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1 Introduction

2 Diffractive Production at COMPASS (2004)
   - Partial Wave Analysis Formalism
   - $3\pi$ Final State PWA Results
   - $5\pi$ Final State

3 COMPASS 2008 Hadron Data
   - Spectrometer Upgrade
   - $3\pi$ Final State

4 Summary and Outlook
Mesons and Spin-Exotic States

Constituent Quark Model

- Color-neutral $q\bar{q}$ systems
- Quantum numbers $I^GJ^{PC}$
- $P = (-1)^{L+1}$, $C = (-1)^{L+S}$, $G = (-1)^{I+L+S}$
- $J^{PC}$ Multiplets: $0^{++}, 0^{--}, 1^{--}, 1^{++}, 1^{+-}, 2^{++}, ...$
- Forbidden: $0^{+-}, 1^{--}, 2^{++}, 3^{--}, ...$

QCD: Additional color-neutral objects

- Tetraquarks $(q\bar{q})(q\bar{q})$
- Hybrids $(q\bar{q})g$
- Glueballs $gg$

Spin Exotic States

- $J^{PC}$ forbidden $\Rightarrow$ cannot be a $q\bar{q}$ state
- No mixing with quark model states
### Lightest Glueballs

- **QCD predictions:**
  \[ M \sim 1.7 \text{ GeV}/c^2 (J^{PC} = 0^{++}) \]
  \[ M \sim 2.4 \text{ GeV}/c^2 (J^{PC} = 2^{++}) \]
- **Experimental candidate:**
  \[ f_0(1500) \ (J^{PC} = 0^{++}) \]
  (Crystal Barrel, WA102)
  → mixing with isoscalar mesons!

### Hybrids

**Light meson sector:**

- Spin-exotics \( J^{PC} = 1^{--} \)
  - \[ \pi^+_1(1400) \]
    (VES, E852, Crystal Barrel)
  - \[ \pi^+_1(1600) \]
    (E852, VES)
- **Still controversial!**

Meson states with \( I^G = 1^- \)
listed in the PDB.
Green = established,
blue = need confirmation,
red = “further states”.
The histogram is stacked.
Light Meson Spectroscopy

Lightest Glueballs

- QCD predictions:
  \[ M \sim 1.7 \text{ GeV}/c^2 (J^{PC} = 0^{++}) \]
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Hybrids

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- \( \pi_1(1400) \)
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  (E852, VES)

Still controversial!

Meson Spectroscopy and Search for Spin-Exotic States (non-\( q\bar{q} \))

- COMPASS can contribute significantly in the low mass region

Meson states with \( I^G = 1^- \)
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COMPASS 2004 Hadron Pilot Run
Experiment Setup

Overview
- **COmmon Muon and Proton Apparatus for Structure and Spectroscopy**
- Located at CERN's SPS
- Fixed-target experiment
- Two-stage magnetic spectrometer
- Data taking since 2002

Physics Goals
- Nucleon spin structure
- Hadron spectroscopy

Second./Tert. SPS Beams
- **Muons**: $4 \times 10^7 s^{-1}$
- **Hadrons**: up to $2 \times 10^7 s^{-1}$
- **100-250 GeV**
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Physics Goals

- Nucleon spin structure
- Hadron spectroscopy

Pilot Hadron Run 2004

- **190 GeV** $\pi^-$ beam
- Nuclear targets (Pb)
- Tracking: Silicons for vertexing
- Trigger: Multiplicity trigger, ECAL trigger
Challenges and Opportunities in the light (u,d) Quark Sector

- High density of states; broad, overlapping states
- **Exploit interference** effects → phase motion
- Requires **high statistics, complete PS coverage** → COMPASS

COMPASS

- Positive and negative beams (p, π, K) at variable energies
- Several decay modes accessible (neutral, kaonic, ...)

Central production

Diffractive Dissociation

(→ J. Bernhard)  
this talk!
**Diffraction:** target particle remains intact
Reggeon t-channel exchange

**Assumptions:** Factorization of meson and Pb vertex, no final state interaction

**Dissociation:** beam pion is excited to a resonance $X^-$, which subsequently decays

- e.g. $\pi^-\text{Pb} \rightarrow X^-\text{Pb} \rightarrow \pi^-\pi^-\pi^+\text{Pb}$
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Diffractive Production of Mesons

- **Diffraction**: target particle remains intact
  - Reggeon t-channel exchange
  - **Assumptions**: Factorization of meson and Pb vertex, no final state interaction

- **Dissociation**: beam pion is excited to a resonance $X^-$, which subsequently decays
  $$\Rightarrow \text{e.g. } \pi^- \text{Pb} \rightarrow X^- \text{Pb} \rightarrow \pi^- \pi^- \pi^+ \text{Pb}$$
  $$\Rightarrow \text{e.g. } \pi^- \text{Pb} \rightarrow X^- \text{Pb} \rightarrow \pi^- \pi^- \pi^+ \pi^- \pi^+ \text{Pb}$$

- Exclusive $3\pi$ or $5\pi$ final state events (pion hypothesis).

- **COMPASS 2004 (few days of data taking)**:
  - $\sim 4\ 000\ 000$ $3\pi$ events
  - $\sim 400\ 000$ events enter analysis (BNL: 250 000)
  - $\sim 380\ 000$ $5\pi$ events
Momentum transfer from target: 
\[-t = -(p_{\text{beam}} - p_{\pi^- \pi^- \pi^+})^2\]

\[\Rightarrow t' = |t| - |t|_{\text{min}}\]

Diffraction pattern: Pb nucleus acts like "black disc" in optics

High-\(t'\): scattering on single nucleons inside Pb nucleus
**3π Data Sample (2004)**

π−π−π⁺ Mass Distributions

### Different t' Ranges

**πPb → ππ⁺Pb**

**COMPASS 2004**

Ranges in t' (GeV²/c²):
- all t'
- t' < 10⁻³
- 10⁻³ < t' < 10⁻²
- 10⁻² < t' < 10⁻¹
- 0.1 < t' < 1
- t' > 1 [x5]

### High-t' Spectrum

**πPb → ππ⁺Pb**

0.1 < t' < 1.0 GeV²/c²

**COMPASS 2004**

- a₂(1320)
- a₁(1260)
- π₂(1670)
**Partial Wave Analysis Formalism**

*Isobar Model, Helicity and Tensor Formalisms, Waveset*

- **Isobar model**: Intermediate 2-particle decays
- **Zemach / Helicity formalism**, reflectivity basis
- **Reggeon exchange**
- **Partial wave**: $J^{PC}M^\epsilon[isobar]L$
- **Nucleon target** $\Rightarrow$ rank 2

**Mass-independent** PWA (40 MeV/$c^2$ mass bins): 42 waves
- Extended log-likelihood method
- Acceptance corrections included
- $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$ from PDG, $(\pi\pi)_s$ with separated $f_0(980)$ from VES

**Mass-dependent** $\chi^2$-fit: 6 waves
- $X$ parameterized by Breit-Wigner (BW) functions
- Coherent background added for some waves: $\exp(-\alpha p^2)$
### Partial Wave Set for Mass-Independent Fit (42 Waves)

**Description of possible Decay Amplitudes**

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#### Waveset Features

- 41 Waves + Flat Background
- Isobars:
  - $(\pi\pi)_s\pi$, $\rho(770)$, $f_0(980)$, $f_2(1270)$, $\rho(3)$
- Larger waveset than all previous analyses

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Extraction of Resonance Parameters from Intensities and Interferences

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FLAT
PWA Results

$1^{++}0^{+}\rho\pi S$ and $2^{-+}0^{+}f_2\pi S$

**COMPASS 2004**

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

Intensity / (40 MeV/c$^2$)

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

**BW for $a_1(1260)$ + background:**

$M = (1.255 \pm 0.006 +^{0.007}_{-0.017})$ GeV/c$^2$

$\Gamma = (0.367 \pm 0.009 +^{0.028}_{-0.025})$ GeV/c$^2$

**BW for $\pi_2(1670)$:**

$M = (1.658 \pm 0.003 +^{0.024}_{-0.008})$ GeV/c$^2$

$\Gamma = (0.271 \pm 0.009 +^{0.022}_{-0.024})$ GeV/c$^2$
Significant $1^{-+}$ amplitude consistent with resonance at $\sim 1.7$ GeV/$c^2$

No leakage observed ($< 5\%$)

BW for $\pi_1(1600)$ + background:

$$M = (1.660 \pm 0.010 \pm 0.000 \pm 0.064) \text{ GeV}/c^2$$

$$\Gamma = (0.269 \pm 0.021 \pm 0.042 \pm 0.064) \text{ GeV}/c^2$$
Summary of Extracted States from $\pi^-\text{Pb} \rightarrow X^-\text{Pb} \rightarrow \pi^-\pi^-\pi^+\text{Pb}$

Comparison with PDG values

- $\pi(1260)$
- $\rho(1320)$
- $a(1600)$
- $p(1670)$
- $p(1800)$
- $p(2040)$

Particle Mass (GeV/c$^2$)

<table>
<thead>
<tr>
<th>Mass (GeV/c$^2$)</th>
<th>COMPASS 2004</th>
<th>PDG 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stefanie Grabmüller (TUM E18)
COMPASS meson spectroscopy
SPIN-Praha-2009
15 / 31
Going to 5 Charged Pions: \( m_X = 2 \text{ GeV}/c^2 \) and beyond

Physics Potential of the Exclusive 5 Charged Pion Final State

**Motivation:**
- Confirmation of hybrid with \( 1^{-+} \)
- Access to mass-range \( > 2 \text{ GeV}/c^2 \)
- Other interesting accessible quantum numbers:
  - \( 1^{-}(0^{++}) \) not accessible in \( 3\pi \)!
  - \( 1^{-}(3^{-+}) \) high J spin exotic?
- BNL: \( \pi^- p \rightarrow f_1 \pi \rightarrow \eta\pi^+\pi^-\pi^- \)
  - 2 exotic \( 1^{-+} \) states

### \( \pi_1(1^{-+}) \) branching ratios

<table>
<thead>
<tr>
<th>( m_{\pi_1} ) \text{ GeV}/c^2</th>
<th>( b_1 \pi )</th>
<th>( f_1 \pi )</th>
<th>( \eta' \pi )</th>
<th>( \rho(1450)\pi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>24:2:2</td>
<td>5:2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>43:10:27:12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Flux-Tube model predictions:
(Page, Swanson, Szczepaniak, Phys. Rev. D59, 034016(1999))

\( m_{\pi_1} = 1450 \text{ MeV}/c^2 \)

\( \rho(1450) \)

\( \eta' \)

\( f_1 \)

\( b_1 \)

COMPASS 2004
\( \pi^- \text{ Pb} \rightarrow \pi^+\pi^-\pi^+\pi^-\text{ Pb} \)

No Acceptance Correction

Computational Diagram
Motivation:

- Confirmation of hybrid with 1\(^{−+}\)
- Access to mass-range \(> 2\) GeV/\(c^2\)
- Other interesting accessible quantum numbers:
  - \(1^{−}(0^{++})\) not accessible in 3\(\pi\)!
  - \(1^{−}(3^{−+})\) high J spin exotic?
- BNL: \(\pi^− p \rightarrow f_1 \pi \rightarrow \eta \pi^+ \pi^− \pi^−\)
  2 exotic 1\(^{−+}\) states

### \(\pi_1(1^{−+})\) branching ratios

Flux-Tube model predictions:
(Page, Swanson, Szczepaniak, Phys. Rev. D59, 034016(1999))

<table>
<thead>
<tr>
<th>(m_{\pi_1}) (GeV/(c^2))</th>
<th>(b_1 \pi)</th>
<th>(f_1 \pi)</th>
<th>(\eta' \pi)</th>
<th>(\rho(1450)\pi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6 GeV/(c^2)</td>
<td>24:</td>
<td>5:</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2.0 GeV/(c^2)</td>
<td>43:</td>
<td>10:</td>
<td>27:</td>
<td>12</td>
</tr>
</tbody>
</table>

### Preliminary COMPASS 2004

\(\pi^+ \text{Pb} \rightarrow \pi^+\pi^−\pi^+\pi^−\pi^−\text{Pb}\)

No Acceptance Correction

Bins in \(t'\) (GeV/\(c^2\))
- \(0 < t' < 0.005\)
- \(0.005 < t' < 0.1\)
- \(0.1 < t' < 2\)
4π Subsystem – the $f_1$ and Friends

Isobar Candidates

**Cut 4π spectrum:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Mass (GeV/$c^2$)</th>
<th>$J^P_C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0$</td>
<td>1370 / 1700</td>
<td>0$^+$ (0$^{++}$)</td>
</tr>
<tr>
<td>$\eta'$</td>
<td>1403</td>
<td>0$^+$ (0$^{−−}$)</td>
</tr>
<tr>
<td>$\rho'$</td>
<td>1450</td>
<td>1$^+$ (1$^{−−}$)</td>
</tr>
<tr>
<td>$b_1$</td>
<td>1235 / 1800</td>
<td>1$^+$ (1$^{−−}$)</td>
</tr>
<tr>
<td>$f_1$</td>
<td>1285 / 1450</td>
<td>0$^+$ (1$^{++}$)</td>
</tr>
<tr>
<td>$\eta_2'$</td>
<td>1645</td>
<td>0$^+$ (2$^{−−}$)</td>
</tr>
<tr>
<td>$f_2$</td>
<td>1565</td>
<td>0$^+$ (2$^{++}$)</td>
</tr>
<tr>
<td>$\rho_3$</td>
<td>1690</td>
<td>1$^+$ (3$^{−−}$)</td>
</tr>
</tbody>
</table>
- Change-over to liquid hydrogen target
- Spectrometer upgrades:
Change-over to liquid hydrogen target

Spectrometer upgrades:
  - CEDARs (→ P. Jasinski)
- Change-over to liquid hydrogen target
- Spectrometer upgrades:
  - CEDARs (→ P. Jasinski)
  - RPD (→ J. Bernhard)
- Change-over to liquid hydrogen target
- Spectrometer upgrades:
  - CEDARs (→ P. Jasinski)
  - RPD (→ J. Bernhard)
  - Silicons
Change-over to liquid hydrogen target

Spectrometer upgrades:
- CEDARs (→ P. Jasinski)
- RPD (→ J. Bernhard)
- Silicons
- **Sandwich Veto** (→ T. Schlüter)
Change-over to liquid hydrogen target

Spectrometer upgrades:
- CEDARs (→ P. Jasinski)
- RPD (→ J. Bernhard)
- Silicons
- Sandwich Veto (→ T. Schlüter)
- PixelGEMs
- Change-over to liquid hydrogen target
- Spectrometer upgrades:
  - CEDARs (→ P. Jasinski)
  - RPD (→ J. Bernhard)
  - Silicons
  - Sandwich Veto (→ T. Schlüter)
  - PixelGEMs
  - ECALs
$0.1 \text{GeV}^2/c^2 < t' < 1.0 \text{GeV}^2/c^2$

COMPASS 2008

\[ \pi^+ p \rightarrow \pi^- \pi^- \pi^+ p \]

$0.1 \text{GeV}^2/c^2 < t' < 1.0 \text{GeV}^2/c^2$

w/o acceptance correction

(21\% of 2008 data)
3π Data Sample (2008)
Dalitz Plots

Dalitz Plot for $a_2(1320)$:
Events selected by $M_{a_2} \pm \Gamma_0$

Dalitz Plot for $\pi_2(1670)$:
Events selected by $M_{\pi_2} \pm 0.5\Gamma_0$
COMPASS 2004 pilot run using a 190 GeV $\pi^-$ beam

- Partial wave analysis on $\sim 400,000 \pi^-\pi^-\pi^+$ events
- Strong evidence for spin-exotic $1^{--}$ state in $\rho\pi$ decay
  $\Rightarrow$ consistent with $\pi_1(1600)$ resonance
- Analysis of $5\pi^\pm$ final state in progress

Two independent PWA Programs

- Illinois / Protvino / Munich Program (D. Ryabtschikov)

COMPASS Hadron Run 2008/2009

- Change-over to liquid hydrogen target
- Spectrometer upgrade (Recoil Detector, PID, ECAL ...)
- $\sim 2$ orders of magnitude more high-$t'$ statistics (2008)
- Analysis in progress

Further Analyses of COMPASS Hadron Data

- low-$t'$ $\pi^-\pi^-\pi^+$ and Primakoff
- Central Production: $\pi^-p \rightarrow \pi^-_{\text{fast}}\pi^-\pi^-\pi^+\pi^+p$ ($\rightarrow$ J. Bernhard)
- Central Production / Diffractive Dissociation: Neutral channels
- Central Production / Diffractive Dissociation: Kaonic final states ($\rightarrow$ T. Schlüter)
- Diffractive Dissociation of Kaons ($\rightarrow$ P. Jasinski)
- ...
Backup Slides: COMPASS Acceptance for $\pi^-\pi^-\pi^+$ Events

COMPASS 2004 MC
$\pi^+\text{Pb} \rightarrow \pi\pi\pi^+\text{Pb}$
$0.1 < t' < 1.0 \text{ GeV}^2/c^2$

COMPASS 2004 MC
$\pi^+\text{Pb} \rightarrow \pi\pi\pi^+\text{Pb}$
$0.1 < t' < 1.0 \text{ GeV}^2/c^2$

COMPASS 2004 MC
$\pi^+\text{Pb} \rightarrow \pi\pi\pi^+\text{Pb}$
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$\pi^+\text{Pb} \rightarrow \pi\pi\pi^+\text{Pb}$
$0.1 < t' < 1.0 \text{ GeV}^2/c^2$

COMPASS 2004 MC
$\pi^+\text{Pb} \rightarrow \pi\pi\pi^+\text{Pb}$
$0.1 < t' < 1.0 \text{ GeV}^2/c^2$
Two Breit-Wigners needed to describe $2^{++}1^+\rho\pi D$ phase motion:

- BW1 for $a_2(1320)$ + BW2 for $a_2(1700)$

- $M = (1.321 \pm 0.001^{+0.000}_{-0.007})$ GeV, \quad \Gamma = (0.110 \pm 0.002^{+0.002}_{-0.015})$ GeV

- $a_2(1700)$ parameters fixed to PDG values: $M = 1.732$ GeV, \quad \Gamma = 0.194$ GeV
**Mass-Independent Cross-Section and Spin Density Matrix**

\[
\sigma_{\text{indep}}(\tau) = \sum_{\epsilon} \sum_{r} \left| \sum_{i} T_{ir}^\epsilon \psi_i^\epsilon(\tau) \sqrt{\int |\psi_i^\epsilon(\tau')|^2 d\tau'} \right|^2 , \quad \rho_{ij}^\epsilon = \sum_{r} T_{ir}^\epsilon T_{jr}^{\epsilon*}
\]

- \( \epsilon \): reflectivity,
- \( r \): rank of density matrix,
- \( i \): different partial waves
- \( T \): complex production amplitudes (fit parameters!)
- \( \psi \): complex decay amplitudes
- \( \tau \): phase space coordinates (5 parameters for 3-body decay)

**Likelihood Function**

\[
\ln L = \sum_n \ln \sigma_{\text{indep}}(\tau_n) - \int \sigma_{\text{indep}}(\tau') \text{Acc}(\tau') d\tau'
\]

- \( n \): analyzed events,
- \( \text{Acc} \): Acceptance

**Mass-Dependent Fit**

\[
\rho_{ij}^\epsilon = \sum_{r} \left( \sum_{k} C_{ikr}^\epsilon \text{BW}_k(m) \sqrt{\int |\psi_i^\epsilon(\tau)|^2 d\tau} \right) \left( \sum_{l} C_{jlr}^\epsilon \text{BW}_l(m) \sqrt{\int |\psi_j^\epsilon(\tau)|^2 d\tau} \right)^* 
\]
Backup Slides: Spin Totals

COMPASS 2004

\[ \pi^{+}\text{Pb} \rightarrow \pi\pi\pi^{+}\text{Pb} \]

Mass of \( \pi\pi\pi^{+} \) System (GeV/c\(^2\))

Intensity / (40 MeV/c\(^2\))

1\(^{++} \) Spin Total (\( \varepsilon = +1 \))

COMPASS 2004

\[ \pi^{+}\text{Pb} \rightarrow \pi\pi\pi^{+}\text{Pb} \]

Mass of \( \pi\pi\pi^{+} \) System (GeV/c\(^2\))

Intensity / (40 MeV/c\(^2\))

2\(^{+} \) Spin Total (\( \varepsilon = +1 \))

COMPASS 2004

\[ \pi^{+}\text{Pb} \rightarrow \pi\pi\pi^{+}\text{Pb} \]

Mass of \( \pi\pi\pi^{+} \) System (GeV/c\(^2\))

Intensity / (40 MeV/c\(^2\))

2\(^{++} \) Spin Total (\( \varepsilon = +1 \))
Backup Slides: $M = 0$ and $M = 1$ Spin Totals

COMPASS 2004

$\pi^+ \text{Pb} \rightarrow \pi^+ \pi^+ \pi^0 \text{Pb}$
$0.1 < t' < 1.0 \text{ GeV}/c^2$

Intensity / (40 MeV/c$^2$)

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

$1^{++}0^+$ Spin Total

$2^{++}0^+$ Spin Total

$1^{++}1^+$ Spin Total

$2^{++}1^+$ Spin Total

COMPASS 2004

$\pi^+ \text{Pb} \rightarrow \pi^+ \pi^+ \pi^0 \text{Pb}$
$0.1 < t' < 1.0 \text{ GeV}/c^2$
Summary of Results and Comparison to PDG (2006)

<table>
<thead>
<tr>
<th>State</th>
<th>(GeV)</th>
<th>COMPASS ± stat ± syst</th>
<th>PDG</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_1(1260)$</td>
<td>$M$</td>
<td>1.256 ± 0.006 + 0.007 - 0.017</td>
<td>1.230 ± 0.040</td>
</tr>
<tr>
<td></td>
<td>$\Gamma$</td>
<td>0.366 ± 0.009 + 0.028 - 0.025</td>
<td>0.250 to 0.600</td>
</tr>
<tr>
<td>$a_2(1320)$</td>
<td>$M$</td>
<td>1.321 ± 0.001 + 0.000 - 0.007</td>
<td>1.3183 ± 0.0006</td>
</tr>
<tr>
<td></td>
<td>$\Gamma$</td>
<td>0.110 ± 0.002 + 0.002 - 0.015</td>
<td>0.107 ± 0.005</td>
</tr>
<tr>
<td>$\pi_1(1600)$</td>
<td>$M$</td>
<td>1.660 ± 0.010 + 0.000 - 0.064</td>
<td>1.653$^{+0.018}_{-0.015}$</td>
</tr>
<tr>
<td></td>
<td>$\Gamma$</td>
<td>0.269 ± 0.021 + 0.042 - 0.064</td>
<td>0.225$^{+0.045}_{-0.028}$</td>
</tr>
<tr>
<td>$\pi_2(1670)$</td>
<td>$M$</td>
<td>1.659 ± 0.003 + 0.024 - 0.008</td>
<td>1.6724 ± 0.0032</td>
</tr>
<tr>
<td></td>
<td>$\Gamma$</td>
<td>0.271 ± 0.009 + 0.022 - 0.024</td>
<td>0.259 ± 0.009</td>
</tr>
<tr>
<td>$\pi(1800)$</td>
<td>$M$</td>
<td>1.785 ± 0.009 + 0.012 - 0.006</td>
<td>1.812 ± 0.014</td>
</tr>
<tr>
<td></td>
<td>$\Gamma$</td>
<td>0.208 ± 0.022 + 0.021 - 0.037</td>
<td>0.207 ± 0.013</td>
</tr>
<tr>
<td>$a_4(2040)$</td>
<td>$M$</td>
<td>1.884 ± 0.013 + 0.050 - 0.002</td>
<td>2.001 ± 0.010</td>
</tr>
<tr>
<td></td>
<td>$\Gamma$</td>
<td>0.295 ± 0.024 + 0.046 - 0.019</td>
<td>0.313 ± 0.031</td>
</tr>
</tbody>
</table>
Backup Slides: BNL-E852 and VES $1^{-+}$ Signal

BNL-E852, Phys. Rev. D65, 072001, 2002

VES, Nucl. Phys. A663, 596, 2000
Backup Slides: BNL-E852 Comparison (proton target)

Phys. Rev. D65, 072001, 2002

Phys. Rev. D65, 072001, 2002
Single pion decay angle in $X^-$ rest frame (Gottfried-Jackson frame).
Backup Slides: 3 and 2\(\pi\) Subsystems

COMPASS 2004
\(\pi^+\) Pb \(\rightarrow\) \(\pi^+\pi^+\pi^-\pi^-\) Pb
6 Entries per Event

Number of Entries

COMPASS 2004
\(\pi^-\) Pb \(\rightarrow\) \(\pi^+\pi^+\pi^-\pi^-\) Pb
6 Entries per Event

Number of Entries

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