A Preliminary Partial-Wave Analysis of the Centrally Produced $\pi^+\pi^-$ System in *pp* Reactions at COMPASS

Alex Austregesilo
for the
COMPASS Collaboration

DPG Frühjahrstagung Mainz
HK 22.3 - 2012/03/21

Supported by bmb+f - Förderschwerpunkt COMPASS Großgeräte der physikalischen Grundlagenforschung

Outline

The COMPASS Experiment

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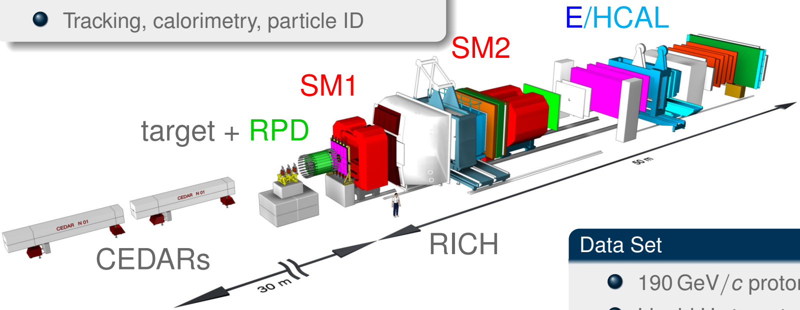
Multi-Purpose Setup

- Fixed-target experiment @ CERN SPS
- Two-stage magnetic spectrometer
- Broad kinematic range
- Tracking, calorimetry, particle ID

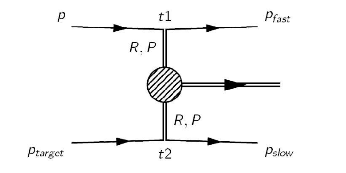


Data Set

- 190 GeV/c proton beam
- Liquid H_2 target
- Approximately 30 % of the available data presented here

Motivation

Central Production:



- QCD predicts **glueballs**, but experimental confirmation still pending
- Aim: Study the formation of glue-rich meson systems at **central rapidities**

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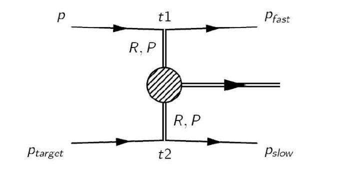
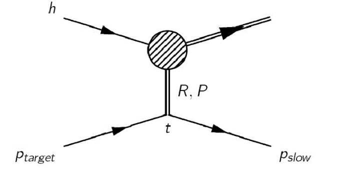


Diffractive Dissociation:



- QCD predicts **glueballs**, but experimental confirmation still pending
- Aim: Study the formation of glue-rich meson systems at **central rapidities**
- Rapidity gap between p_s and the central system X introduced by the principal trigger, but not between p_f and X
  $\rightarrow$ high contribution of diffractive dissociation of the beam proton

Invariant Mass of $p\pi$ Sub-Systems

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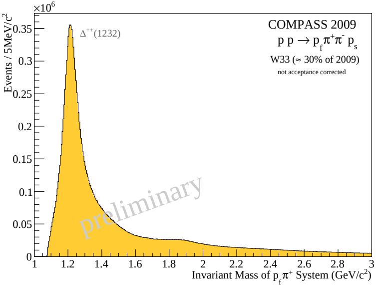
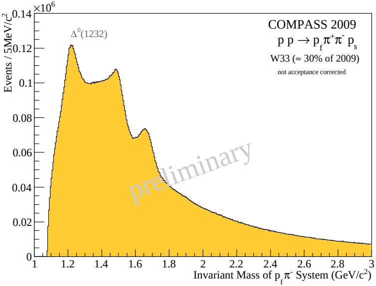
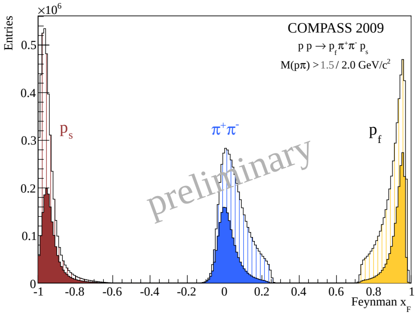




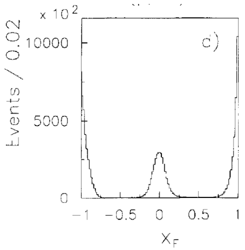
- Clear $\Delta(1232)$ signals in $p_f\pi$
- Evidence for higher mass Δ and N^*
  $\rightarrow M(p\pi) > 1.5\,\mathrm{GeV}/c^2$ required
- Cut on $M(p_s\pi)$ for symmetry purposes
- Structures up to $2\,\mathrm{GeV}/c^2$, but no significant influence on the result

Resulting x_F Distributions

COMPASS

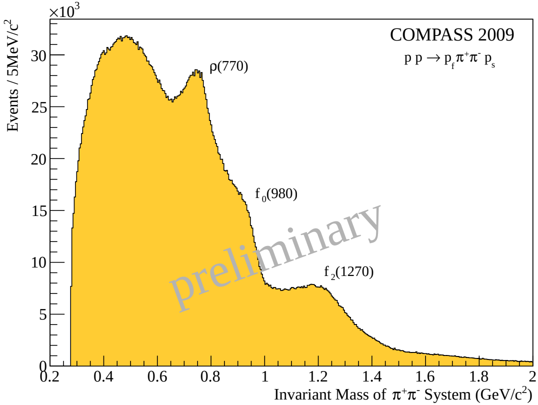


WA102 (Omega @ CERN SPS)



- Red: p_s, Blue: $\pi^+\pi^-$, Yellow: p_f
- $\pi^+\pi^-$ within $|x_f| \leq 0.25$
- Open: $M(p\pi) > 1.5\,\mathrm{GeV}/c^2$, solid: $M(p\pi) > 2.0\,\mathrm{GeV}/c^2$

Invariant Mass of $\pi^+\pi^-$ System



- $\rho(770)$ and $f_2(1270)$ signals
- Sharp drop at 1 GeV/c^2: $f_0(980)$

$\sqrt{s}$-Dependence

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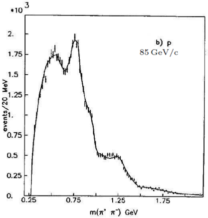
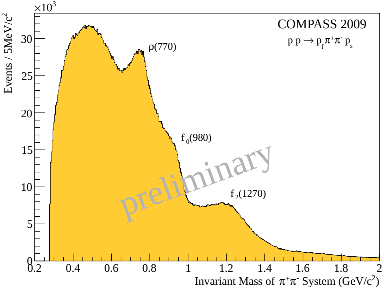
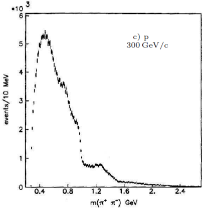
Study of the centrally produced $\pi\pi$ and $K\bar{K}$ systems at 85 and 300 GeV$/c$
T.A. Armstrong et al. [Z. Phys. C51 (1991) 351]



$\sqrt{s} = 12.7\,\text{GeV}/c^2$



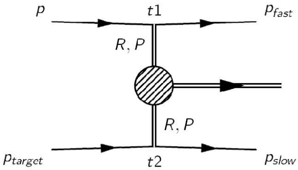
$\sqrt{s} = 18.9\,\text{GeV}/c^2$



$\sqrt{s} = 23.7\,\text{GeV}/c^2$

- Production of $\rho(770)$ disappears rapidly with increasing $\sqrt{s}$
- Low mass enhancement (σ) and $f_0(980)$ remain practically unchanged
  $\rightarrow$ characteristic for s-independent Pomeron-Pomeron scattering

Reference Frame



- **Assumption:** central $\pi^+\pi^-$ system produced by the collusion of two objects
- Space-like exchange particles (Reggeons/Pomerons) define z-axis and production plane

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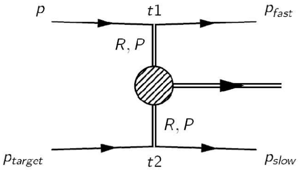
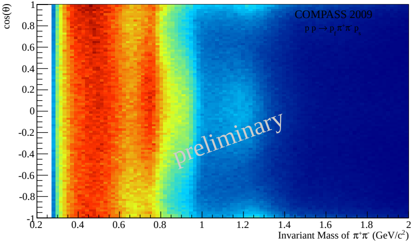
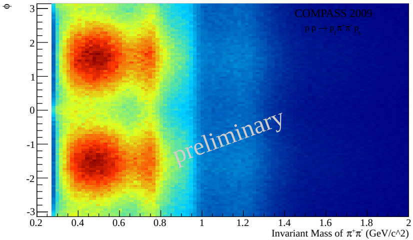


- **Assumption:** central $\pi^+\pi^-$ system produced by the collusion of two objects
- Space-like exchange particles (Reggeons/Pomerons) define z-axis and production plane
- Decay fully described by $M(\pi^+\pi^-)$, θ and ϕ





Construction of Wave-Set

Strong Interaction Conserves Parity

- Linear combination of spherical harmonics as eigenstates of **reflectivity** $\varepsilon = \pm 1$, limiting the spin projection $m \geq 0$, waves with opposite ε do not interfere

$$Y_m^{\varepsilon \ell}(\theta, \phi) = c(m) \left[Y_m^{\ell}(\theta, \phi) - \varepsilon (-1)^m Y_{-m}^{\ell}(\theta, \phi) \right]$$

Techniques of amplitude analysis for two-pseudoscalar systems
S.U. Chung, [Phys. Rev. D 56 (1997), 7299]

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Wave-set [in WA102 notation J_m^{ε}]

- Negative reflectivity waves: $\mathbf{S_0^-}$, P_0^-, P_1^-, D_0^-, D_1^-
- Positive reflectivity waves: $\mathbf{P_1^+}$, D_1^+

Techniques of amplitude analysis for two-pseudoscalar systems
S.U. Chung, [Phys. Rev. D 56 (1997), 7299]

Partial-Wave Decomposition

Expand intensity $I(\theta, \phi)$ in terms of partial-waves:

$$I(\theta, \phi) = \sum_{\varepsilon} \left| \sum_{\ell m} T_{\varepsilon \ell m} Y_m^{\varepsilon \ell}(\theta, \phi) \right|^2$$

- with the complex transition amplitudes $T_{\varepsilon \ell m}$
- and an explicit incoherent sum over the reflectivities ε

$\Rightarrow$ **Maximum Likelihood Fit in Mass Bins**

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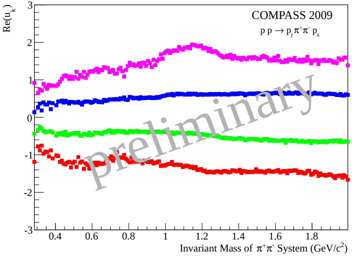
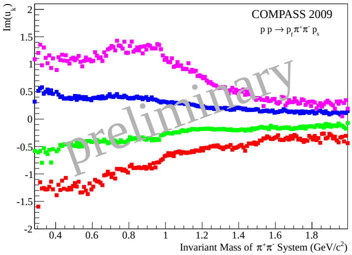
Inherent Ambiguities of Two-Pseudoscalar Final State

- Expansion can also be written as a 4^{th}-order polynomial
- Complex conjugation of the roots ('Barrelet zeros') results in the same angular distribution, i.e. the same likelihood

Barrelet Zeros



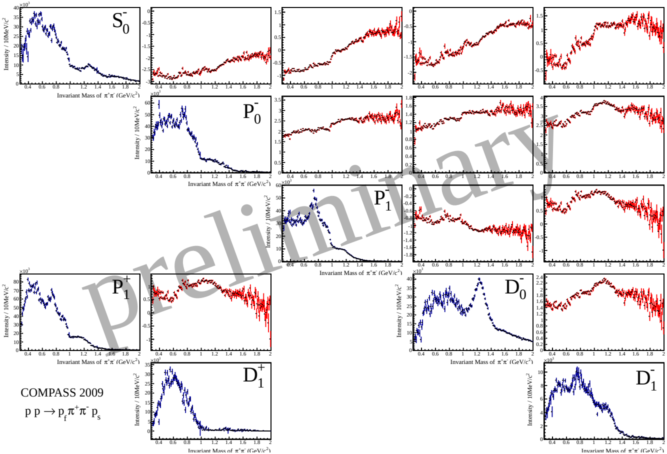


- Real (left) and imaginary (right) part of polynomial roots
- Well separated, imaginary parts do not cross the real axis

$\Rightarrow$ Solutions can be uniquely identified, no linking procedure necessary

- 8 different solutions can be calculated analytically
- Differentiation requires additional input (e.g. behaviour at threshold, physics content)

Fit to the $\pi^+\pi^-$ System



One solution compatible with physical constraints

Conclusion

Summary

- Selected **centrally produced** sample
- Order-of-magnitude **better statistics** than previous experiments
- Performed **acceptance corrected PWA** in 2-body framework
- Studied **ambiguous** solutions

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Outlook

- Interpretation only with **mass dependent fit**, may also help the choice of solutions
- Many **other channels** (K^+K^-, K_SK_S, $\pi^0\pi^0$, $\eta\eta$, ...) possible

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Thank you for your attention!

Glueball Filter

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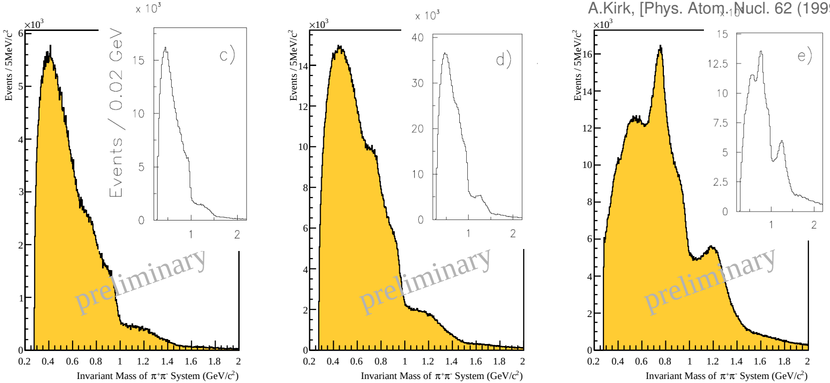
A search for non-$q\bar{q}$ mesons at the CERN Omega Spectrometer
A.Kirk, [Phys. Atom. Nucl. 62 (1999) 398]



- $dP_T = |\vec{p}_{T_1} - \vec{p}_{T_2}|$ in *pp* centre-of-mass
- WA91/102 binned the data in $dP_T \leq 0.2$, $0.2 \leq dP_T < 0.5$ and $dP_T \geq 0.5\,\mathrm{GeV}$
- Only scalar signals remain for small *dPt*

Maximum Likelihood Fit in Mass Bins

Maximise likelihood function

$$\ln L = \sum_{i=1}^{N} \ln I(\theta_i, \phi_i) - \int d\Omega\, I(\theta, \phi)\, \eta(\theta, \phi)$$

- by choosing $T_{\varepsilon\ell m}$ such that the intensity fits the observed N events
- the normalisation integral is evaluated by a phase-space Monte Carlo sample
- with the acceptance $\eta(\theta, \phi)$

PWA Ambiguities

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- Angular distribution can be written as a function of $|G(u)|^2$ with the polynomial
  $G(u) = a_4 u^4 - a_3 u^3 + a_2 u^2 - a_1 u + a_0$
  where coefficients a_i are functions of amplitudes
- or in terms of 4 complex roots u_i (*'Barrelet zeros'*)
  $G(u) = a_4(u - u_1)(u - u_2)(u - u_3)(u - u_4)$
- Complex conjugation of one/more of these roots result in the same measured angular distribution
  $\rightarrow$ **8 different ambiguous solutions** (same likelihood per definition!)
- *Laguerre's method* to find polynomial roots numerically

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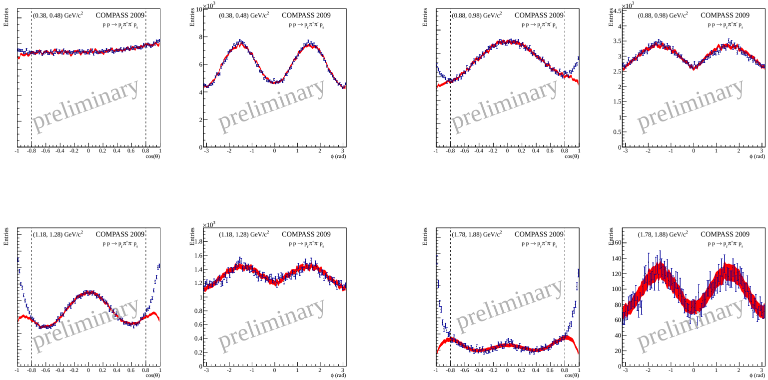
Evaluation of Fit with Weighted MC



- Blue: data, red: weighted MC
- Sharply peaking distribution for $|cos(\theta)| > 0.8$ cannot be described by fit
- May hint to different production process
  $\Rightarrow$ Excluded from fit, loss of $\approx 20\%$ of data