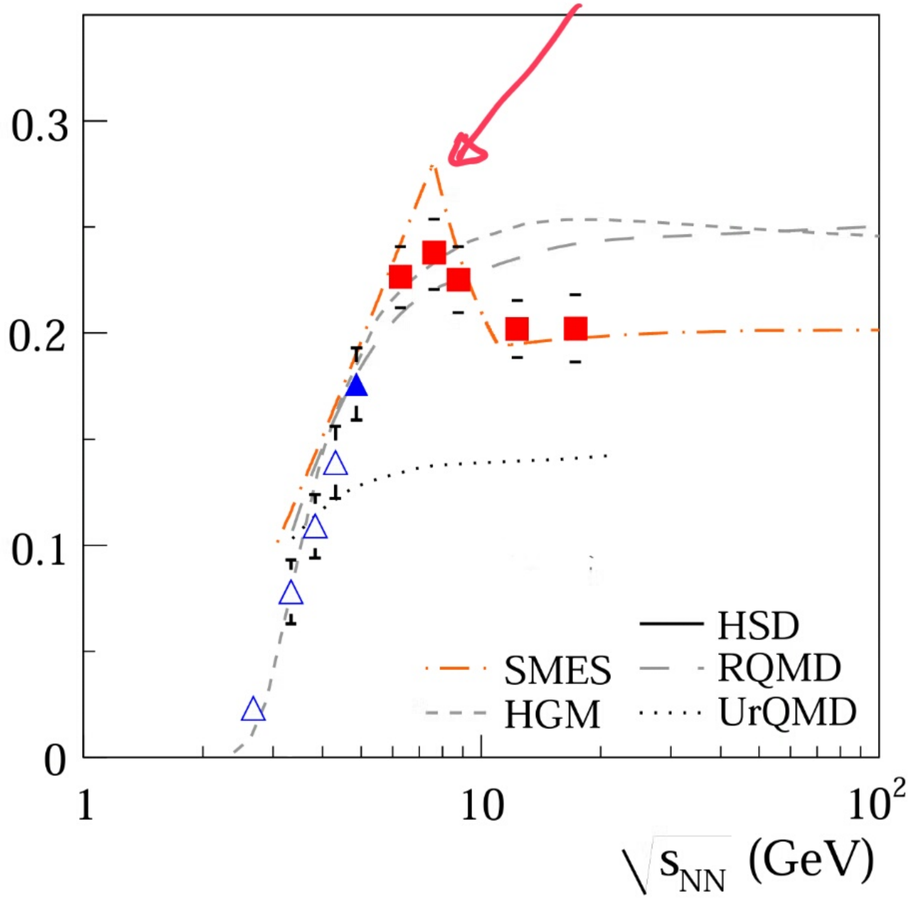
SMALL CLUSTERS

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

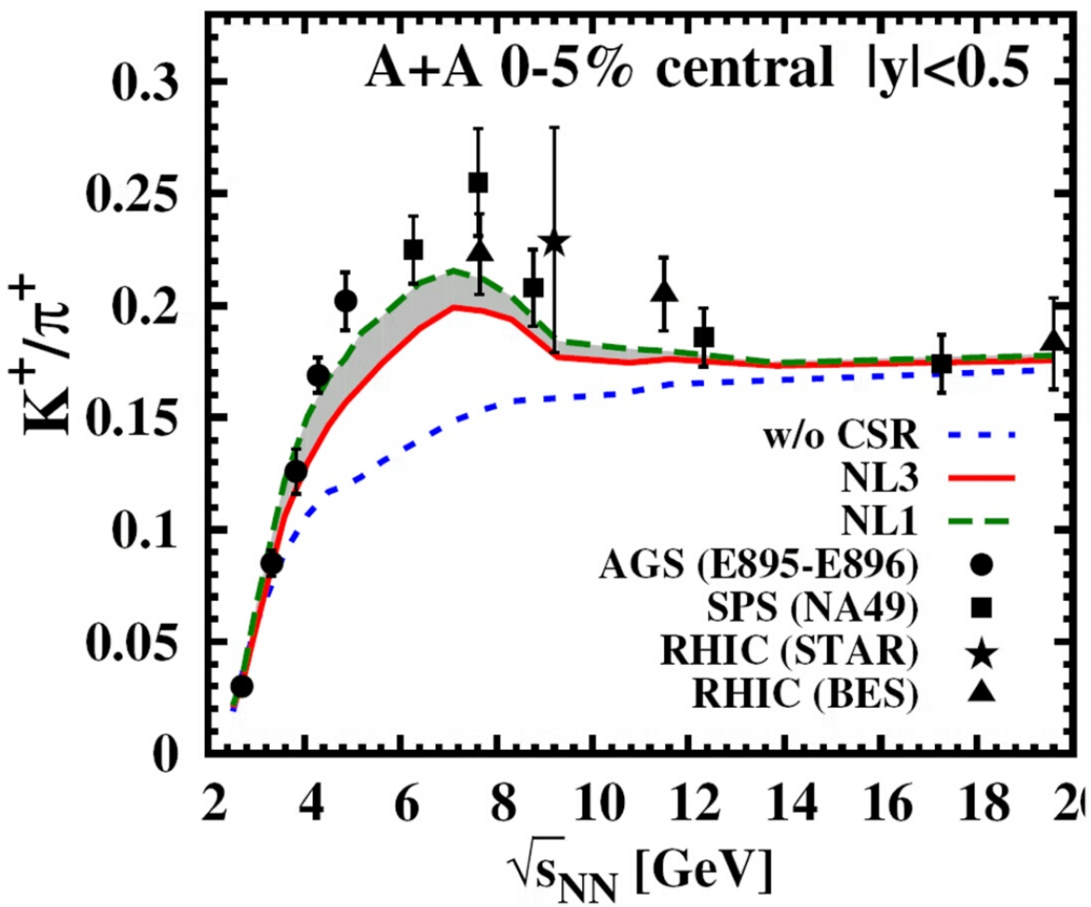
$E_s \equiv \frac{\langle K+\bar{K}\rangle + \langle \Lambda \rangle}{\langle \pi \rangle}$

ONSET OF DECONFINEMENT IN MODELS

STATISTICAL: SMES

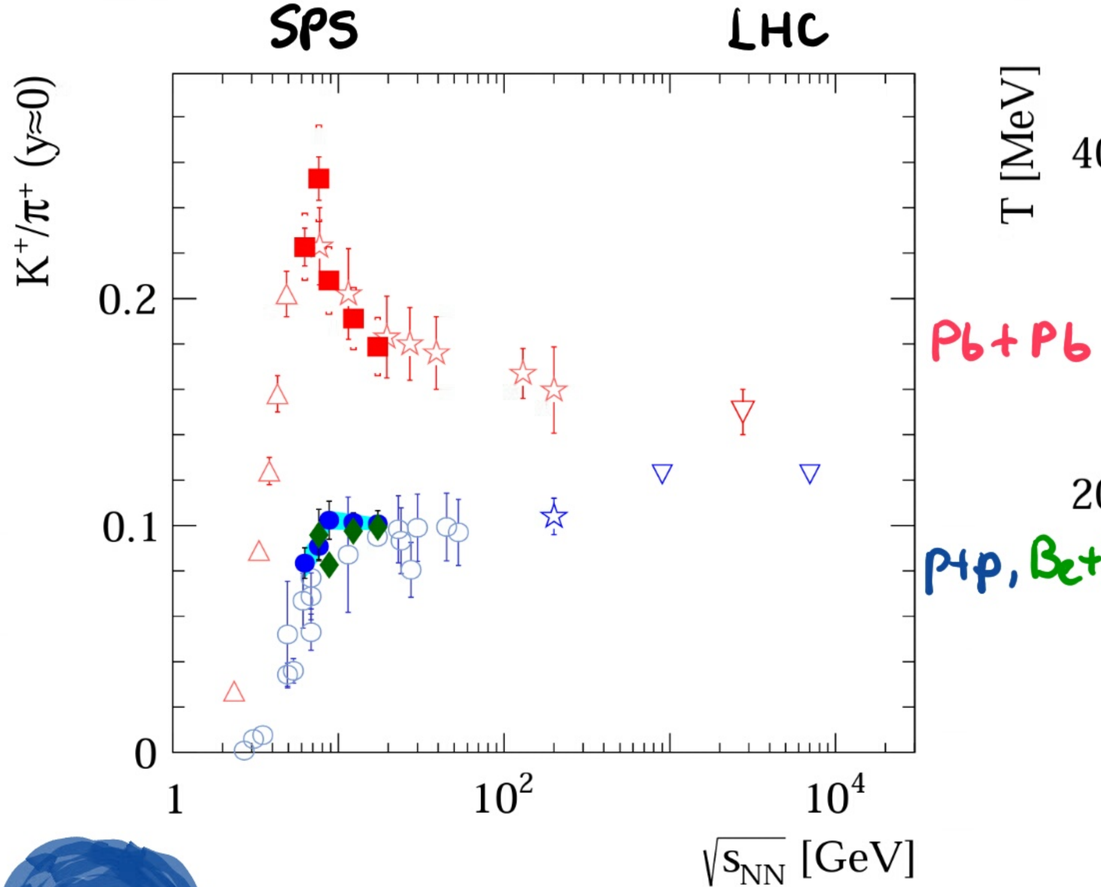


DYNAMICAL: pHSD



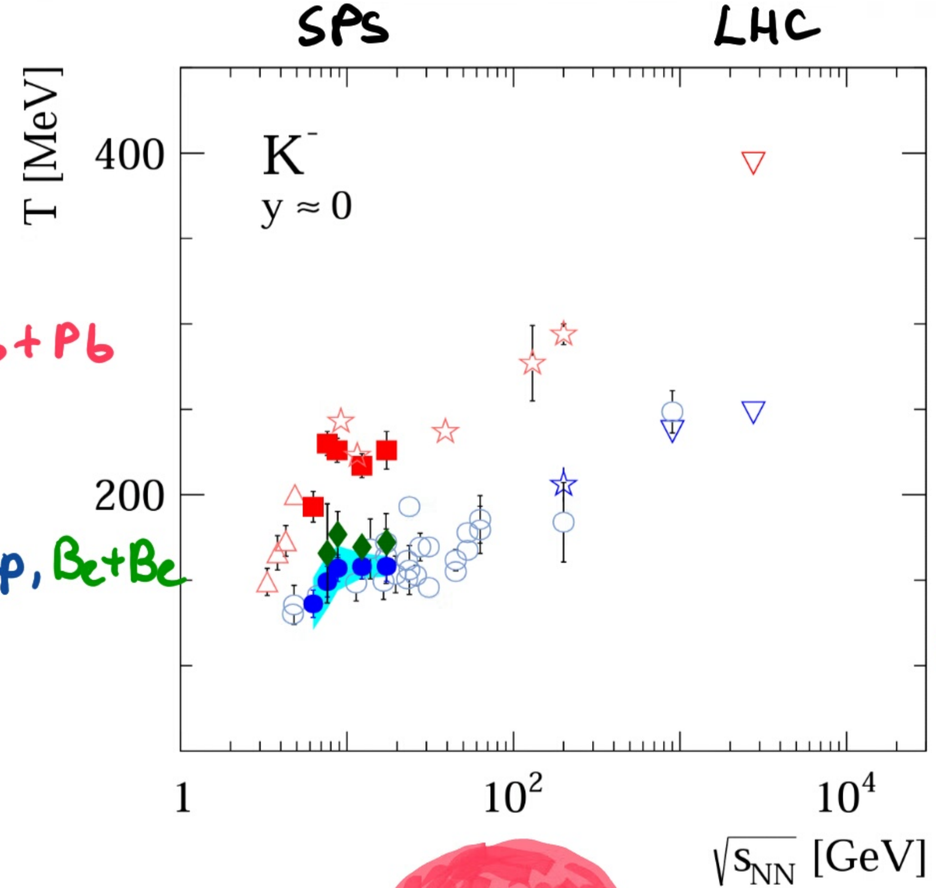
STATISTICAL AND DYNAMICAL MODELS WITH CHIRAL SYMMETRY RESTORATION AND DECONFINEMENT FIT Pb+Pb DATA

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



Pb+Pb

PHP, Be+Be



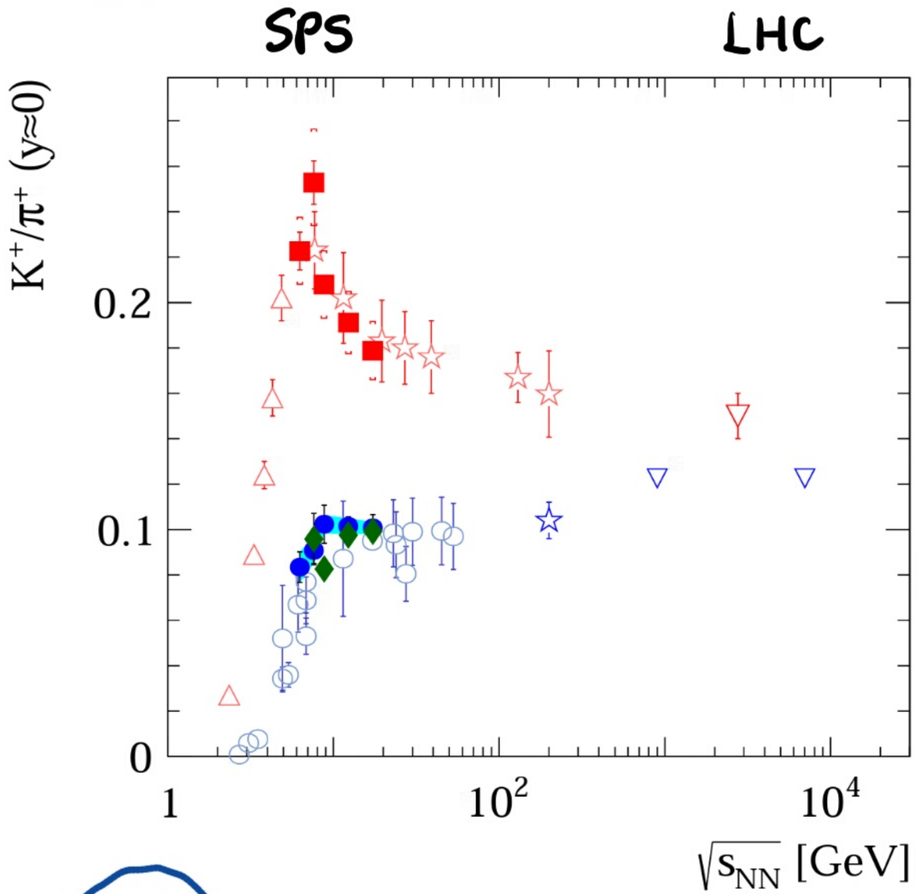
FIREBALL

SMALL CLUSTERS

↑ ONSET OF DECONFINEMENT ↑

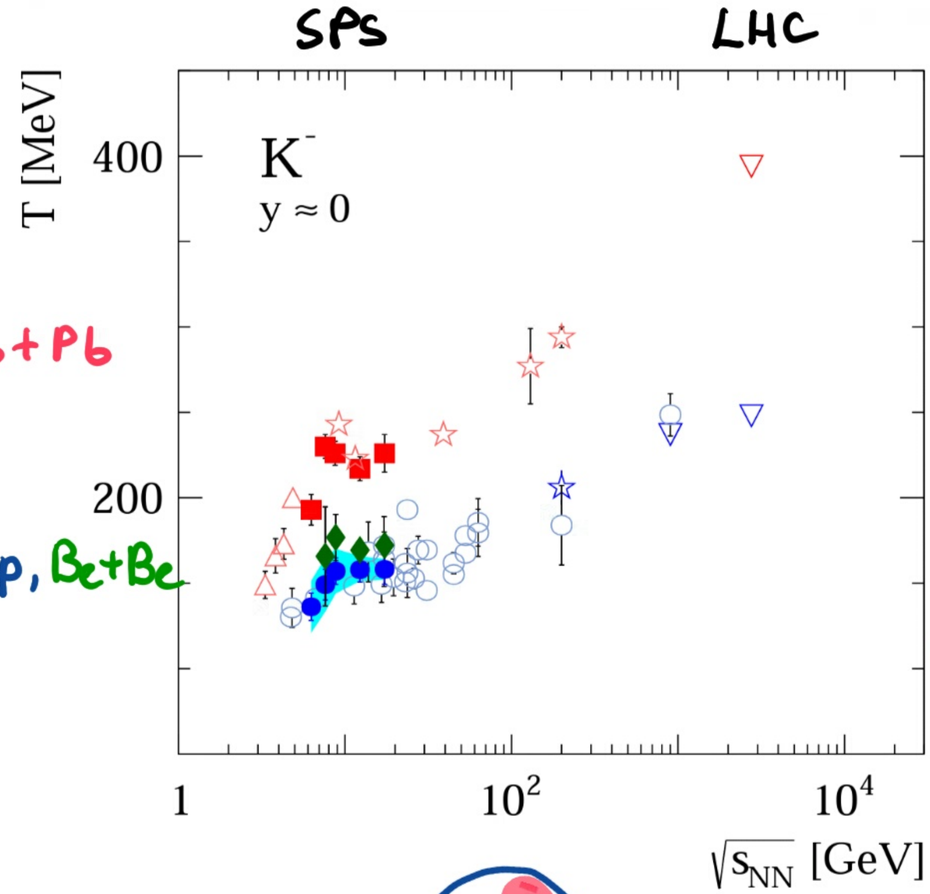
EVIDENCE FOR ONSET OF DECONFINEMENT

CHALLENGE TO UNDERSTAND pTp AND Be+Be DATA



Pb+Pb

pTp, Be+Be

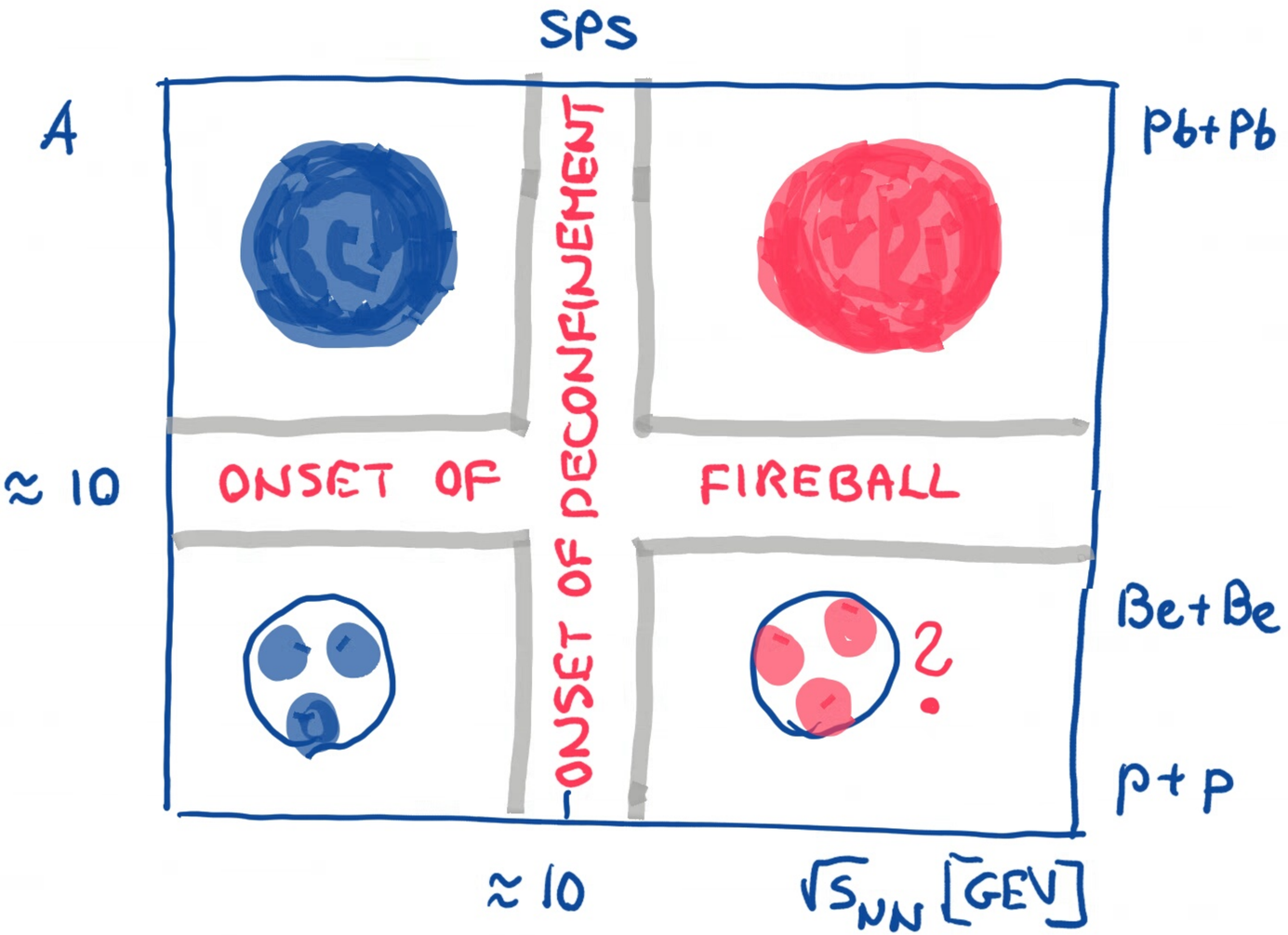


FIREBALL

SMALL CLUSTERS

↑ ONSET OF DECONFINEMENT? ↑

RESULTS ON ONSET OF FIREBALL AND ONSET OF DECONFINEMEN 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 $C \equiv \langle N\rangle \cdot \omega[P_T]$, $\quad P_T = \sum_1^N p_T^i$

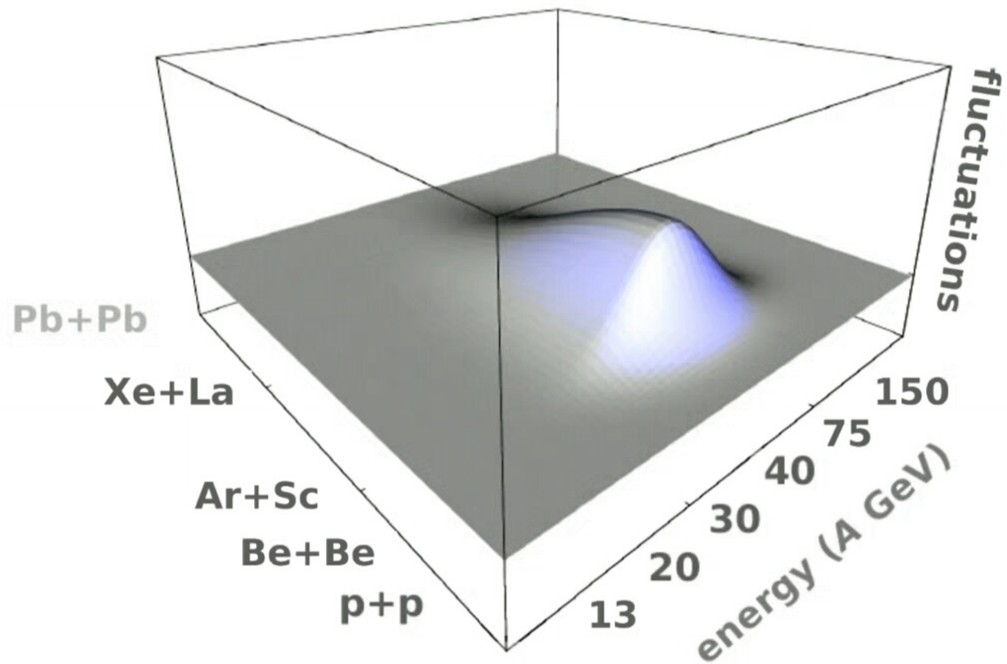
IB-GCE AND
IB-CE WITH V FLUCTUATIONS

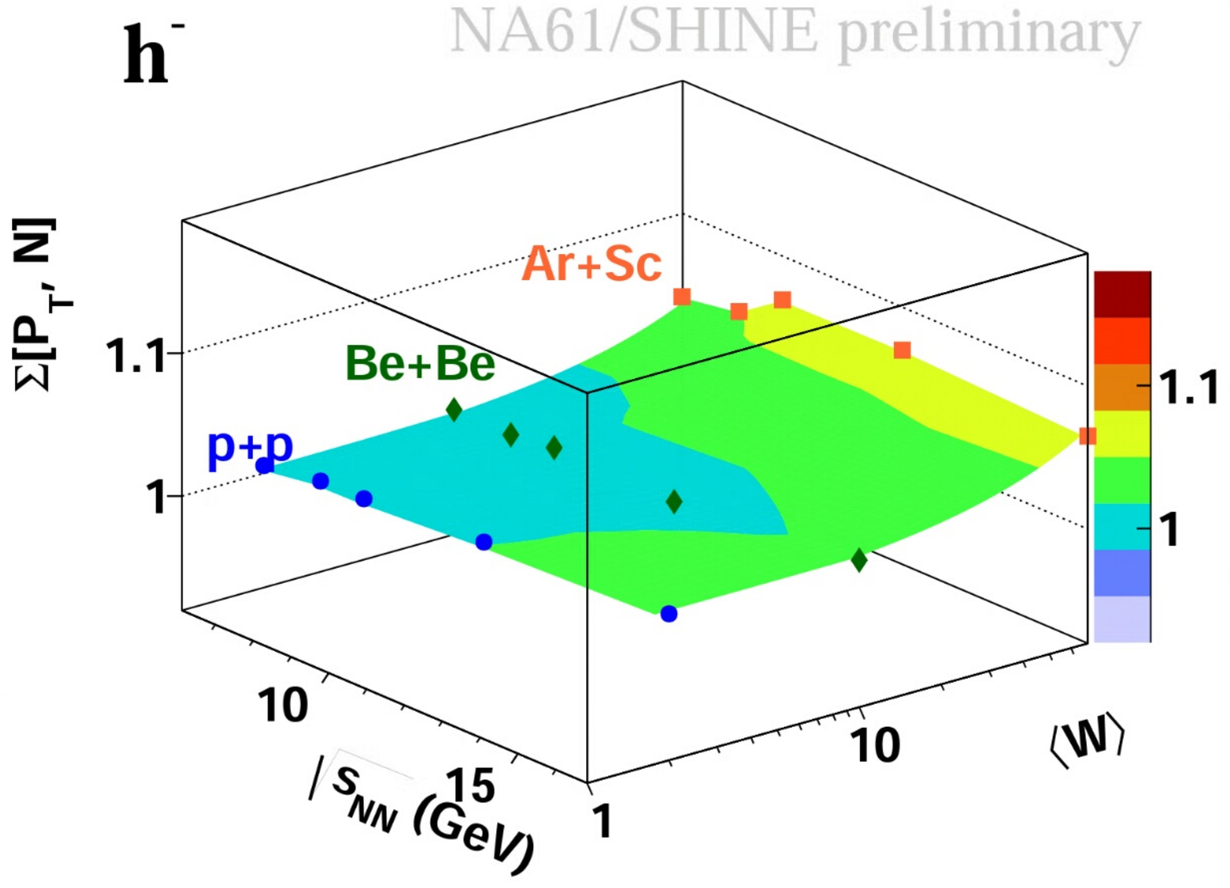
⇓

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

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

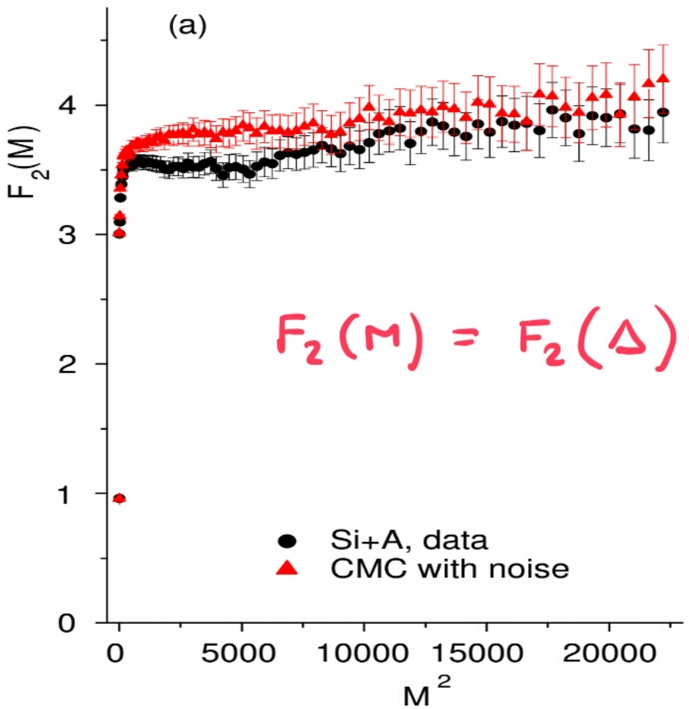
$$F_2(M) = F_2(\Delta) \cdot M^{\phi_2}$$

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

SEARCH FOR CRITICAL POINT : FLUCTUATIONS VS M

PROTONS

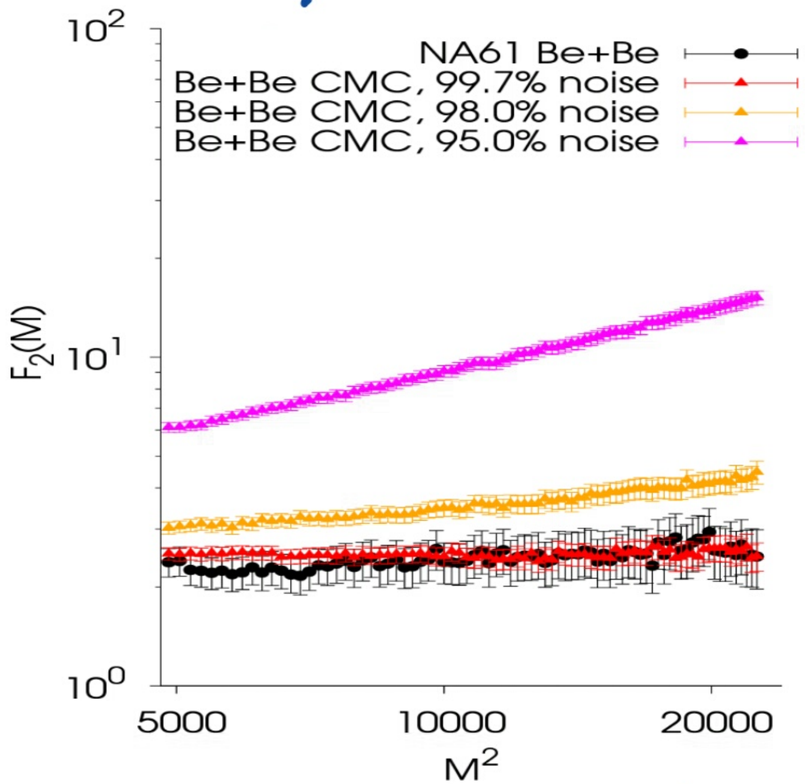
Si+A AT 158A GEV/c
NA49



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

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%

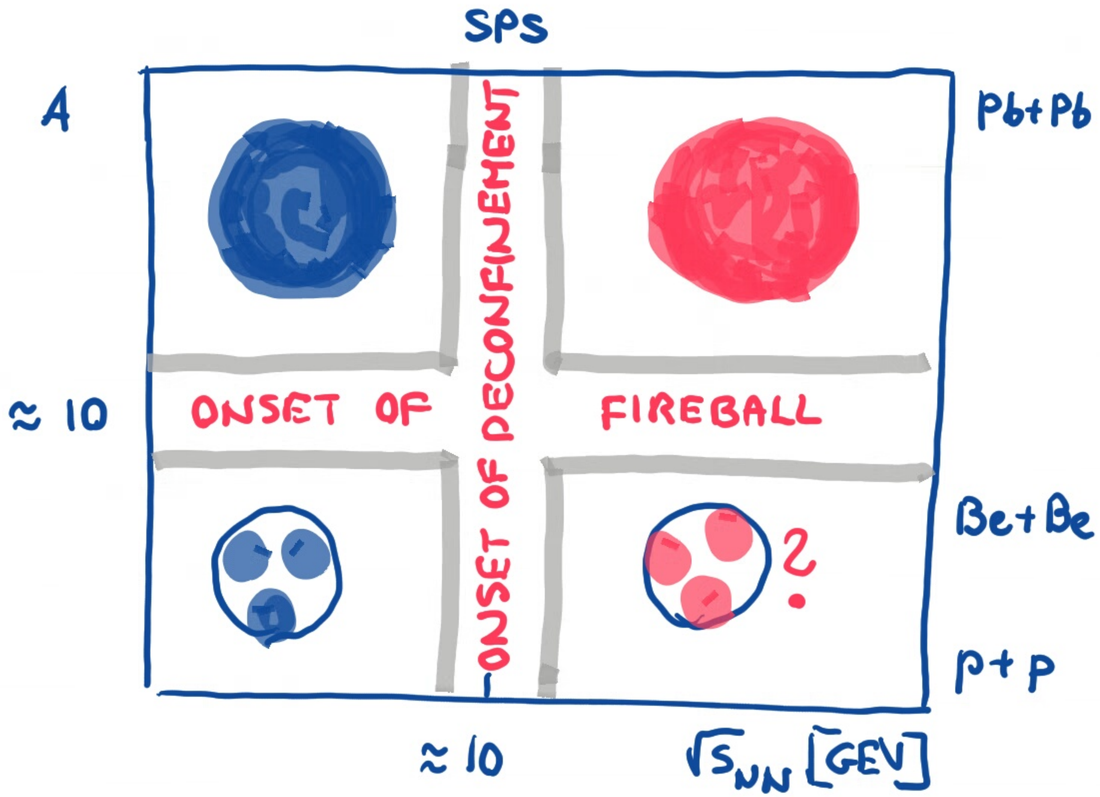
SUMMARY

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

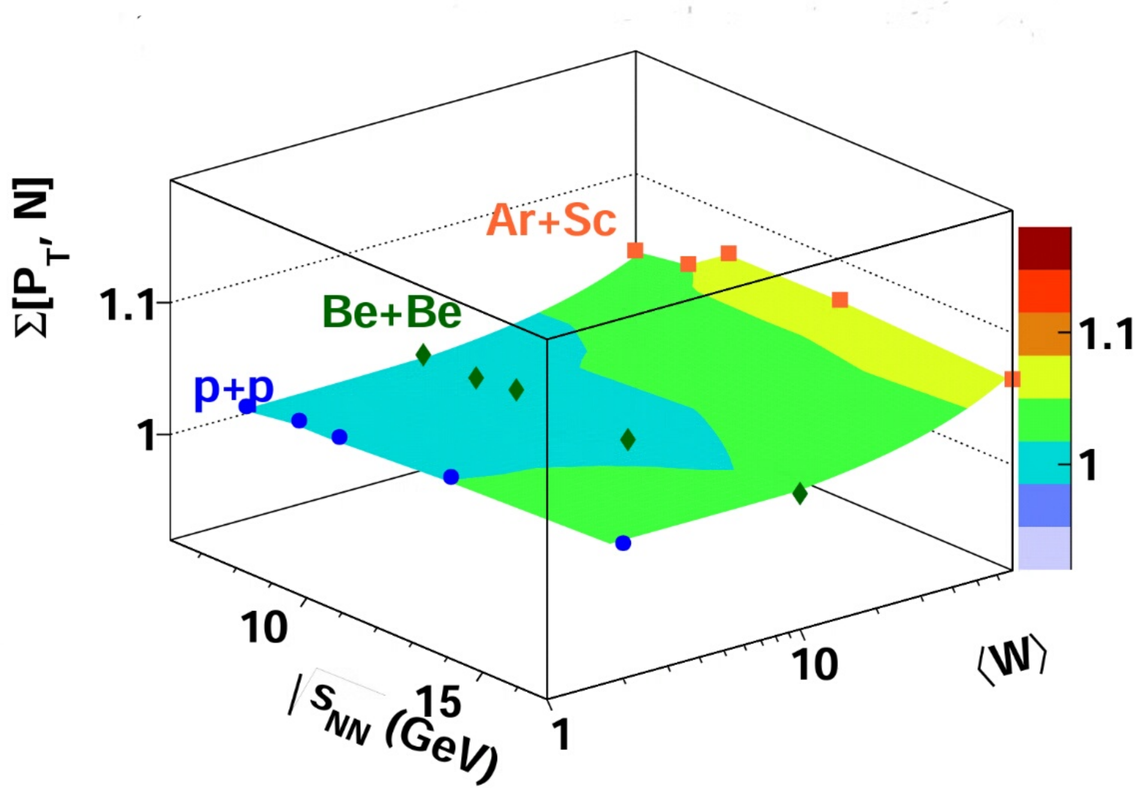
- EVIDENCE FOR ONSET OF DECONFINEMENT IN Pb+Pb
  → CHALLANGE TO UNDERSTAND p+p, Be+Be

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

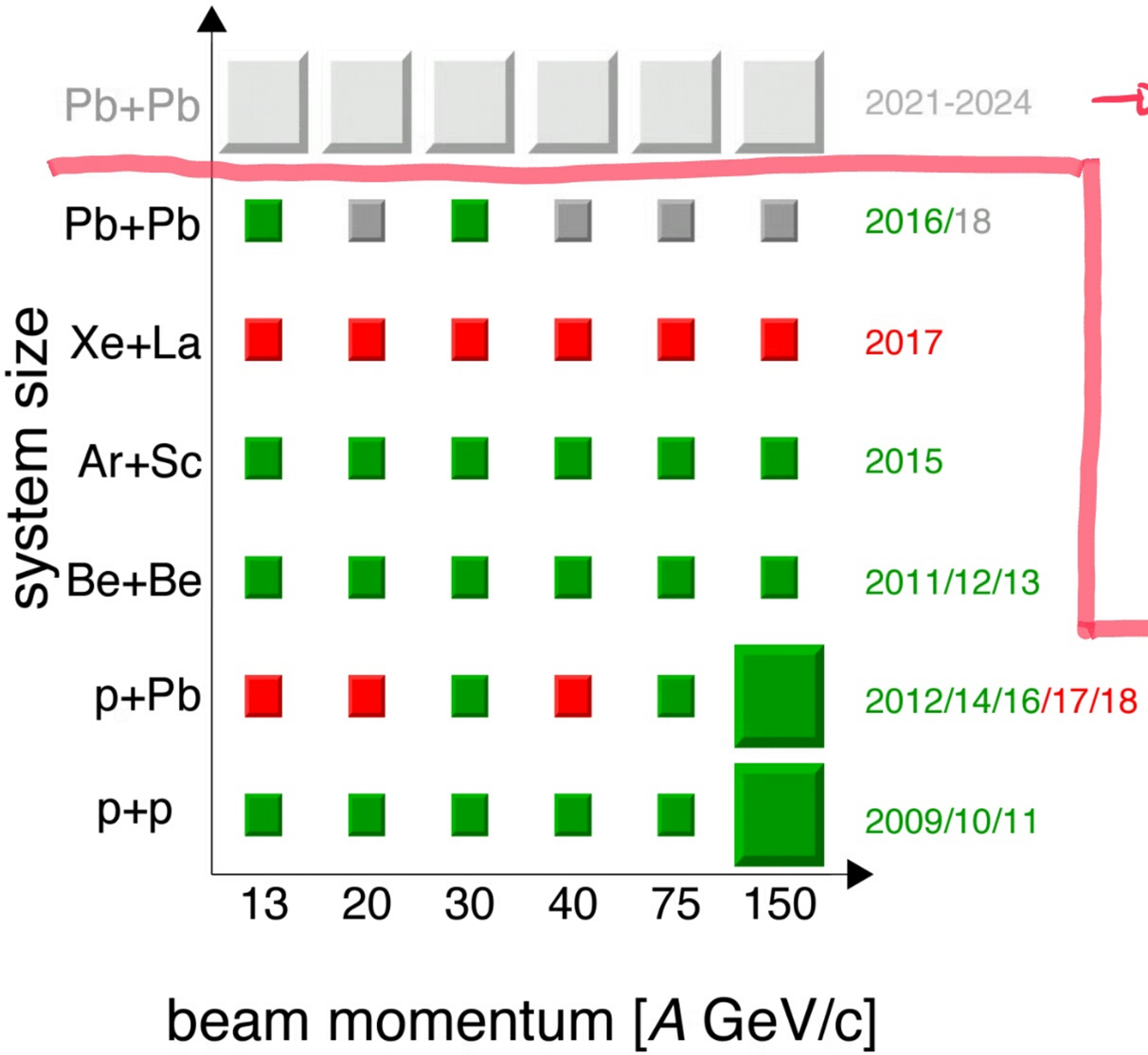
ONSETS



CRITICAL POINT



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
  - 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

∼150 physicists from ∼30 institutes