Experimental Hadron Physics in Sweden

Karin Schöning, Uppsala University, NuPECC meeting
June 17th 2016, Uppsala, Sweden
Outline

• Introduction
• Hadron physics at Swedish universities
• Hadron physics facilities
  – Current facilities
  – PANDA @ FAIR
• Funding sources
• Heavy Ion Physics (on behalf of Anders Oskarsson, LU)
Hadron physics

- Physics of the hadrons: composite, colour neutral systems of quarks.
- Explores the first level of complexity of strongly interacting particles.
- Search for physics beyond the Standard Model at the high precision frontier.

Image credit: ETH Zürich
QCD and the strong interaction

Missing in the Standard Model of particle physics:
A complete understanding of the strong interaction.

• Short distances / high energies: pQCD rigorously and successfully tested.

• Charm scale and below: pQCD fails, no analytical solution possible.
QCD and the strong interaction

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The playground of the hadron physicist
Million dollar questions

- How is mass generated by the strong interaction?
  - Only ~1% of nucleon mass generated by the Higgs mechanism, remaining 99% from strong interaction.

- Spin of the nucleon?
  - Only ~1/3 from valence quarks.

- Why and how are quarks confined into hadrons?
  - Structure?
  - Exotic hadrons?
  - Dynamics?

- What is the role of charm and strangeness in complex system (nuclei, neutron stars)?
Experimental hadron physics in Sweden

Uppsala University:
WASA, KLOE-2, BES III and PANDA

Stockholm University:
PANDA
KTH Stockholm:
PANDA

Lund University:
PANDA
Uppsala University

- Senior faculty: 5 (WASA, KLOE-2, BES III, PANDA)
- Post doc: 2 (1 PANDA, 1 BES III)
- PhD students:
  - Presently 4 (1 WASA, 1 KLOE, 2 BES III + PANDA)
  - Recently finished 2 (1 KLOE-2, 1 WASA+KLOE-2)

Main activities:

- Physics: Meson production and decay, hadron EM structure, hyperon physics.
- Software: track finding algorithms for PANDA
- Hardware:
  - Readout electronics for KLOE-2, BES III.
  - Readout electronics for PANDA (coll. with SU).
  - Forward EMC for PANDA (coll. with LU and SU).
  - Pellet target tracking for PANDA
Stockholm University

- Senior faculty 2 (PANDA)
- PhD students 2 (PANDA)

Main activities:

- Physics: hypernuclei
- Hardware:
  - Readout electronics for PANDA (coll. with UU)
  - Forward EMC for PANDA (coll. with UU and LU)
KTH: The Royal Institute of Technology, Stockholm

• Senior faculty 1

Main activities:

• Physics: hypernuclei
• Hardware: Cryostat developments for PANDA (synergies with DEGAS/NUSTAR)
Lund University

- Senior faculty 1

Main activity

- Forward EMC for PANDA (coll. with UU and SU).
Current Facilities

WASA at
(COSY (FZ Jülich))

KLOE-2 at
(DAφNE (INFN Frascati))

BESIII at
(BEPC-II (IHEP Beijing))
Current Facilities

WASA
Closed in 2014

KLOE-2

BESIII

at

COSY
(FZ Jülich)

DAφNE
(INFN Frascati)

BEPC-II
(IHEP Beijing)
WASA highlight

- Lorentzian peak in $np \to d\pi^0\pi^0$ cross section, 4 times narrower than $\Delta\Delta$.
- Proposed explanation: $J^P = 3^+ \Delta\Delta$ resonance*
- Supporting evidence by np elastic PWA**.

* PRL 106 (2011) 242302, ** PRL 112 (2014) 020114
BES III highlight

- Charged charmonium: $Z_c(3900)^-\bar{\tau}$ observed in $J/\psi \pi^-\bar{\tau}$ in 2013.*
- Confirmed in other channels and by other experiments.
- Isospin partner found in $J/\psi \pi^0$ **.
- APS highlight of the year 2013.
- Multi-quark?
- Molecule?
- Other states found: e.g. $Z_c(4025)^-\bar{\tau}$***

*** PRL 111 (2013) 242001
Electromagnetic structure of hadrons:

- Observable: electromagnetic form factors
  - $G_E$ and $G_M$ for spin $\frac{1}{2}$ hadrons
- Space-like and time-like.

**Scattering**

SPACE-LIKE
Real FFs
$q^2 < 0$

**Annihilation**

"Unphysical region"
Complex FFs
$q^2 > 0$

$\vec{p}p \rightarrow \pi^0 e^+ e^-$

$q^2 < 0$

$\gamma^*(q)$
BES III physics in Uppsala

Uppsala @ BES III:
- $\eta_c$ transition form factors
- Hyperon form factors:

“What happens if you replace a light quark in the nucleon with a heavier one?”
BES III physics in Uppsala

Time-like hyperon EMFF’s accessible in $\left( e^+ e^- \rightarrow \gamma^* \rightarrow YY \right)$ → $G_E$ and $G_M$ complex with a relative phase.

- The phase induces polarization of the final state.
- The polarization experimentally accessible from the hyperon decay.
- Analysis in progress: first measurement ever of the phase!
BES III hardware development

- Similar type as recently installed at KLOE-2.
- Analog readout.
- Data concentrators under development in Uppsala.
- Collaboration with Beijing, Frascati, Mainz and Torino.
KLOE-2 physics in Uppsala

- Search for rare decays of $\eta$ and $\omega$ mesons.
- Precision measurements of known decays.
- Provides test of e.g. ChPT.

Dalitz decay of

$$\eta \rightarrow \pi^+ \pi^- \pi^0$$

Li Caldeira Balkeståhl,
Future facility: PANDA @ FAIR
Physics with PANDA @ FAIR

- Hadron spectroscopy
  - Charmonium
  - Multi-strange baryons (UU)
- Nucleon structure
- Hyperon spin physics (UU)
- CP violation in baryon decays (UU)
- Hypernuclear physics (SU, KTH)
- Hadrons in nuclear media
Advantages of $\bar{p}p$ annihilations:

- Gluon-rich environment:
  - Gluonic excitations accessible!
- Formation of all $q\bar{q}$-like $J^{PC}$ states:
  - Improved resolution by resonance scans!
- Strangeness factory:
  - Probes the confinement domain!
The High Energy Storage Ring

- Provides anti-protons within $1.5 \text{ GeV/c} < p_{\bar{p}p} < 15 \text{ GeV/c}$
- Internal targets
  - Cluster jet and pellet ($\bar{p}p$)
  - Foils ($\bar{p}A$)
- High Resolution Mode (HESRr)
  - $L = 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
  - $\Delta p/p < 5 \cdot 10^{-5}$
  - Available from Day One
- High Luminosity Mode
  - $L = 2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
  - $\Delta p/p < 10^{-4}$
  - Available a few years after start-up
The PANDA detector

- **Vertex detector**
- **Modular design**
- **Time-based data acquisition with software trigger**

- **4\pi coverage**
- **Precise tracking**
- **PID**
- **Calorimetry**
PANDA in Sweden

- PWO Calorimeters
- Pellet Tracking
- Software Development
- Physics Simulations
- Ge detectors hypernuclei
## Funding sources

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Location</th>
<th>Swedish participation</th>
<th>Funding source</th>
<th>Status</th>
<th>Remark</th>
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<tbody>
<tr>
<td>WASA</td>
<td>FZ Jülich</td>
<td>UU</td>
<td>EC (prev. also VR)</td>
<td>Closed down 2014</td>
<td>All hadron activities @ FZJ closed in 2014</td>
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<td>KLOE-2</td>
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<td>EC (prev. also VR)</td>
<td>Running</td>
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<tr>
<td>BES III</td>
<td>IHEP Beijing</td>
<td>UU</td>
<td>VR, EC</td>
<td>Running</td>
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And now to the next topic: heavy ion physics!

The following presentation is on behalf of Anders Oskarsson, Lund.
Heavy Ion Physics in Sweden

Slides from Anders Oskarsson
Lund University

We apologize that we can not be here but we are local organizers of LHCP2016 taking place in Lund this week.
The Lund group is the only Swedish group in Heavy Ion Physics

<table>
<thead>
<tr>
<th>Units %</th>
<th>Research fraction</th>
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<tr>
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</table>
Lund is one of the instigators of Heavy ion Physics. In the field since the 70’s.

**Present engagements**

PHENIX@RHIC 90’s -now

In the PHENIX since day-1, 1992
- central tracking
- Invented original pixelized readout of MWPC
- 2 DIGITAL ASICs with Swedish industry
- 1 ANALOG ASIC with ORNL
- Developed, financed and fabricated unique 300kchannels FEE
- 1 M€ invested

In 2 weeks end of PHENIX after 16 Years.
Lund has not capacity to participate in SuperPhenix.
Heavy Ions important part of LHC programme. Out of 23 physics papers with >250 citations (standing April 1), 10 are heavy ions.
Lund detector involvement: the TPC

500,000 readout channels manufactured, delivered and tested in Lund

Sweden has contributed with 20% of the TPC costs
2nd largest after Germany
2.5M€ invested

PID is the speciality of ALICE. The TPC is the key detector
Clean PID - No combinatorial mistakes btw p and dE/dx
Excellent for identification of rare species like antialpha.
ALICE TPC sensitivity Upgrades.

For RUN 2
• Lund contribution LS1 to RCU-2 project. Modernizing Data readout.
• Doubles the DAQ rate from TPC → Doubles HI running time
• Exhausts the sensitivity of ALICE for pA and AA energy during Run 2

For RUN 3, the major ALICE upgrade
• 50kHz PbPb expected
• ~5 overlapping events in TPC
• Tracking and HLT performance simulated OK
• Present TPC 280 microsecs deadtime after each event (gate off all ions)
• With GEM readout, ~1% ion backflow without gating
• Continuous operation i.e. 50kHz TPC events analyzed

4 GEMs
No holes may line up
Physics reach by online cluster finding and tracking compression factor 20. (analyze 50kHz)
• Heavy flavour in wide PT. Thermalization of heavy flavour
• Low PT charmonium
• Low mass dileptons

High density environment of all sorts of flavours gives high density hadron environment
With different flavour content. These hadrons can coalesce to nuclei and antinuclei
• Multistrange Hypernuclei
• Antinuclei
• ...

Lund upgrade work
• Coordinating simulations
• Coordinating testing of SAMPA chip
• Production testing of SAMPA chip
• FEE together with ORNL
All Heavyioners in action (one behind the Camera)
+ 1 bachelor and 1 master student
Thanks for your attention!