NA61/SHINE program beyond 2020

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for the NA61/SHINE Collaboratıon

II International Workshop on Simulations of HIC for NICA energies,
Dubna, 16 - 18 April, 2018

Super Proton Synchrotron Heavy Ion and Neutrino Experiment

Institute of Radiation Problems, Azerbaijan
Faculty of Physics, University of Sofia, Bulgaria
Ruder Boskovic Institute, Croatia
LPNHE, University of Paris VI and VII, France
Karlsruhe Institute of Technology, Germany
Fachhochschule Frankfurt, Germany
Institut für Kernphysik, Goethe-Universität, Germany
Nuclear and Particle Physics Division, University of Athens, Greece
Wigner RCP, Hungary
Institute for Particle and Nuclear Studies (KEK), Japan
University of Bergen, Norway
Institute of Physics, Jan Kochanowski University, Poland
National Center for Nuclear Research, Poland
Institute of Physics, Jagiellonian University, Poland
Institute of Physics, University of Silesia, Poland
Faculty of Physics, University of Warsaw, Poland
Department of Physics and Astronomy, University of Wroclaw, Poland
Faculty of Physics, Warsaw University of Technology, Poland
Institute for Nuclear Research, Russia
Joint Institute for Nuclear Research, Russia
St. Petersburg State University, Russia
National Research Nuclear University, Russia
University of Belgrade, Serbia
ETH Zürich, Switzerland
University of Bern, Switzerland
University of Geneva, Switzerland
University of Colorado Boulder, USA
Los Alamos National Laboratory, USA
Department of Physics and Astronomy, University of Pittsburgh, USA
Fermilab, Neutrino Division, USA

NA61/SHINE – about

❖ Located at the CERN SPS

❖ Successor of NA49

❖ Large acceptance spectrometer for fixed target experiment on primary (ions) and secondary (ions, hadrons) beams

❖ Data taking since 2009

❖ NA61/SHINE is the second largest non-LHC experiment at CERN

Physics program

Strong interactions program

•search for the critical point of strongly interacting matter
•study of the properties of the onset of deconfinement
•study high p T particles production (energy dependence of nuclear modification factor)

Hadron-production measurements for neutrino experiments

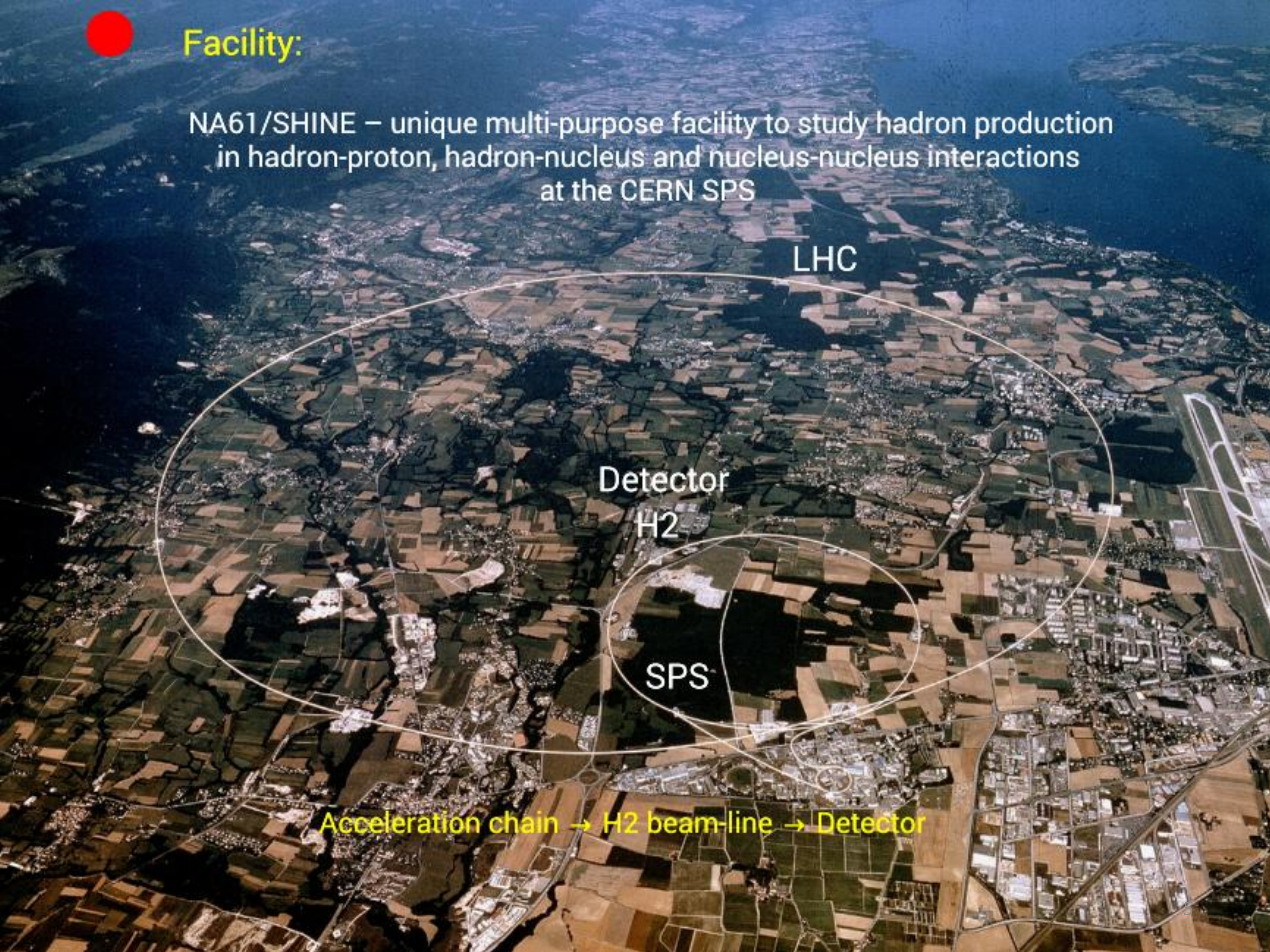
•reference measurements of p+C interactions for the T2K experiment for computing initial neutrino fluxes at J-PARC

Hadron-production measurements for cosmic ray experiments

•reference measurements of p+C, p+p, π+C, and K+C interactions for cosmic-ray physics (Pierre-Auger and KASCADE experiments) for improving air shower simulations

Facility:

NA61/SHINE – unique multi-purpose facility to study hadron production in hadron-proton, hadron-nucleus and nucleus-nucleus interactions at the CERN SPS



Acceleration chain → H2 beam-line → Detector

HIC programs @ SPS energy range

- RHIC Beam Energy Scan (BNL, Brookhaven),
- NICA (JINR, Dubna),
- SIS-100/300 (FAIR GSI, Darmstadt)
- NA61/SHINE (CERN)

HIC programs to perform a two-dimensional scan in beam momentum and mass number of colliding nuclei

- NA61/SHINE (CERN)

NA61/SHINE is a fixed target experiment
the acceptance of NA61 starts from P_T = 0 MeV/c

This gives

- *better analysis of spectra*
- *better analysis of fluctuations due to the CP (critical point), which show up mainly in low p_T particles*

NA61/SHINE Facility

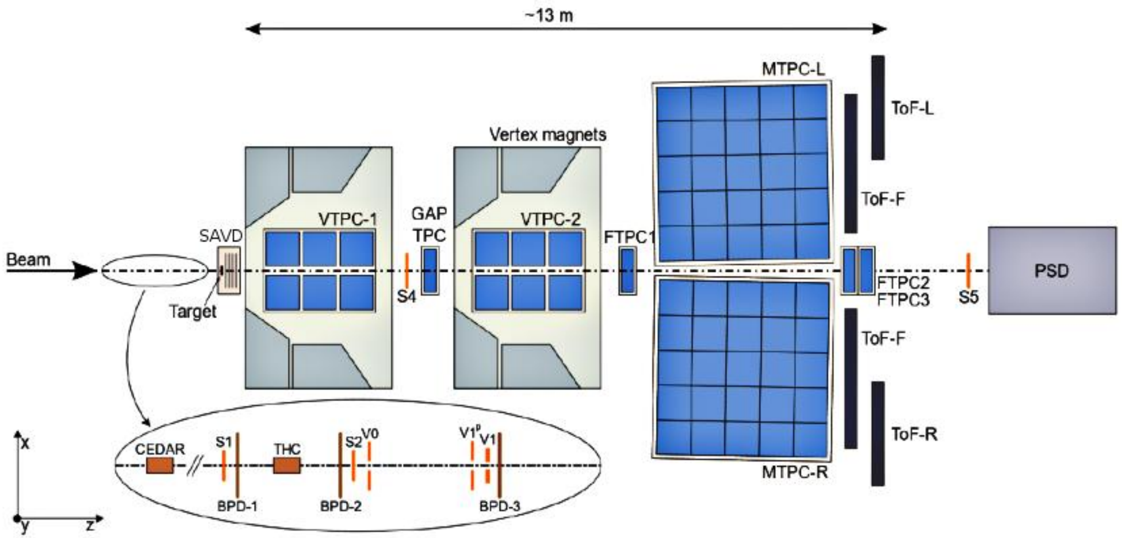
Acceleration chain → H2 beam-line → **Detector** + SAVD

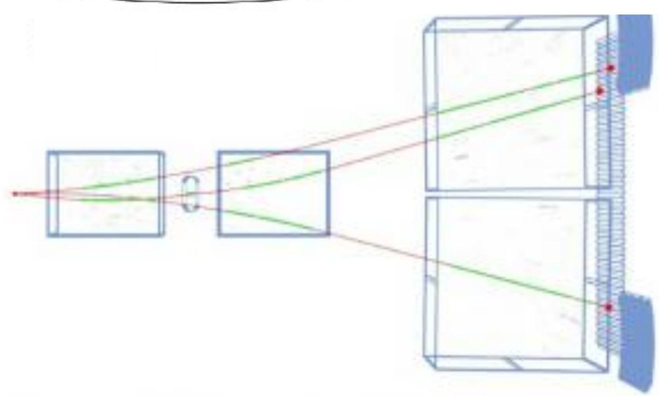
Commissioned December 2016

A small acceptance vertex detector

NA61/SHINE detector

SPS H2





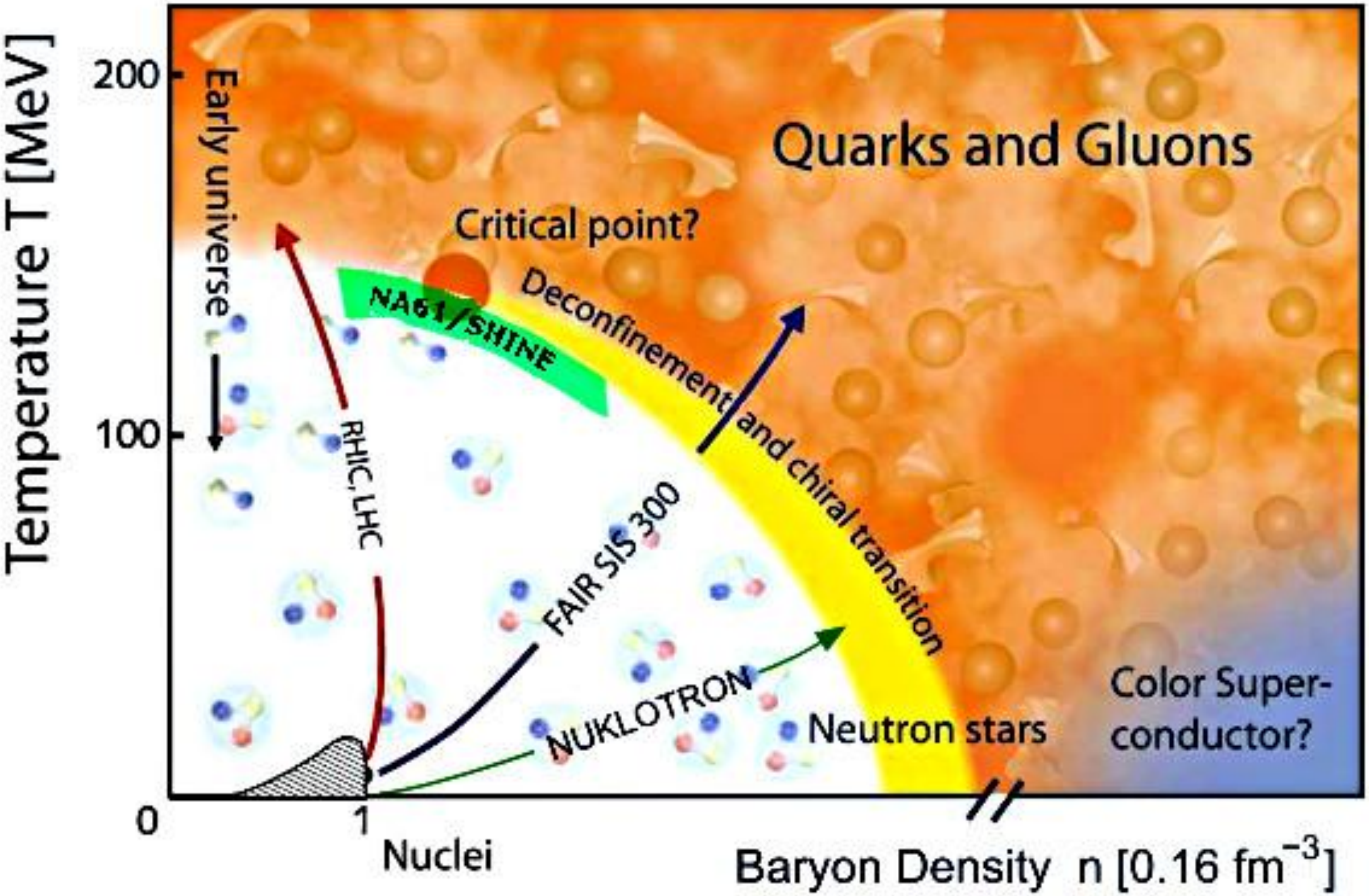
(p+p interaction at 40 GeV/c measured in the NA61/SHINE detector)

A large acceptance hadron spectrometer

Beam particles measured in set of counters and MWPC detectors

Charged tracks measured in set of 5 **TPCs** → measurement of q, p and identification via dE/dx

- 3 ToF walls: identification via time of flight measurement
- **Projectile Spectator Detector** counts the non-interacting nucleons of the beam particle


Temperature T [MeV]
200
100
0
Early universe
Quarks and Gluons
Critical point?
NA61/SHINE
Deconfinement and chiral transition
RHIC, LHC
FAIR SIS 300
NUKLOTRON
Neutron stars
Color Super-
conductor?
1
Nuclei
Baryon Density n [0.16 fm^{-3}]

Beams and targets

Possible beams

<u>Hadrons</u>

I. Primary protons at 400 GeV/c
II. Secondary (π,K,p) at 13-350 GeV/c

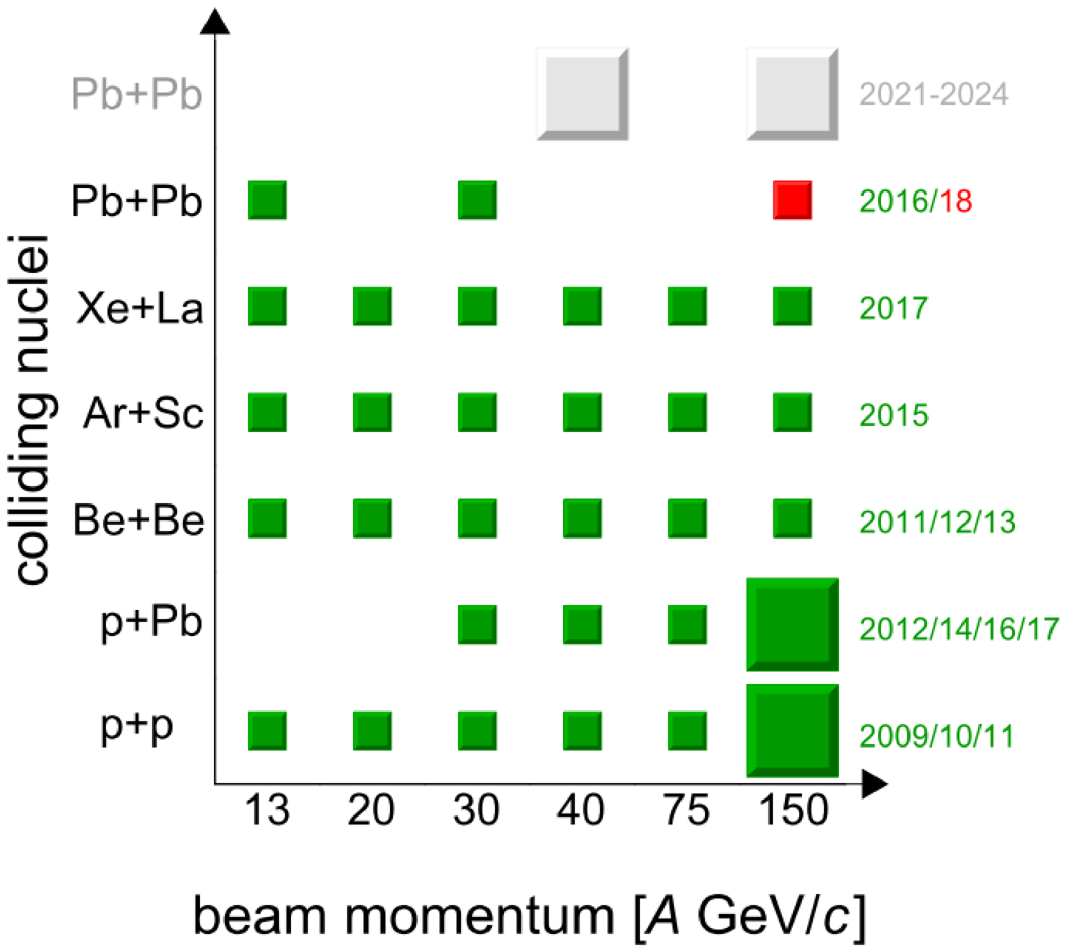
<u>Ions</u>

I. Primary: Ar, Xe, Pb at 13A-150A GeV/c
II. Secondary from Pb fragmentation (e.g. Be) a 13A-150A GeV/c

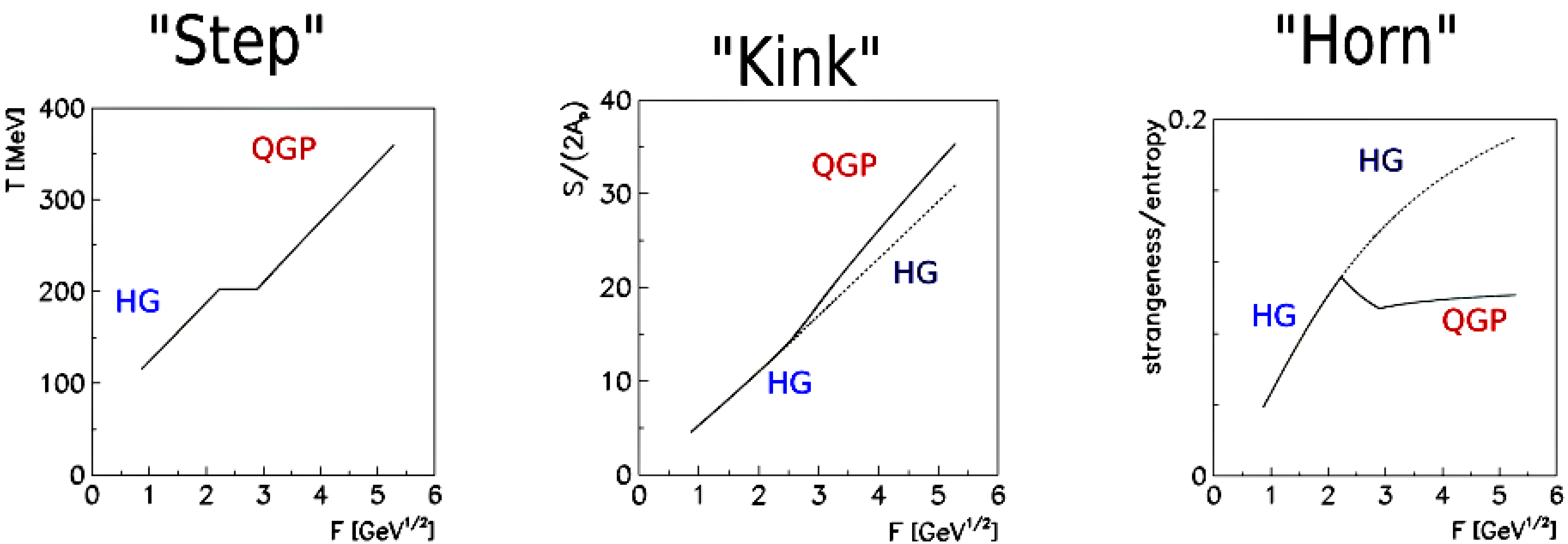
Targets

I. Almost any solid state (from 500 μm to 1 m)
II. Liquid hydrigen (20cm)

Data taking – strong interaction program



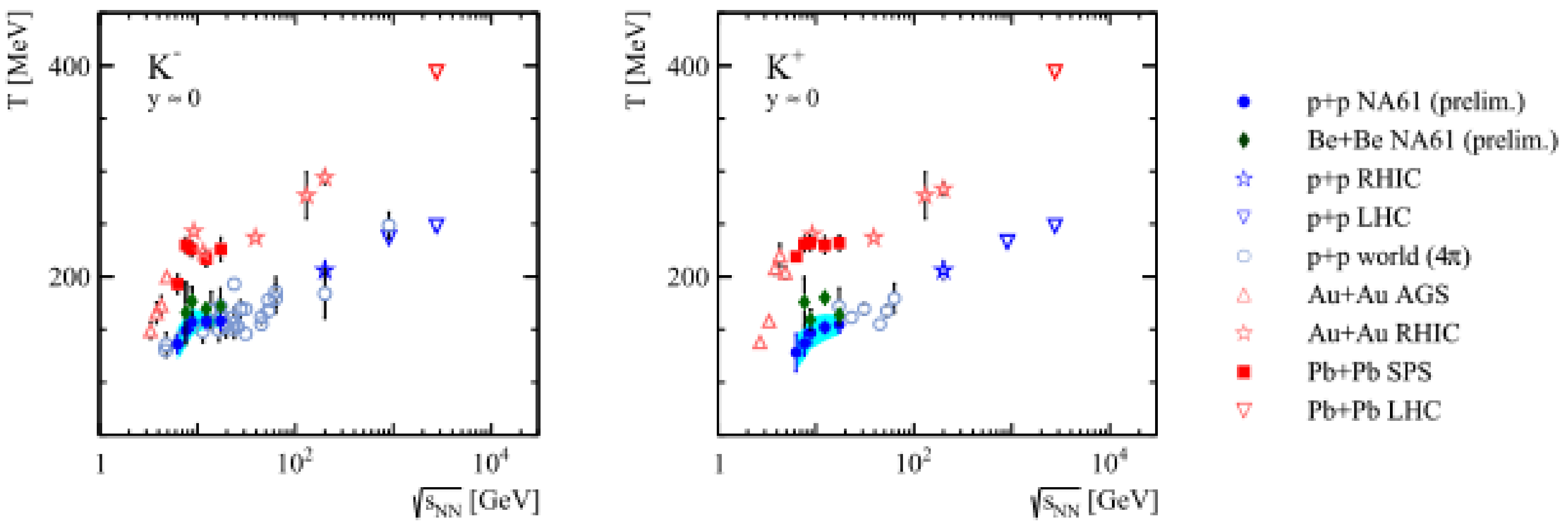
Theoretical predictions of evidences for phase transition at SPS and its volume dependence



$$F \approx \sqrt[4]{s_{NN}}$$

Gazdzicki, Gorenstein, Acta Phys. Polon. B30, 2705 (1999)

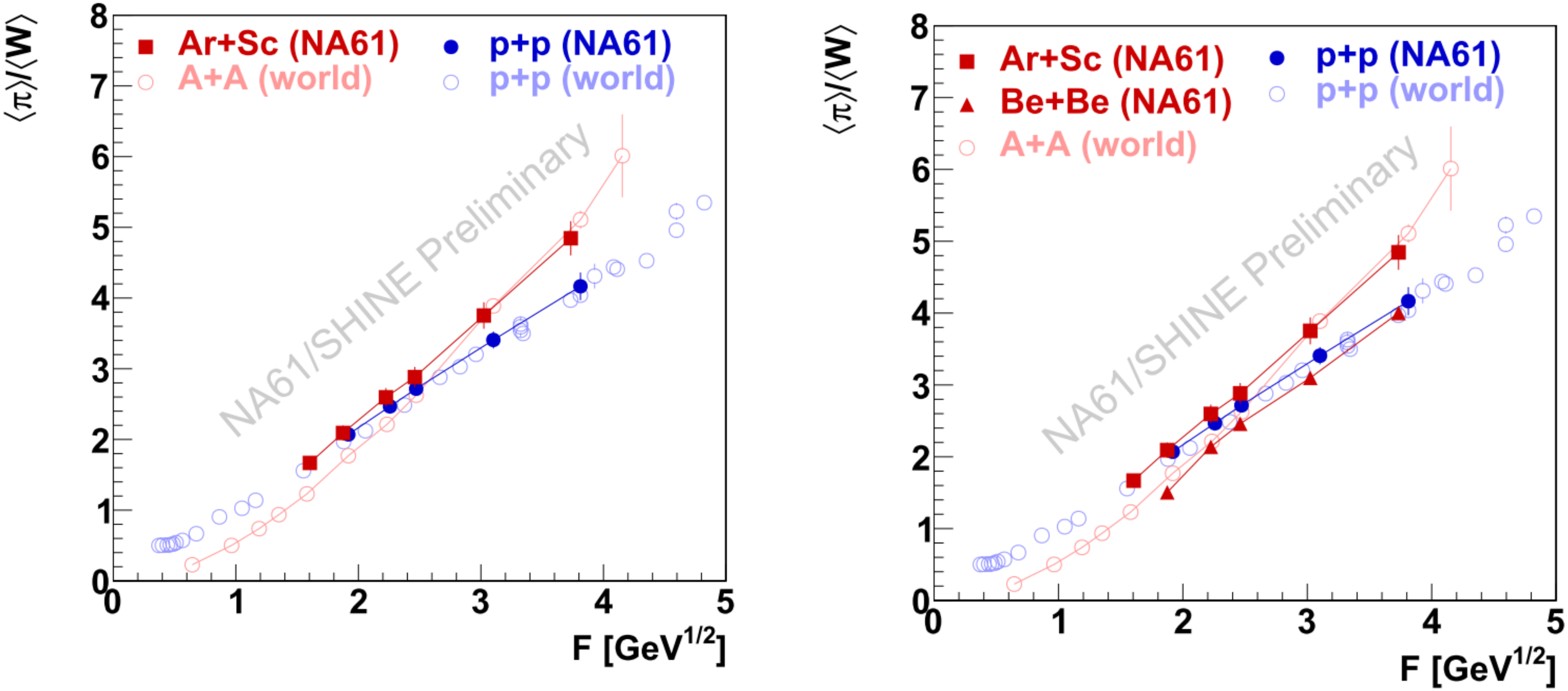
Evidence for phase transition at SPS and its volume dependence - *the Step*



step plots

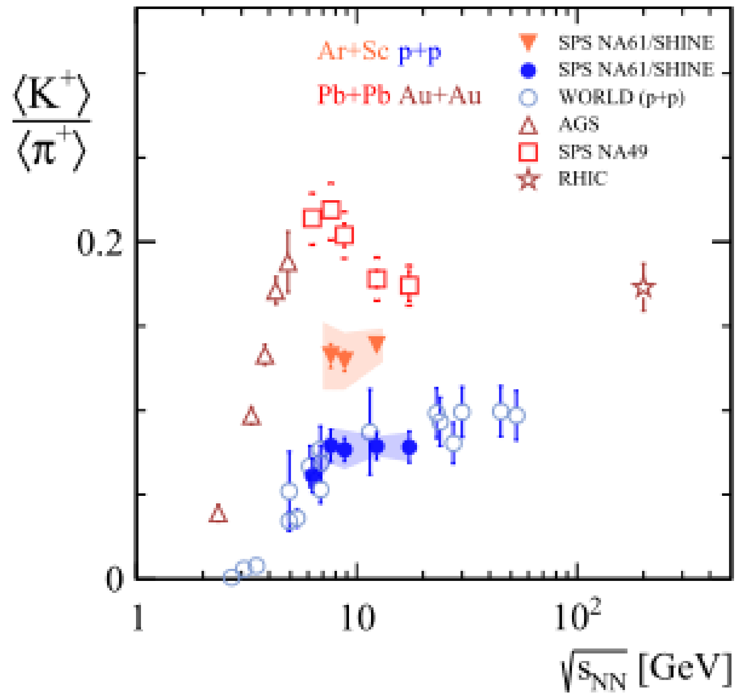
signal the onset of deconfinement located at the low CERN SPS energies

Evidence for phase transition at SPS and its volume dependence – the *Kink*



kink plots

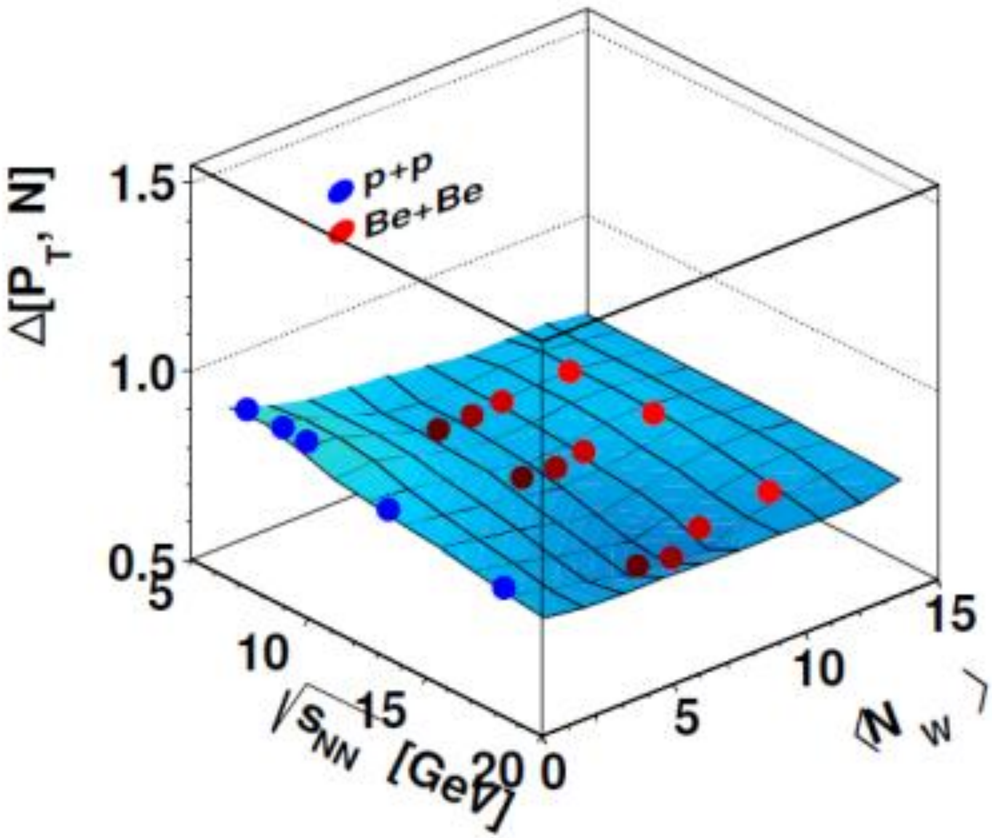
Evidence for phase transition at SPS and its volume dependence – the *Horn*



horn plot

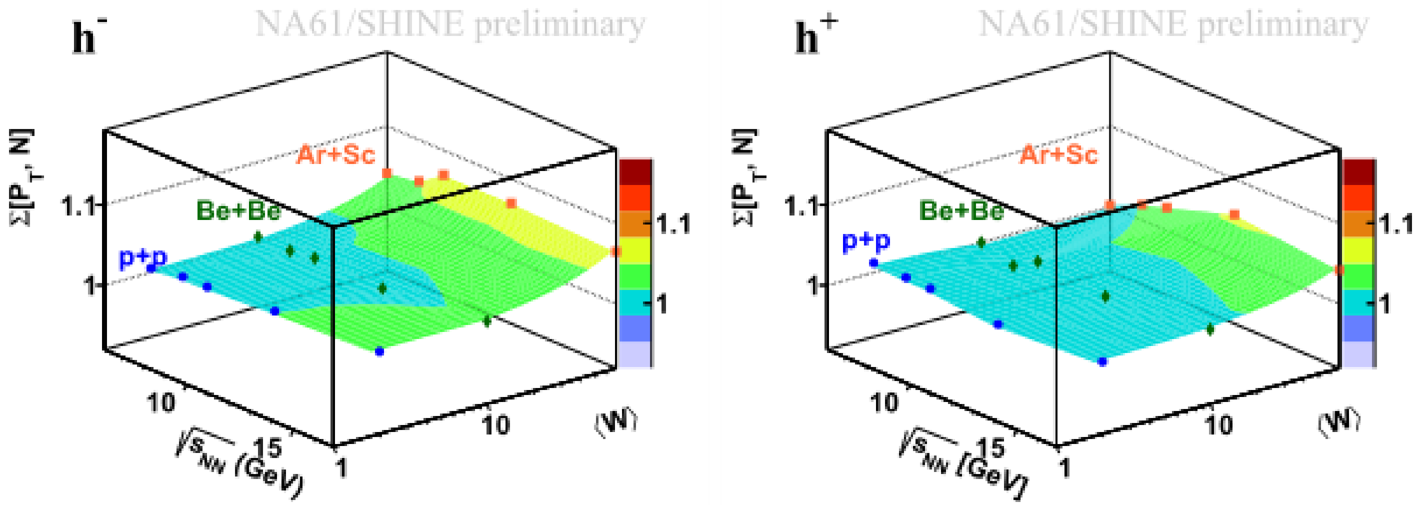
signal the onset of deconfinement located at the low CERN SPS energies

Transverse momentum fluctuations



- Search for the critical point of strongly interacting matter
- No sign of any anomaly that can be attributed to the critical point (neither in p+p nor Be+Be)

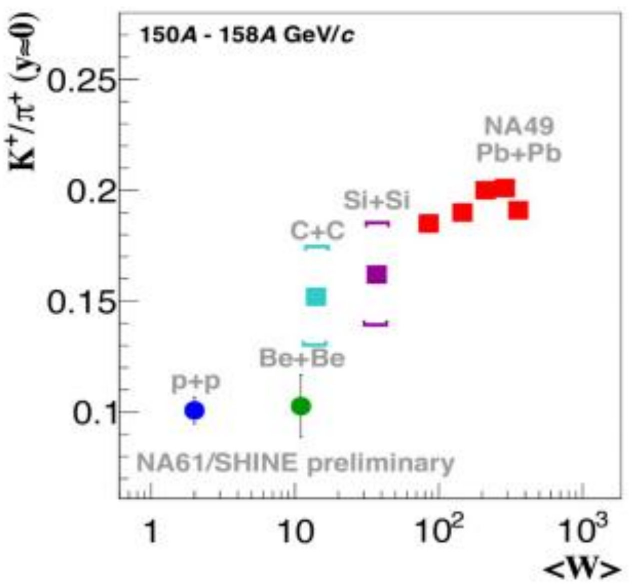
Evidence for phase transition at SPS and its volume dependence - *Transverse momentum fluctuations*



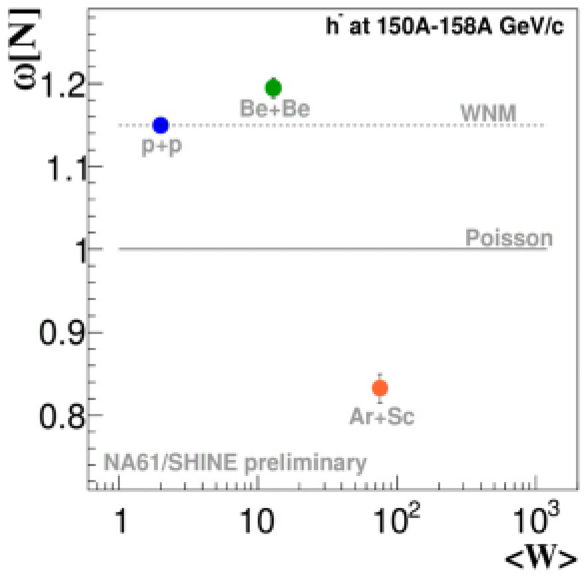
No signs of critical behaviour

Rapid changes in system size dependence

1. Be+Be results are very close to p+p at different collision energies.
2. It seems as cluster (fireball) size rapidly increases – jumps above Be+Be size collisions.



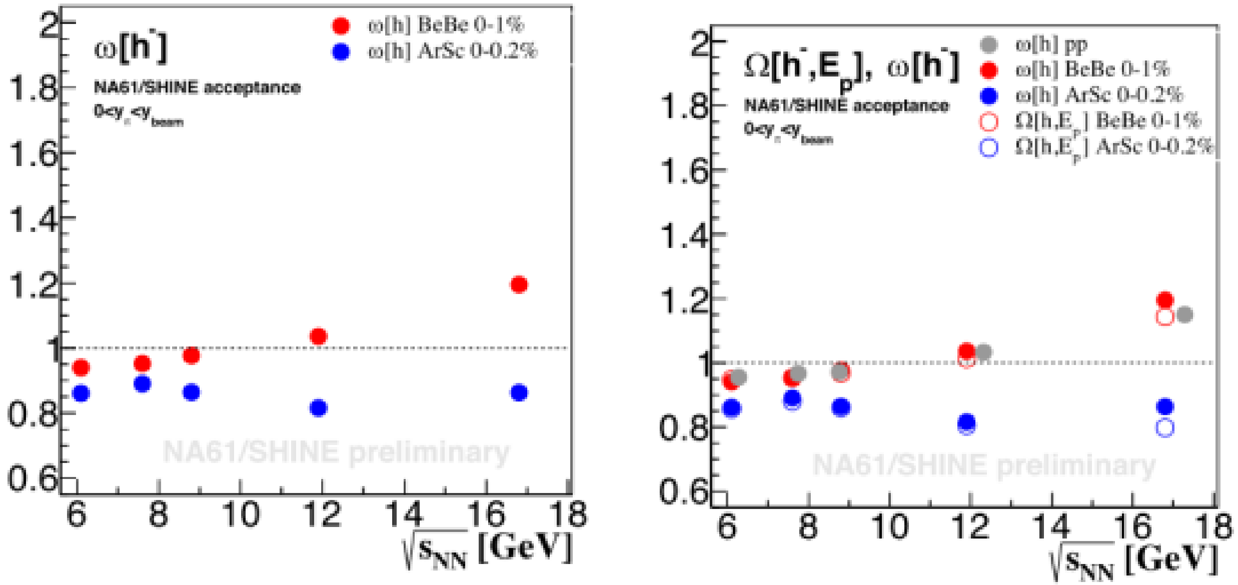
Mean multiplicities ratio



Scaled multiplicity fluctuations

versus mean number of wounded nucleons <W>

Rapid changes in system size dependence



Scaled multiplicity and energy fluctuations of negatively charged hadrons undergo rapid changes between BeBe and ArSc sizes

With the increasing size of colliding systems light clusters are produced more and more copiously, as at some densitythey start to overlap – to reach ***percolation*** threshold.

Effect does not depend on energy – only on the size of the system.

New measurements requested post LS-2

(i) charm hadron production in Pb+Pb collisions for heavy ion physics,
(ii) nuclear fragmentation cross sections for cosmic ray physics
(iii) hadron production in hadron-nucleus interactions for neutrino physics

as NA61/SHINE is the only experiment which could conduct such measurements in the near future. Together with other HIC experiments creates a full-tone physical picture of QCD in dense medium.

Charm hadron production measurements

First data on mean number of $c\bar{c}$ pairs produced **in the full phase space** in heavy ion collisions

Questions to answer:
(i) What is the mechanism of open charm production?
(ii) How does the onset of deconfinement impact open charm production?
(iii) How does the formation of quark-gluon plasma impact J/ψ production?

<u>To do it:</u>
42 days of primary Pb beam at 150A GeV/c for data taking on charm hadron production in Pb+Pb collisions

to begin with in 2022 - the first year after the LS2

Nuclear fragmentation cross section measurements

High-precision data needed for the interpretation of results from current-generation cosmic ray experiments

Questions to answer:

(i) the characteristics of the diffuse propagation of cosmic rays in the Galaxy
(ii) the origin of Galactic cosmic rays
(iii) the cosmic-ray background for signatures of astrophysical dark matter.

<u>To do it:</u>
21 days of secondary light ion beam at 13A GeV/c for data taking on nuclear fragmentation cross section

to begin with in 2022 - the first year after the LS2

New hadron production measurements for neutrino physics

i. Precision of hadron production measurements for the currently used T2K replica target, with special attention to the extrapolation of produced particles to the target surface;
ii. Measurements for a new target material (super-sialon), both in thin target and replica target configurations, for T2K-II and Hyper-Kamiokande;
iii. Measurements at low incoming beam momenta (below12 GeV/c) relevant for improved predictions of both atmospheric and accelerator neutrino fluxes;
iv. Hadron production measurements with prototypes of Hyper-Kamiokande and DUNE targets.

To do it:

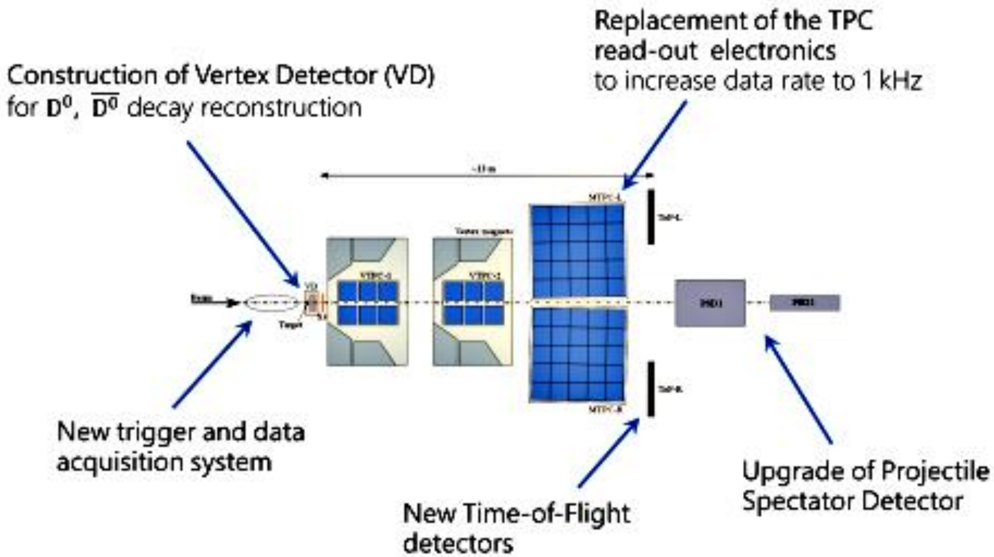
I. 35 days of proton beam at 31 GeV/c for data taking on hadron production from the T2K replica target the Super-Sialon thin target
II. 28 days of K beam at 60 GeV/c for data taking on hadron production induced by K^+ mesons

to begin with in 2022 - the first year after the LS2

Detector upgrades

Requied:

I. Construction of a new Large Acceptance Vertex Detector.
II. Replacement of the TPC read-out electronics.
III. Construction of a new trigger and data acquisition system.
IV. Upgrade of the Projectile Spectator Detector.



Desirable:

The construction of new Time-of-Flight detectors

On the way to the Large Acceptance Vertex Detector

The Small Acceptance VD:

- Commissioned in December 2016
- Vertex resolution enough (30 μm) to distinguish D^0 decay
- Pb+Pb data taking at 150 GeV/c (2016) – test run
- Xe+La data taking at 150 GeV/c (2017) – $5 \cdot 10^6$ events
- Improvement in the primary vertex reconstruction precision (2.5 μm, 1.5 μm, 15 μm)

Fixed target effect!
Lorenz factor ($\beta\gamma \approx 10$)

Data are currently under analysis. One expects to reconstruct several hundred of D^0 and D^0 decays. These statistics could by itself lead to interesting physical results.

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This is just the beginning!