A Discovery of a new Particle $a_1(1420)$

and a Rediscovery of the exotic $\pi_1(1600)$ at COMPASS

and Future Prospects for ALICE

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Plan of Talk

- An elementary overview of particle physics
Plan of Talk

- An elementary overview of particle physics
- DISCOVERY of a NEW particle by COMPASS at CERN:
  \[ I^G(J^{PC}) = 1^-(1^{++}) \quad a_1(1420) \quad m = 1420^{+10}_{-12.3} \text{ and } \Gamma = 140^{+06}_{-21} \text{ MeV} \]
  — NOT yet cited in PDG, 1 July 2012
  — The First Main Topic for today

- Rediscovery of an EXOTIC MESON by COMPASS:
  \[ I^G(J^{PC}) = 1^-(1^{--}) \quad \pi_1(1600) \quad m = 1608^{+20}_{-20} \text{ and } \Gamma = 587^{\pm40} \text{ MeV} \]
  (the errors are my guesses)
  — The Second Main Topic for today

- Conclusions and Future Prospects for ALICE
  Central Production of \( \pi^+ \pi^- \)
  Central Production of \( \pi^+ \pi^- \pi^+ \pi^- \)
Plan of Talk

- An elementary overview of particle physics

- **DISCOVERY** of a **NEW** particle by **COMPASS** at **CERN**:

  \[ I^G(J^{PC}) = 1^-(1^{++}) \quad a_1(1420) \quad m = 1420^{+10}_{-12.3} \text{ and } \Gamma = 140^{+06}_{-21} \text{ MeV} \]

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- **REDISCOVERY** of an **EXOTIC MESON** by **COMPASS**:

  \[ I^G(J^{PC}) = 1^-(1^{--}) \quad \pi_1(1600) \quad m = 1608^{+20}_{-20} \text{ and } \Gamma = 587 \pm 40 \text{ MeV} \]

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- An elementary overview of particle physics

- DISCOVERY of a NEW particle by COMPASS at CERN:
  \[ I^G(J^{PC}) = 1^- (1^{++}) \]
  \[ a_1(1420) \]
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- REDISCOVERY of an EXOTIC MESON by COMPASS:
  \[ I^G(J^{PC}) = 1^- (1^{-+}) \]
  \[ \pi_1(1600) \]
  \[ m = 1608^{+20}_{-20} \text{ MeV} \]
  \[ \Gamma = 587^{+40}_{-40} \text{ MeV} \]
  (the errors are my guesses)
  — The Second Main Topic for today

- Conclusions and Future Prospects for ALICE
  Central Production of $\pi^+\pi^-$ under way
  Central Production of $\pi^+\pi^-\pi^+\pi^-$ planned
• Hadrons: strongly interacting particles: bound state of two or three quarks
\[ \{ q \bar{q} \} \text{(mesons)} \text{ or } \{ q q q \} \text{(baryons)} \]
• Hadrons: strongly interacting particles: bound state of two or three quarks
\( \{ q \bar{q} \} \) (mesons) or \( \{ q \ q q \} \) (baryons)

• **Exotic mesons of the first kind:**
\( J^{PC} = 0^{--}, 0^{+-}, 1^{--}, 1^{+-}, 2^{--}, \cdots \) are NOT \( \{ q \bar{q} \} \) mesons

Mesons can be more complicated—
\( \{ q \bar{q} + q \bar{q} \} \) (tetraquarks) or gluonic hybrids \( \{ q \bar{q} + \text{gluon} \} \)

Examples: \( \pi_1(1400) \rightarrow \eta \pi \) or \( \pi_1(1600) \rightarrow \rho \pi \rightarrow 3\pi \) have \( J^{PC} = 1^{--} \) and so exotic.

— COMPASS paper in preparation
To be Published in 2014
• Hadrons: strongly interacting particles: bound state of two or three quarks
\(\{q \bar{q}\}\) (mesons) or \(\{q q q\}\) (baryons)

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• **Exotic mesons of the second kind:** \(J^{PC}\) is NOT exotic but its very small cross section points to its exotic nature, i.e. NOT a quarkonium.
\(l^G(J^{PC}) = 1^{-}(1^{++})\)

\(a_1(1420) \to f_0(980)\pi, \quad f_0(980) \to (2\pi)^0\)

\(\sigma[a_1(1420)]/\sigma[a_1(1260)] \leq 7.5\%\)

— COMPASS paper in preparation
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Diffractive Dissociation Processes for a Meson System $c$

Consider a reaction

$$a + b \rightarrow c + d, \quad c \rightarrow 1 + 2 + \cdots + (n - 1) + n$$

which is mediated by the Reggeon-exchange process:

$$a \rightarrow c + R$$

$$c \rightarrow 1 + 2 + \cdots + (n - 1) + n$$

Diffractive Dissociation

$$b + R \rightarrow d$$

$R$ is likely to be a Pomeron with $I^G(J^{PC}) = 0^+(2^{++})$

—“Pomeron Physics and QCD,”

S. Donnachie, G. Dosch, P. Landshoff, O. Nachtmann
• COMPASS data on

\[ \pi^- + p \rightarrow X^- + p, \quad X^- \rightarrow (\pi^+\pi^-)_{\text{isobar}} + \pi^- \]  (the isobar model)

at 190 GeV/c (the \(\pi^-\) beam momentum) on a liquid hydrogen target. The statistics on the 2008 data: \(50 \times 10^6\) events—some 20\(\times\) the original BNL-E852 data.
COMPASS data on

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Partial waves:

\[ I^G J^{PC} (\text{isobar for the neutral } \pi^+\pi^- \text{ systems}) \pi^- L \]

where \(L\) is the orbital angular momentum between the isobar and the bachelor \(\pi^-

Here \(I^G = 1^-\) and \(C = +1\) always.
COMPASS data on

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The techniques of the partial-wave analysis via extended likelihood method: The Poisson distribution for the observed number of events in a given bin is included in the likelihood function.
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- The techniques of the partial-wave analysis via extended likelihood method:
The Poisson distribution for the observed number of events in a given bin is included in the likelihood function.

- Fit a set of partial waves for a given mass for \( X, m_{3\pi} \) in 20 MeV bins, and the \( t' = |t| - |t|_{\text{min}} \) in 11 bins, from 0.100 to 1.00 (GeV/c)^2.
Spins included in the fits: $0 \leq J \leq 6$

Isobars for the neutral $\pi^+\pi^-$ systems used in the current analysis:

$(\pi\pi)_S$ or $f_0(500)$ (the $\sigma$ meson), $\rho^0(770)$, $f_0(980)$, $f_2(1270)$, $f_0(1500)$, $\rho_3(1690)$, $f_4(2050)$
$\pi^+ p \rightarrow \pi^- \pi^+ \pi^- p$ (COMPASS 2008)

Number of Events / (5 MeV/$c^2$)

Mass of $\pi^- \pi^+ \pi^-$ System (GeV/$c^2$)

- $0.6$
- $0.8$
- $1$
- $1.2$
- $1.4$
- $1.6$
- $1.8$
- $2$
- $2.2$
- $2.4$

$\pi p \rightarrow \pi^+ \pi^- \pi^- p$ (COMPASS 2008)

Number of Events (3.33 $\cdot 10^3$ GeV$^2$/c$^2$)

Squared Four-Momentum Transfer $t'$ (GeV$^2$/c$^2$)

- $0$
- $0.2$
- $0.4$
- $0.6$
- $0.8$
- $1$
- $1.2$
\( \pi^- p \rightarrow \pi^- \pi^+ \pi^- p \) (COMPASS 2008)

- \( 0.10 \leq t' \leq 0.12 \text{ GeV}^2/c^2 \)
- \( 0.44 \leq t' \leq 1.0 \text{ GeV}^2/c^2 \)

**Number of Events / (5 MeV/c^2) vs. Mass of \( \pi^- \pi^+ \pi^- \) System (GeV/c^2)**

**Number of Events / (5 MeV/c^2) vs. Mass of \( \pi^- \pi^- \pi^+ \) System (GeV/c^2)**
The $a_2(1320)$
$J^G(J^{PC}) = 1^-(2^{++})$
$\rho^0 \pi \ D$: $\simeq 8\%$ of total

The $\pi_2(1670)$
$J^G(J^{PC}) = 1^-(2^{--})$
$\rho^0 \pi \ D$: $\simeq 0.9\%$ of total
The π(1800) \( I^G(J^{PC}) = 1^- (0^{-+}) \)
\( \sigma(600) \pi \) \( S \): \( \simeq 8\% \) of total

The π(1800) \( I^G(J^{PC}) = 1^- (0^{-+}) \)
\( f_0(980) \pi \) \( S \): \( \simeq 2.4\% \) of total
The $a_4(2040)$
$I^G(J^{PC}) = 1-(4++)$
$\rho^0\pi S$: $\simeq 0.8\%$ of total

The $a_1(1260)$
$I^G(J^{PC}) = 1-(1++)$
$\rho^0\pi S$: $\simeq 4\%$ of total
NEW to physics

\[ I^G(J^{PC}) = 1^- (1^{++}) \]

\[ f_0(980) P: < 0.3\% \]

\[ a_1(1420) \rightarrow f_0(980) \pi \]

\[ f_0(980) \rightarrow \pi \pi \]

Likely to be EXOTIC:

\[ \frac{\sigma[a_1(1420)]}{\sigma[a_1(1260)]} \leq 7.5\% \]
$J^{PC} = 1^{--}$ Meson: the $\pi_1^-(1600) \rightarrow (\rho)^0 \pi^- \rightarrow (3\pi)^-$
COMPASS and ALICE Experiments at CERN
Meson Spectroscopy on Exotics September 12, 2014 16/24

$\pi p \rightarrow \pi\pi\pi p$ (COMPASS)

$1^+ 1^+ \rho(770) \pi p$

$0.100 \leq t' \leq 0.113 \text{ GeV}^2/c^2$ 0.66%

$0.127 \leq t' \leq 0.144 \text{ GeV}^2/c^2$ 0.78%

$0.74\%$

$0.78\%$
\[ \pi p \rightarrow \pi \pi \pi' p \] (COMPASS)

Mass of the \( \pi \pi \pi' \) System (GeV):

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\[ \Gamma^{\ast} \Gamma^0 \rho(770) \pi P \] (COMPASS)

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\[ \pi p \rightarrow \pi \pi \pi' p \] (COMPASS 2008)

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COMPASS and ALICE Experiments at CERN

Meson Spectroscopy on Exotics
September 12, 2014

\[ \pi p \rightarrow \pi \pi \pi p \ (\text{COMPASS 2008}) \]

Intensity (20 MeV/c)

Mass of the \( \pi \pi \pi \) System (GeV/c²)

\[ 0.94\% \]

\[ 0.449 \leq t' \leq 0.724 \text{ GeV}^2/c^2 \]

\[ \Gamma^{1+} \rho(770) \text{\ P} \]

\[ 0.96\% \]

\[ 0.734 \leq t' \leq 1.00 \text{ GeV}^2/c^2 \]
COMPASS and ALICE Experiments at CERN
Meson Spectroscopy on Exotics
September 12, 2014
21/24
Conclusions I

- DISCOVERY of a NEW particle by COMPASS at CERN:

\[ I^G(J^{PC}) = 1^-(1^{++}) \quad a_1(1420) \quad m = 1420 \pm 10 \quad \text{MeV} \quad \Gamma = 140 \pm 0.6 \quad \text{MeV} \]

\[ \sigma[a_1(1420)]/\sigma[a_1(1260)] \leq 7.5\% \]

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--- The First Main Topic for today
• DISCOVERY of a NEW particle by COMPASS at CERN:

\[ I^G(J^{PC}) = 1^-(1^{++}) \]

\[ a_1(1420) \quad m = 1420 \pm 10 \text{ and } \Gamma = 140 \pm 6 \text{ MeV} \]

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• REDISCOVERY of an Exotic MESON by COMPASS at CERN:

\[ I^G(J^{PC}) = 1^-(1^{+-}) \]

\[ \pi_1(1600) \quad m = 1608 \pm 20 \text{ and } \Gamma = 587 \pm 80 \text{ MeV} \]

(errors are my guesses)

— To be published by COMPASS in 2014

— The Second Main Topic for today
• NOT covered in this talk:

**Central Production** of $\pi^+\pi^-$ and $K^+K^-$ at COMPASS  
—A. Austregesilo/TU München


$\pi_1(1600)$ from $\pi^- + \text{Pb} \rightarrow (\pi^+\pi^-\pi^-) + \text{Pb}$ at 190 GeV/c


• NOT covered in this talk:

Central Production of $\pi^+\pi^-$ and $K^+K^-$ at COMPASS  
—A. Austregesilo/TU München

$\pi_1(1600)$ from $\pi^- + \text{Pb} \rightarrow (\pi^+\pi^-\pi^-) + \text{Pb}$ at 190 GeV/c


• Note: Florian Haas (TU/München) reproduced all the previous analyses on $3\pi$ by simply using the selections applied previously
• NOT covered in this talk:

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• Note: Florian Haas (TU/M"unchen) reproduced all the previous analyses on $3\pi$
by simply using the selections applied previously

• Expect new results from ALICE on
  Central production of $\pi^+\pi^-$
  Central production of $\pi^+\pi^-\pi^+\pi^-$ planned
Thank you for your attention