NA61/SHINE at the CERN SPS: Status and Plans

(SHINE – SPS Heavy Ion and Neutrino Experiment)

- Fundamentals
- Physics of strongly interacting matter in NA61
- Detector, upgrades, performance
- Plans and experimental landscape

M. Gazdzicki, Frankfurt, Kielce for the NA61 Collaboration
Physics goals:

Physics of strongly interacting matter

Discovery potential:

Search for the critical point of strongly interacting matter

Precision measurements:

Study the properties of the onset of deconfinement in nucleus-nucleus collisions

Measure hadron production at high transverse momenta in p+p and p+Pb collisions as reference for Pb+Pb results

Data for neutrino and cosmic ray experiments

Precision measurements:

Measure hadron production in the T2K target needed for the T2K (neutrino) physics

Measure hadron production in p+C interactions needed for T2K and cosmic-ray, Pierre Auger Observatory and KASCADE, experiments
The NA61/SHINE Collaboration:

121 physicists from 24 institutes and 14 countries:

University of Athens, Athens, Greece
University of Bergen, Bergen, Norway
University of Bern, Bern, Switzerland
KFKI IPNP, Budapest, Hungary
Cape Town University, Cape Town, South Africa
Jagiellonian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Fachhochschule Frankfurt, Frankfurt, Germany
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
Forschungszentrum Karlsruhe, Karlsruhe, Germany
Jan Kochanowski University, Kielce, Poland
Institute for Nuclear Research, Moscow, Russia
LPNHE, Universites de Paris VI et VII, Paris, France
Pusan National University, Pusan, Republic of Korea
Faculty of Physics, University of Sofia, Sofia, Bulgaria
St. Petersburg State University, St. Petersburg, Russia
State University of New York, Stony Brook, USA
KEK, Tsukuba, Japan
Soltan Institute for Nuclear Studies, Warsaw, Poland
Warsaw University of Technology, Warsaw, Poland
University of Warsaw, Warsaw, Poland
Rudjer Boskovic Institute, Zagreb, Croatia
ETH Zurich, Zurich, Switzerland
NA61 Detector:

Upgraded NA49 apparatus

NA61 upgrades:  CERN-SPSC-2006-034, SPSC-P-330
Location:

NA61/SHINE at the CERN SPS
Status and plans:

- NA61 was approved at CERN in June 2007,
- the pilot run was performed during October 2007,
- the commissioning of the TPC read-out upgrade and DAQ was performed during September 2008
- the 2008 run has been cut due to the LHC incident

- 2009-2010: runs with proton beam,
- 2011-2013: runs with secondary ion beams produced from the primary Pb beam (compatibility with I-LHC is requested)
Documents:


Report from the NA61/SHINE experiment at the CERN SPS, CERN-OPEN-2008-012
Physics of strongly interacting matter in NA61

Critical point

1st order phase transition

water

strongly interacting matter

quark gluon plasma

hadrons

Baryochemical potential (MeV)

Temperature (K)

Pressure (Pa)

Temperature (MeV)
Freeze-out parameters in Pb+Pb collisions:

Freeze-out points of central heavy ion collisions at SPS are close to the phase boundary.

Early stage crosses the phase boundary at SPS energies (onset of deconfinement).

Onset of deconfinement: M.G., Gorenstein

HG fits: Becattini et al., Cleymans, Redlich et al.

CP: Fodor, Katz
Onset of deconfinement:
Evidence for the onset of deconfinement in central Pb+Pb collisions at the low SPS energies (PRC66:054902, PRC77:024903)
Two main events in nucleus-nucleus collisions

Onset of Deconfinement: early stage hits transition line, observed signals: kink, horn, step

Critical Point: freeze-out close to critical point, expected signal: a hill in fluctuations

\[ E(OoD) \approx 30A \text{ GeV} \leq E(OoC) \]
NA61/SHINE energy-system size scan:

**NA61 ion program**

- Pb+Pb
- In+In
- S+S
- C+C
- p+p
- p+Pb

Registered collisions: $2 \cdot 10^6$

NA49

10 20 30 40 80 158

energy (A GeV)

energy (A GeV)
Study the onset of deconfinement:

Search for the onset of the horn (kink, step) in collisions of light nuclei
Search for the critical point:

Search for the hill of fluctuations

In+In
S+S
C+C
p+p

energy (A GeV)

T (MeV)

158A
10A GeV

extrapolation

NA49

p+p

In+In

μ_B (MeV)
System size scan:

- a change of the freeze-out \( T \) at the approximately constant \( \mu_B \)

\[ T \not\sim N_w \not\sim \text{consistent with the dynamical freeze-out condition: } \lambda \approx R \]

- chemical freeze-out: PRC73:044905
- kinetic freeze-out: JPG31:S147
Predictions for the critical point vs data (I):

central Pb+Pb collisions (NA49)
transverse momentum fluctuations

the predicted CP fluctuations are not observed,
freeze-out far from CP?
too large system?
Predictions for the critical point vs data (II):

central Pb+Pb collisions (NA49)
multiplicity fluctuations

the predicted CP fluctuations are not observed, freeze-out far from CP? 
Pb+Pb - too large system?
Fluctuations in string-hadronic models show smooth dependence on collision energy and mass of the colliding nuclei.
Detector, upgrades, performance

NA61 apparatus:

Upgrades: CERN-SPSC-2006-034, SPSC-P-330
Basic upgrades:

2007: Modification and replacement of obsolete equipment, construction of the forward ToF wall
  reestablish the full functionality of NA49 and T2K acc.
  \( \text{(2007 total cost 300k CHF)} \)

2008: Replacement of the TPC digital read-out and DAQ:
  an increase of the event rate by about 20 to 80 Hz
  \( \text{(2008 total cost 500k CHF)} \)

2011: Replacement of the VETO Calorimeter by a Projectile Spectator Detector:
  an increase of the resolution in the measurement of the number of projectile spectators by a factor \( \approx 5 \)
  to \( \Delta E/E \approx 50\%/E \),
  a possible determination of the reaction plane

  Installation of the Helium beam pipe in the VTPC cage
  a reduction of the delta-electron background by a factor of 10
  \( \text{(<2011 total cost 670k CHF)} \)
Secondary ion beams for NA61:

$10^9$ Pb ions/sec from SPS

$10^5$ P ions/sec to NA61

(<2011 total cost 100k CHF)
Secondary hadron beams for NA61:

Beam and trigger counters

C1 and C2                        - proton identification,
S1, S2, V0, V1, BPD1/2/3 – determination of proton trajectory,
S4                                    – selection of p+target interactions
Performance of the NA61 detector (I):

Results of the 2007 run:

- Large acceptance: \( \approx 50\% \)
- High momentum resolution:
  \[ \frac{\sigma(p)}{p^2} \approx 10^{-4} \left( \text{GeV}/c \right)^{-1} \]
  at full magnetic field
- Good particle identification:
  \[ \sigma(\text{TOF}) \approx 100 \text{ ps}, \]
  \[ \sigma(\frac{dE}{dx})/\langle \frac{dE}{dx} \rangle \approx 0.04, \]
  \[ \sigma(m_{\text{inv}}) \approx 5 \text{ MeV} \]
- High detector efficiency:
  \( > 95\% \)
Performance of the NA61 detector (II): Proton beam properties:
- Momentum from TPC
- Beam spot from BPD-3
- dE/dx from TPC

**Beam momentum [GeV/c]**
- Entries: 2514
- Mean: 30.77
- RMS: 0.1504
- $\chi^2$/ndf: 113.67/77
- Constant: 135.86 ± 4.32
- Mean: 30.773 ± 0.002
- Sigma: 0.11669 ± 0.000511

**Beam spot from BPD-3**

**dE/dx from TPC**
- All beam particles
  - $\pi$
  - $p$
- Triggered protons
  - $\pi$
  - $p$
Performance of the NA61 detector (iii):

Particle identification by dE/dx measurements:

Positive tracks

Negative tracks
Performance of the NA61 detector (IV):

Particle identification by *tof* measurements:

ToF-F raw spectrum

ToF-L/R raw spectrum

$1 < p < 3 \text{ GeV/c}$
Performance of the NA61 detector (V):

Particle identification by combined dE/dx and _tof_ measurements:

ToF-F and TPCs

2 < \( p < 3 \) GeV/c

4 < \( p < 5 \) GeV/c
Test of the PSD super-module (array of 3x3 modules):

PSD = Projectile Spectator Detector
Modular compensating lead/scintillator calorimeter with a MAPD optical read-out
Needed for a precise determination of the number of projectile spectators in the NA61 ion programme

energy spectra: data and simulation

Extrapolated energy resolution for Pb+Pb collisions at 158A GeV
<table>
<thead>
<tr>
<th>Year</th>
<th>Experiment</th>
<th>Energy</th>
<th>Days</th>
<th>Scan Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>p+p</td>
<td>158A GeV</td>
<td>30</td>
<td>high pt</td>
</tr>
<tr>
<td></td>
<td>p+p</td>
<td>6 energies*</td>
<td>30</td>
<td>e-scan</td>
</tr>
<tr>
<td>2010</td>
<td>p+Pb</td>
<td>158A GeV</td>
<td>30</td>
<td>high pt</td>
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<td>p+Pb</td>
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<tr>
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<td>30+30</td>
<td>6 energies*</td>
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<td>e-scan</td>
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<tr>
<td></td>
<td>(Pb primary, A≈30 secondary ion beam)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2012</td>
<td>10+10</td>
<td>6 energies*</td>
<td>30</td>
<td>e-scan</td>
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<td></td>
<td>(Pb primary, A≈10 secondary ion beam)</td>
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<tr>
<td>2013</td>
<td>100+100</td>
<td>6 energies*</td>
<td>30</td>
<td>e-scan</td>
</tr>
<tr>
<td></td>
<td>(A≈100 primary ion beam, to be agreed with I-LHC)</td>
<td></td>
<td></td>
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</tbody>
</table>

*(6 energies: 10A, 20A, 30A, 40A, 80A and 158A GeV)*
Experimental landscape of complementary programs of nucleus-nucleus collisions around the SPS energies

<table>
<thead>
<tr>
<th>Facility:</th>
<th>SPS</th>
<th>RHIC</th>
<th>NICA</th>
<th>SIS-300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp.:</td>
<td>NA61</td>
<td>STAR</td>
<td>MPD</td>
<td>CBM</td>
</tr>
<tr>
<td>Pb Energy:</td>
<td>4.9-17.3</td>
<td>4.9-50</td>
<td>≤9</td>
<td>≤8.5</td>
</tr>
<tr>
<td>(GeV/(N+N))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Event rate:</td>
<td>100 Hz</td>
<td>1 Hz(?)</td>
<td>≤10 kHz</td>
<td>≤10 MHz</td>
</tr>
<tr>
<td>(at 8 GeV)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Physics:</td>
<td>CP&amp;OD</td>
<td>CP&amp;OD</td>
<td>OD&amp;HDM</td>
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</tr>
</tbody>
</table>

- **CP** – critical point
- **OD** – onset of deconfinement, mixed phase, 1\(^{st}\) order PT
- **HDM** – hadrons in dense matter
Experimental landscape of complementary programs of nucleus-nucleus collisions around the SPS energies
Experimental landscape

Quark gluon plasma

Hadrons

The onset of deconfinement

T (MeV)

μB (MeV)
The NA61/SHINE program gives the unique opportunity to reach exciting physics goals in a very efficient and cost effective way.

It has the potential to discover the critical point of strongly interacting matter and guarantees a broad set of important precision measurements.

It is complementary to the efforts of other international and national laboratories, FAIR, JINR, KEK and RHIC and to the heavy ion program at the CERN LHC.

It is of common interest for different physics communities, heavy ions, neutrino and cosmic-rays.
欢迎
NA61/SHINE
我们正在等待着您的挑战！
Additional slides
The 2007 pilot run:

**Upgrades**

Additional ToF

**Data**

p+C at 31 GeV/c

**R&D**

PSD prototype

on thin target and

**T2K replica target**