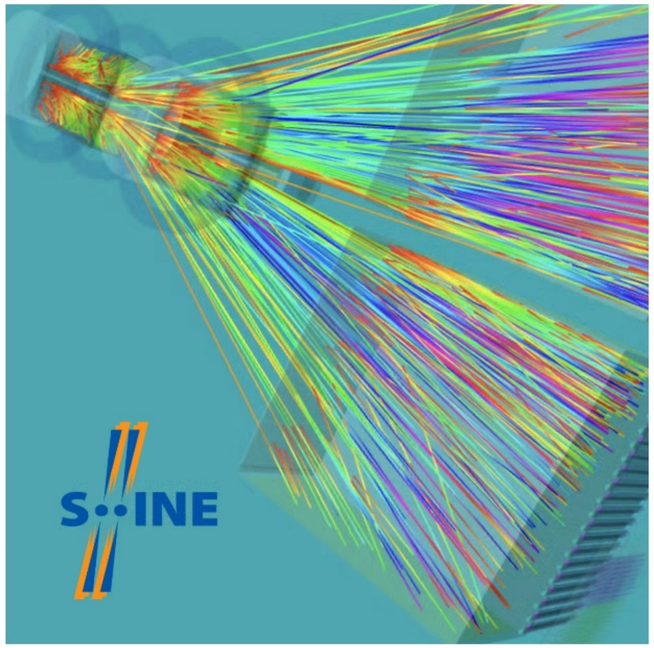
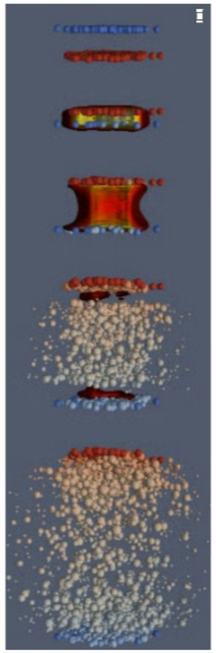
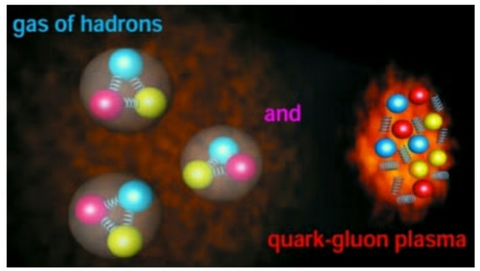
DATA ON
NUCLEUS- NUCLEUS
COLLISIONS AT HIGH ENERGY

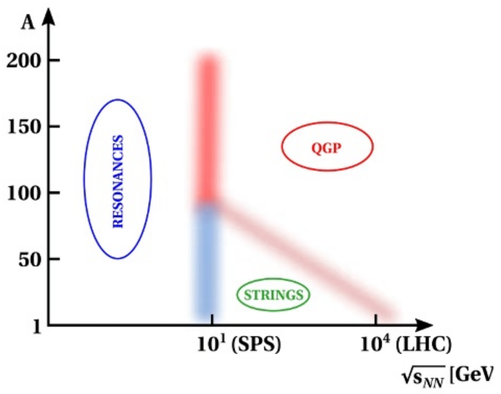



MODELS



STATISTICAL AND
HYDRODYNAMICAL
MODELS




PHASE DIAGRAM OF
STRONGLY INTERACTING MATTER

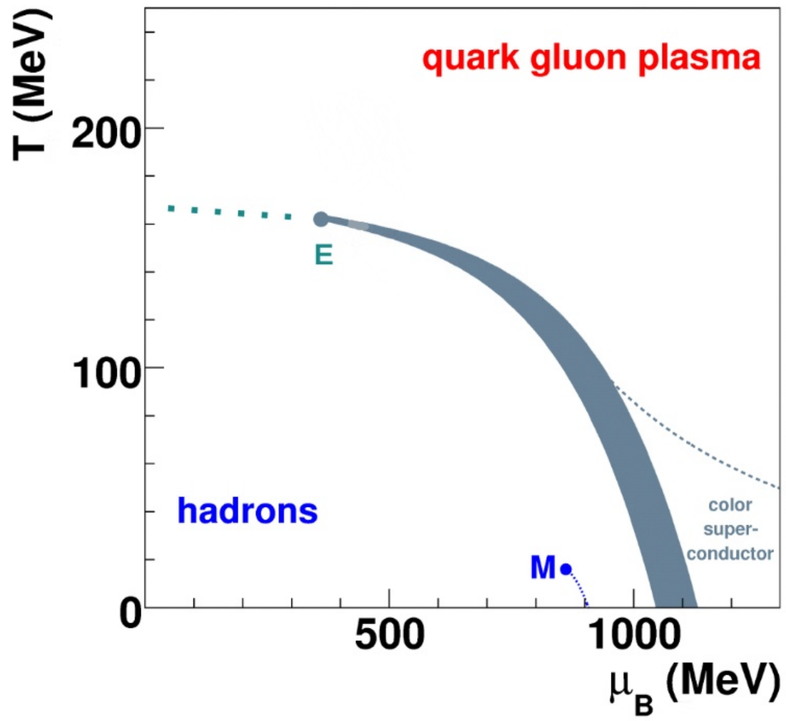
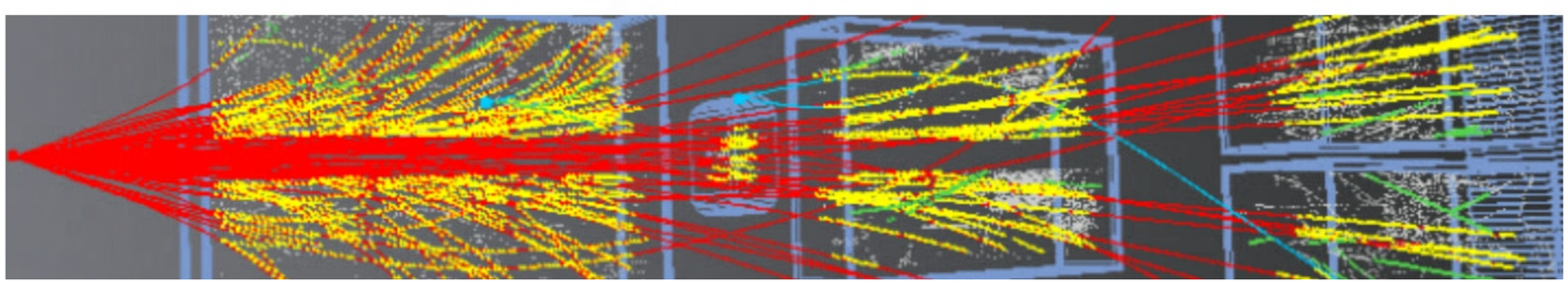



DIAGRAM OF HIGH-ENERGY
NUCLEAR COLLISIONS

# DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS FROM NA61/SHINE

M. GAZDZICKI, UJK KIELCE
IKF FRANKFURT

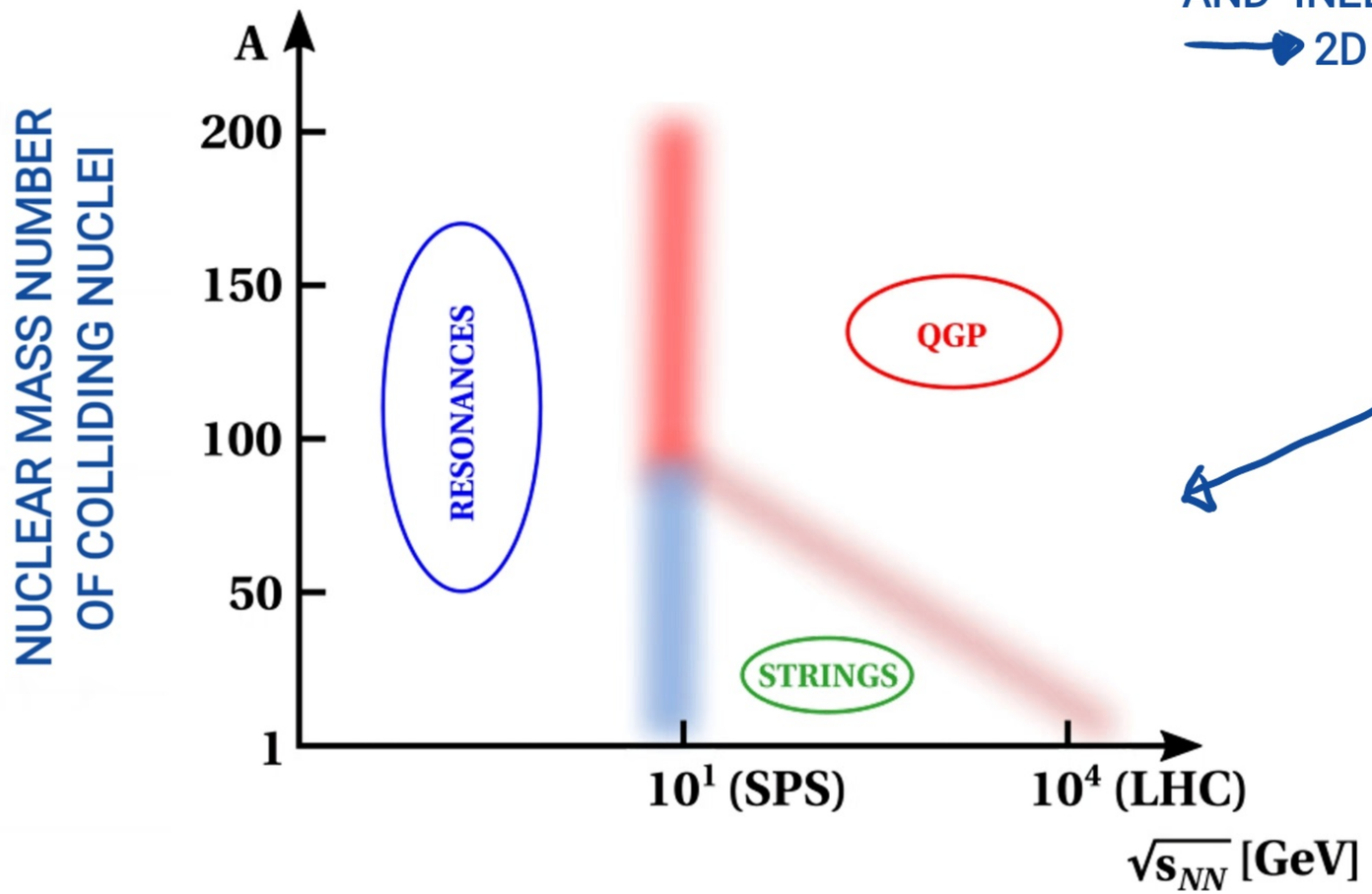
- DEFINITIONS
- IDEAS AND DATA
- DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS



# DEFINITIONS: DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS

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

THE EXAMPLE DISCUSSED HERE: ONLY CENTRAL A+A COLLISIONS
AND INELASTIC p+p INTERACTIONS
→ 2D PLOT




HADRON PRODUCTION PROCESSES

COLLISION ENERGY



ANDRONOV, KUICH, MG
2205.06726

# DEFINITIONS: HADRON PRODUCTION PROCESSES

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

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

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

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

# DEFINITIONS: QUANTITATIVE MODELS

TWO POPULAR MODELS OF HIGH-ENERGY NUCLEAR COLLISIONS
COVERING THE DATA RANGE IN COLLISION ENERGY AND NUCLEAR-MASS NUMBER:

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, $K^+/\pi^+$

- APPROXIMATELY PRPORTIONAL TO THE RATIO OF (ANTI-)STRANGE QUARKS TO ENTROPY

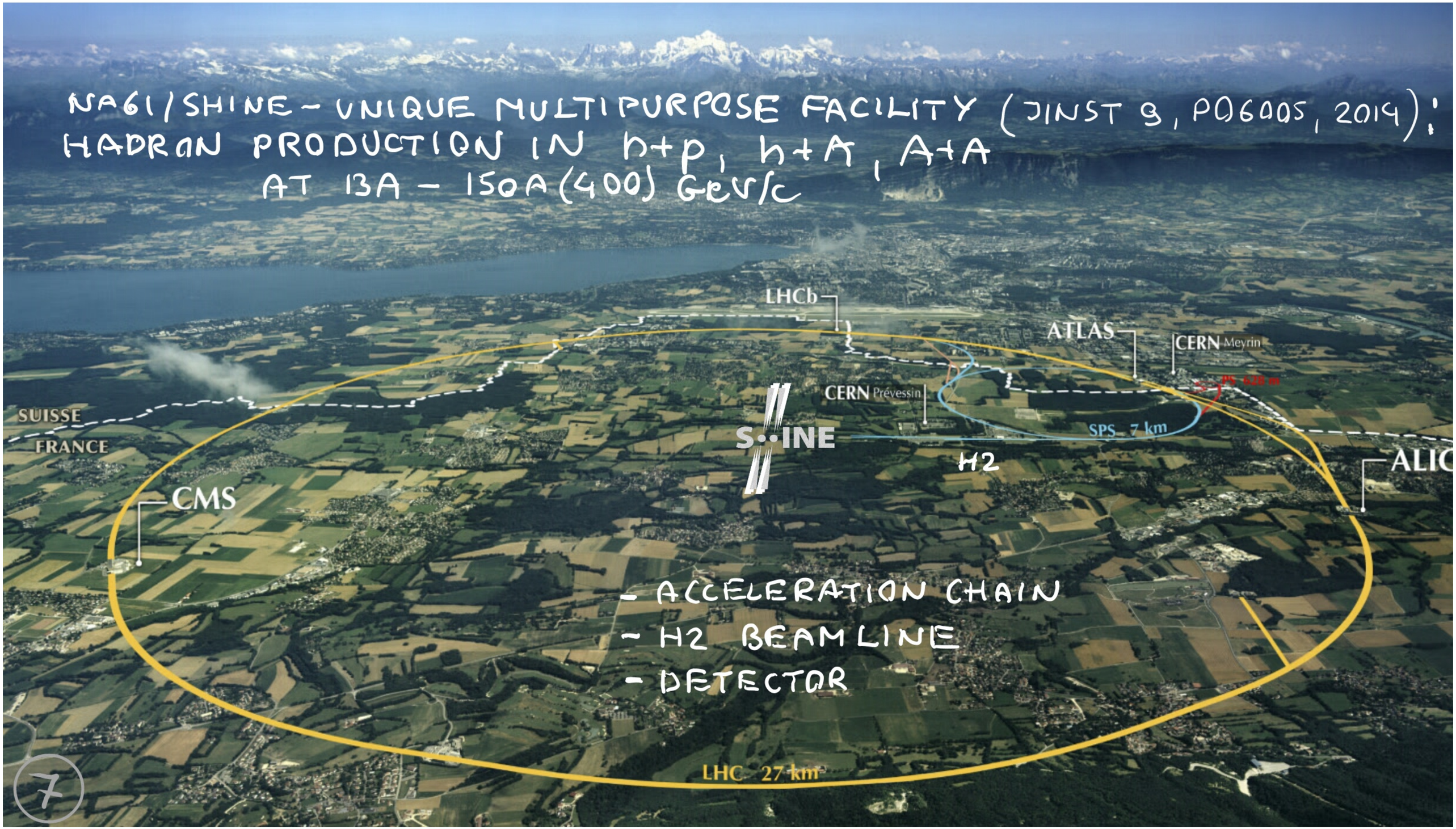
- SENSITIVE TO HADRON-PRODUCTION PROCESSES DUE TO MASS AND NUMBER DIFFERENCES BETWEEN STRANGE AND NON-STRANGE PARTICLES - QUARKS AND GLUONS OR HADRONS

RAFELSKI, MULLER
PRL 48, 1066 (1982)

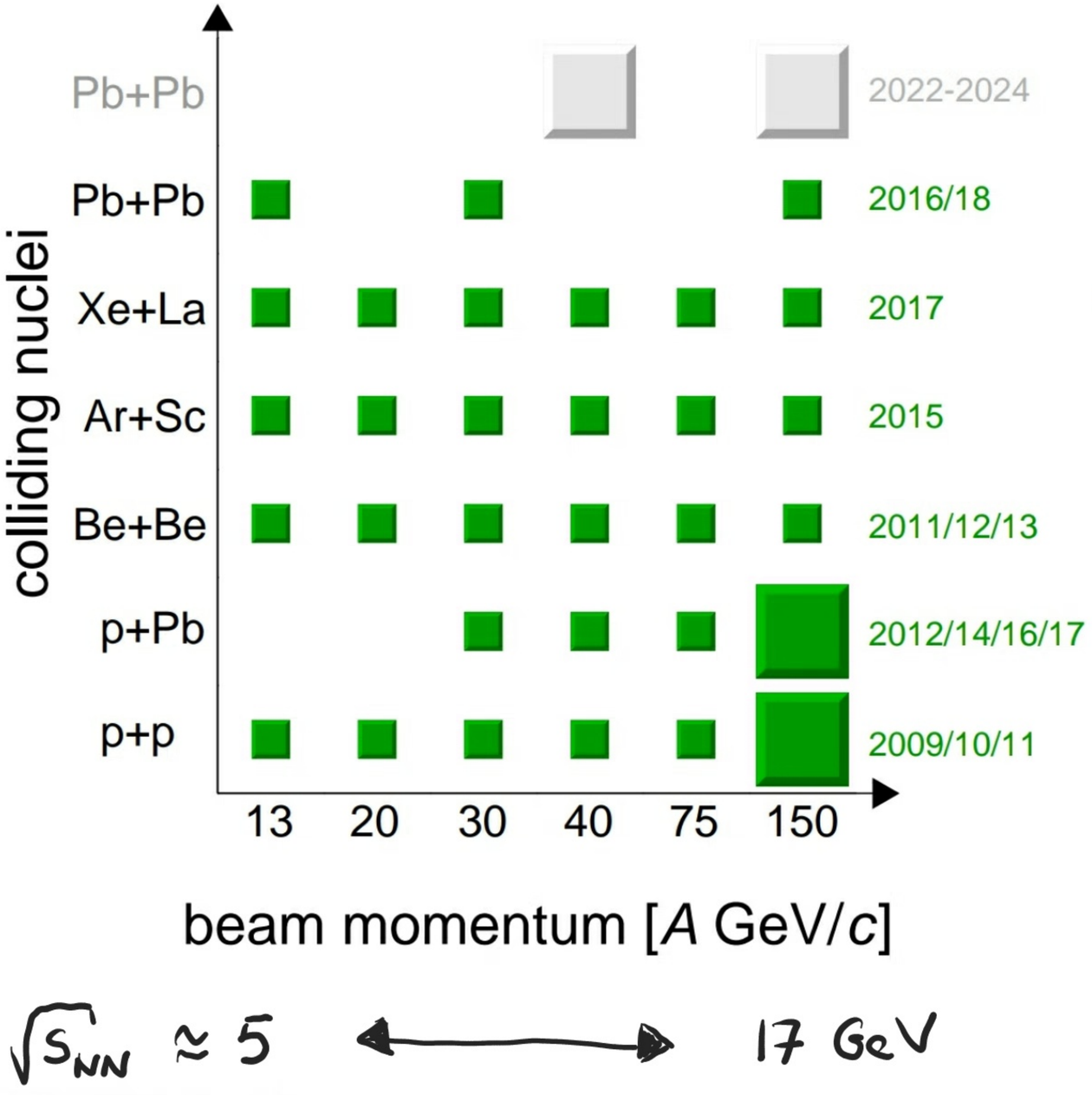
MG, GORENSTEIN
APP B 30, 2705 (1999)

- RICH EXPERIMENTAL DATA IN HIGH-ENERGY NUCLEAR COLLISIONS

# DEFINITIONS: NA61/ SHINE



# DEFINITIONS: NA61/SHINE DATA ON HIGH-ENERGY NUCLEAR COLLISIONS

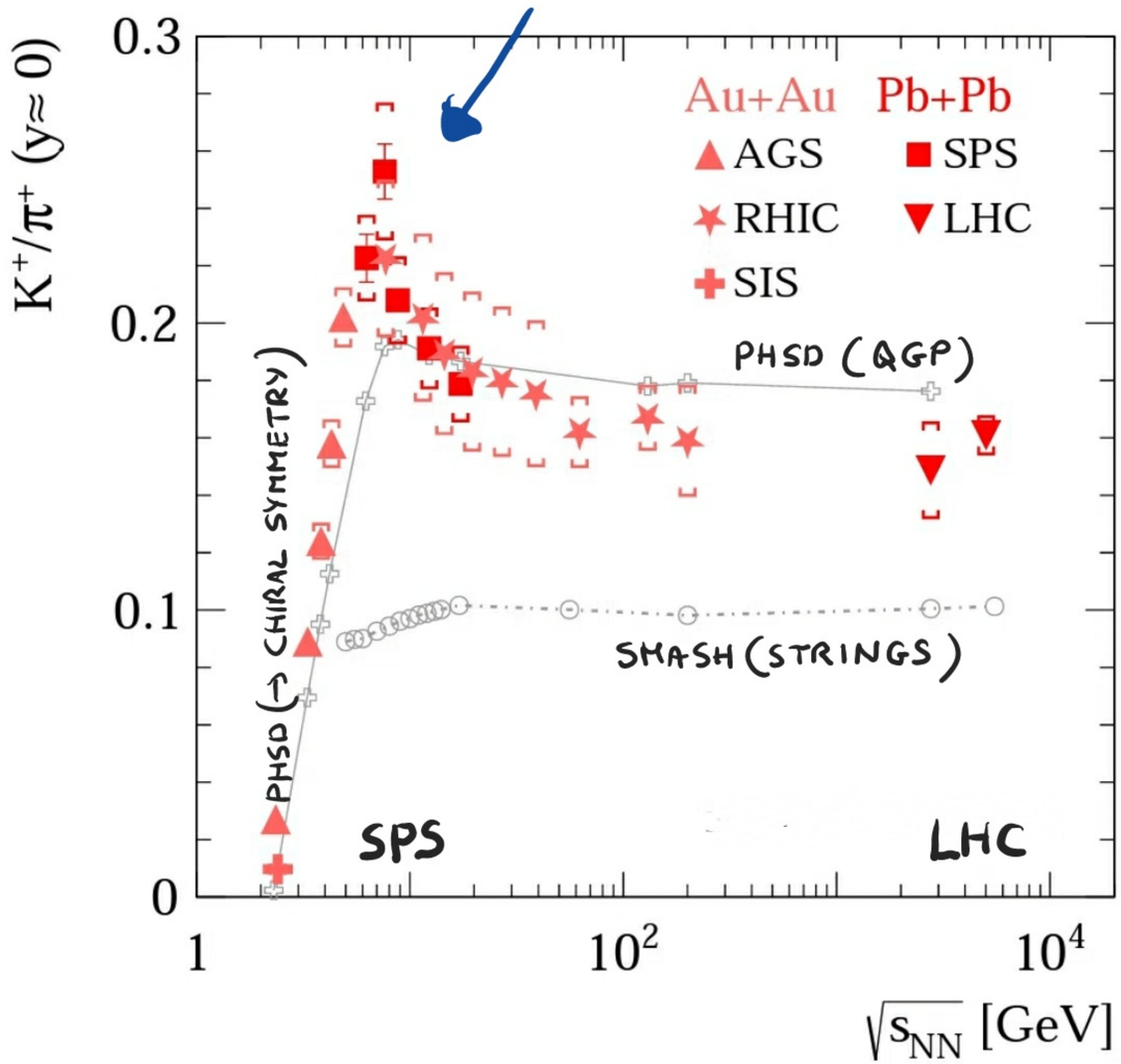



UNIQUE INPUT TO ESTABLISH DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS

$\sqrt{s_{NN}} \approx 5$ ⟷ 17 GeV

# IDEAS AND DATA: HEAVY- ION COLLISIONS

THE HORN STRUCTURE




NA49, PRC 66, 054902

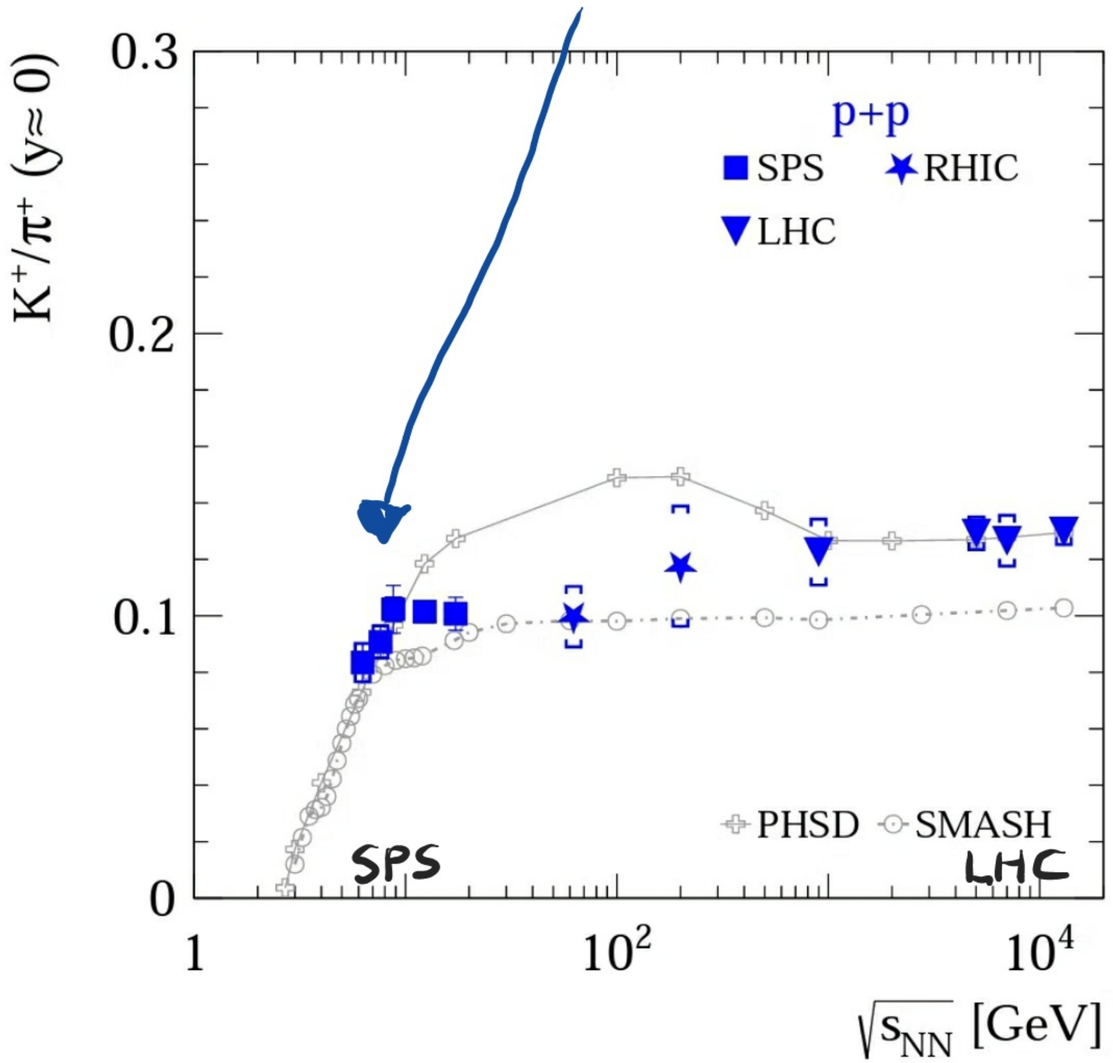
RESONANCES - QGP CHANGEOVER (ONSET OF DEECONFINEMENT)

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



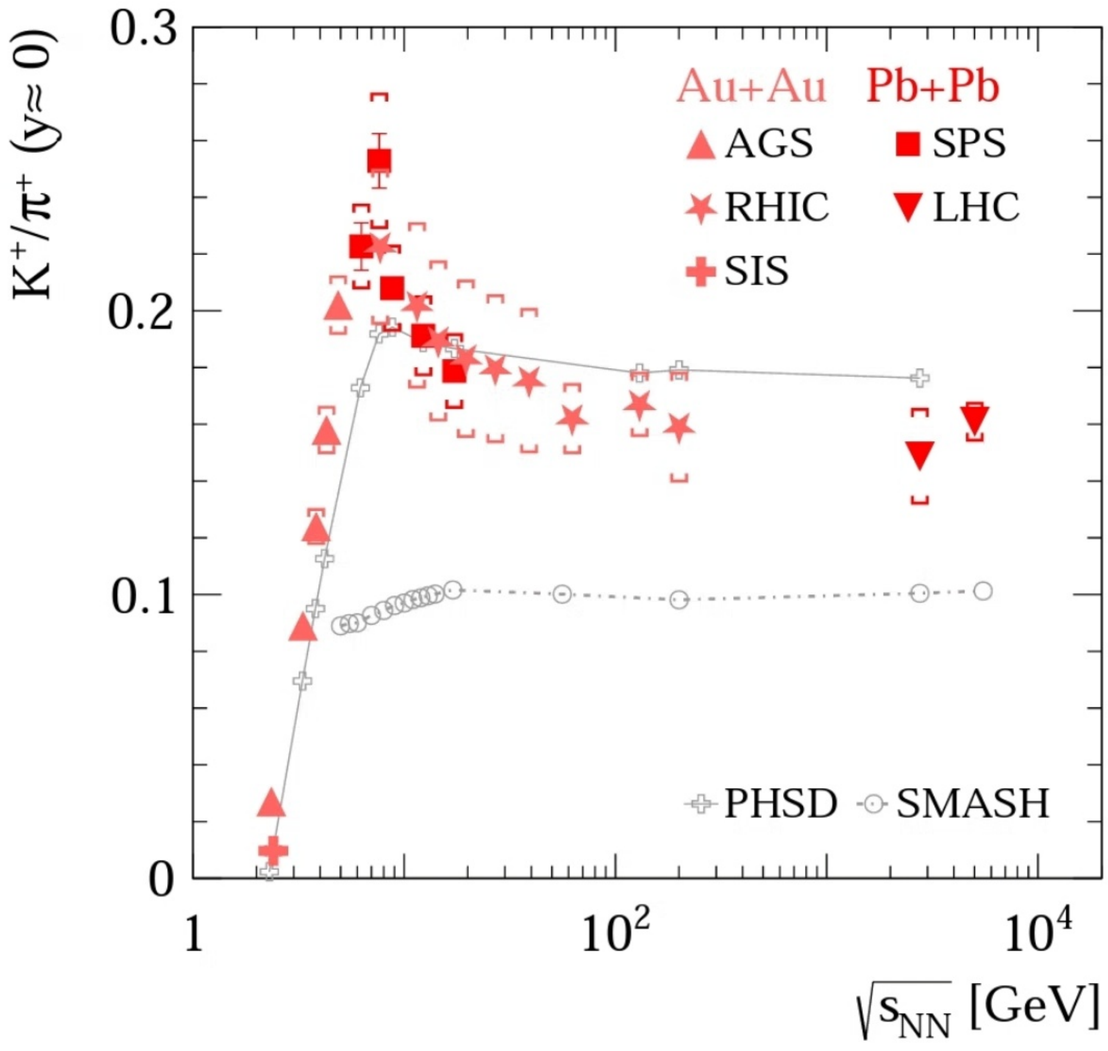

NA61/SHINE, PRC 102, 011901 (2020)

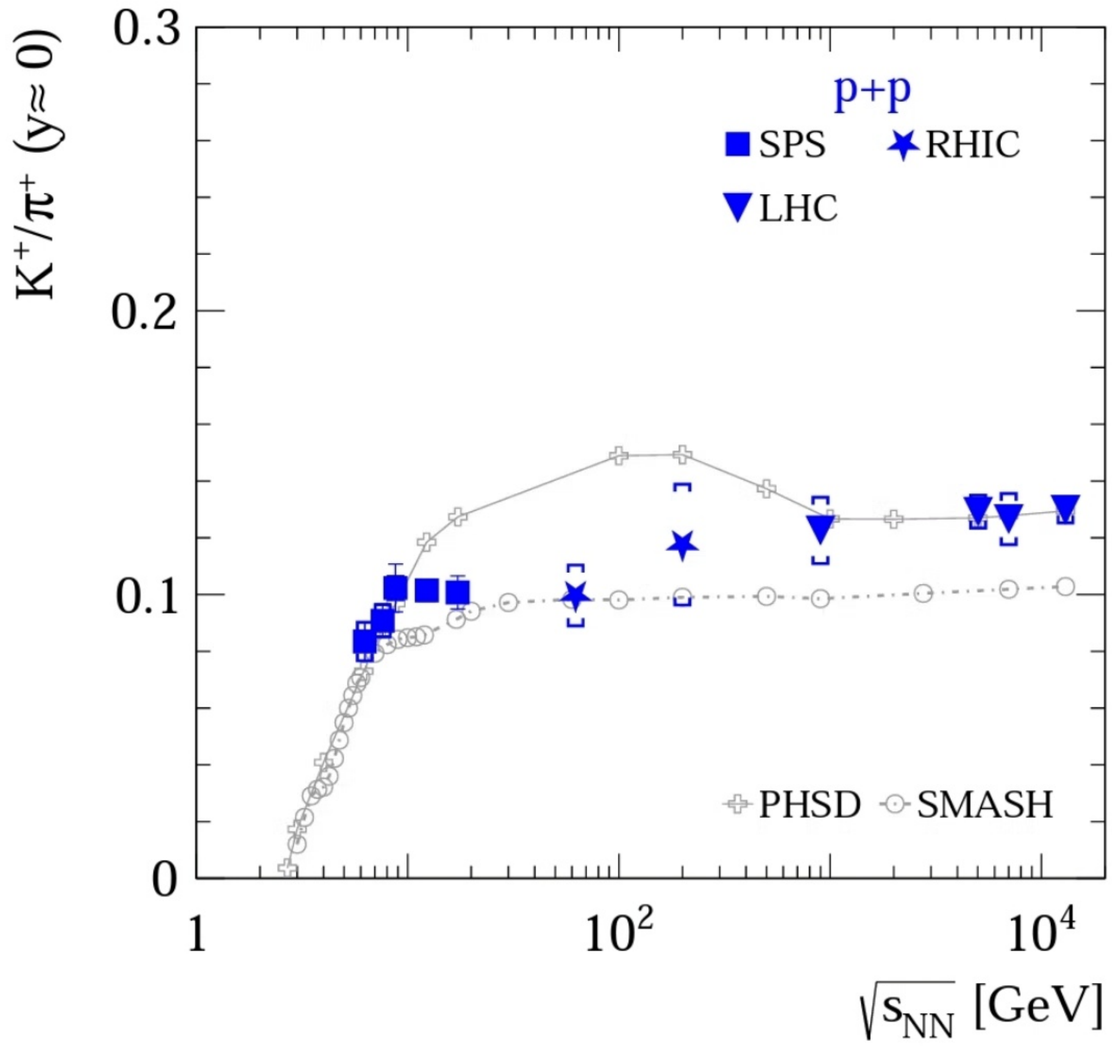
## RESONANCES-STRINGS CHANGEOVER

SMASH AND PHSD INCLUDE RESONANCES-STRINGS CHANGEOVER, BUT LOCATE IT AT LOWER ENERGIES (3-4 AND 2.6 GeV)

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

# IDEAS AND DATA: Pb+Pb vs p+p

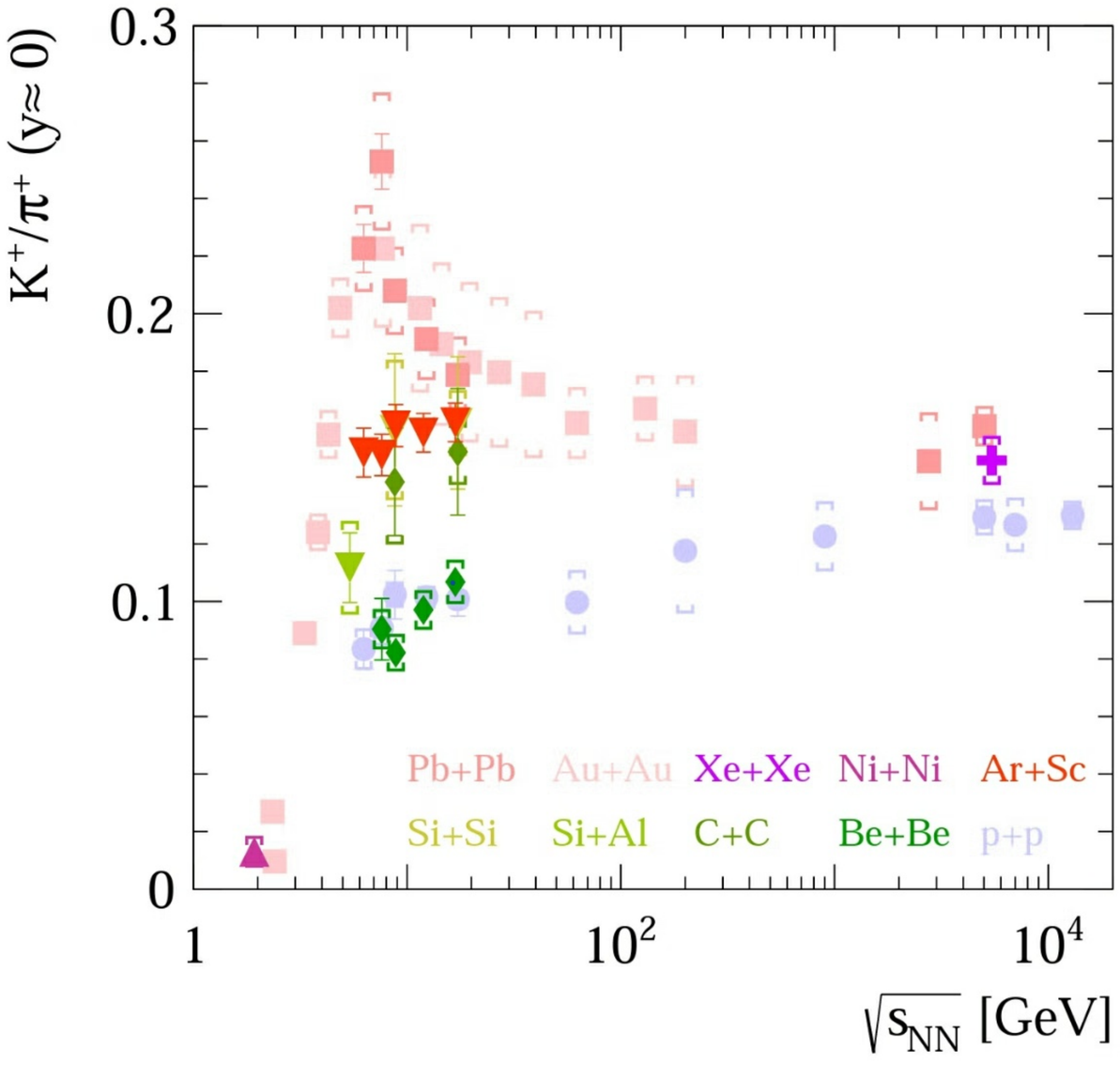



VERY DIFFERENT ENERGY DEPENDENCE

→ 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 THE TOP SPS

NO HORN IN Ar + Sc

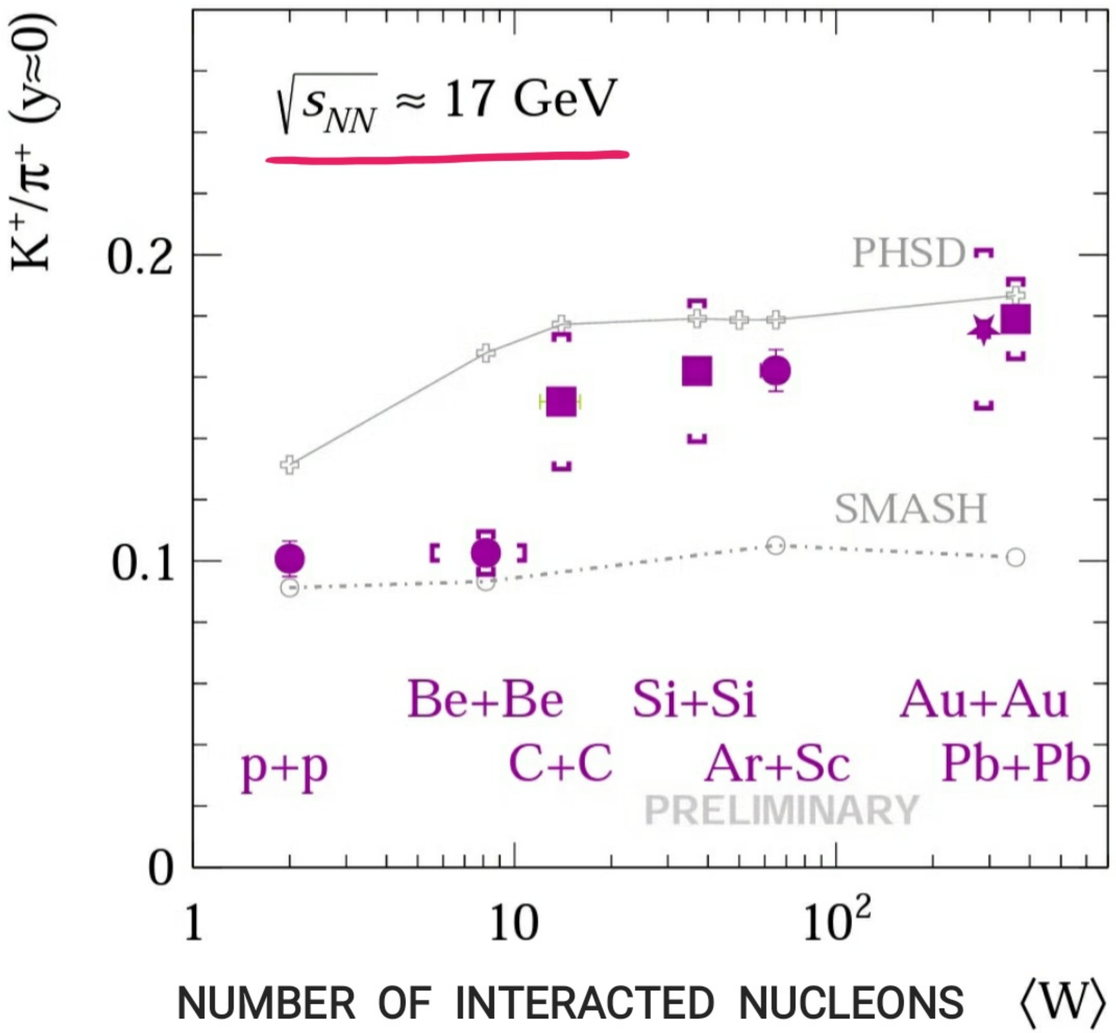
NA61/SHINE:
EPJ C81, 397 (2021)

p + p ≈ Xe + Xe ≈ Pb + Pb AT LHC

ALICE
NATURE PHYS. 13, 535 (2017)

2 → QGP IN p + p AT LHC

# IDEAS AND DATA: COLLISIONS OF INTERMEDIATE MASS NUCLEI



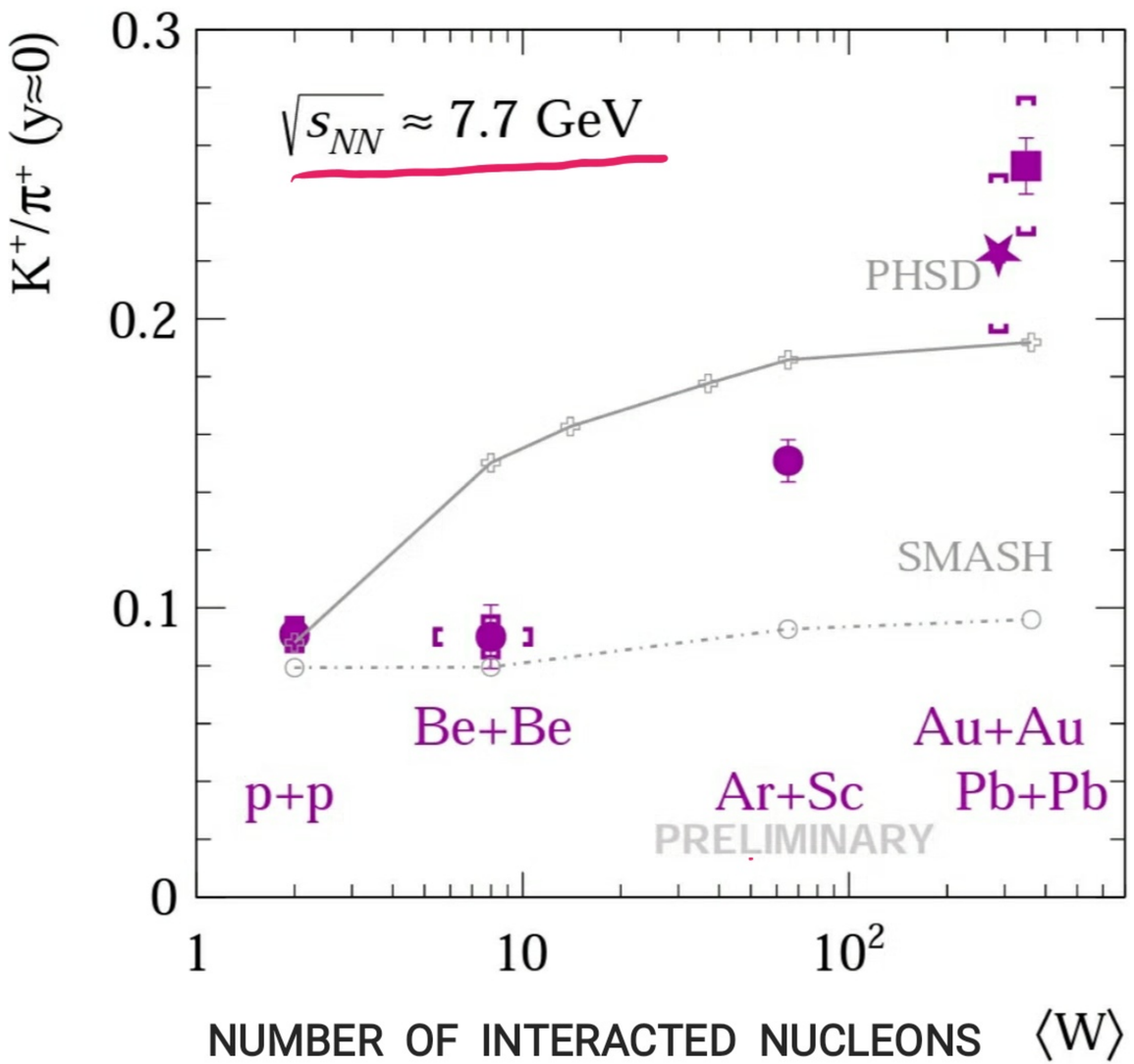

JUMP BETWEEN p + p, Be + Be AND Ar + Sc, Pb+ Pb AT THE TOP SPS ENERGIES

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



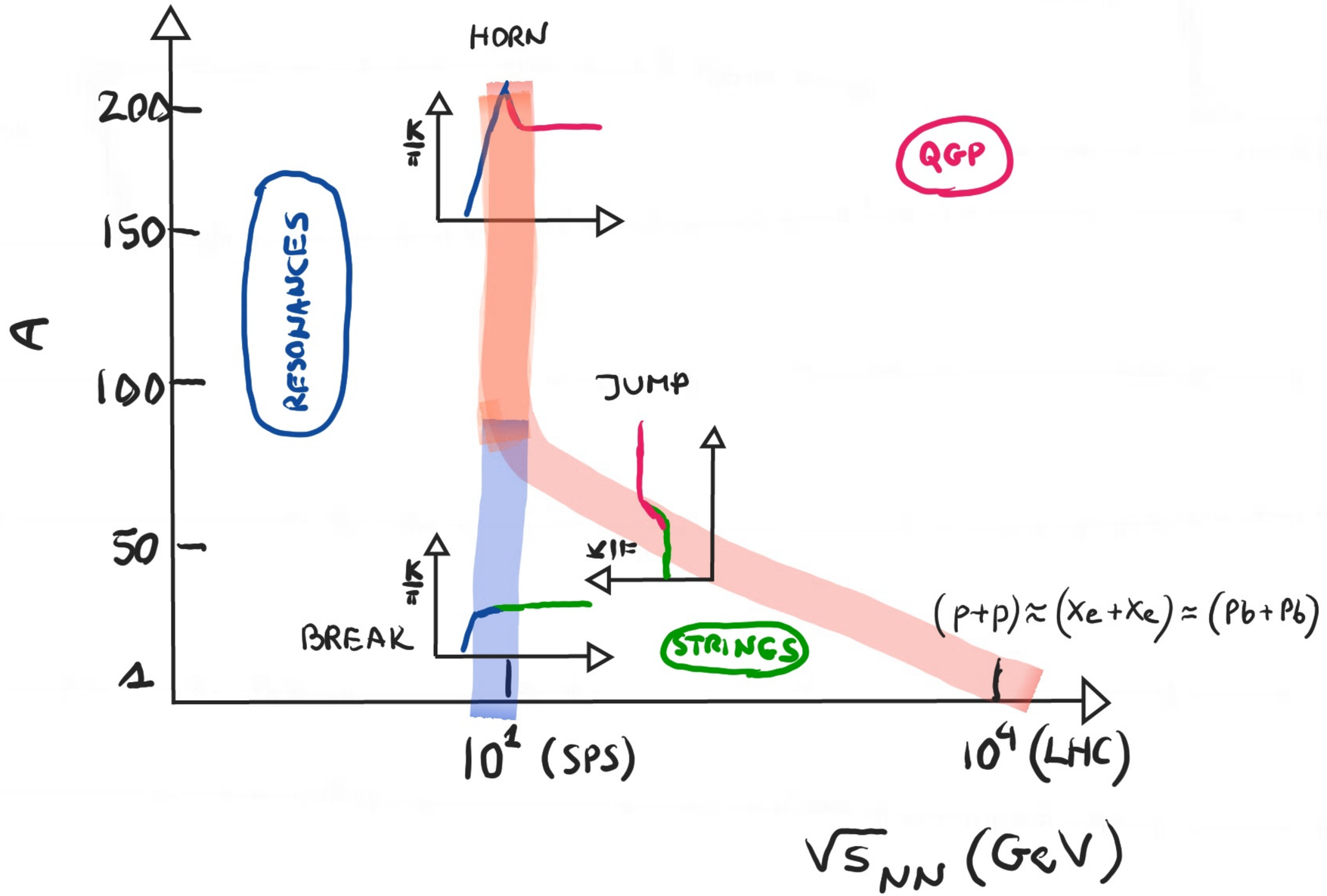

SMOOTH INCREASE BETWEEN
Be + Be, Ar + Sc AND Pb + Pb
AT THE LOW SPS ENERGIES

POSSIBLY DUE TO:

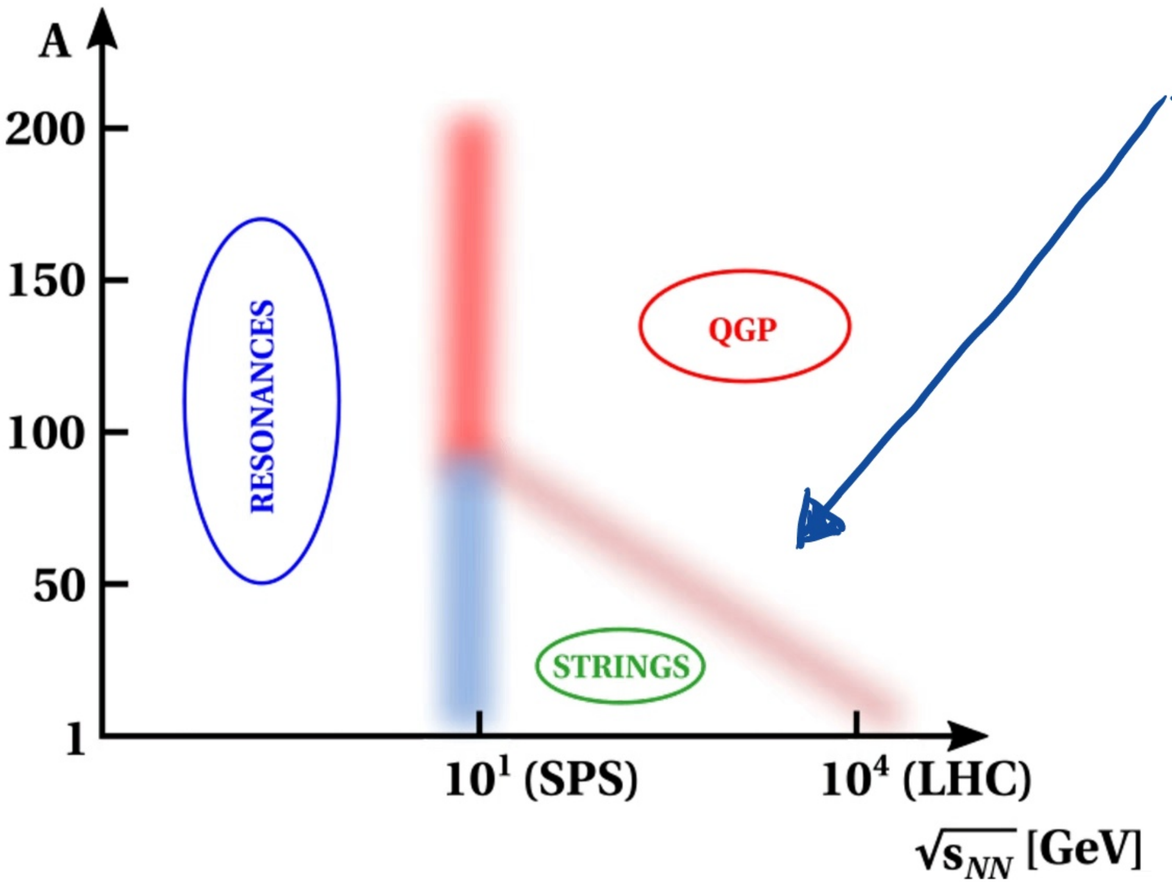
- APPROACHING EQUILIBRIUM WITH INCREASING <W> AND SYSTEM LIFE-TIME
- WEAKENING OF CANONICAL STRANGENESS SUPPRESSION WITH INCREASING <W>
- INCREASING ROLE OF CHIRAL-SYMMETRY RESTORATION

# DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS

CARTOON



# DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS ON FUTURE MEASUREMENTS




TO ESTABLISH COLLISION-ENERGY DEPENDENCE OF THE STRINGS-QGP CHANGEOVER

PRECISION DATA ON COLLISIONS OF LIGHT AND MEDIUM-MASS NUCLEI AT CERN SPS, FIXED-TARGET LHC AND LHC ARE NEEDED

MEASUREMENTS WITH OXYGEN BEAM ARE PLANNED IN 2024 BY LHC EXPERIMENTS AND NA61/SHINE AT SPS

POST-LS3 MEASUREMENTS WITH LIGHT AND MEDIUM-MASS NUCLEI ARE DISCUSSED