NA61/SHINE at the CERN SPS – upgrade status and future plans

Szymon Puławski
for the NA61/SHINE Collaboration
Outlook

- **2019-2024:**
  - Detector upgrade
  - Strong interaction programme Pb+Pb at 150A and 40A GeV/c
    - Open charm production
  - Measurements of nuclear fragmentation cross section for cosmic ray physics
  - Measurements of hadron production induced by proton and kaon beams for neutrino physics
  - SPSC recommended
- **2026-2029:** 2D scan phase II
  - Study of the onset of fireball
  - The very first idea
NA61/SHINE 2019-2024

- Measurements of charm hadron production in Pb+Pb collisions for heavy ion physics
- Measurements of nuclear fragmentation cross section for cosmic ray physics
- Measurements of hadron production induced by proton and kaon beams for neutrino physics
NA61/SHINE and European Strategy for Particle Physics

- Towards the European Particle Physics Strategy Update
  - Summary Report of Physics Beyond Colliders at CERN
  - Physics Beyond Colliders: QCD Working Group Report
  - Conclusions of the Neutrino Town Meeting
  - Conclusions of the Heavy Ion Town Meeting

The Briefing Book for the 2020 European Strategy Particle Physics

“… The NA61/SHINE experiment at SPS, currently being upgraded with vertex capability (using pixel sensors developed for ALICE), will extend in the coming years its suite of observables into the charm sector… NA61 and its upgrade are an important component of this programme for the determination of the neutrino fluxes…”
Detector upgrade during LS2

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

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

Higher ion intensities $10^6$ ions/spill for charm programme

Low energy beam (<30 GeV/c) for neutrino physics

New trigger and data acquisition system

Upgrade of Projectile Spectator Detector

New Time-of-Flight detectors
Upgrade status

- Design of TPC electronics adapters and mechanical support is ongoing.
  - The test was performed during Pb+Pb 2018 runs
- Design of Vertex Detector is completed
- Main and Forward PSD was installed.
  - Installation of the FEE is ongoing
  - Forward PSD shielding is designed
- New DAQ and trigger test bench was constructed and infrastructure for new DAQ system is almost ready
- New ToF detector based on MRPC is under construction

The first physics data taking is planned in 2021 (default financial scenario) or in 2022 (contingency financial scenario)
Test measurements - open charm signal in A+A at 150A GeV/c

\[ \sigma_{D_0} = 10 \pm 4 \text{ MeV} \]

yield \approx 50

\[ \sigma_{D_0} = 14.6 \pm 3.2 \text{ MeV} \]

yield = 62 \pm 19

NA61/SHINE analysis ongoing
Identification of Isotopes Produced in Target

$^{12}\text{C}$ beam:

$^{12}\text{C}$ purity: 99.2%
B contamination: < 0.1%
Test measurement: nuclear fragmentation cross section

\[ \sigma(^{12}\text{C} + p \rightarrow ^{10}\text{B} + X) + \sigma(^{12}\text{C} + p \rightarrow ^{11}\text{B} + X) = 47.7 \pm 3.0 \text{ (stat.)} \pm 2.3 \text{ (syst.) mb} \]

2018 Pilot Run on Nuclear Fragmentation:

- demonstrated unique capabilities of NA61/SHINE + SPS for nuclear fragmentation measurements
- preliminary results presented at ICRC2019
- test data already useful to constrain asymptotic \( \sigma(^{12}\text{C} + p \rightarrow B + X) \)

Future Plans:

- precise reaction data base for Galactic cosmic-ray studies
NA61/SHINE 2026-2029

- Detailed 2D scan to study onset of fireball region
- Measurements of hadron production from the HYPER-K replica target
Onset of fireball

Onset of fireball – beginning of creation of strongly interacting matter with increasing nuclear mass number. Transition from non-equilibrium strings and resonances to equilibrium hadron gas or quark gluon plasma.

\[ p + p \approx Be + Be \neq Ar + Sc \leq Pb + Pb \]
Onset of fireball – ion beam request for 2026-2029

The very first idea

Example ion:

- $^{40}\text{Ca}$ – synergy with Gamma Factory
- $^{30}\text{P}$
- $^{16}\text{O}$ – synergy with CR-LHC
- $^{4}\text{He}$

beam ion

beam momentum [A GeV/c]
Summary

- **2019-2026:**
  - NA61/SHINE in The Briefing Book for the 2020 European Strategy Particle Physics
  - The upgrade is progressing according to schedule
  - Results from test measurements:
    - $D^0$ meson signal for open charm programme
    - Nuclear fragmentation for space cosmic-ray programme

- **2026-2029**
  - The very preliminary idea to extend physics programme beyond 2026
    - Study of the onset of fireball – 2D scan with low and medium size ions
    - Hadron production from the HYPER-K replica target

NA61/SHINE would like to thank the CERN EP, BE, HSE and EN Departments for the strong support
THANK YOU
Onset of fireball – ion beam request for 2026-2029

The very first idea

<table>
<thead>
<tr>
<th>A</th>
<th>synergy</th>
</tr>
</thead>
<tbody>
<tr>
<td>≈ 40</td>
<td>Gamma Factory</td>
</tr>
<tr>
<td>≈ 30</td>
<td></td>
</tr>
<tr>
<td>≈ 15</td>
<td>CR-LHC</td>
</tr>
<tr>
<td>≈ 5</td>
<td></td>
</tr>
</tbody>
</table>

Detailed scan in nuclear mass number and collision energy should be possible at:

- NICA (<11 GeV) – 2022+
- FAIR (< 5 GeV) – 2025+
- SPS (5-17 GeV) – 2025+
- J-PARC (<6 GeV) - ?
## Financial scenarios

### Default spending profile

<table>
<thead>
<tr>
<th>year</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>sum</th>
<th>source of funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPC</td>
<td>-</td>
<td>115k</td>
<td>459k</td>
<td>-</td>
<td>-</td>
<td>574k</td>
<td>DFG grant (44%), CF (22%), or Polish/Norwegian Grant (66%), US DOE SHINE Request (17%), CF (17%)</td>
</tr>
<tr>
<td>VD</td>
<td>-</td>
<td>-</td>
<td>130k</td>
<td>-</td>
<td>-</td>
<td>130k</td>
<td>NCN OPUS (100%)</td>
</tr>
<tr>
<td>PSD</td>
<td>-</td>
<td>55k</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>55k</td>
<td>INR grant - contribution to NA61-CF (55%), NA62 payment for old PSD (45%)</td>
</tr>
<tr>
<td>MRPCToF</td>
<td>50k</td>
<td>90k</td>
<td>376k</td>
<td>10</td>
<td>-</td>
<td>526k</td>
<td>JINR grant (100%)</td>
</tr>
<tr>
<td>BPD</td>
<td>-</td>
<td>-</td>
<td>60k</td>
<td>-</td>
<td>-</td>
<td>60k</td>
<td>NCN/DFG Beethoven (100%) or Japan grant (100%)</td>
</tr>
<tr>
<td>TDAQ</td>
<td>30k</td>
<td>93k</td>
<td>93k</td>
<td>-</td>
<td>-</td>
<td>216k</td>
<td>NCN Maestro (55%), NCN/DFG Beethoven (24%), CF 2018 (21%)</td>
</tr>
<tr>
<td>DRS4</td>
<td>-</td>
<td>40k</td>
<td>90k</td>
<td>-</td>
<td>-</td>
<td>130k</td>
<td>US DOE SHINE Request (55%), JINR grant (16%), CF (29%)</td>
</tr>
</tbody>
</table>

### Contingency spending profile

<table>
<thead>
<tr>
<th>year</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>sum</th>
<th>source of funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPC</td>
<td>-</td>
<td>115k</td>
<td>165k</td>
<td>175k</td>
<td>-</td>
<td>455k</td>
<td>CF (100%)</td>
</tr>
<tr>
<td>VD</td>
<td>-</td>
<td>-</td>
<td>40k</td>
<td>90k</td>
<td>130k</td>
<td>130k</td>
<td>CF (100%)</td>
</tr>
<tr>
<td>PSD</td>
<td>-</td>
<td>55k</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>55k</td>
<td>INR grant - contribution to NA61-CF (55%), NA62 payment for old PSD (45%)</td>
</tr>
<tr>
<td>MRPCToF</td>
<td>50k</td>
<td>90k</td>
<td>376k</td>
<td>10</td>
<td>-</td>
<td>526k</td>
<td>JINR grant (100%)</td>
</tr>
<tr>
<td>BPD</td>
<td>-</td>
<td>-</td>
<td>30k</td>
<td>30k</td>
<td>60k</td>
<td>60k</td>
<td>CF (100%)</td>
</tr>
<tr>
<td>TDAQ</td>
<td>30k</td>
<td>93k</td>
<td>41k</td>
<td>-</td>
<td>-</td>
<td>164k</td>
<td>NCN Maestro (73%), CF 2018 (27%)</td>
</tr>
<tr>
<td>DRS4</td>
<td>-</td>
<td>40k</td>
<td>20k</td>
<td>30k</td>
<td>90k</td>
<td>90k</td>
<td>JINR grant (23%), CF (77%)</td>
</tr>
</tbody>
</table>

The upgrade of TPC read-out, Trigger and DAQ, PSD, DCS, MRPC is progressing according to schedule
The SPSC considers that the NA61 run foreseen for 2021 could be postponed to 2022, if compatible with the NA61 funding, given the status of work in the PBC study together with the indication that there is no competition for the North Area beam line used by NA61. The Research Board agreed that the run of NA61 can be included in the beam-line planning for the moment; however, full funding for the detector should be available before final approval of the run in 2021 is given, or before granting operation beyond 2021.
NA61/SHINE programme - outlook

- **2009-2018:**
  - Strong interaction programme - 2D scan:
    - Study of the onset of deconfinement
    - Search for critical point
    - Unexpected result: onset of fireball
  - Measurements of hadron production properties for neutrino and cosmic-ray physics
  - Data taking completed

- **2021-2024:**
  - Strong interaction programme Pb+Pb at 150A and 40A GeV/c
    - Open charm production
    - Measurements of nuclear fragmentation cross section for cosmic ray physics
    - Measurements of hadron production induced by proton and kaon beams for neutrino physics
    - SPSC recommended

- **2026-2029:** 2D scan phase II
  - Study of the onset of fireball
  - The very first idea
Study of the onset of deconfinement - Step

Plateau – STEP – in the inverse slope parameter $T$ of kaon $m_T$ spectra in Pb+Pb collisions observed at SPS.

Predicted signature of the onset of deconfinement.

Qualitatively similar energy dependence is seen in $p+p$, Be+Be and Pb+Pb collisions.

Magnitude of $T$ in Be+Be slightly higher than in $p+p$.

Ar+Sc results between $p+p$/Be+Be and Pb+Pb.
Study of the onset of deconfinement - Horn

Rapid changes in $K^+/\pi^+$ energy dependence – HORN – were observed in Pb+Pb collisions at SPS (NA49). Predicted signature of onset of deconfinement.

NA61/SHINE: unexpected system size dependence

- Plateau like structure visible in p+p
- Be+Be close to p+p

Ar+Sc is significantly higher than p+p≈Be+Be (at the top SPS energy Ar+Sc ≈Pb+Pb). No horn structure in Ar+Sc.
Search for the critical point

Expected region of enhanced fluctuations

NA61/SHINE:
No prominent structures which could be related to the critical point

\[
\Sigma[P_T, N] = \frac{1}{C_{\Sigma}} \left[ \langle N \rangle \omega[P_T] + \langle P_T \rangle \omega[N] - 2 \cdot \langle P_T \cdot N \rangle - \langle P_T \rangle \langle N \rangle \right]
\]

\[
\Delta[P_T, N] = \frac{1}{C_{\Delta}} \left[ \langle N \rangle \omega[P_T] - \langle P_T \rangle \omega[N] \right], \quad C_{\Sigma} = C_{\Delta} = \langle N \rangle \omega(p_T)
\]