Dear Summer School Participant,

Having provided you with some detailed information about our school in our first circular, this final circular is intended to give you a short overview on the program and some info on weather and clothing.

Program & Schedule

Link to INDICO-page with timetable:
https://indico.desy.de/getFile.py/access?resId=7&materialId=5&confId=4039

Link to INDICO-page with program of parallel sessions:
https://indico.desy.de/getFile.py/access?resId=6&materialId=5&confId=4039

Weather & Clothing

The Chiemsee is located at 518 m above sea level and due to its special micro-climate the weather may change unexpectedly. The temperature varies from a maximum of 15-23 degrees Celsius during the day to 7-12 degrees Celsius during the night. We advise you to bring some warm, wind- and rain-proof clothes, sturdy shoes, and sun protection especially for the hiking excursion which will take us to 1467 m above sea level.

Summer School Address

Summer School 'Symmetries, Fundamental Interactions & Cosmology'
c/o Abtei Frauenwörth
D-83256 Frauenchiemsee
Phone: +49 8054 - 9070
Mobile: 0175 – 72 50 985 (only Sept.10.–16.)
Fax: +49 8054 - 7967
E-Mail: lugert@uni-mainz.de; fischer@kph.uni-mainz.de

Please note that we are on an island! For the nearest shop you will need to leave the island by boat and take a 30 minutes walk to the city center of Prien.

Please make sure to carry any essential medication with you!

Presentations

Please prepare your talk as pdf-file, which will be uploaded on a conference laptop prior to your talk.

For University Mainz employees and students:

For those of you, who have not yet done so, please fill in a travel request form (Dienstreiseantrag) promptly!

If you can offer a ride in your car from Mainz to Chiemsee, please let the organizers know!
Introduction

Why study baryons?

- 3-quark bound states
  ⇒ excellent probe to study QCD
- baryon spectrum only poorly known
  ▶ many states with * or ** in PDG listings
  ▶ many missing states
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How to study baryons?

- $\pi N$ scattering
  - no new data available
  - still dominates PDG listings
- $\gamma N$ scattering
  - MAMI, ELSA (HK 84.2),...
- $J/\psi$ decays
  - BESIII (HK 61.1)
- $NN$ scattering
  - HADES (HK 1.2)
  - COMPASS
What do we measure at COMPASS?

- 2009 data taking
- 190 GeV/c proton beam on liquid hydrogen target
- So far only two channels investigated:
  - $pp \rightarrow p_f \pi^+ \pi^- p_{\text{recoil}}$
  - $pp \rightarrow p_f K^+ K^- p_{\text{recoil}}$
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The COMPASS Experiment

- **CO**mmon **Mu**on and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
- Located at SPS at CERN
The COMPASS Experiment

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75% $p$
24% $\pi^+$
190 GeV/c
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CEDARs
The COMPASS Experiment

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![Diagram of COMPASS setup]

- 75% $p$
- 24% $\pi^+$
- 190 GeV/c

CEDARs

Target
The COMPASS Experiment

- **COmmom Muon and Proton Apparatus for Structure and Spectroscopy**
- Located at SPS at CERN

![Diagram of COMPASS Experiment]

- 75% p
- 24% π⁺
- 190 GeV/c

CEDARs

Target

Large Angle Spectrometer

RICH
The COMPASS Experiment

- **COMMON** **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
- Located at SPS at CERN

- 75% $p$
- 24% $\pi^+$
- 190 GeV/c

CEDARs

Large Angle Spectrometer

Small Angle Spectrometer

Target

RICH
### Cuts

- **minimum bias trigger**
  - incoming beam + recoiling proton
- **exactly 1 primary vertex reconstructed inside the target**
- **identified incoming proton**
- **1 reconstructed recoil proton**
- **3 outgoing charged particles**
  - $\sum Q = +1$
- **outgoing $\pi^+$ or $K^+$ identified by RICH**
**Exclusivity and Coplanarity**

Exclusive events selected by 2 cuts:

- energy sum of outgoing system around peak value (exclusivity)
- azimuthal angles of outgoing system and recoil proton differ by $\pi$ (coplanarity)

### Exclusivity

![Exclusivity histogram](chart1)

**COMPASS 2009**

$pp \rightarrow p_f \pi^+ \pi^- p_{\text{recoil}}$

- before cut
- after coplanarity cut

### Coplanarity

![Coplanarity histogram](chart2)

**COMPASS 2009**

$pp \rightarrow p_f \pi^+ \pi^- p_{\text{recoil}}$

- before cut
- after exclusivity cut

Tobias Weisrock (JGU Mainz)
Baryon Spectroscopy at COMPASS

\[ pp \rightarrow p_f \pi^+ \pi^- p_{\text{recoil}} \]

**Invariant Mass of \( \pi^+ \pi^- p_f \)**

- More than 56M events
- Small structure at \( \approx 1450 \text{ MeV} \)
- Dominant structure at \( \approx 1700 \text{ MeV} \)
  - Possible candidates: \( N(1700)^{3/2^-} \) (***)
  - \( \Delta(1700)^{3/2^-} \) (****)
  - \( N(1710)^{1/2^+} \) (***)
  - \( N(1720)^{3/2^+} \) (****)
- Shoulder at \( \approx 2200 \text{ MeV} \)
pp $\rightarrow p_f \pi^+ \pi^- p_{\text{recoil}}$

**Invariant Mass of $\pi^+ p_f$-subsystem**

- $\Delta^{++}(1232)$ dominates
- Small shoulder at $\approx 1900$ MeV
Baryon Spectroscopy at COMPASS

\[ pp \rightarrow pf \pi^+ \pi^- p_{\text{recoil}} \]

Invariant Mass of \( \pi^- p_f \)-subsystem

- \( \Delta^0(1232) \)
- \( N(15??) \) \( \leftarrow \) dominant decay mode of 1700 MeV structure
- \( N(16??), \Delta(16??) \)

COMPASS 2009

pp \( \rightarrow p_f \pi^+ \pi^- p \)

(no acceptance correction)

preliminary

\( \Delta^0(1232) \)
$pp \rightarrow pf\pi^+\pi^-p_{recoil}$

**Invariant Mass of $\pi^+\pi^-$-subsystem**

- $\rho(770)$
- $f_0(980)$
- $f_2(1270)$
Baryon Spectroscopy at COMPASS

\[ pp \rightarrow p_\ell K^+K^- p_{\text{recoil}} \]

Cuts

Exclusivity

Coplanarity

COMPASS 2009

pp → p_\ell K^+K^- p_{\text{recoil}}
(no acceptance correction)
preliminary

COMPASS 2009

pp → p_\ell K^+K^- p_{\text{recoil}}
(no acceptance correction)
preliminary
Baryon Spectroscopy at COMPASS

\[ pp \rightarrow p_f K^+ K^- p_{\text{recoil}} \]

**Invariant Mass of** $K^+ K^- p_f$

- more than 900k events
- no clear structures seen
- some pion contributions still visible

⇒ RICH selection still to be optimised
Baryon Spectroscopy at COMPASS

\[ pp \rightarrow p_f K^+ K^- p_{\text{recoil}} \]

**Invariant Mass of \( K^+ p_f \)-subsystem**

- no resonances expected for \( q = +2 \) and \( s = +1 \)
- no structures seen

COMPASS 2009
\[ pp \rightarrow p f K^+ K^- p \]
(no acceptance correction)
preliminary

\[ \times 10^3 \]

Events / 5 MeV/c\(^2\)

- \( 4 \times 10^3 \)
- \( 3.5 \times 10^3 \)
- \( 3 \times 10^3 \)
- \( 2.5 \times 10^3 \)
- \( 2 \times 10^3 \)
- \( 1.5 \times 10^3 \)
- \( 1 \times 10^3 \)
- \( 0.5 \times 10^3 \)
- \( 0 \times 10^3 \)

**Invariant Mass of \( K^+ p_f \) System (GeV/c\(^2\))**

- \( 1 \)
- \( 1.2 \)
- \( 1.4 \)
- \( 1.6 \)
- \( 1.8 \)
- \( 2 \)
- \( 2.2 \)
- \( 2.4 \)
- \( 2.6 \)
- \( 2.8 \)
- \( 3 \)
pp → p_fK^+K^-p_{recoil}

Invariant Mass of K^-p_{f}-subsystem

- clear $\Lambda(1520)$ contribution
  - good resolution
- further structure at $\approx 1800$ MeV ($\Lambda(18??)$?)

COMPASS 2009
$pp \rightarrow p_K^+K_p$ (no acceptance correction)
preliminary

$\Lambda(1520)$

Events / 5 MeV/c^2

Inv. Mass of Kp_f System (GeV/c^2)
**Invariant Mass of $K^+K^-$-subsystem**

- clear $\phi(1020)$ contribution
- good resolution
- shoulder by $a_2(1320)$?
- structure at $\approx 1500$ MeV ($f_0(1500)$? $f'_2(1525)$?)

PWA of centrally produced system performed by A. Austregesilo (HK 2.5)
Conclusion and Outlook

- COMPASS has large datasets for baryon spectroscopy in $pp$ scattering.
- So far $pp \rightarrow p\pi^+\pi^-p$ and $pp \rightarrow pK^+K^-p$ analysed.
- Rich structures visible in most mass spectra.

Next steps:
- Extend to further channels.
- $p\pi^0\pi^0p$, $pK^0\bar{K}^0p$.
- Start of partial wave analysis (PWA).
Conclusion and Outlook

- COMPASS has large datasets for baryon spectroscopy in $pp$ scattering
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Next steps:
- Extend to further channels
  - $p\pi^0\pi^0 p$, $pK^0\bar{K}^0 p$
  - $p\pi^0 p$, $p\eta p$, $p\omega p$, $\Lambda K^+ p$, …
- start of partial wave analysis (PWA)
Thank you for your attention