

Meson Production from Diffractive Pion Dissociation at COMPASS

Sebastian Neubert for the COMPASS Collaboration

Physik Department E18
Technische Universität München

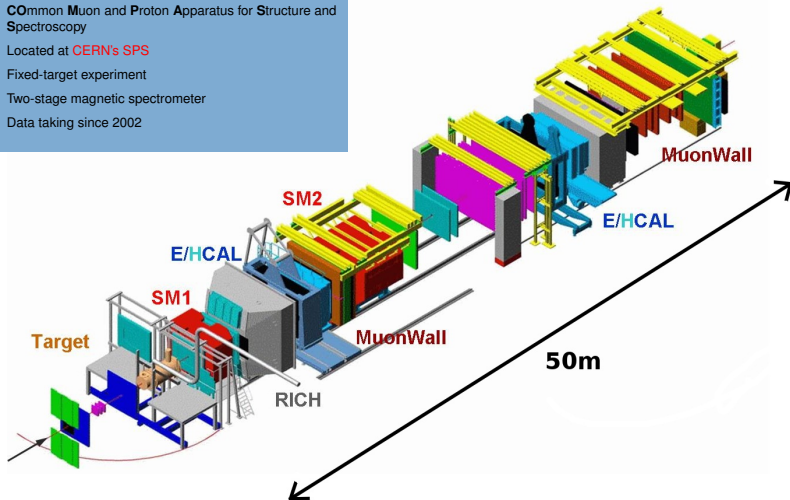
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Cluster of Excellence: Origin and Structure of the Universe,
BMBF, EU



Overview

- **CO**mmun **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
- Located at **CERN's SPS**
- Fixed-target experiment
- Two-stage magnetic spectrometer
- Data taking since 2002

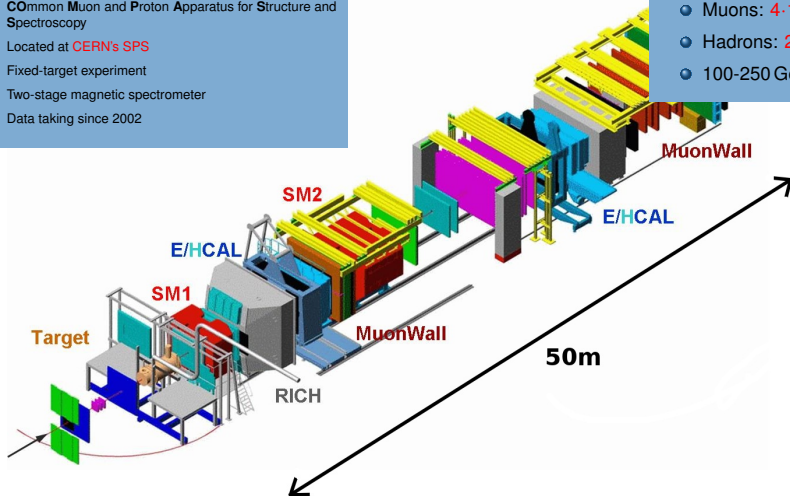


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Second./Tert. SPS Beams

- Muons: $4 \cdot 10^7 \text{s}^{-1}$
- Hadrons: $2 \cdot 10^7 \text{s}^{-1}$
- 100-250 GeV

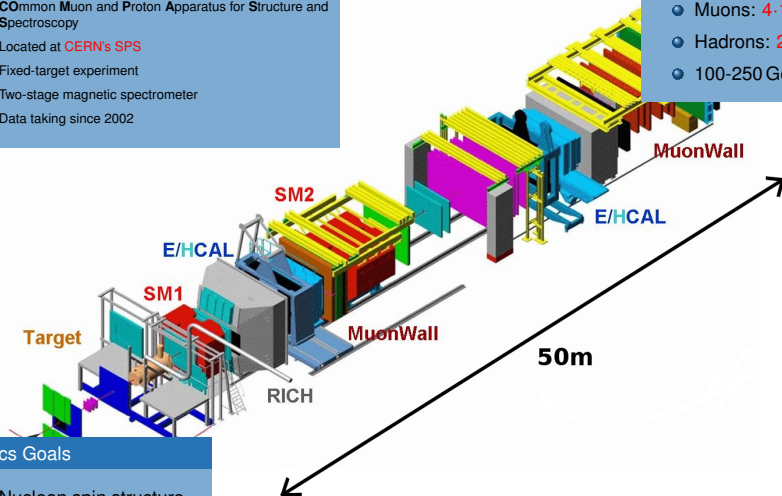


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Physics Goals

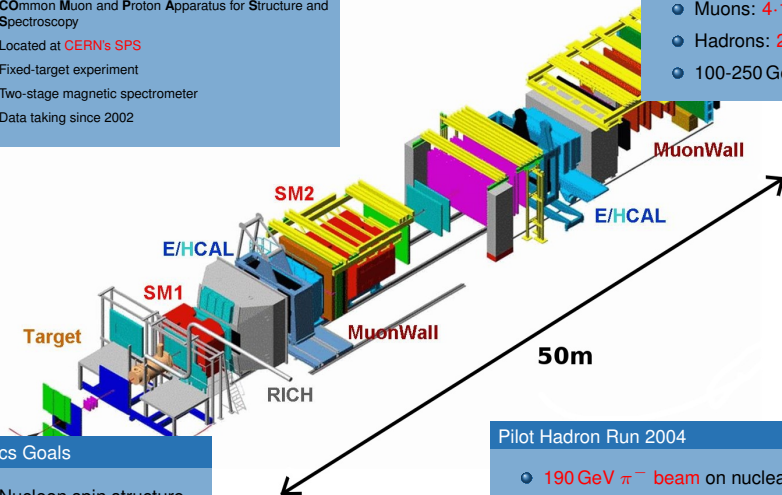
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- **Hadron spectroscopy**

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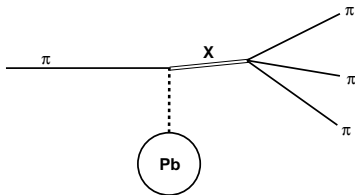
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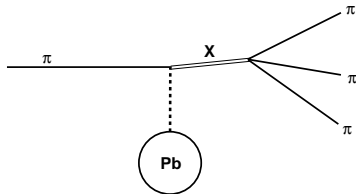
Pilot Hadron Run 2004

- **190 GeV π^- beam** on nuclear targets
- Tracking: Silicons, SciFis, GEMs, MicroMegs, MWPCs, Drift Chambers

- Diffractive**: incident particle only grazes the target, which remains intact
 \Rightarrow **dominantly strong interaction**
- Dissociation**: beam pion is excited to some resonance X^- , which subsequently decays
 \Rightarrow e.g. $\pi^- \text{Pb} \Rightarrow X^- \text{Pb} \Rightarrow \pi^- \pi^- \pi^+ \text{Pb}$



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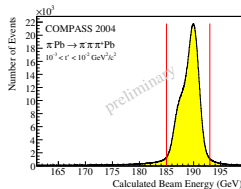
Meson Spectroscopy and Search for **Exotic States** (non- $q\bar{q}$)

- **Diffractive pion dissociation** produces rich meson spectrum
- Evidences for spin-exotic $\pi_1(1600)$ state with $J^{PC} = 1^{-+}$ in $\rho\pi^- \rightarrow \pi^- \pi^+ \pi^-$

[BNL-E852, Phys. Rev. **D65**, 072001, 2002], [VES, Nucl. Phys. **A663**, 596, 2000]

controversial situation!

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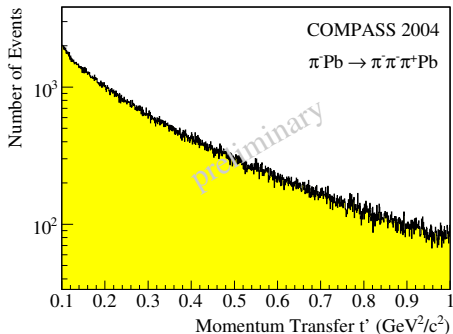
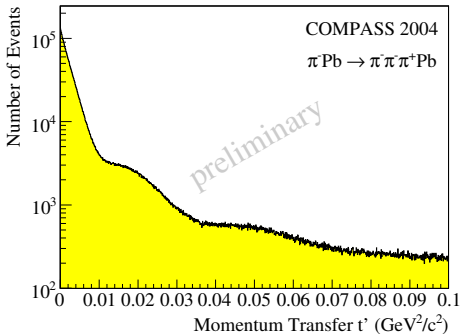
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controversial situation!

- **Selection**: primary vertex in target, 3 outgoing part. ($- - +$), **exclusivity**
- **COMPASS 2004**: $\sim 4\,000\,000$ 3π events on Pb (few days of running),
 $\sim 400\,000$ events with $0.1 < t' < 1.0 \text{ GeV}^2/c^2$

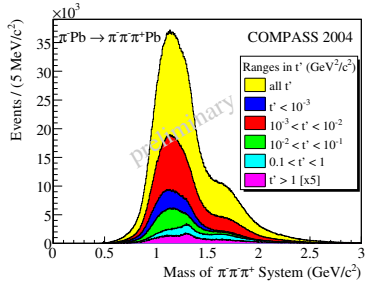
Momentum transfer from target: $-t = -(\mathbf{p}_{\text{beam}} - \mathbf{p}_{(\pi^-\pi^-\pi^+)})^2$
 $\Rightarrow t' = |t| - |t|_{\text{min}}$



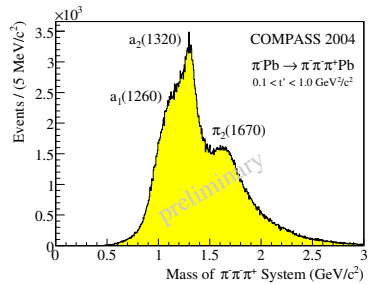
Diffraction pattern: Pb nucleus acts like "black disc" in optics

High- t' : scattering on single nucleons inside Pb nucleus

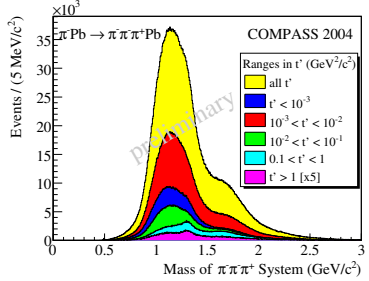
Invariant mass for different t'



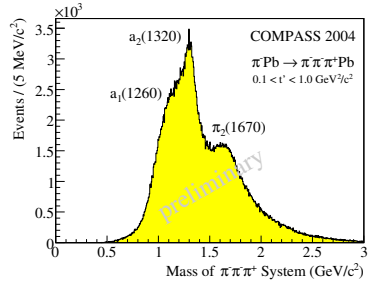
High- t' Spectrum



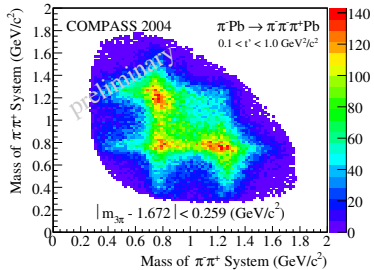
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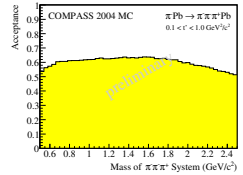
High- t' Spectrum

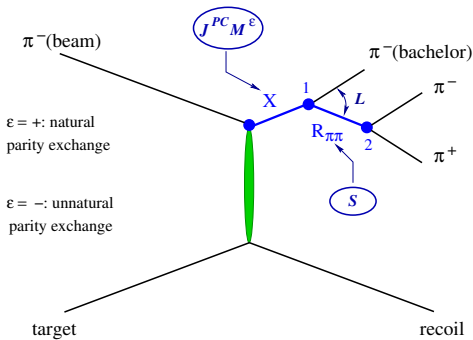


Dalitz plot for $\pi_2(1670)$ region



Flat acceptance: 55-60%





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

- **Software:** Illinois \rightarrow Protvino \rightarrow TUM (D. Ryabchikov, VES/COMPASS)
- **Mass-independent PWA (40 MeV/c² mass bins): 42 waves**
 - ▶ Extended log-likelihood method (Ascoli/Kachaev fitter)
 - ▶ Acceptance corrections included
 - ▶ $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$ from PDG, $(\pi\pi)_s$ with separated $f_0(980)$ from VES
 - ▶ Multiple solutions ($\Delta \ln L \leq 1$) added as additional error
- **Mass-dependent χ^2 -fit: 7 waves**
 - ▶ Only positive reflectivity waves (natural parity exchange dominant)
 - ▶ 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



$J^{PC} M^{\epsilon}$	L	Isobar π	Thresh. [GeV]
$0^{-+}0^{+}$	S	$f_0\pi$	1.40
$0^{-+}0^{+}$	S	$(\pi\pi)_S\pi$	-
$0^{-+}0^{+}$	P	$\rho\pi$	-
$1^{-+}1^{+}$	P	$\rho\pi$	-
$1^{++}0^{+}$	S	$\rho\pi$	-
$1^{++}0^{+}$	P	$f_2\pi$	1.20
$1^{++}0^{+}$	P	$(\pi\pi)_S\pi$	0.84
$1^{++}0^{+}$	D	$\rho\pi$	1.30
$1^{++}1^{+}$	S	$\rho\pi$	-
$1^{++}1^{+}$	P	$f_2\pi$	1.40
$1^{++}1^{+}$	P	$(\pi\pi)_S\pi$	1.40
$1^{++}1^{+}$	D	$\rho\pi$	1.40
$2^{-+}0^{+}$	S	$f_2\pi$	1.20
$2^{-+}0^{+}$	P	$\rho\pi$	0.80
$2^{-+}0^{+}$	D	$f_2\pi$	1.50
$2^{-+}0^{+}$	D	$(\pi\pi)_S\pi$	0.80
$2^{-+}0^{+}$	F	$\rho\pi$	1.20
$2^{-+}1^{+}$	S	$f_2\pi$	1.20
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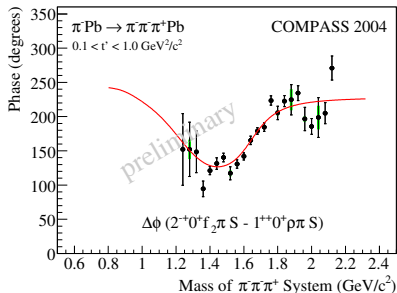
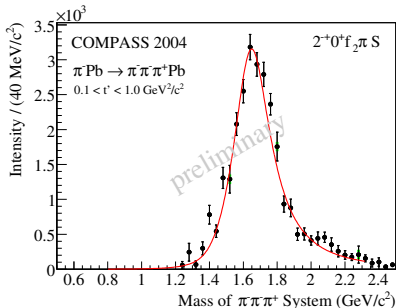
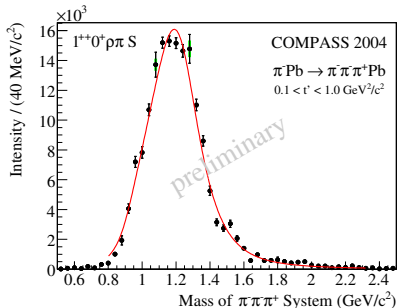
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$2^{++}1^{+}$	P	$f_2\pi$	1.50
$2^{++}1^{+}$	D	$\rho\pi$	-
$3^{++}0^{+}$	S	$\rho_3\pi$	1.50
$3^{++}0^{+}$	P	$f_2\pi$	1.20
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$3^{++}1^{+}$	D	$\rho\pi$	1.50
$4^{-+}0^{+}$	F	$\rho\pi$	1.20
$4^{-+}1^{+}$	F	$\rho\pi$	1.20
$4^{++}1^{+}$	F	$f_2\pi$	1.60
$4^{++}1^{+}$	G	$\rho\pi$	1.64
$1^{-+}0^{-}$	P	$\rho\pi$	-
$1^{-+}1^{-}$	P	$\rho\pi$	-
$1^{++}1^{-}$	S	$\rho\pi$	-
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FLAT			

Partial Wave Set for Mass-dependent. Fit (7 Waves)

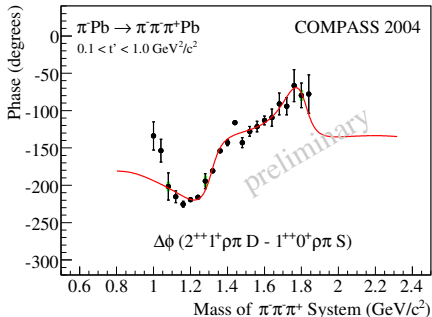
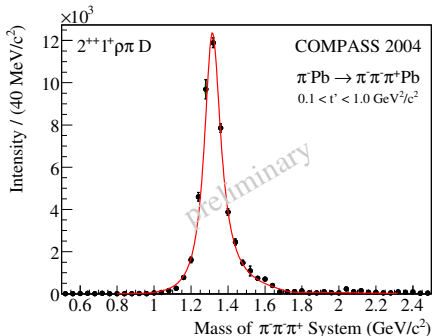
Extraction of Resonance Parameters from Intensities and Interferences

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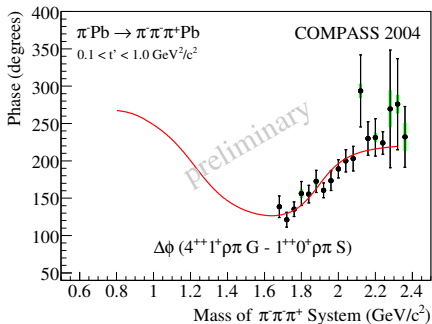
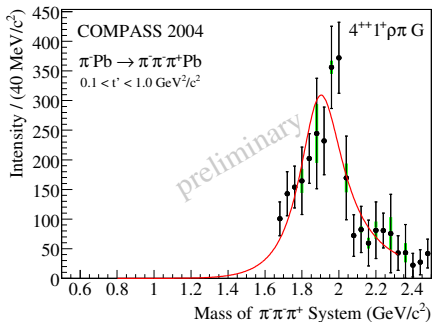
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FLAT			



- BW for $a_1(1260)$ + background:
 $M = (1.256 \pm 0.006^{+0.007}_{-0.017}) \text{ GeV}$
 $\Gamma = (0.366 \pm 0.009^{+0.028}_{-0.025}) \text{ GeV}$
- BW for $\pi_2(1670)$:
 $M = (1.659 \pm 0.003^{+0.024}_{-0.008}) \text{ GeV}$
 $\Gamma = (0.271 \pm 0.009^{+0.022}_{-0.024}) \text{ GeV}$



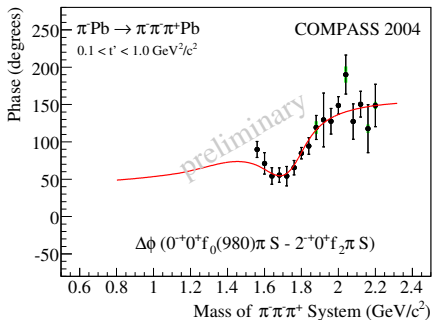
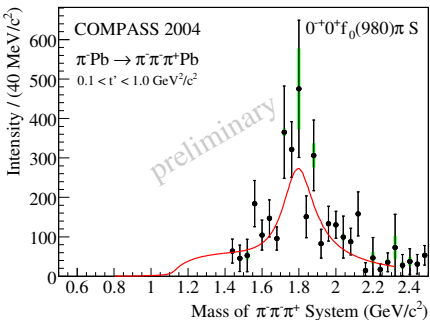
- Two Breit-Wigners needed to describe $2^{++}1^+ \rho \pi D$ phase motion:
 BW1 for $a_2(1320)$ + BW2 for $a_2(1700)$
- $M = (1.321 \pm 0.001^{+0.000}_{-0.007}) \text{ GeV}$, $\Gamma = (0.110 \pm 0.002^{+0.002}_{-0.015}) \text{ GeV}$
- $a_2(1700)$ parameters fixed to PDG values: $M = 1.732 \text{ GeV}$, $\Gamma = 0.194 \text{ GeV}$



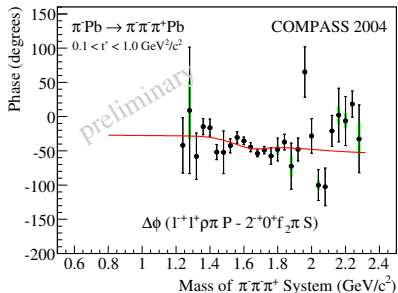
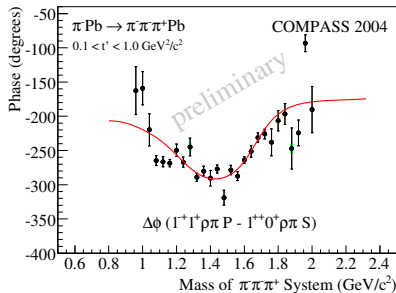
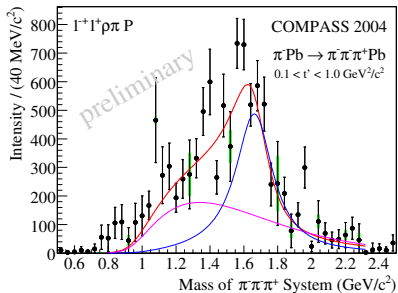
- Constant width Breit-Wigner used for $a_4(2040)$

- ▶ No branching ratios known \rightarrow no dynamic factors in BW
- ▶ \rightarrow Fitted mass differs from PDG value

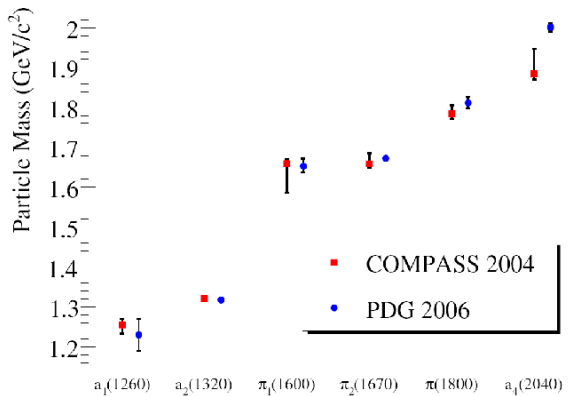
- $M = (1.884 \pm 0.013^{+0.050}_{-0.002}) \text{ GeV}$, $\Gamma = (0.295 \pm 0.024^{+0.046}_{-0.019}) \text{ GeV}$



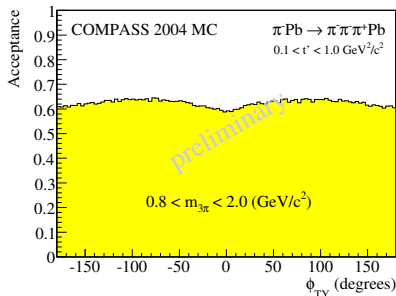
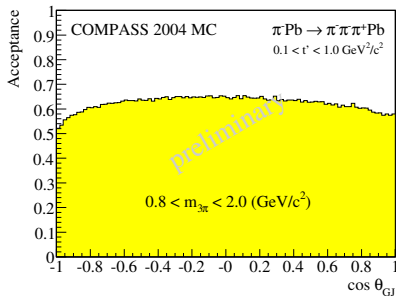
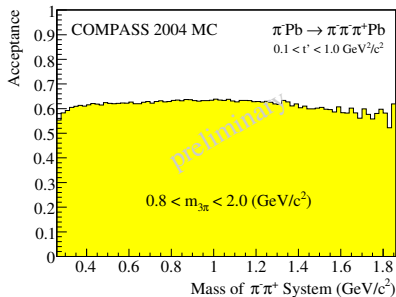
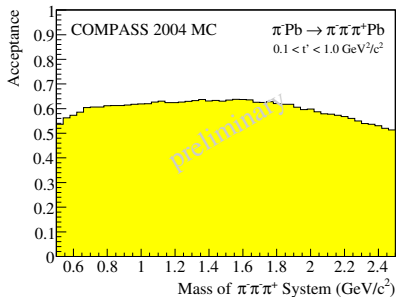
- Constant width Breit-Wigner for $\pi(1800)$ and low-mass background
- $M = (1.785 \pm 0.009^{+0.012}_{-0.006}) \text{ GeV}$, $\Gamma = (0.208 \pm 0.022^{+0.021}_{-0.037}) \text{ GeV}$



- Significant 1^{-+} amplitude consistent with resonance at $\sim 1.6 \text{ GeV}$
- No leakage observed
- BW for $\pi_1(1600)$ + background:
 $M = (1.660 \pm 0.010^{+0.000}_{-0.064}) \text{ GeV}$
 $\Gamma = (0.269 \pm 0.021^{+0.042}_{-0.064}) \text{ GeV}$



- **COMPASS 2004** pilot run using a 190 GeV π^- beam
 - ▶ **Diffraction dissociation** on lead targets exploited for meson production
 - ▶ $\sim 4\,000\,000$ events recorded within a **few days of data taking**
 - ▶ Large range in momentum transfer t' covered (10^{-3} -few GeV^2/c^2)
 - ▶ **Excellent acceptance** for diffractive $\pi^- \pi^- \pi^+$ events (~ 55 -60%)
- **Partial wave analysis** has been performed on $\sim 400\,000$ $\pi^- \pi^+ \pi^-$ events with $0.1 < t' < 1.0 \text{ GeV}^2/c^2$
 - ▶ Dominant $a_1(1260)$, $a_2(1320)$ and $\pi_2(1670)$ states resolved
 - ▶ Also small, well-known resonances $\pi(1800)$ and $a_4(2040)$ can be fitted
 - ▶ Spin-exotic 1^{--} state observed in $\rho\pi$ decay channel both in intensity and phase motion
⇒ consistent with $\pi_1(1600)$ resonance
- Cross check with independent software in progress
- Analysis of low- t' data from COMPASS 2004 will be performed
- **COMPASS** Hadron run 2008
 - ▶ Change-over to **liquid hydrogen target**
 - ▶ Proton Recoil Detector
 - ▶ Higher beam intensity, improved trigger system
 - ▶ $\sim 50\times$ more high- t' statistics has been collected
 - ▶ Analysis in progress



Mass-Independent Cross-Section and Spin Density Matrix

$$\sigma_{\text{indep}}(\tau) = \sum_{\epsilon} \sum_r \left| \sum_i T_{ir}^{\epsilon} \psi_i^{\epsilon}(\tau) / \sqrt{\int |\psi_i^{\epsilon}(\tau')|^2 d\tau'} \right|^2, \quad \rho_{ij}^{\epsilon} = \sum_r T_{ir}^{\epsilon} T_{jr}^{\epsilon*}$$

- ϵ : reflectivity, r : rank of density matrix, i : different partial waves
- T : complex production amplitudes (**fit parameters!**)
- ψ : complex decay amplitudes
- τ : phase space coordinates (5 parameters for 3-body decay)

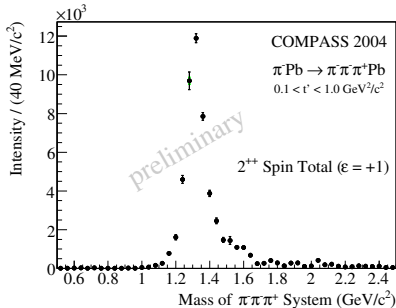
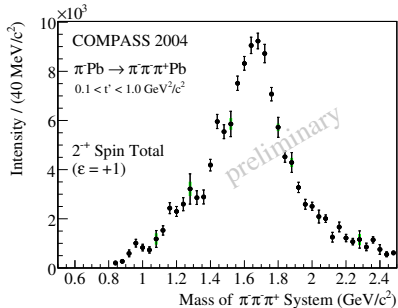
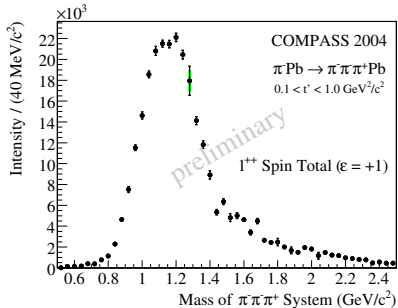
Likelihood Function

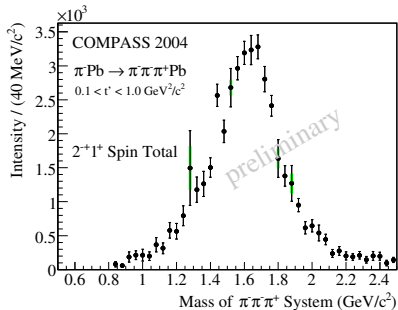
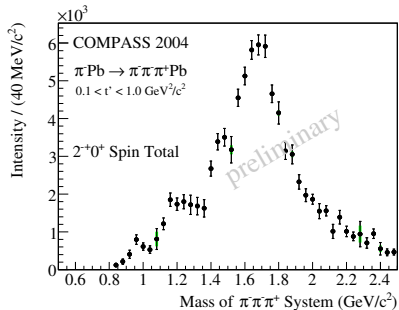
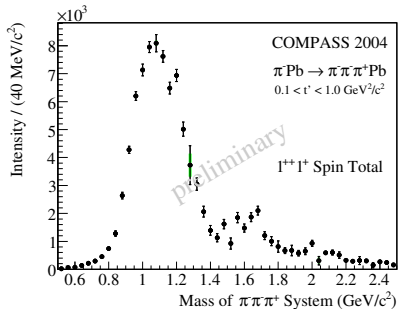
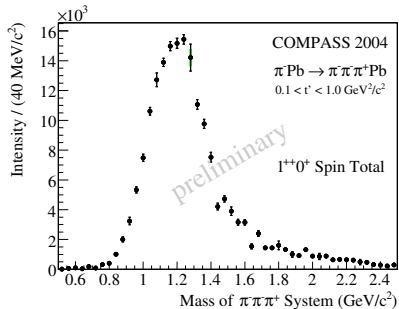
$$\ln L = \sum_n \ln \sigma_{\text{indep}}(\tau_n) - \int \sigma_{\text{indep}}(\tau') \text{Acc}(\tau') d\tau'$$

- n : analyzed events, **Acc**: Acceptance

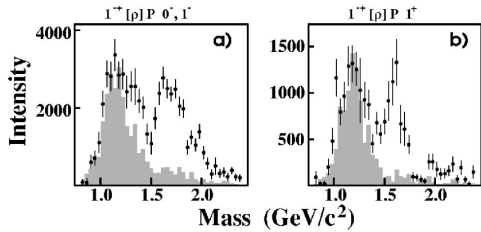
Mass-Dependent Fit

$$\rho_{ij}^{\epsilon} = \sum_r \left(\sum_k C_{ikr}^{\epsilon} \text{BW}_k(m) \sqrt{\int |\psi_i^{\epsilon}(\tau)|^2 d\tau} \right) \left(\sum_l C_{jlr}^{\epsilon} \text{BW}_l(m) \sqrt{\int |\psi_j^{\epsilon}(\tau)|^2 d\tau} \right)^*$$

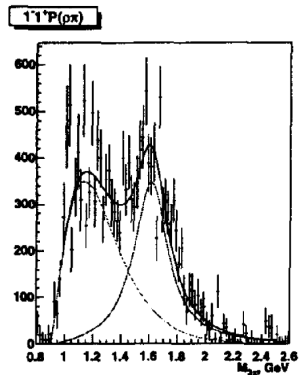




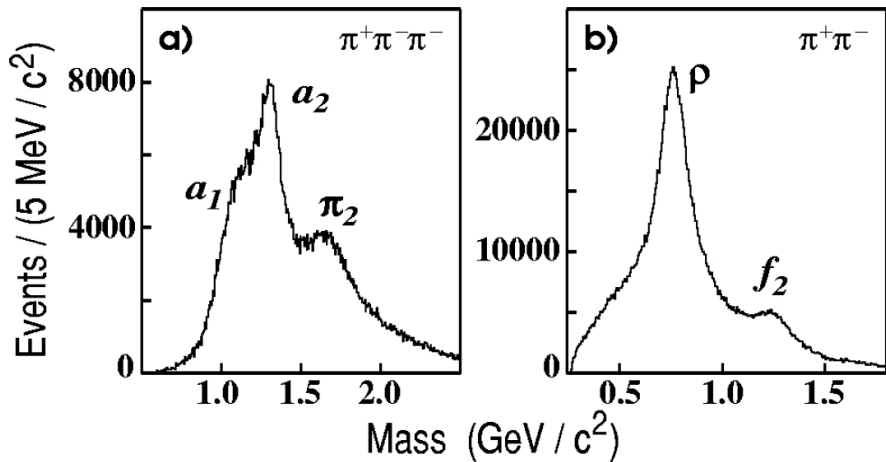
State	(GeV)	COMPASS \pm stat \pm syst	PDG
$a_1(1260)$	M	$1.256 \pm 0.006 + 0.007 - 0.017$	1.230 ± 0.040
	Γ	$0.366 \pm 0.009 + 0.028 - 0.025$	0.250 to 0.600
$a_2(1320)$	M	$1.321 \pm 0.001 + 0.000 - 0.007$	1.3183 ± 0.0006
	Γ	$0.110 \pm 0.002 + 0.002 - 0.015$	0.107 ± 0.005
$\pi_1(1600)$	M	$1.660 \pm 0.010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



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



VES, Nucl. Phys. **A663**, 596, 2000

Phys. Rev. **D65**, 072001, 2002