DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS FROM NA61/SHINE

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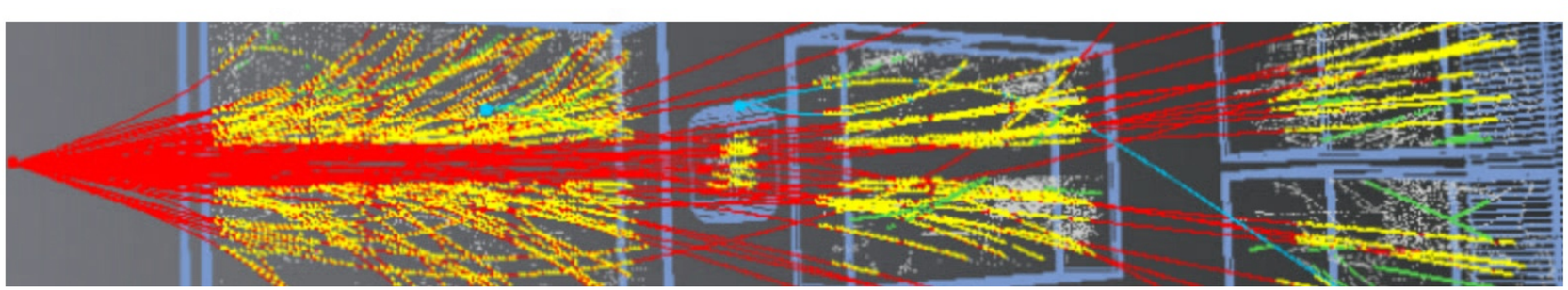
FOR NA61/SHINE

- DEFINITIONS
- IDEAS AND DATA
- DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS

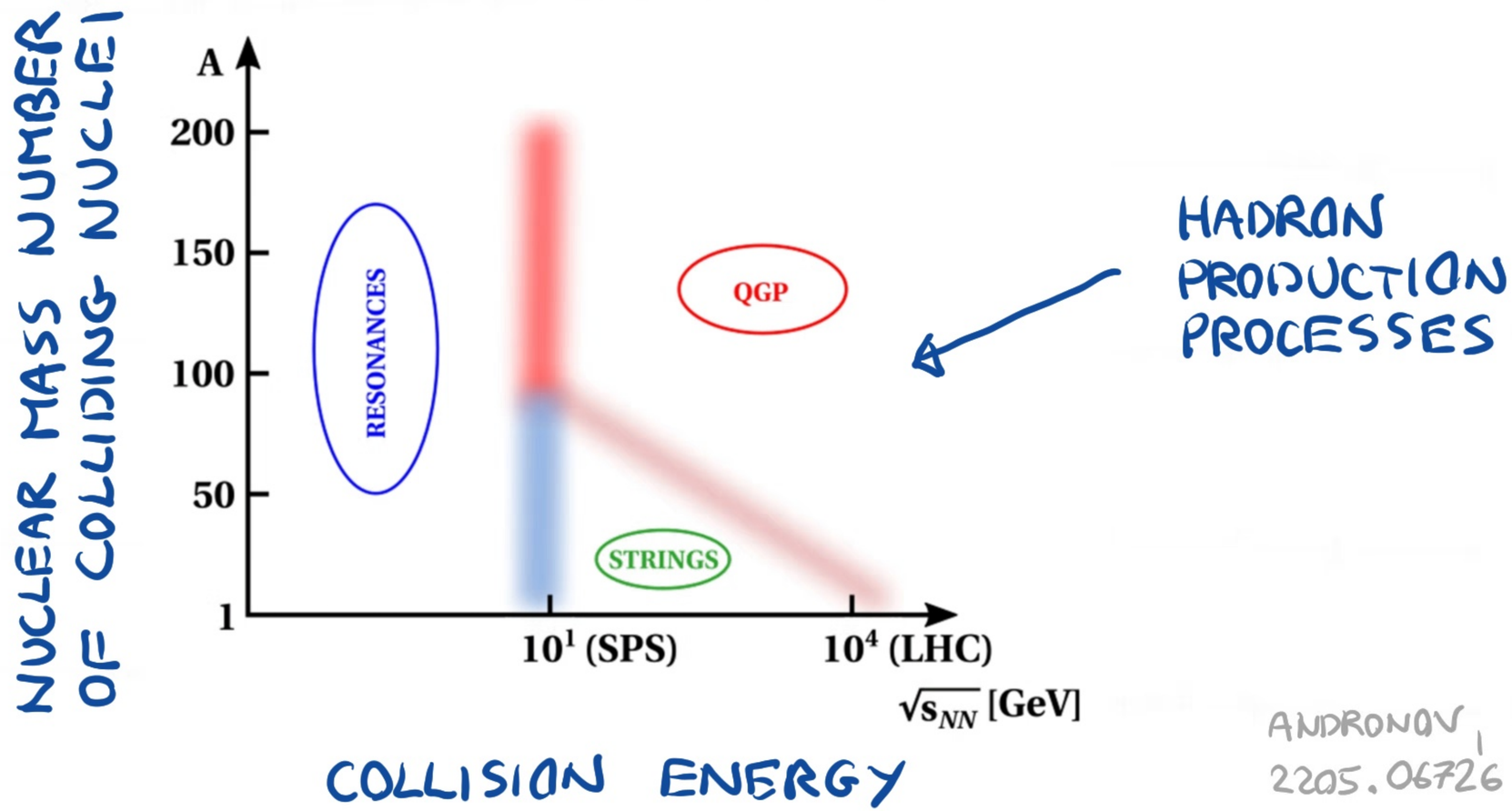


DEFINITIONS: DIAGRAM OF NUCLEAR COLLISIONS

≡ CHART SHOWING CONDITIONS (COLLISION ENERGY, NUCLEAR MASS NUMBER, ...) AT WHICH DISTINCT HADRON PRODUCTION PROCESSES DOMINATE

AN EXAMPLE DISCUSSED HERE:

ONLY CENTRAL A+A AND INELASTIC p+p → 2D PLOT



ANDRONOV, KUICH, MG 2205.06726

DEFINITIONS: HADRON PRODUCTION PROCESSES

POPULAR PROCESSES FOR MODELLING HADRON PRODUCTION IN PROTON-PROTON AND NUCLEUS-NUCLEUS COLLISIONS:

QGP – CREATION, EVOLUTION AND HADRONISATION OF QUARK-GLUON PLASMA

STRINGS – FORMATION, EVOLUTION AND FRAGMENTATION OF STRINGS – GLUON-FLUX TUBES BETWEEN A PAIR OF COLOUR CHARGES

RESONANCES – CREATION, EVOLUTION AND DECAYS OF RESONANCES – EXCITED STATES OF STABLE HADRONS

DEFINITIONS: QUANTITATIVE MODELS

TWO POPULAR MODELS OF HIGH-ENERGY NUCLEAR COLL.:

PHSD – INCLUDES RESONANCES, STRINGS AND QGP

CASSING, BRATKOVSKAYA
NPA 831, 215 (2009)

SMASH – INCLUDES RESONANCES AND STRINGS

MOHS, RYU, ELFNER
JPG 47, 065101 (2020)

DEFINITIONS: EXPERIMENTAL PROBE

THE RATIO OF POSITIVELY CHARGED KAONS AND PIONS MEASURED AT MID-RAPIDITY, K^+/π^+

- IN GOOD APPROXIMATION $K^+/\pi^+ \sim$ (STRANGE/NON-STRANGE QUARKS RATIO)

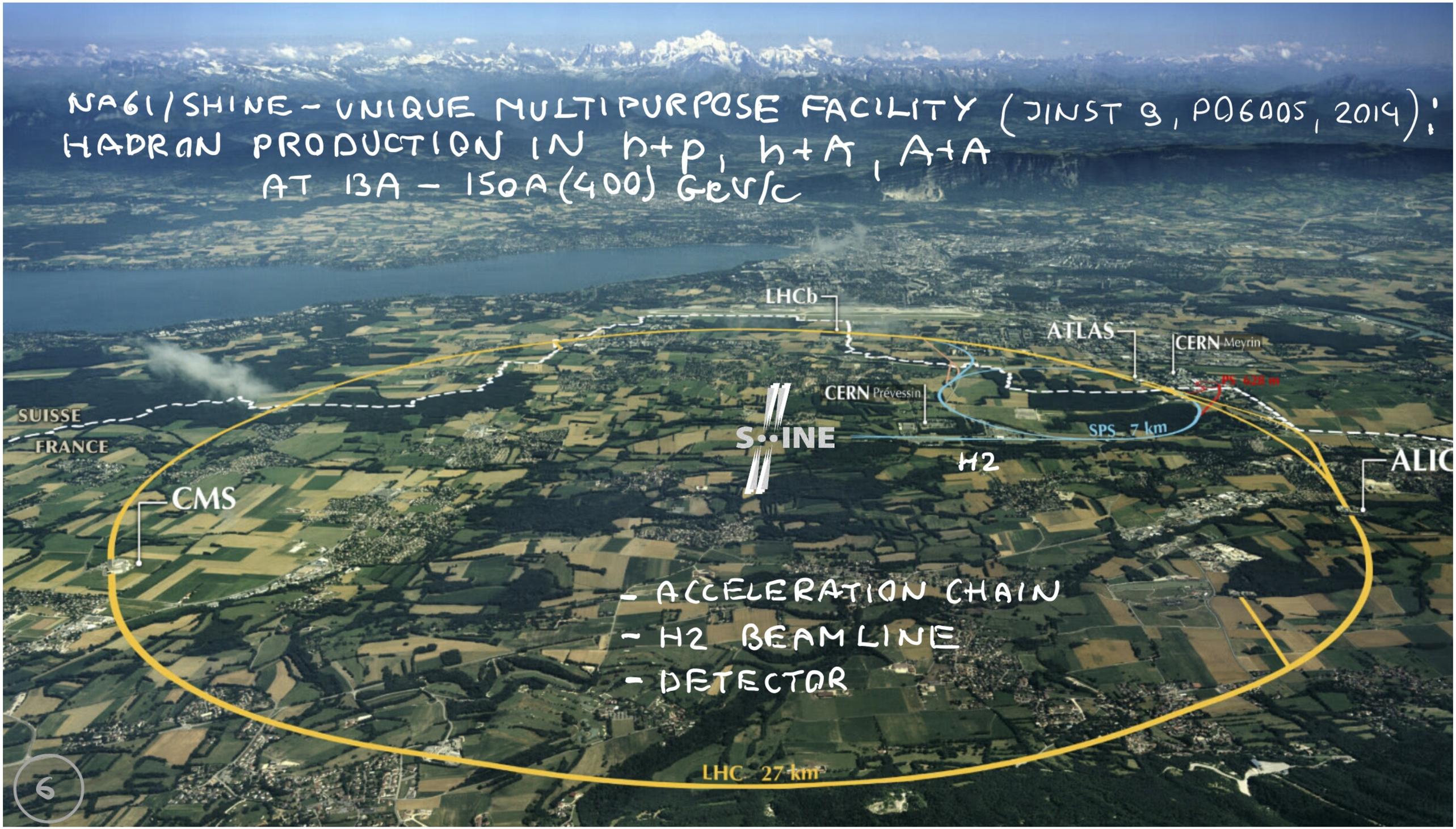
- K^+/π^+ SENSITIVE TO HADRON-PRODUCTION PROCESSES DUE TO MASS AND NUMBER DIFFERENCES BETWEEN STRANGE AND NON-STRANGE PARTICLES – QUARKS AND GLUONS OR HADRONS

RAFELSKI, MULLER
PRL 48, 1066 (1982)

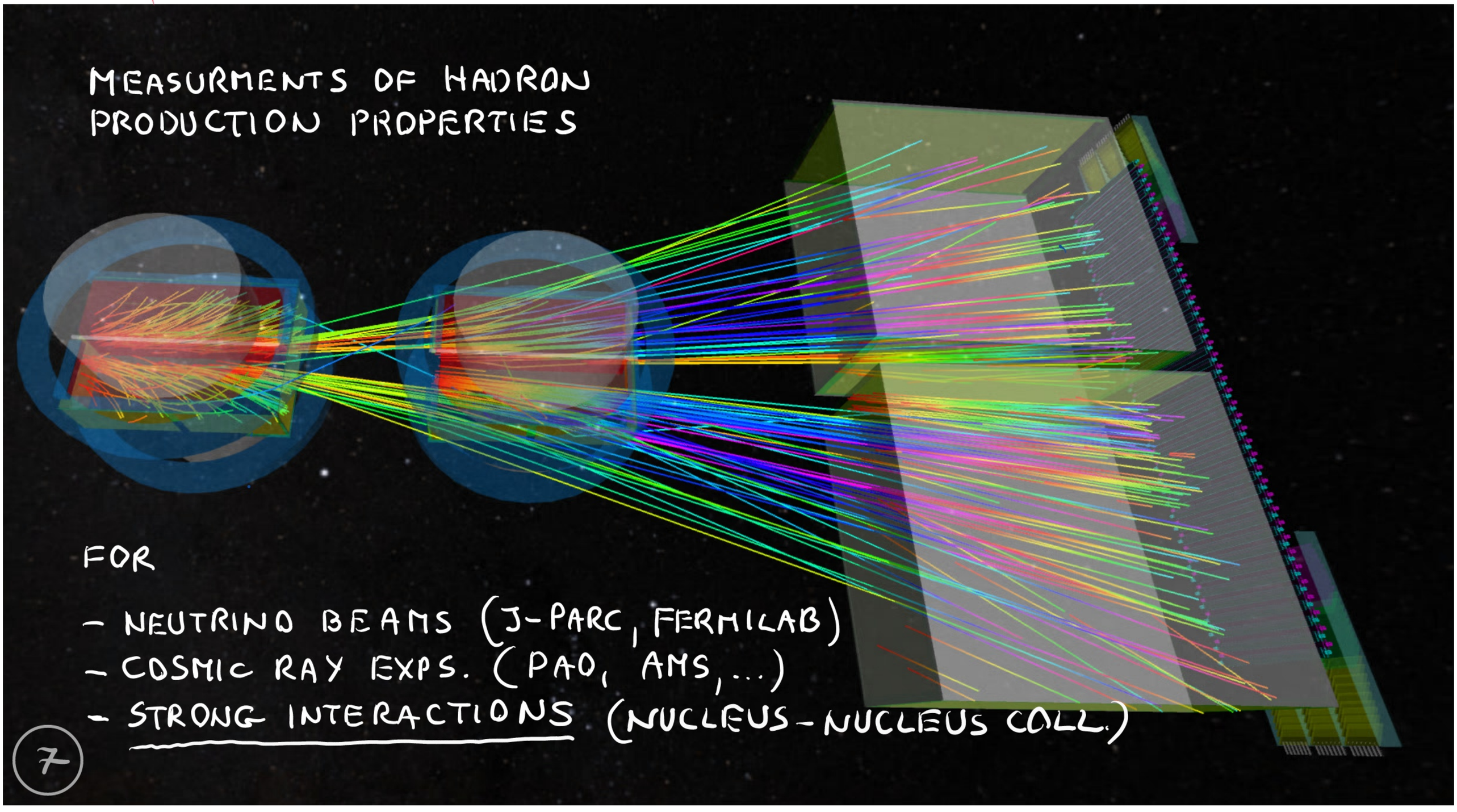
MG, GORENSTEIN
APP B 30, 2705 (1999)

- RICH EXPERIMENTAL DATA ON K^+/π^+ IN HIGH-ENERGY NUCLEAR COLLISIONS

DEFINITIONS: NA61/SHINE



DEFINITIONS: NA61/SHINE PHYSICS PROGRAMMES

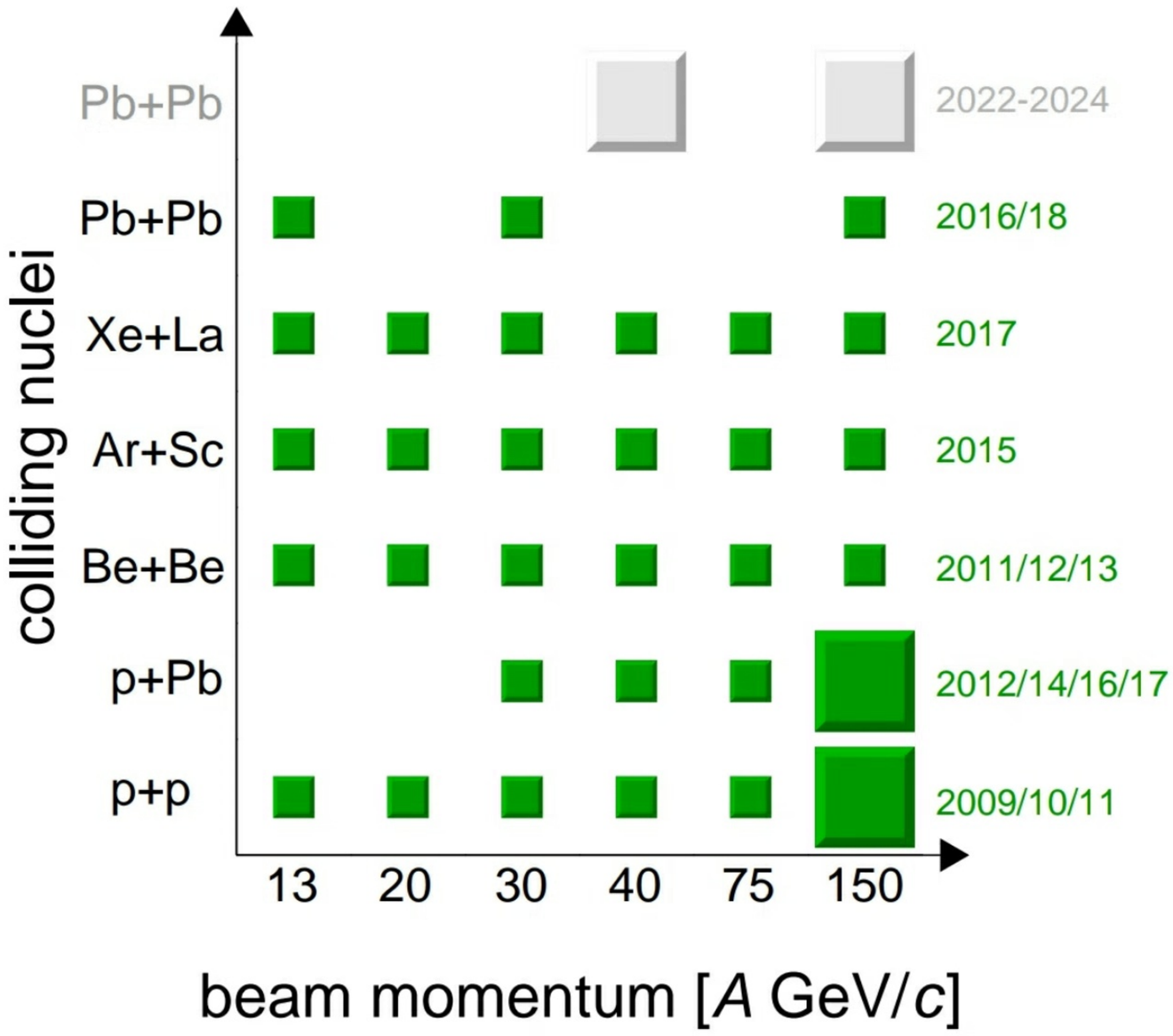


MEASURMENTS OF HADRON PRODUCTION PROPERTIES

FOR

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

DEFINITIONS: NA61/SHINE DATA FOR HIGH-ENERGY NUCLEAR COLL.

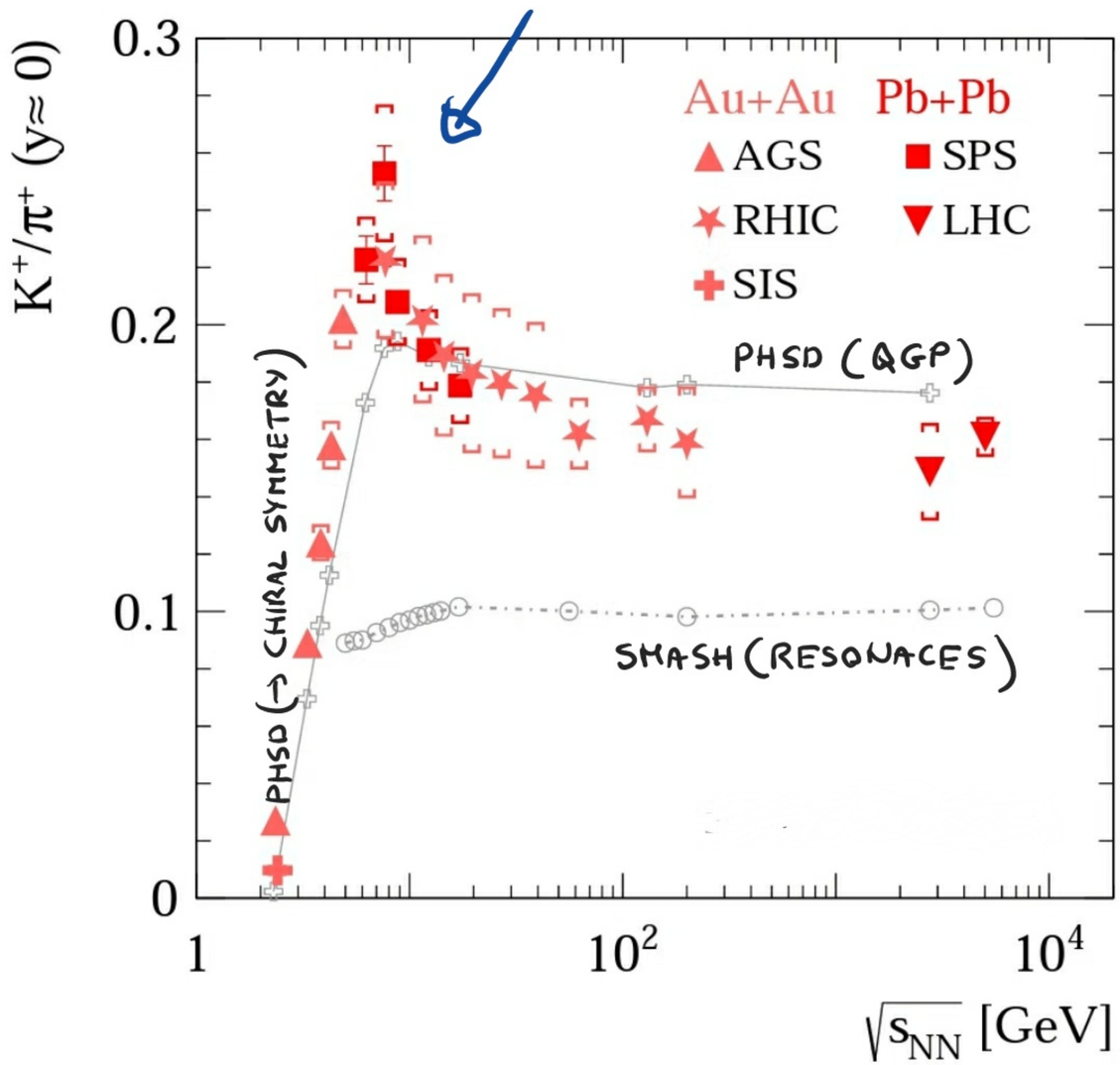


UNIQUE INPUT TO ESTABLISH DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS

$\sqrt{s_{NN}} \approx 5 \longleftrightarrow 17$ GeV

IDEAS AND DATA: HEAVY-ION COLLISIONS

THE HORN STRUCTURE



NA49, PRC 66, 054902

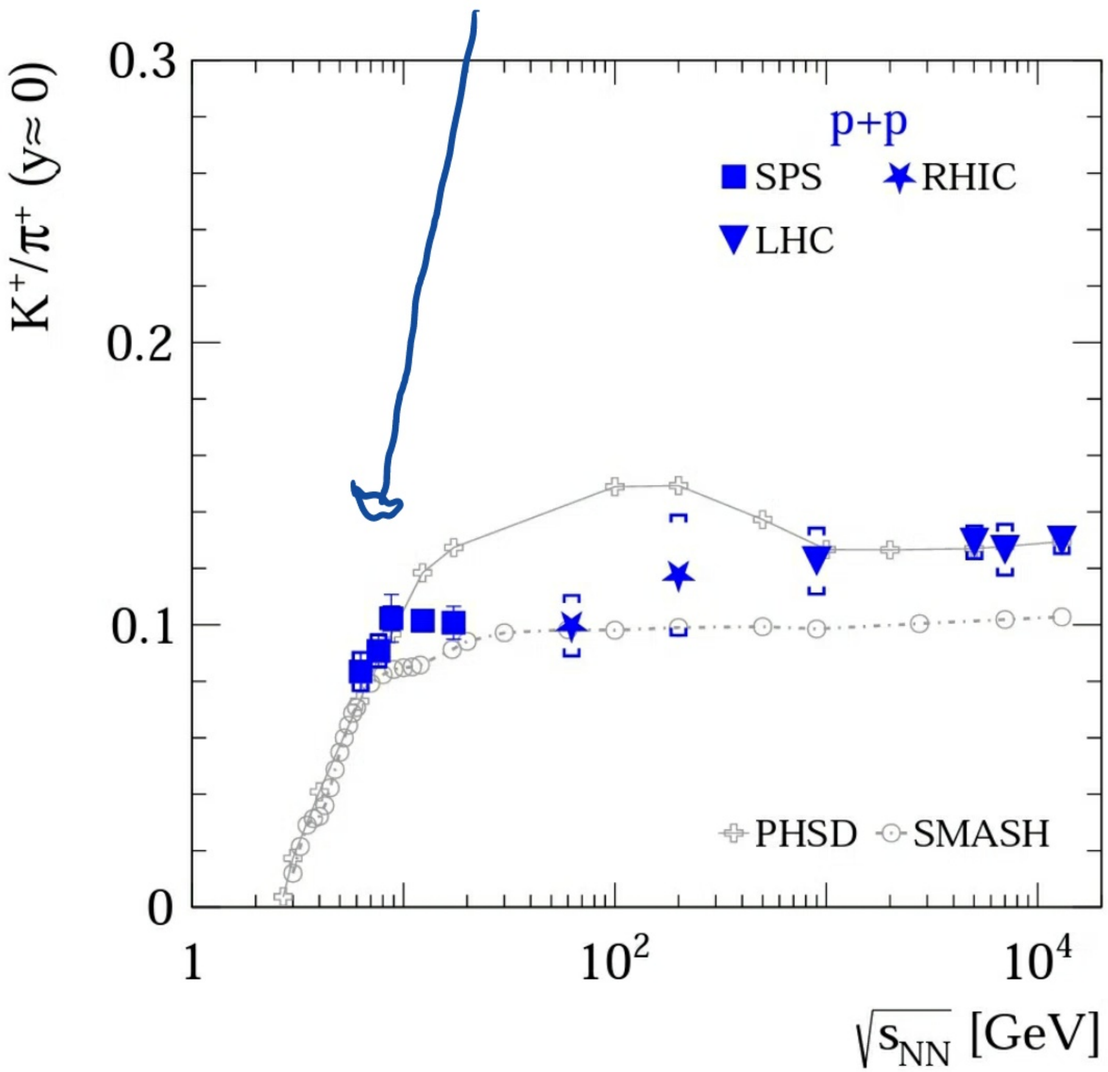
RESONANCES - QGP CHANGEOVER (ONSET OF DECONFINEMENT)

MG, GORENSTEIN APP'B 30, 2705 (1999)

SUPPORTED BY AGREEMENT OF PHSD (DECONFINEMENT + CHIRAL SYMMETRY RESTORATION) AND DISAGREEMENT OF SMASH (STRINGS)

IDEAS AND DATA: PROTON-PROTON INTERACTIONS

THE BREAK STRUCTURE $\xrightarrow{?}$ RESONANCES-STRINGS CHANGEOVER

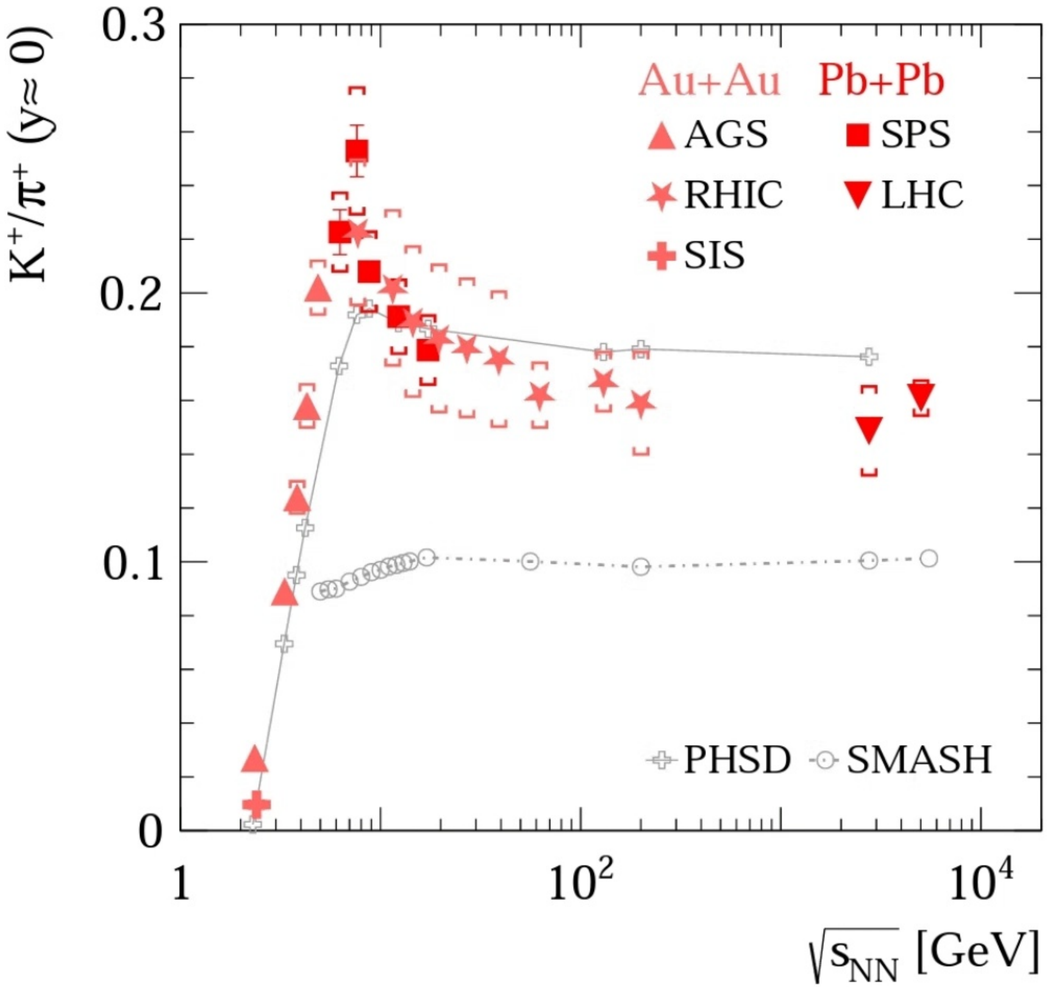


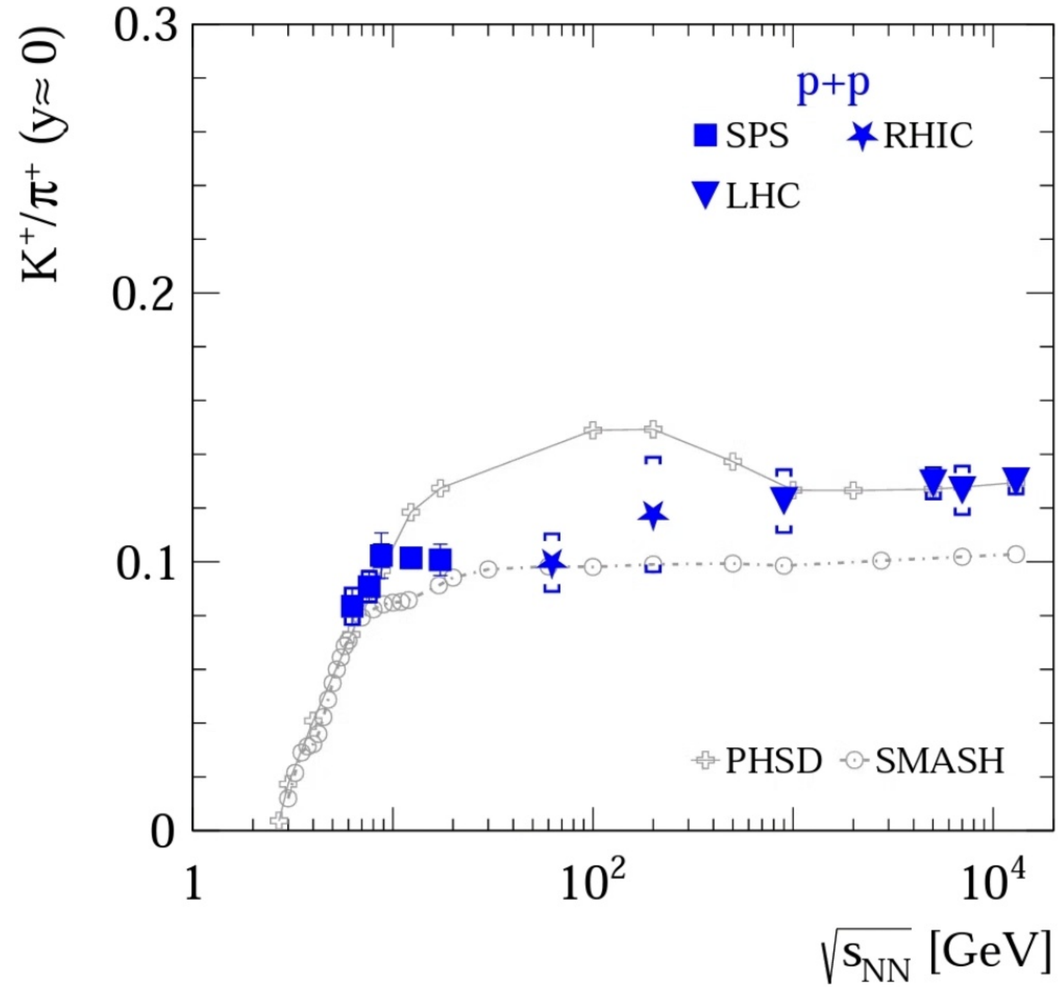
SMASH AND PHSD INCLUDE RESONACES-STRINGS CHANGEOVER BUT LOCATE IT LOWER ENERGIES ($\sqrt{s} \approx$ 3-4 AND 2.6 GeV)

FOR p+p THE SAME UNDERLYING PHYSICS BUT DIFFERENT PREDICTIONS OF SMASH AND PHSD

NA61/SHINE, PRC 102, 011901 (2020)

IDEAS AND DATA: Pb+Pb vs p+p

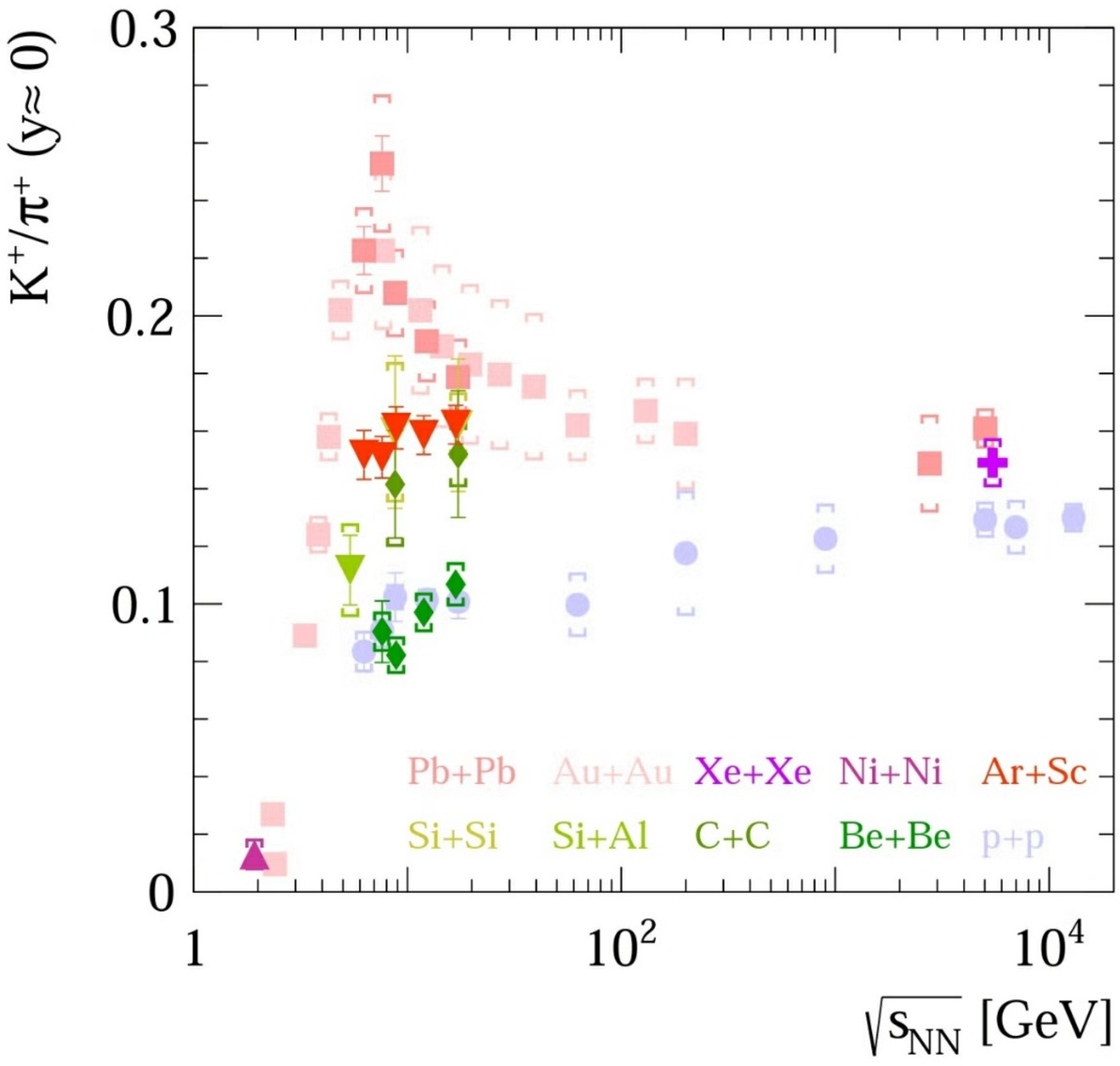




VERY DIFFERENT ENERGY DEPENDENCE

→ COLLISIONS OF INTERMEDIATE MASS NUCLEI

IDEAS AND DATA: COLLISIONS OF INTERMEDIATE MASS NUCLEI



- Be+Be ≈ p+p

  NA61/SHINE:
  EPJ C80, 961 (2020)
  EPJ C81, 73 (2021)

- Ar+Sc ≈ Pb+Pb
  AT $\sqrt{s_{NN}}$ ≈ 17 GeV

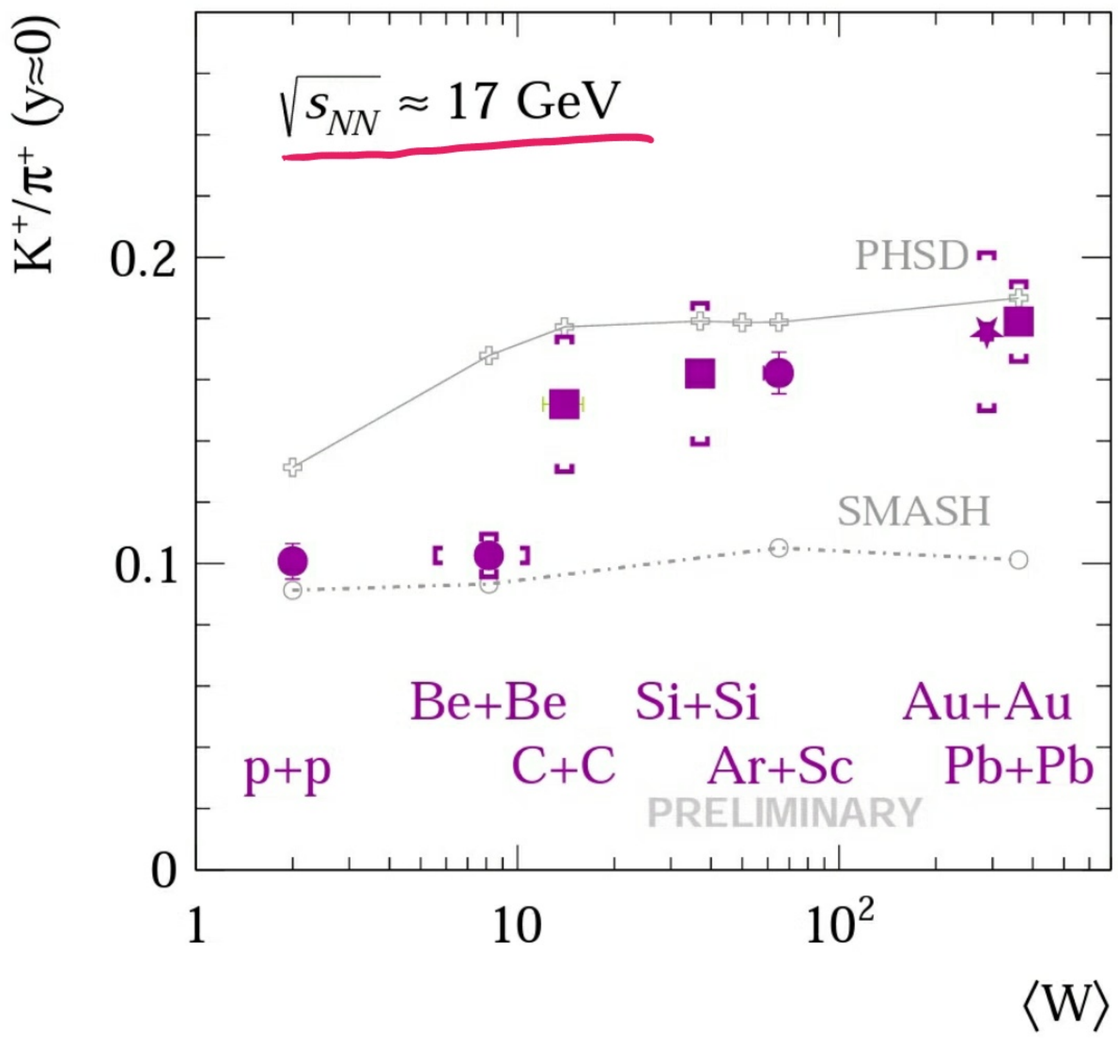
- NO HORN IN Ar+Sc

  NA61/SHINE:
  EPJ C81, 397 (2021)

- p+p ≈ Xe+Xe ≈ Pb+Pb
  AT LHC $\xrightarrow{?}$
  QGP IN p+p AT LHC

  ALICE, NATURE PHYS. 13, 535 (2017)

IDEAS AND DATA: COLLISIONS OF INTERMEDIATE MASS NUCLEI



NUMBER OF WOUNDED NUCLEONS

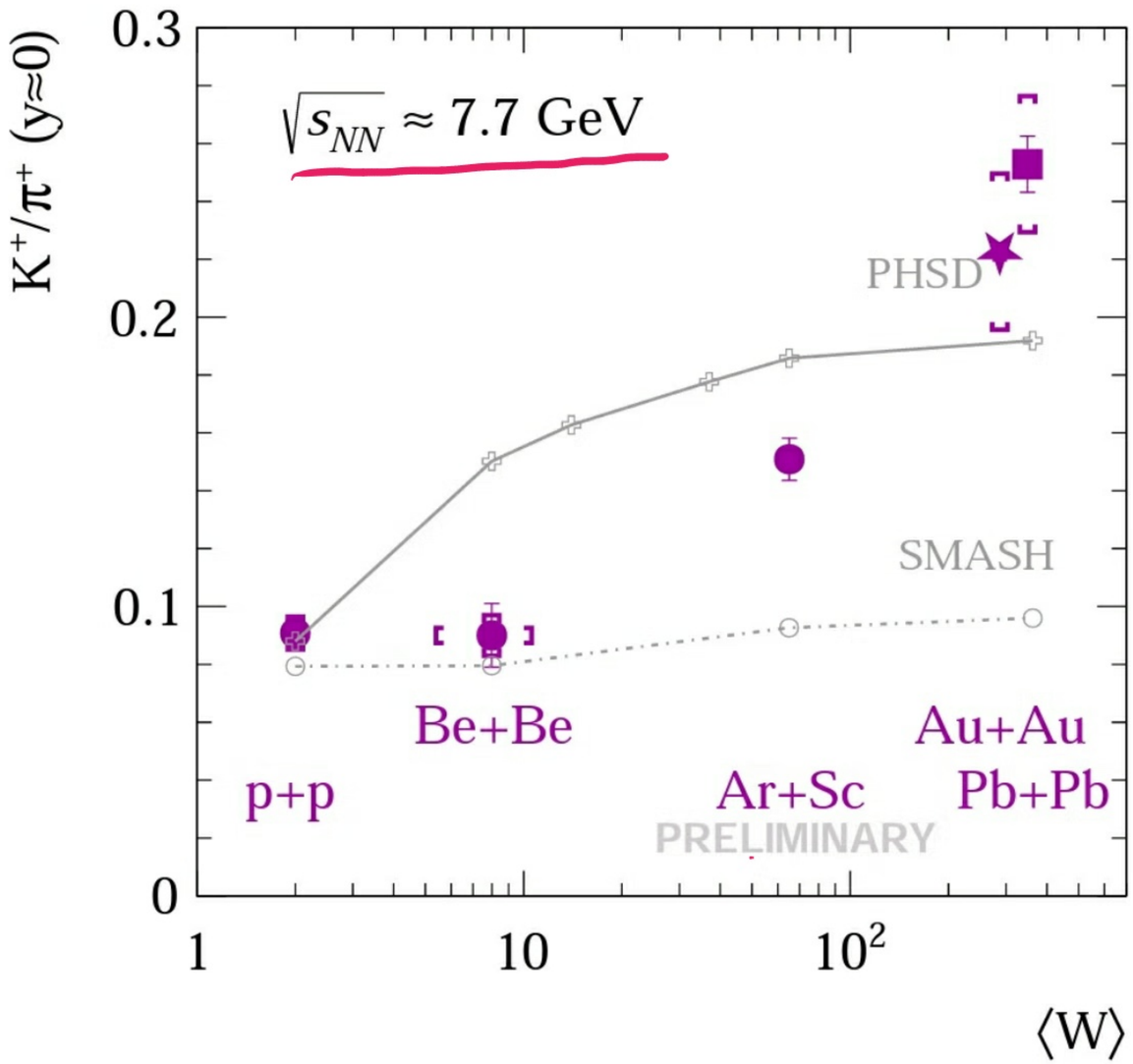
JUMP BETWEEN p+p / Be+Be AND Ar+Sc / Pb+Pb

NOT REPRODUCED BY THE MODELS

IDEA: JUMP IS DUE TO STRINGS' TO QGP COLLAPSE PICTURED AS THE BLACK HOLE FORMATION USING AdS/CFT DUALITY

KALAYDZHYAN, SHURYAK
PRC 90, 014901 (2014)
PRD 90, 025031, (2014)

IDEAS AND DATA: COLLISIONS OF INTERMEDIATE MASS NUCLEI



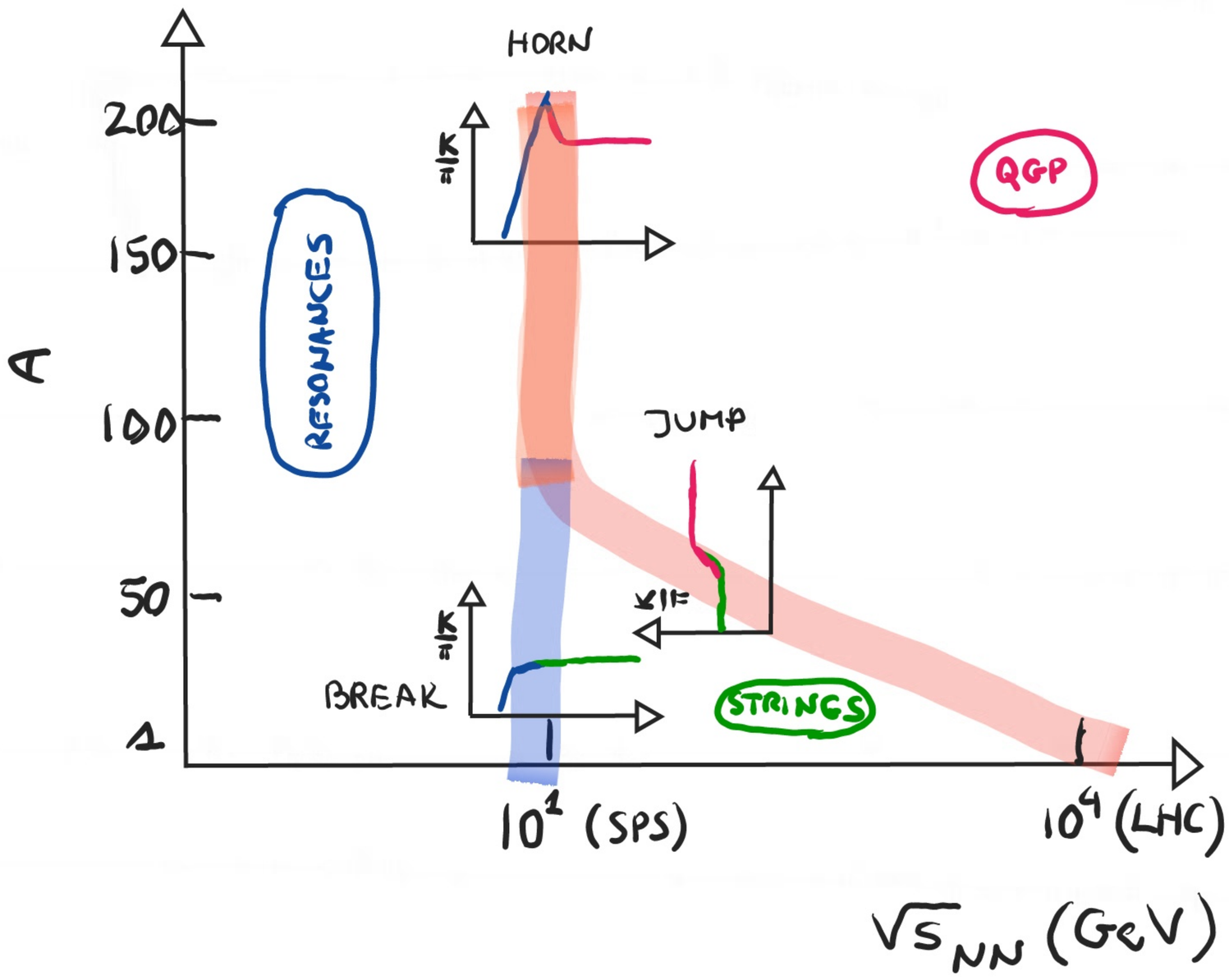
NUMBER OF WOUNDED NUCLEONS

CONTINUOUS INCREASE BETWEEN Be+Be, Ar+Sc AND Pb+Pb

POSSIBLY DUE TO:

- APPROCHING EQULIBRIUM WITH INCREASING ⟨W⟩ AND TIME
- WEAKENING OF CANONICAL STRANGENESS SUPPRESSION WITH INCREASING ⟨W⟩
- INCREASING ROLE OF CHIRAL SYMMETRY RESTORATION

DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS



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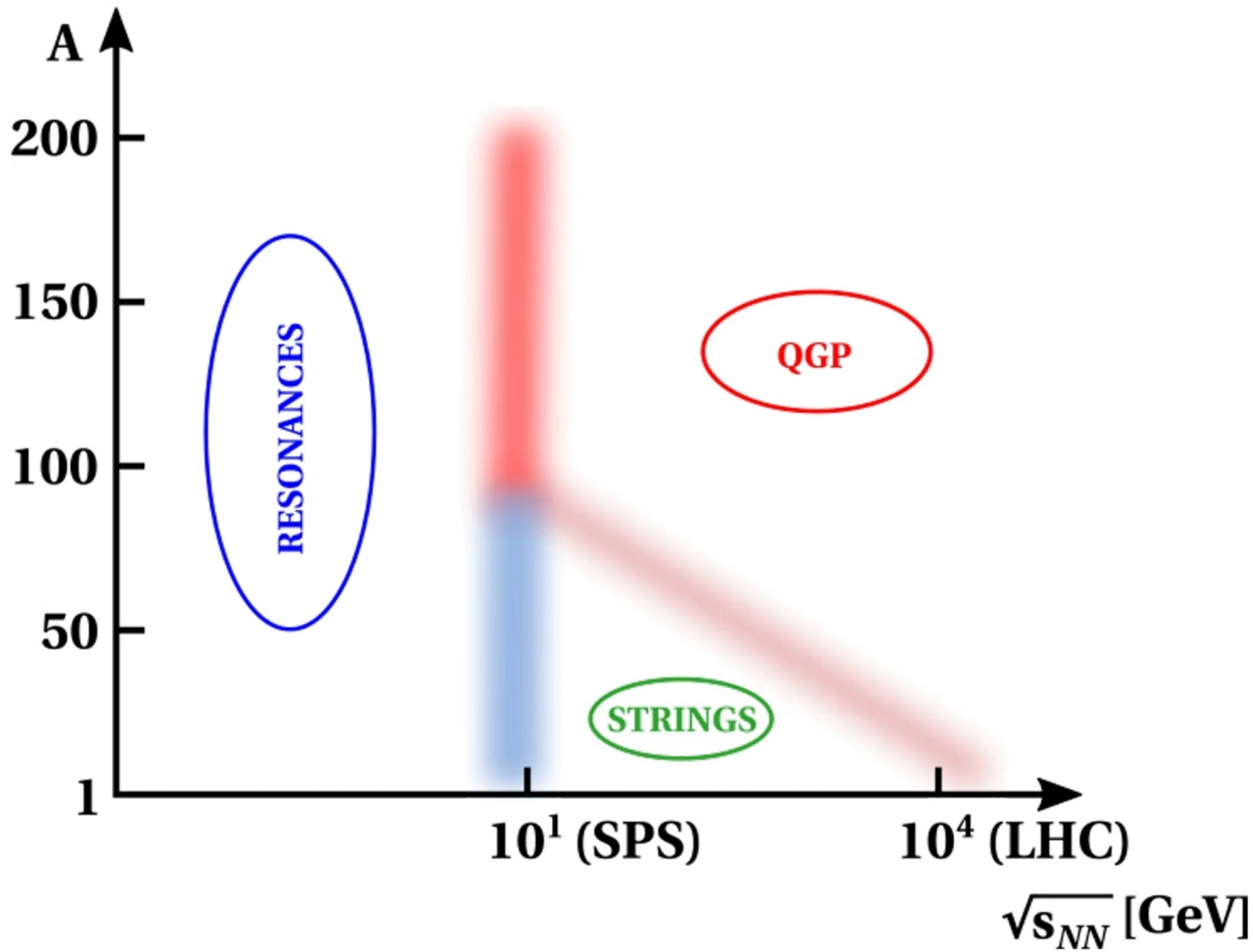


DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS AND CRITICAL POINT

PHASE DIAGRAM

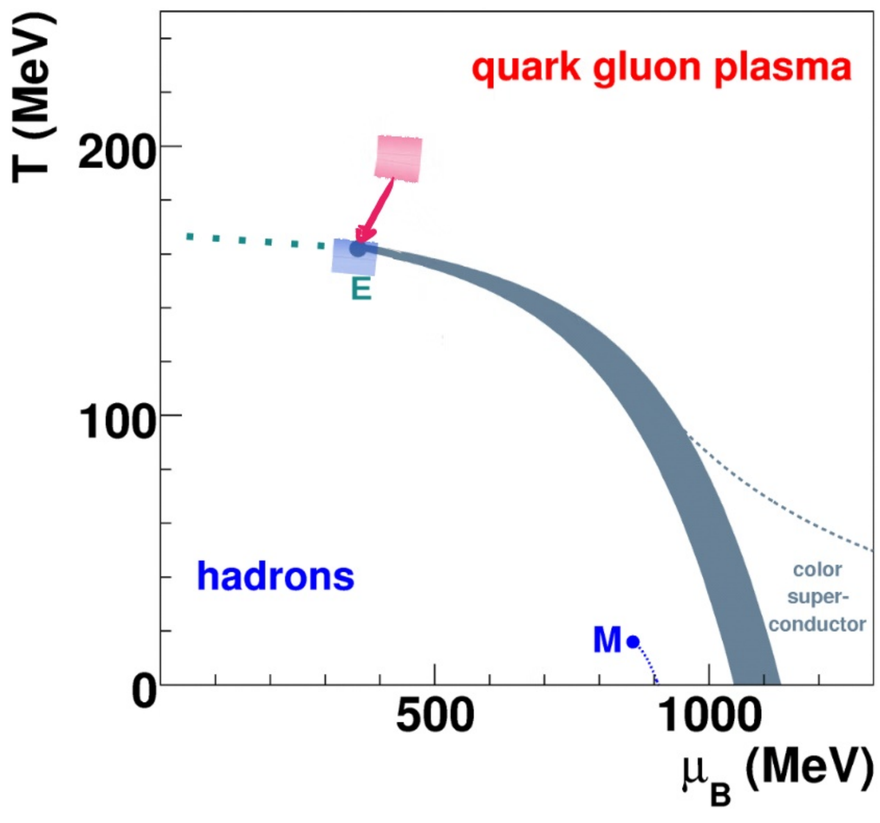
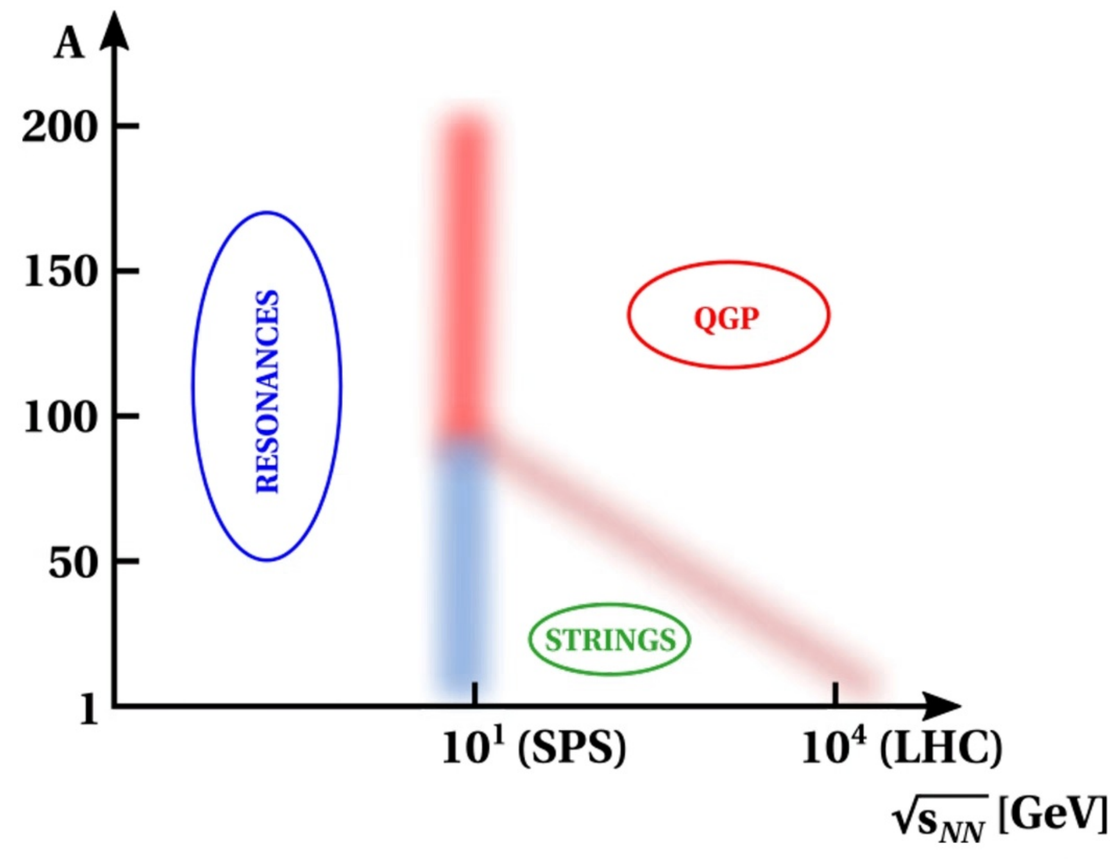


DIAGRAM OF ...



CP SEARCH IN HIC:
→ FREEZOUT CLOSE TO CP
→ QGP EARLY STAGE ⟶ SEARCH FOR CP MAKES SENSE IN THE QGP-DOMAIN OF THE DIAGRAM