S··INE

NA61/SHINE PLANS FOR 2018 - 2024

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

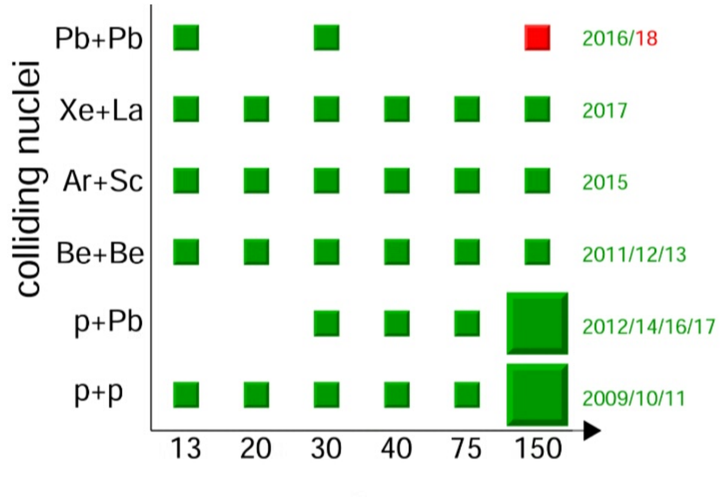
RESULTS FROM DATA RECORDED IN 2009 - 18

NA61/SHINE RECORDED UNIQUE DATA FOR:

- HEAVY ION PHYSICS (ONSET OF DECONFINEMENT, ONSET OF FIREBALL, CRITICAL POINT)

- NEUTRINO PHYSICS (T2K AT J-PARC, FERMILAB EXPERIMENTS)

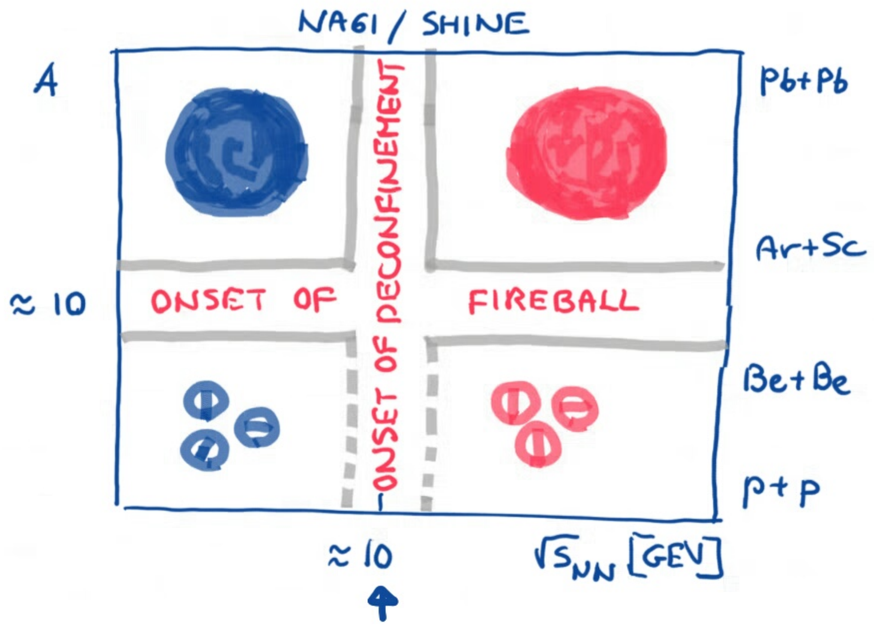
- COSMIC-RAY PHYSICS (EXTENSIVE AIR SHOWERS, AUGER, KASCADE)

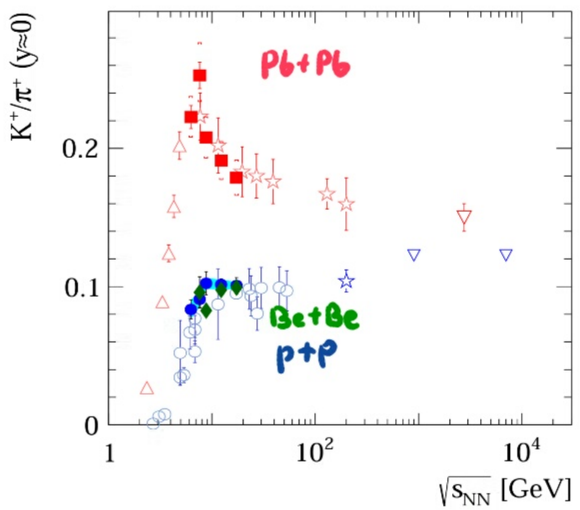


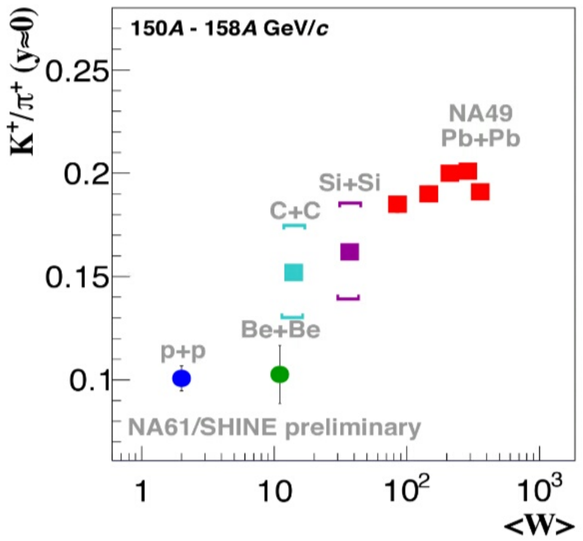
DATA ANALYSIS WILL CONTINUE FOR AT LEAST FIVE YEARS

UNIQUENESS OF HEAVY ION PHYSICS AT THE CERN SPS

ONSET OF DECONFINEMENT AND ONSET OF FIREBALL:







TWO ONSETS AT SPS

UNIQUENESS OF HEAVY ION PHYSICS AT THE CERN SPS:

CRITICAL POINT:

→ 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 POINT POWER LAW DEPENDENCE IS EXPECTED

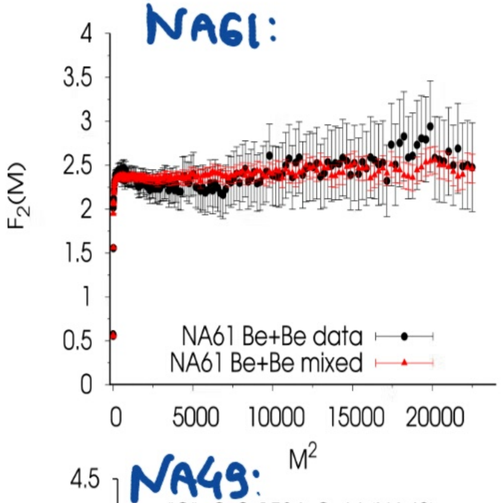
$$F_2(M) = F_2(\Delta) \cdot M^{\phi_2}$$

WOSIEK (1988)
BIALAS, PESZANSKI
SATZ
ANTONIOU, DIAKONOS, KAPOYANIS

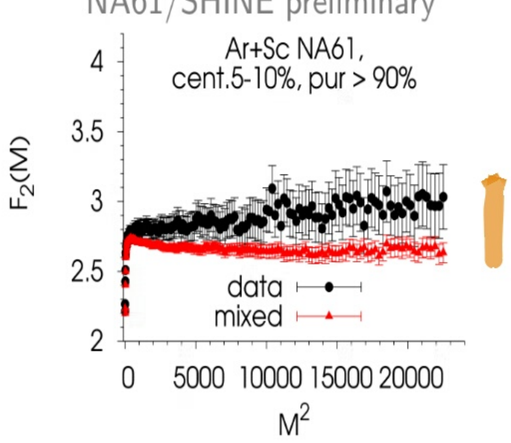
UNIQUENESS OF HEAVY ION PHYSICS AT THE CERN SPS:

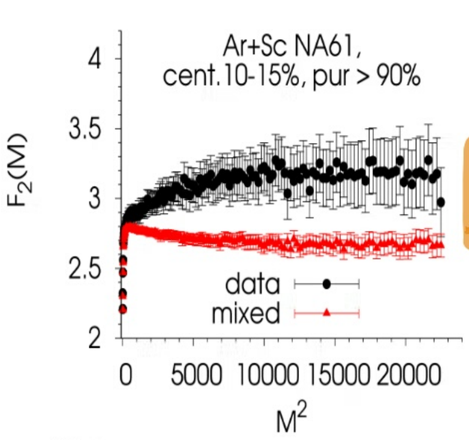
INDICATION OF CP IN Ar+Sc AT 150A GeV/c:

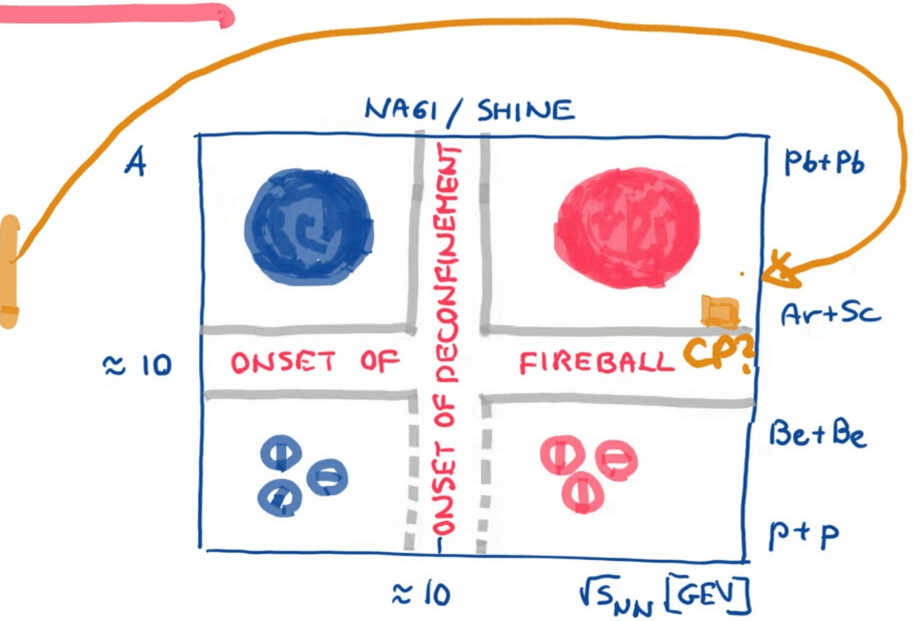
NA61:



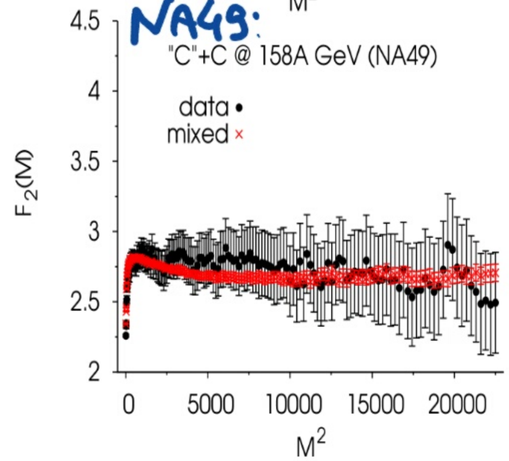
NA61/SHINE preliminary

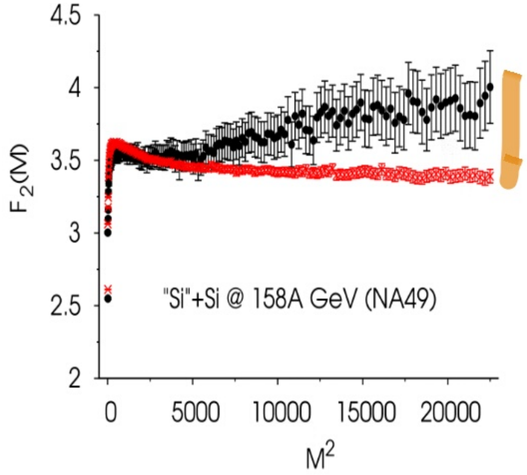


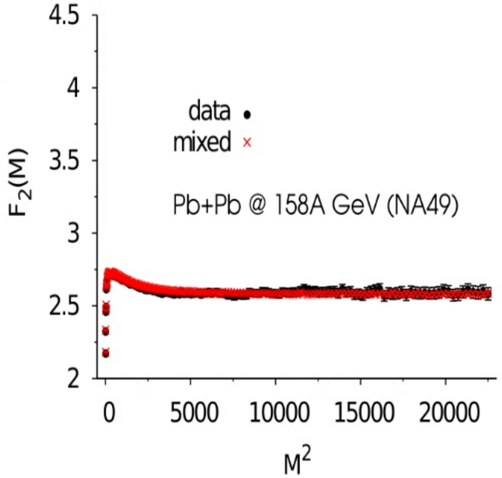




NA49:

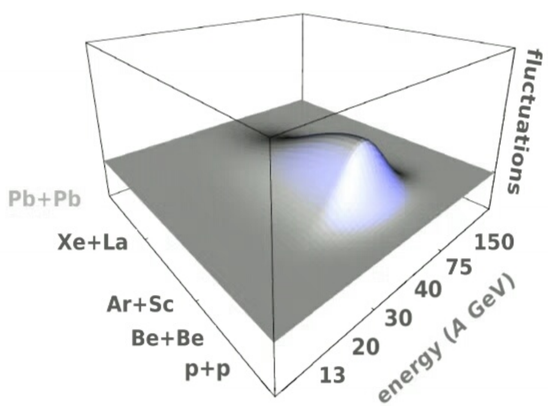






↑ FLUCTUATIONS OF PROTON NUMBER: ↑
DATA, MIXED EVENTS

HOPE FOR "HILL OF FLUCTUATIONS"



REQUESTED NEW MEASURMENTS (2021-2024)

- HEAVY ION PHYSICS:
  - OPEN CHARM MEASUREMENTS IN Pb+Pb AT SPS
- REFERENCE MEASUREMENTS:
  - NUCLEAR FRAGMENTATION CROSS-SECTION FOR COSMIC RAY EXPERIMENTS
  - HADRON PRODUCTION FOR NEUTRINO EXPERIMENTS

RECENT DOCUMENTS:

- March 21, 2018, Addendum 10:
  Study of Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS: Early Post-LS2 Measurements and Future Plans,
  CERN-SPSC-2018-008, SPSC-P-330-ADD-10
- June 5, 2018, Addendum 11:
  Reply to the SPSC questions on Addendum CERN-SPSC-2018-008,
  CERN-SPSC-2018-019, SPSC-P-330-ADD-11

OPEN CHARM MEASURMENTS IN Pb+Pb AT SPS: MOTIVATION

Q1: WHAT IS THE MECHANISM OF CHARM PRODUCTION?

Q2: HOW DOES THE ONSET OF DECONFINEMENT IMPACT CHARM PRODUCTION?

Q3: HOW DOES THE FORMATION OF QGP IMPACT J/ψ PRODUCTION?

TO ANSWER ONE NEEDS TO KNOW:

MEAN NUMBER OF CHARM QUARK PAIRS PRODUCED IN THE FULL PHASE SPACE, $\langle c\bar{c} \rangle$, IN Pb+Pb COLLISIONS

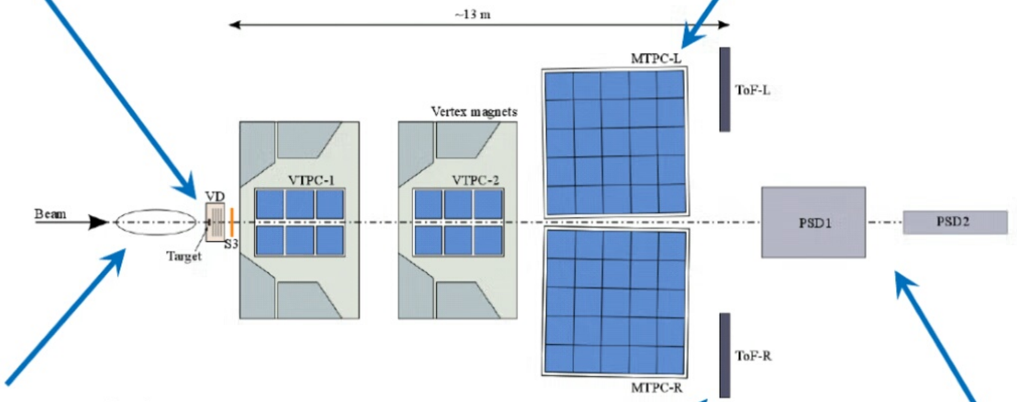
UP TO NOW NO CORRESPONDING EXPERIMENTAL DATA

ONLY NA61/SHINE CAN PERFORM NEEDED MEASUREMENTS IN THE NEAR FUTURE

DETECTOR UPGRADES (2018-2021)

Construction of Vertex Detector (VD)
for D^0, $\overline{D}^0$ decay reconstruction

Replacement of the TPC
read-out electronics
to increase data rate to 1 kHz



New trigger and data
acquisition system

New Time-of-Flight
detectors (STAGE 2)

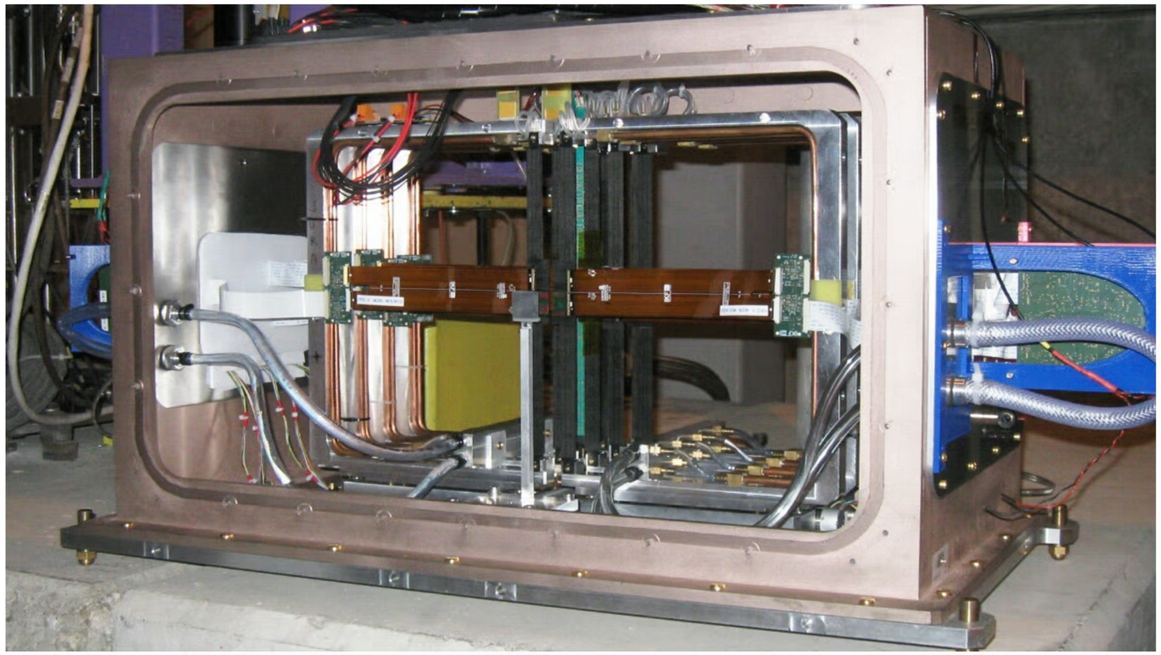
Upgrade of Projectile
Spectator Detector

IN TOTAL: ≈ 1M CHF (STAGE 1, HARDWARE ONLY)

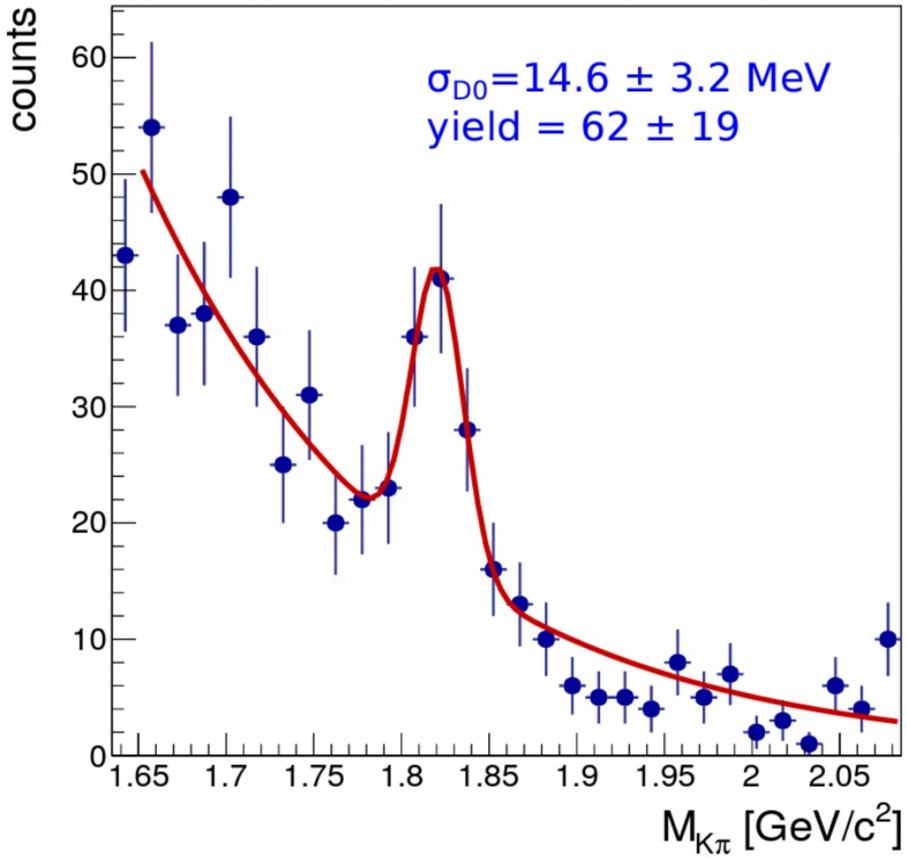
MODERATE COSTS THANKS TO COLLABORATION WITH ALICE (TPC, VD), CBM (PSD), (NICA (ToF))

RESULTS FROM THE 2016 TEST (Pb+Pb AT 150A GEV/c)

2016 - 2018:
SMALL ACCEPTANCE VERTEX DETECTOR



BASED ON TECHNOLOGIES DEVELOPED FOR ALICE AND CBM

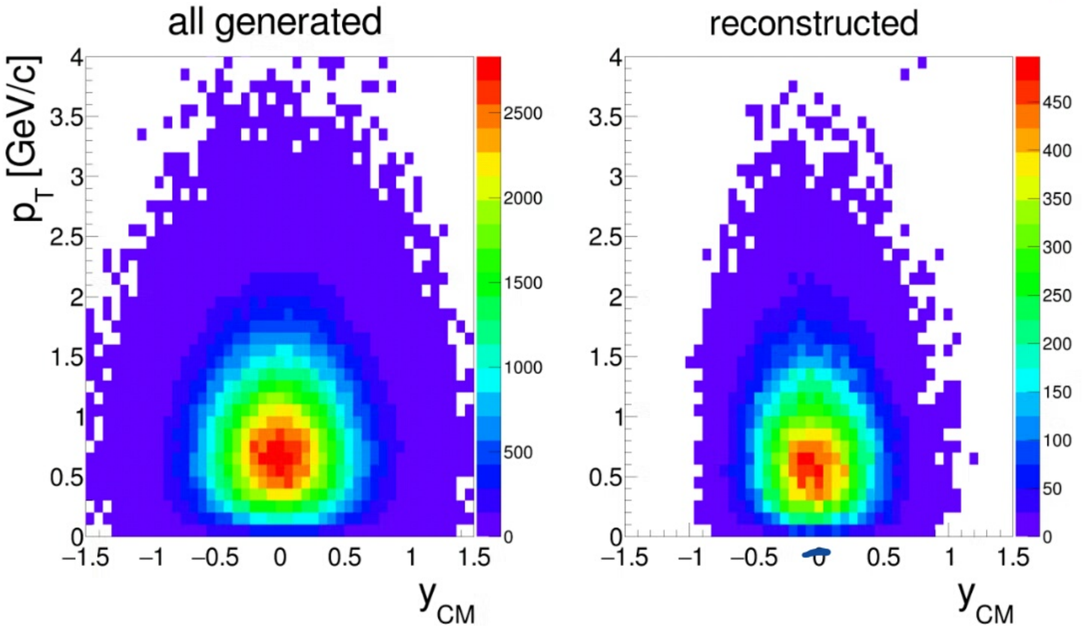


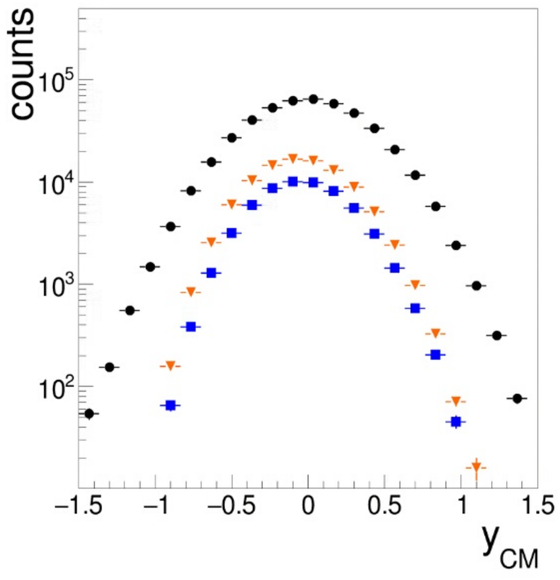
INDICATION OF $D^0 + \bar{D}^0$ PEAK

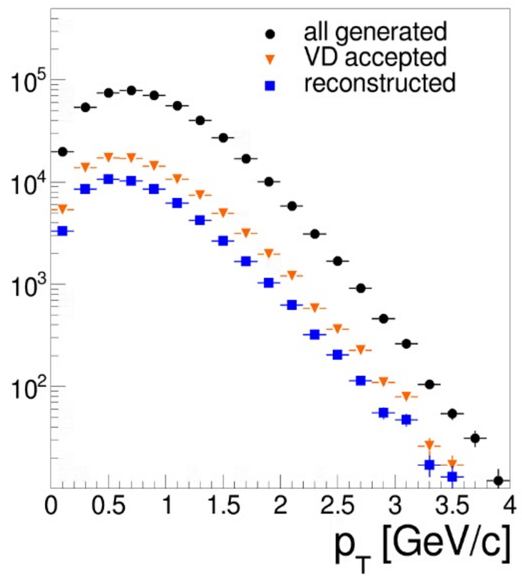
DATA STATISTICS (2021-24) AND ACCEPTANCE

Reaction	days	events	$\#(D^0 + \overline{D}^0)$	$\#(D^+ + D^-)$
Pb+Pb at 150A GeV/c	84	500M	76k	46k
Pb+Pb at 40A GeV/c	42	250M	3.6k	2.1k

$D^0+\bar{D}^0$ ACCEPTANCE: Pb+Pb AT 150A GEV/c



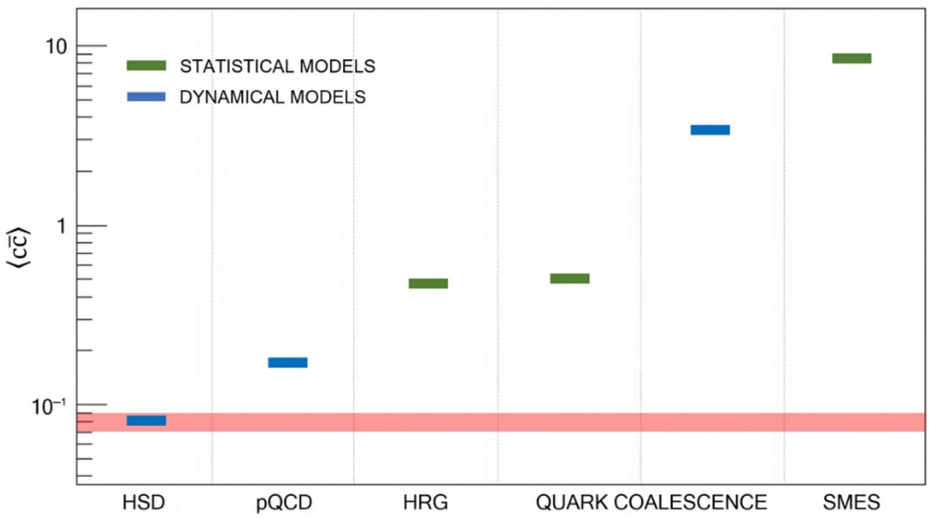




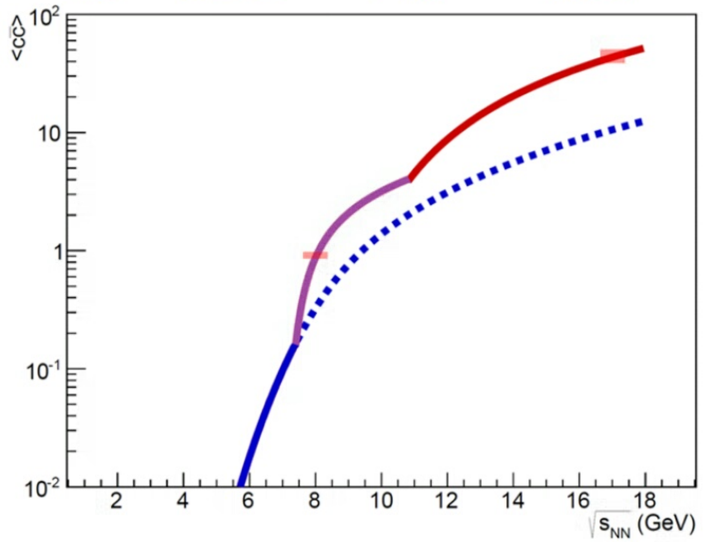
CENTRALITY	0–10%	10–20%	20–30%	30–60%	60–90%	0–90%
$\#(D^0 + \overline{D}^0)$	31k	20k	11k	13k	1.3k	76k
$\#(D^+ + D^-)$	19k	12k	7k	8k	0.8k	46k

EXPECTED PHYSICS IMPACT OF NA61/SHINE $\langle c\bar{c} \rangle$ MEASUREMENTS

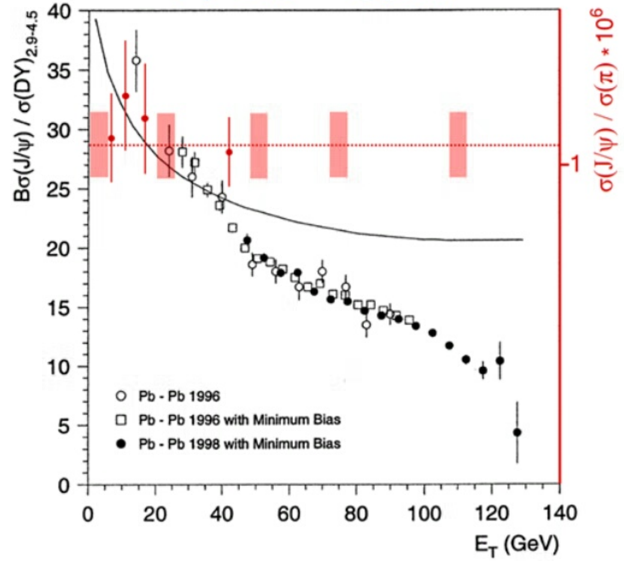
Q1: $\langle c\bar{c} \rangle$ AND MODELS



Q2: $\langle c\bar{c} \rangle$ AND ONSET OF DECONFINEMENT



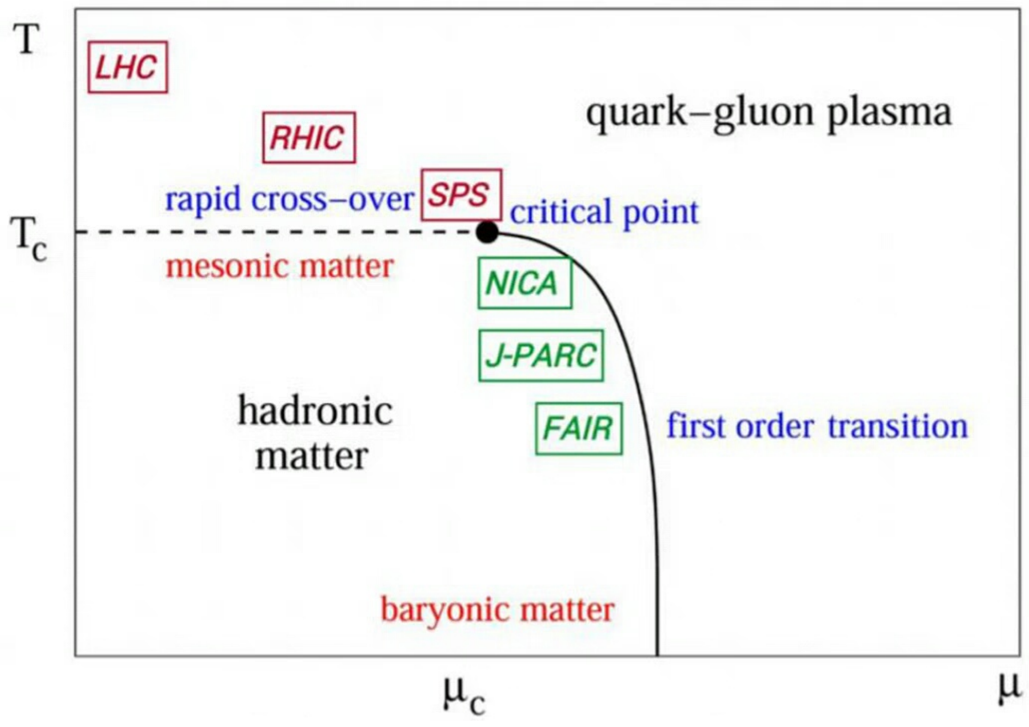
Q3: $\langle c\bar{c} \rangle$, $\langle J/\psi \rangle$ AND QGP



FORESEEN NA61/SHINE RESOLUTION
IS SUFFICIENT TO ANSWER Q1, Q2 AND Q3

UNIQUENESS OF NA61/SHINE PROGRAMME

LANDSCAPE OF PRESENT AND FUTURE HEAVY ION EXPERIMENTS



LHC and RHIC at high energies ($\sqrt{s_{NN}} \geq 200$ GeV):
measurements in limited phase space due to collider geometry and kinematics

RHIC BES ($3 - 39$ GeV):
measurement not under consideration

NICA (< 11 GeV):
under consideration during stage 2

J-PARC (< 6 GeV) :
maybe possible after 2025

FAIR SIS-100 (< 5 GeV):
not possible at SIS-100,
planned at SIS-300 (< 7 GeV)

ONLY NA61/SHINE IS ABLE TO MEASURE OPEN CHARM PRODUCTION IN HEAVY ION COLLISIONS IN FULL PHASE SPACE AND IN THE NEAR FUTURE

NA61/SHINE 2020+ COLLABORATION : 33 INSTITUTIONS ≈150 AUTHORS

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The NA61/SHINE Collaboration

A. Aduszkiewicz[16], E.V. Andronov[22], T. Antićić[3], B. Baatar[20], M. Baszczyk[14], S. Bhosale[11], A. Blondel[24], M. Bogomilov[2], A. Brandin[21], A. Bravar[24], W. Bryliński[18], J. Brzychczyk[13], S.A. Bunyatov[20], O. Busygina[19], A. Bzdak[14], H. Cherif[7], M. Ćirković[23], T. Czopowicz[18], A. Damyanova[24], N. Davis[11], M. Deveaux[7], W. Dominik[16], P. Dorosz[14], J. Dumarchez[4], R. Engel[5], G.A. Feofilov[22], L. Fields[25], Z. Fodor[8,17], A. Garibov[1], M. Gaździcki[7,10], O. Golosov[21], M. Golubeva[19], K. Grebieszkow[18], F. Guber[19], A. Haesler[24], S.N. Igolkin[22], S. Ilieva[2], A. Ivashkin[19], S.R. Johnson[26], K. Kadija[3], E. Kaptur[15], N. Kargin[21], E. Kashirin[21], M. Kiełbowicz[11], V.A. Kireyeu[20], V. Klochkov[7], V.I. Kolesnikov[20], D. Kolev[2], A. Korzenev[24], V.N. Kovalenko[22], K. Kowalik[12], S. Kowalski[15], M. Koziel[7], A. Krasnoperov[20], W. Kucewicz[14], M. Kuich[16], A. Kurepin[19], D. Larsen[13], A. László[8], T.V. Lazareva[22], M. Lewicki[17], K. Łojek[13], B. Łysakowski[15], V.V. Lyubushkin[20], M. Maćkowiak-Pawłowska[18], Z. Majka[13], B. Maksiak[18], A.I. Malakhov[20], D. Manić[23], A. Marchionni[25], A. Marcinek[11], A.D. Marino[26], K. Marton[8], H.-J. Mathes[5], T. Matulewicz[16], V. Matveev[20], G.L. Melkumov[20], A.O. Merzlaya[13], B. Messerly[27], Ł. Mik[14], S. Morozov[19,21], S. Mrówczyński[10], Y. Nagai[26], M. Naskręt[17], V. Ozvenchuk[11], V. Paolone[27], M. Pavin[4,3], O. Petukhov[19], R. Płaneta[13], P. Podlaski[16], B.A. Popov[20,4], B. Porfy[8], M. Posiadała-Zezula[16], D.S. Prokhorova[22], S. Puławski[15], J. Puzović[23], W. Rauch[6], M. Ravonel[24], R. Renfordt[7], E. Richter-Wąs[13], D. Röhrich[9], E. Rondio[12], M. Roth[5], B.T. Rumberger[26], A. Rustamov[1,7], M. Rybczynski[10], A. Rybicki[11], A. Sadovsky[19], K. Schmidt[15], I. Selyuzhenkov[21], A.Yu. Seryakov[22], P. Seyboth[10], M. Słodkowski[18], A. Snoch[7], P. Staszel[13], G. Stefanek[10], J. Stepaniak[12], M. Strikhanov[21], H. Ströbele[7], T. Šuša[3], A. Taranenko[21], A. Tefelska[18], D. Tefelski[18], V. Tereshchenko[20], A. Toia[7], R. Tsenov[2], L. Turko[17], R. Ulrich[5], M. Unger[5], F.F. Valiev[22], D. Veberič[5], V.V. Vechernin[22], A. Wickremasinghe[27], Z. Włodarczyk[10], A. Wojtaszek-Szwarc[10], O. Wyszyński[13], L. Zambelli[4,1], E.D. Zimmerman[26], and R. Zwaska[25]

[1] National Nuclear Research Center, Baku, Azerbaijan
[2] Faculty of Physics, University of Sofia, Sofia, Bulgaria
[3] Ruđer Bošković Institute, Zagreb, Croatia
[4] LPNHE, University of Paris VI and VII, Paris, France
[5] Karlsruhe Institute of Technology, Karlsruhe, Germany
[6] Fachhochschule Frankfurt, Frankfurt, Germany
[7] University of Frankfurt, Frankfurt, Germany
[8] Wigner Research Centre for Physics of the Hungarian Academy of Sciences, Budapest, Hungary
[9] University of Bergen, Bergen, Norway
[10] Jan Kochanowski University in Kielce, Poland
[11] H. Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences, Kraków, Poland
[12] National Centre for Nuclear Research, Warsaw, Poland
[13] Jagiellonian University, Cracow, Poland
[14] University of Science and Technology, Cracow, Poland
[15] University of Silesia, Katowice, Poland
[16] University of Warsaw, Warsaw, Poland
[17] University of Wrocław, Wrocław, Poland
[18] Warsaw University of Technology, Warsaw, Poland
[19] Institute for Nuclear Research, Moscow, Russia
[20] Joint Institute for Nuclear Research, Dubna, Russia
[21] National Research Nuclear University (Moscow Engineering Physics Institute), Moscow, Russia
[22] St. Petersburg State University, St. Petersburg, Russia
[23] University of Belgrade, Belgrade, Serbia
[24] University of Bern, Bern, Switzerland
[25] University of Geneva, Geneva, Switzerland
[26] Fermilab, Batavia, USA
[27] Los Alamos National Laboratory, Los Alamos, USA
[28] University of Colorado, Boulder, USA
[29] University of Pittsburgh, Pittsburgh, USA

The NA61/SHINE Limited Members

N. Antoniou[1], N. Benekos[3], S. Bordoni[3], P. Christakoglou[1], A. Datta[4], A. De Roeck[3], F. Diakonos[1], P. von Doetinchem[4], T. Hasegawa[2], A. Kapoyannis[1], T. Kobayashi[2], U. Kose[3], S.A. Monsalve[3], T. Nakadaira[2], K. Nishikawa[2], A.D. Panagiotou[1], K. Sakashita[2], P. Sala[3], T. Sekiguchi[2], M. Shibata[2], A. Shukla[4], D. Sgalaberna[3], M. Tada[2], M. Vassiliou[1], and L. Whitehead[3]

[1] University of Athens, Athens, Greece
[2] Institute for Particle and Nuclear Studies, Tsukuba, Japan
[3] CERN, Geneva, Switzerland
[4] University of Hawaii at Manoa, USA

REQUESTED BEAMS

2021: 6 WEEKS FOR DETECTOR COMMISSIONING

5 WEEKS OF PROTON BEAM AT 31 GEV/c FOR DATA TAKING FOR NEUTRINO PHYSICS

4 WEEKS OF Pb BEAM AT 150A GEV/c FOR OPEN CHARM MEASUREMENT

RECOMMENDED BY SPSC

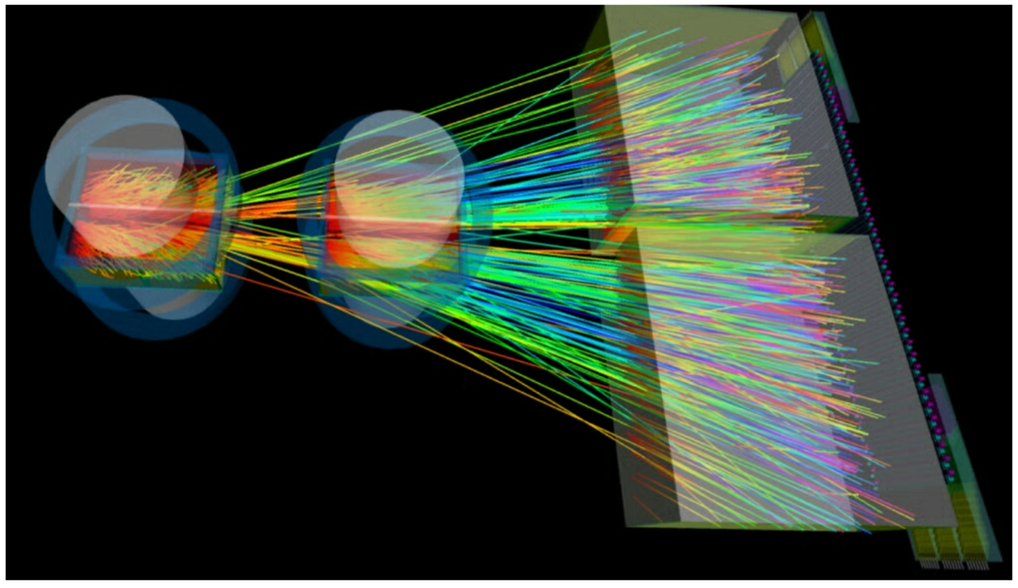
2022-24: HADRON, LIGHT ION (SECONDARY) AND Pb BEAMS IN ACCORDANCE TO THE PROPOSED PHYSICS PROGRAM

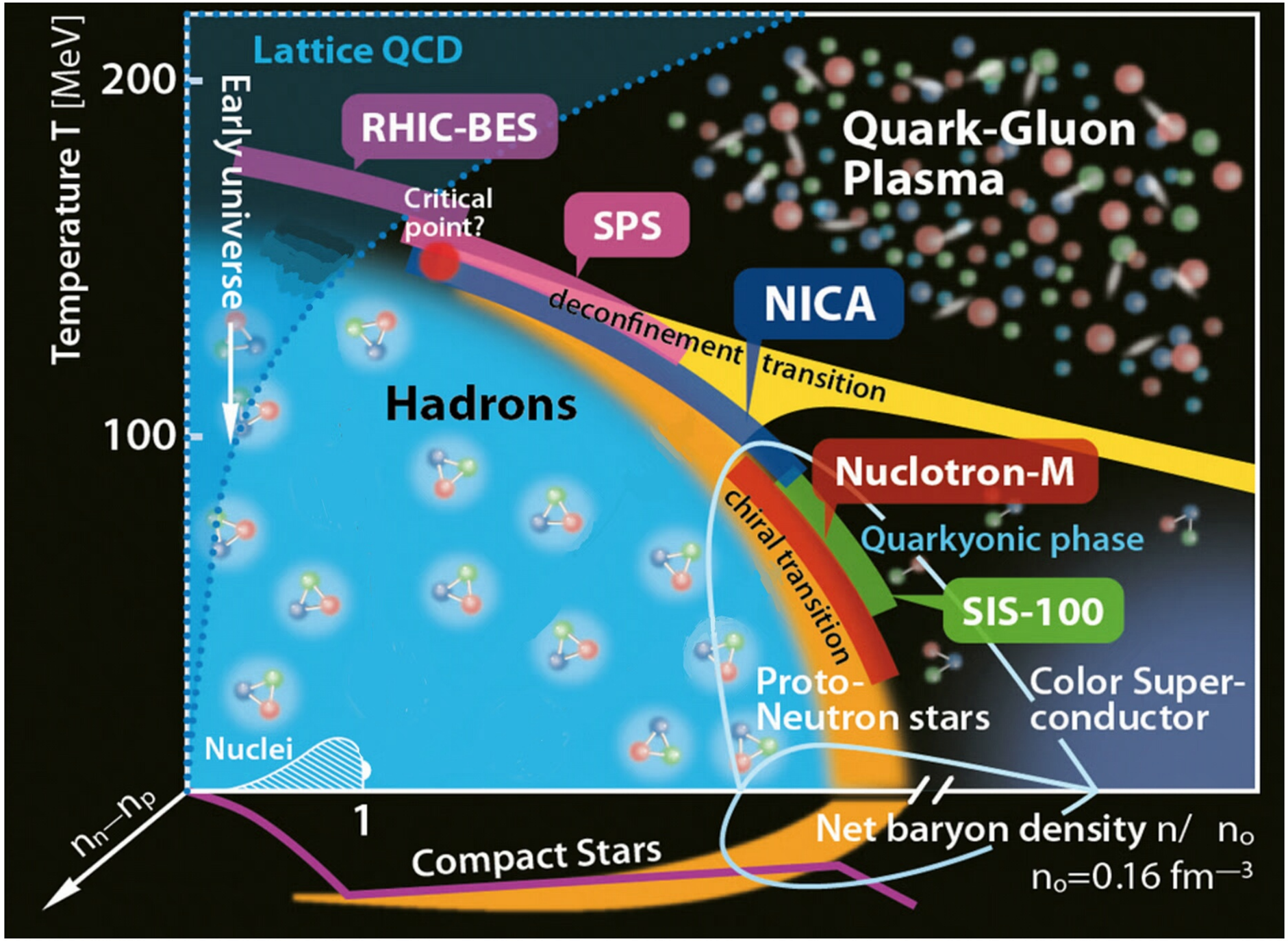
SUMMARY

- NA61/SHINE PLANS UNIQUE OPEN CHARM MEASURMENTS IN Pb+Pb COLLISIONS AT SPS AS WELL AS NEW REFERENCE MEASUREMENTS FOR COSMIC RAY AND NEUTRINO EXPERIMENTS

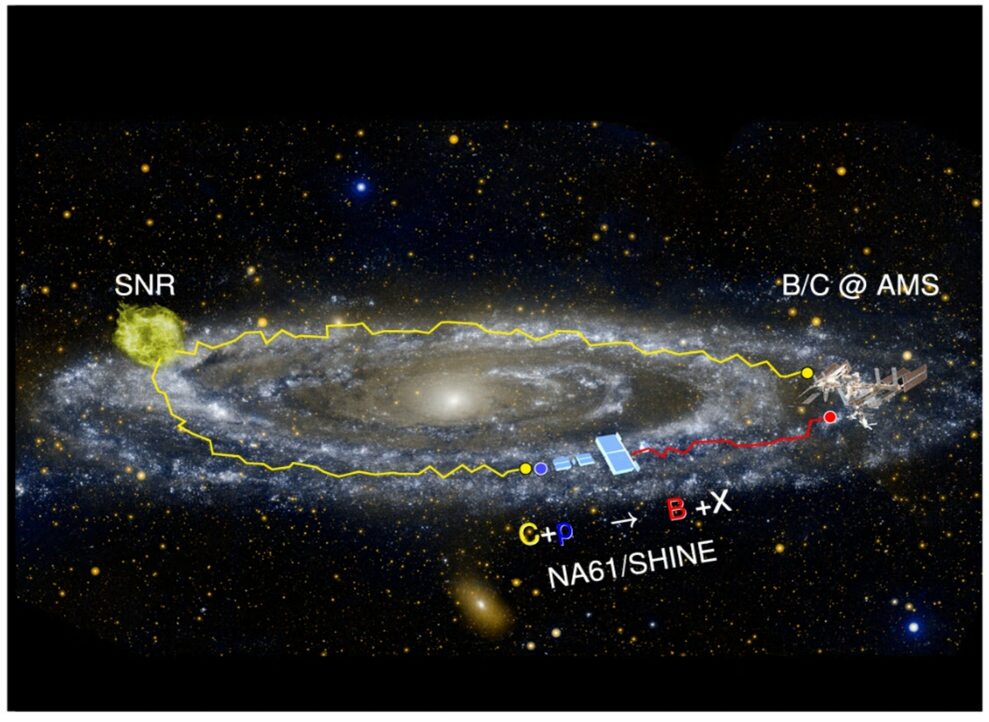
- DATA TAKING IN 2021 IS RECOMMENDED BY SPSC
- DATA TAKING IN 2022 – 2024 ← SPSC ← ESPP ← PBC, TOWN MEETINGS, NA61/SHINE

- WORK ON DETECTOR UPGRADES HAS STARTED




Temperature T [MeV]
200
100
Lattice QCD
Early universe
RHIC-BES
Critical point?
SPS
NICA
Quark-Gluon Plasma
deconfinement transition
Hadrons
Nuclotron-M
chiral transition
Quarkyonic phase
SIS-100
Proto-Neutron stars
Color Super-conductor
Nuclei
$n_n - n_p$
1
Compact Stars
Net baryon density n/ n_o
n_o=0.16 fm^{-3}

REFERENCE MEASUREMENTS: NUCLEAR FRAGMENTATION CROSS SECTION FOR COSMIC RAY EXPERIMENTS



- Primary cosmic rays from supernova remnants
- Secondary cosmic rays from interactions with interstellar matter during propagation e.g.
  $^{12}C + p \overset{frag.}{\rightarrow} B + X$
  $^{12}C + p \overset{frag.}{\rightarrow} {}^{11}C + p \overset{decay}{\rightarrow} B + Y$
- Primary-to-secondary ratios (e.g. B/C)
  $\rightarrow$ traversed mass density
- Unstable-to-stable ratios (e.g. $^{10}Be/^{9}Be$)
  $\rightarrow$ traversed distance
- Important for the understanding of origin of Galactic cosmic rays and backgrounds for DM searches

UNDERSTANDING OF COSMIC RAY PROPAGATION LIMITED BY UNCERTAINTIES OF FRAGMENTATION CROSS SECTIONS

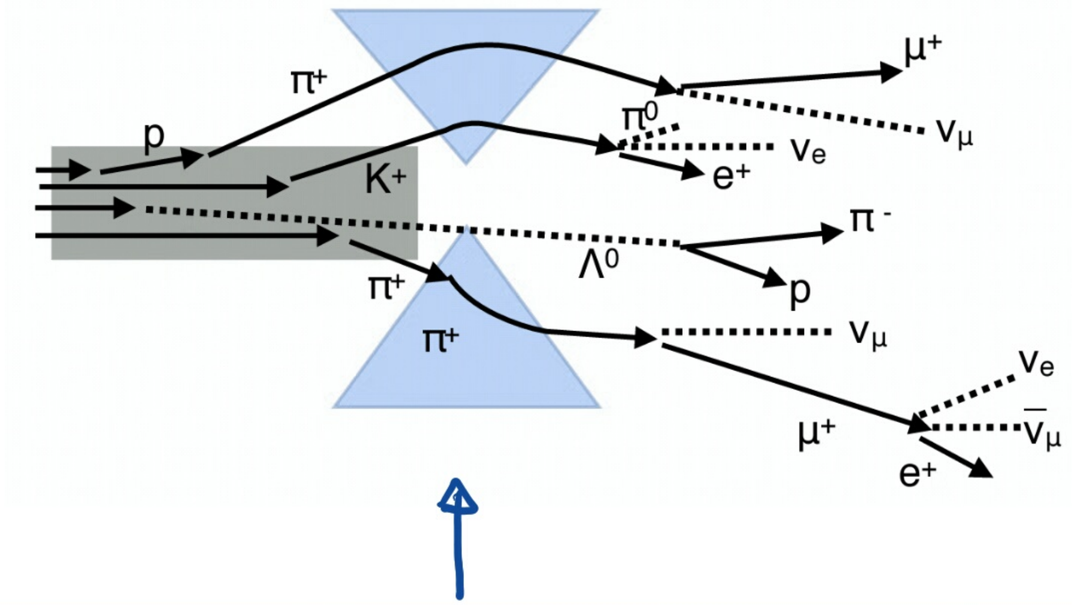
NA61/SHINE WILL SIGNIFICANTLY REDUCE THE UNCERTAINTIES.
(FROM $\approx$ 20% TO $\approx$ 0.5%)

REFERENCE MEASUREMENTS: HADRON PRODUCTION FOR NEUTRINO EXPERIMENTS

PROTON BEAM

JUNGLE OF h+A INTERACTIONS AND DECAYS

NEUTRINO BEAM



- Further improvement of the precision of measurements for the currently used T2K replica target,
- Measurements for a new target material (super-sialon) for T2K-II and Hyper-Kamiokande,
- Study of the possibility of measurements with beams <12 GeV/c for improved predictions of atmospheric and accelerator ν fluxes,
- Ultimate hadron production measurements with prototypes of Hyper-Kamiokande and DUNE targets.

NAGI/SHINE WILL DECREASE SYSTEMATIC UNCERTAINTIES OF NEUTRINO FLUX (FOR T2K-II, HYPER-K FROM ≈10% TO ≈3%)