Results from the NA61/SHIνE experiment and future plans

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136 members, 27 institutes, 14 countries
**SHINE: SPS Heavy Ion & Neutrino Experiment**

**Heavy Ions**
- Search for the critical point of strongly interacting matter
- Study the onset of the deconfinement

**Astro-particle**
- Precise hadro-production measurements for Comic Rays
  Extensive Air Shower prediction

  → **Pierre Auger Observatory**
  → **KASCADE**

**Neutrinos**
- Precise hadro-production measurements for precise characterization of the neutrino flux.
  → **T2K** experiment (Japan)

Future:
- Involvement in the Fermilab neutrino program
Strongly interacting matter

Structure of the region of transition from Hadron Gas (HG) to Quark Gluon Plasma (QGP).

Lattice QCD calculation:
- 1st order phase boundary (Onset of the Deconfinement)
- the end point of the phase transition line is the Critical Point → 2nd order transition

- SPS covers the most important region of the Phase Space diagram

- Evidence for Onset of the Deconfinement observed in NA49 at E~30A GeV

- Critical Point should be searched above the Onset of the Deconfinement E > 30A GeV

- Critical Point may be located at SPS energies:
  \[(T, \mu_B) = (162 \pm 2, 360 \pm 40) \text{ MeV}\]

\[
\mu_B = 360 \text{ MeV} \Leftrightarrow E \approx 50A \text{ GeV}
\]
Beccatini, Manninen, Gazdzicki
PRC 73 044905 (2006)
Onset of the Deconfinement status of the observations

Energy dependence of specific hadron-production properties exhibit peculiar structures which are difficult to explain without including HG-QGP transitions.


→ study of the intermediate systems → NA61/SHINE Heavy Ion program

The kink in pion multiplicity

Entropy increase at the onset of the deconfinement

The horn in strangeness yield

K/π yields ratio at high energy approach a constant level as expected for deconfined matter

The step in T parameter:

inverse slope of $m_T$

Onset: mixed phase where T do not increase with collision energy
Study of the properties of the **Onset of the Deconfinement**, establishing the system size dependence of its signals

Energy system scan: verify the observation of similar structures (kink, horn, step) vanishing for lighter nuclei
Search for the **Critical Point** of strongly interacting matter by studying the system size and collision energy dependence of hadron fluctuations and correlations.

**Search for the hill of fluctuations**
Increase of critical point signal (multiplicity and average $p_T$ fluctuations,...) for system freeze-out close to the critical point.
Experimental Apparatus

- **TOF**
- **Vertice TPCs**
- **Super conduction magnets**

- **TPC**

- **Large acceptance**: \( \approx 50\% \)

- **High momentum resolution**:
  \[ \frac{\sigma(p)}{p^2} \approx 10^{-4}\left(\text{GeV/c}^{-1}\right) \]
  at full magnetic field

- **Good particle identification**:
  \[
  \frac{\sigma(\text{TOF})}{100\text{ps}},
  \frac{\sigma(dE/dx)}{\langle dE/dx \rangle} \approx 0.04,
  \frac{\sigma(m_{inv})}{5\text{MeV/c}^2}
  \]

- **High detector efficiency**: \( > 95\% \)
Several Upgrades of the Detector inherited by NA49

2007: construction of the forward ToF wall to extend particle identification acceptance

2008: replacement of the TPC readout and central DAQ: x10 event rate increase (80 Hz)

2010: modification of beamline for production of fragmented ion beams

2011: replacement of the old calorimeter (VCAL) used for event centrality measurement in A+A spectator energy by the new Projectile Spectator Detector (PSD) to get 1 nucleon precision (x5 improvement)

2011: insertion of He beam pipes to VTPCs to reject $\delta$-electrons

2011: Z-detectors (Cerenkov) to measure beam charge of secondary ion beam

2011: A-detector (time-of-flight) to measure isotope composition of secondary ion beams

2011: construction of Low Momenta Particle Detector (LMPD) to count number of low momentum protons in h+A collision for centrality determination (“target spectator detector”)
The He beam pipe

- δ-electrons produced along the beam line → background for fluctuations measurement related to the search for the critical point
- double wall He beam pipes placed inside both Vertex TPCs
- significant background reduction

Longitudinal position of the reconstructed interaction vertex

(p+p 30 GeV)
The Projectile Spectator Detector

Precise measurement of the energy of the projectile spectator:
- trigger level centrality selection
- event-by-event fluctuations
- reconstruction of the reaction plane

High energy resolution: $55\%/\sqrt{E}+2\%$  Resolution of ±1 nucleon

Compensating calorimeter. Pb/Scintillator (4/1) sandwich
\( \pi^- \) from p+C at 31 GeV/c

rapidity spectrum

\[ (\pi^-) \text{ yield} \propto \langle N_{\text{wounded}} \rangle \]

\( p+C \) at 31 GeV/c data taken in 2007 pilot run

- \( p+C \): projectile-target asymmetry: spectra shifted towards target rapidity
  
- Pb+Pb points are divided by the number of wounded projectile nucleons
  
- NA61 points at the energy of the onset of the deconfinement confirm approximate proportionality of the \( \pi \) yield to the mean number of wounded nucleons
\( \pi^- \) from p+C at 31 GeV/c

transverse mass spectrum

- Shape of \( m_T \) spectra at mid-rapidity change form convex in p+C to concave in central Pb+Pb
- According to hydrodynamical model this is due to strong radial collective flow in Pb+Pb collisions which is absent in p+C collisions.
Secondary ion beam

- **Fragmentation target** length optimized to maximize the needed fragment production
- double **magnetic spectrometer** separate fragments according to the selected magnetic rigidity
- **Degrader**, Cu plate where ions lose energy ($dE/dx \sim Z^2$): allows to reach required beam purity

2010 Test:
Successful data taking with secondary Be beam (40A, 75A, 150A GeV/c) from fragmentation of primary Pb beam.
Main physics goal: measurement of the last unknown neutrino flavor mixing angle $\theta_{13}$

Observe the oscillation $\nu_\mu \rightarrow \nu_e$ (\nu_\mu appearance)

High precision data on Pion and Kaon production in the T2K target needed to determine the initial neutrino flux

Proton production important to measure reinteractions in the target
NA61/SHINE Particle Identification

dE/dx or dE/dx+ToF information needed for particle identification over a wide momentum range

p+C @ 31 GeV/c (2007 pilot run)
Results on hadroproduction

Data: p+C at 31 GeV/c.

$\pi^+$  

$p+C \rightarrow \pi^+ + X$

$\mathcal{K}^+$  

$\mathcal{K}^0_S$  
$\textbf{Preliminary}$

$\rho^0$  
$\textbf{Preliminary}$
Summary

Ion program:

• p-p energy scan completed
• Be-Be to be completed in 2012: successful secondary ion beam
• Next: Ar and Xe primary ion beam scan

Future plans:

➢ measurement of open charm production
➢ Pb+Pb energy scan: improve NA49 measurement with high precision NA61 measurements

Neutrino program:p+C 31 GeV/c

• $\pi^\pm$, K$^+$ production cross sections
• p, K$^0$: preliminary
• ongoing analysis on high statistics runs
Backup slides
Study of the properties of the **Onset of the Deconfinement**, establishing the system size dependence of its signals

Search for the **Critical Point** of strongly interacting matter by studying the system size and collision energy dependence of hadron fluctuations and correlations
In near future NA61/SHINE may remain the only large acceptance hadron spectrometer at the non-LHC energies.
Secondary Ion beam line for NA61

The H2 Beam Line as Ion Fragment Separator

- Double magnetic spectrometer to separate ion fragments corresponding to selected magnetic rigidity $B_\rho$
- Fragmentation target (T2) length optimized to the desired fragment production
- Degrader (Cu plate where ions lose energy $dE/dx \sim Z^2$) allows to reach required beam purity

Tested in 2010 for 13.9A and 80A GeV Pb ion beams
Recent important upgrades – Z and A detectors (2011)

- For secondary ion beams, triggering on charge of beam nucleus is necessary.
- Constructed Z-detectors (gas and quartz Cerenkov, sensitive to $Z^2$):

For secondary ion beams, monitoring isotope composition is necessary (given the Z).

- Constructed diagnostic A-detector (ToF on 140m) to monitor purity:
Recent important upgrades – Low Momentum Particle Detector (2011)

- Counts number of low momentum protons in h+A collisions for centrality determination ("target spectator detector").
- Two small size TPCs with 4 absorber layers. PID + momentum determination by $dE/dx +$ range measurement.

Results and plans of the NA61/SHINE experiment at the CERN-SPS – p. 18