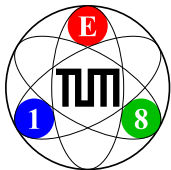


# Light-Meson Spectroscopy at COMPASS

Fabian Krinner  
for the COMPASS collaboration

Physik-Department E18  
Technische Universität München

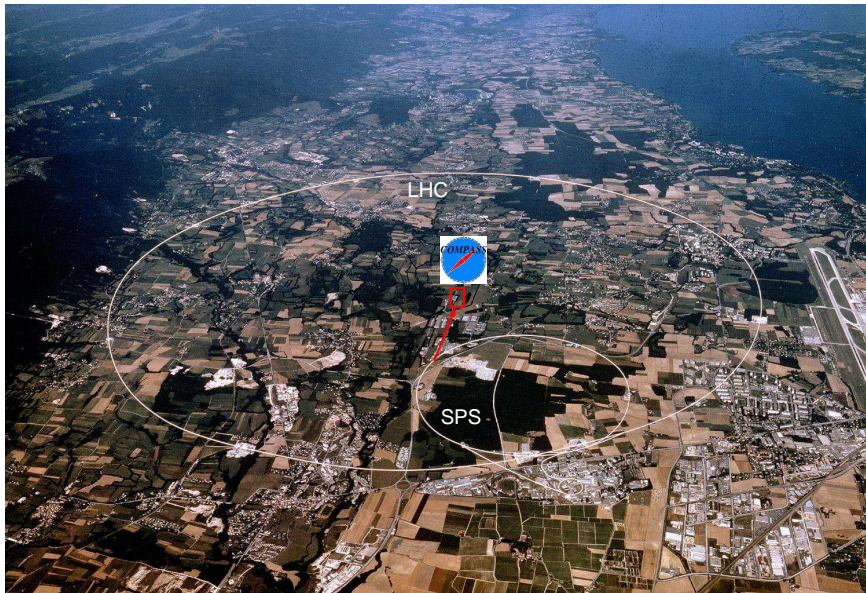


Sep 2<sup>nd</sup> 2016



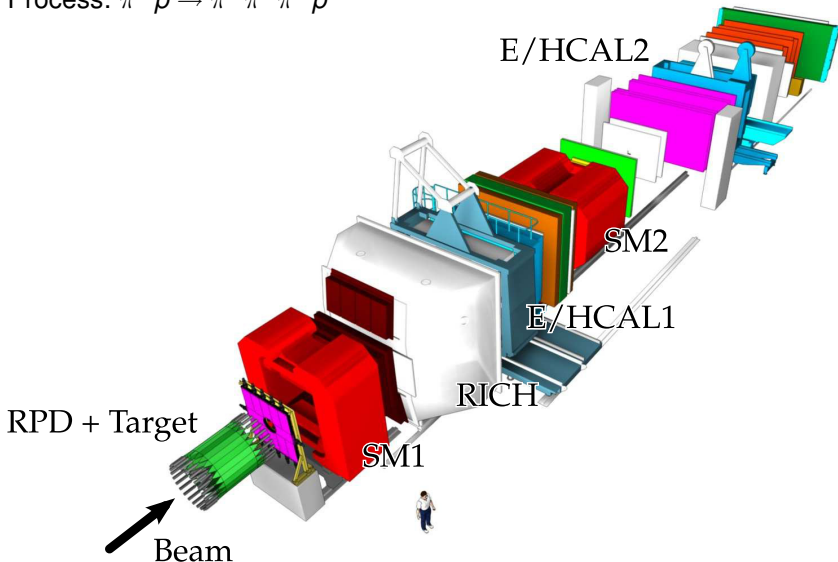
# The COMPASS experiment

Located at CERN





Process:  $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$



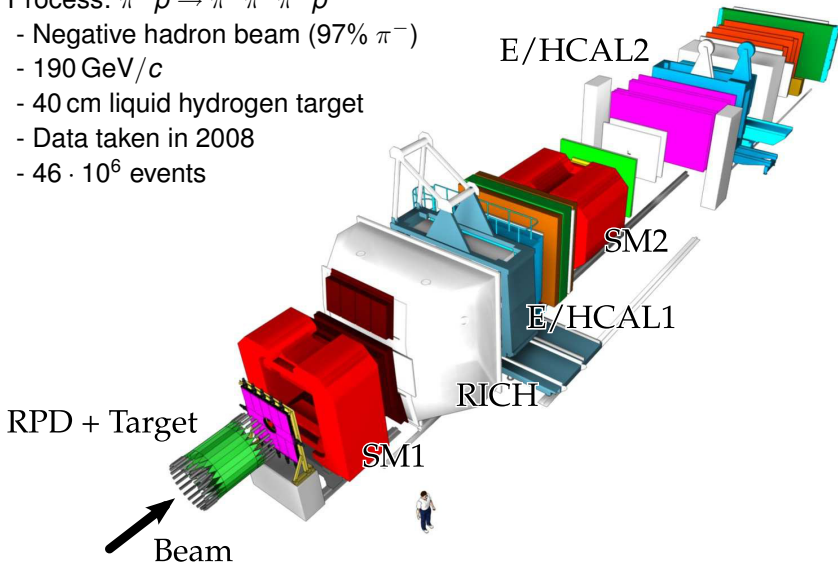


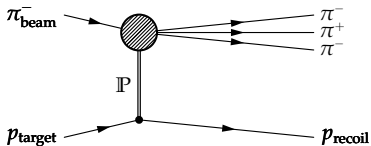
# The COMPASS experiment

Common Muon Proton Apparatus for Structure and Spectroscopy

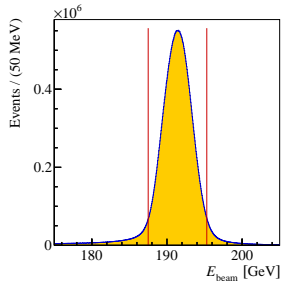
Process:  $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$

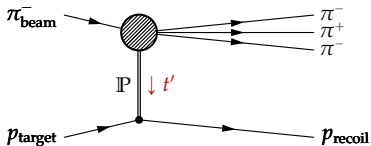
- Negative hadron beam (97%  $\pi^-$ )
- 190 GeV/c
- 40 cm liquid hydrogen target
- Data taken in 2008
- $46 \cdot 10^6$  events



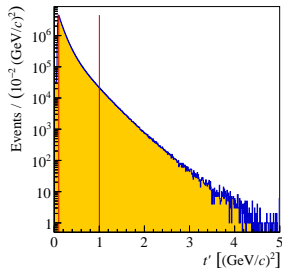


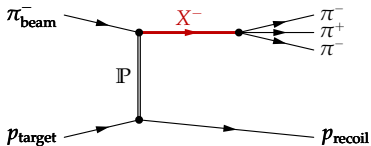
● Exclusive measurement



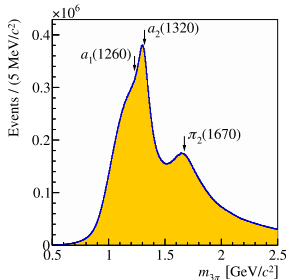


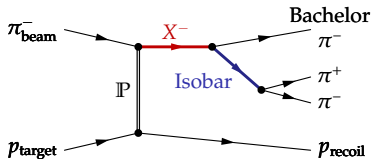
- Exclusive measurement
- Four-momentum transfer  $t'$  by Pomeron  $\mathbb{P}$



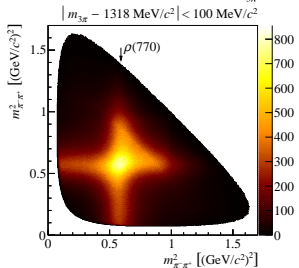
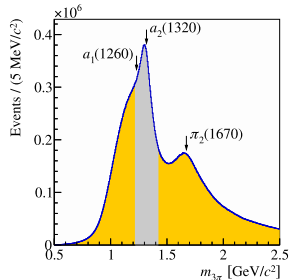


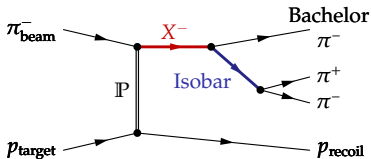
- Exclusive measurement
- Four-momentum transfer  $t'$  by Pomeron  $\mathbb{P}$
- Rich structure in  $\pi^- \pi^+ \pi^-$  mass spectrum



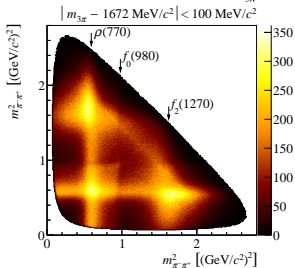
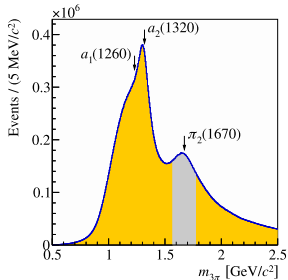


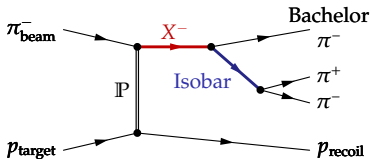
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- Also structure in  $\pi^+ \pi^-$  subsystem



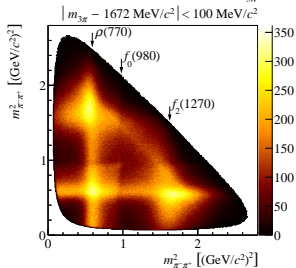
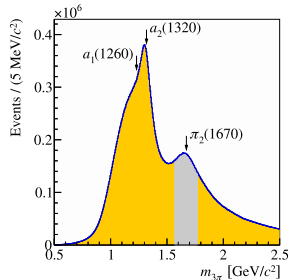


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- Correlated with  $m_{3\pi}$





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- Correlated with  $m_{3\pi}$   
→ Isobar model



**Data**

**Resonance Parameters**

Masses and widths of the meson resonances



**Data**

(I) Partial-Wave  
Decomposition

**Partial Waves**

Intensities and relative phases of the partial waves

**Resonance Parameters**

Masses and widths of the meson resonances

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(I) Partial-Wave  
Decomposition

**Partial Waves**

Intensities and relative phases of the partial waves

(II) Resonance-Model Fit

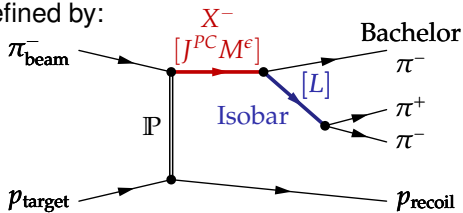
**Resonance Parameters**

Masses and widths of the meson resonances

$$\text{Intensity } \mathcal{I} = \left| \sum_{\text{waves}} T^{\text{wave}} \mathcal{A}^{\text{wave}} \right|^2$$

Waves defined by:

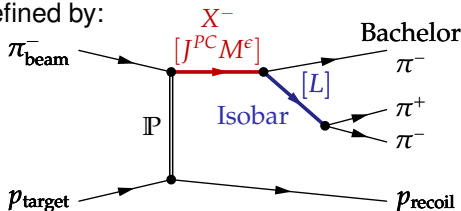
$$J^{PC} M^{\epsilon} \xi \pi L$$



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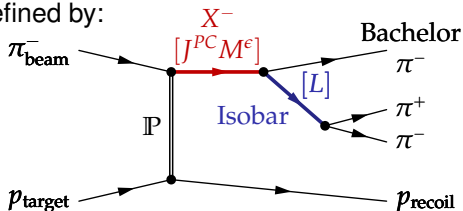


- $J^{PC}$ : Spin and eigenvalues under parity and charge conjugation of  $X^-$

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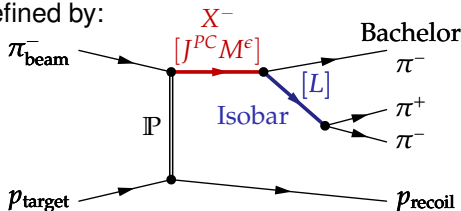


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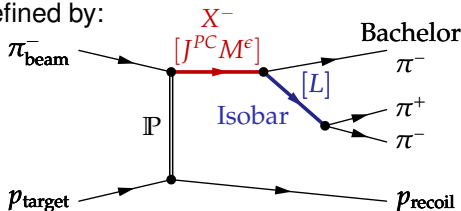


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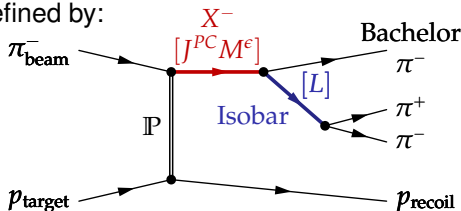


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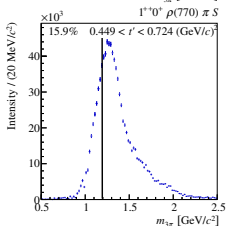
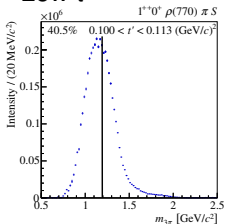


- $J^{PC}$ : Spin and eigenvalues under parity and charge conjugation of  $X^-$
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- $L$ : Orbital angular momentum between isobar and bachelon pion



## Selected Waves (1 of 88)

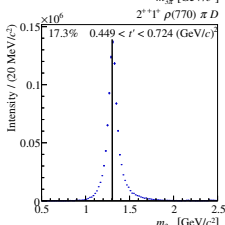
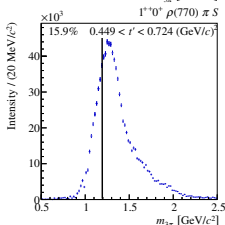
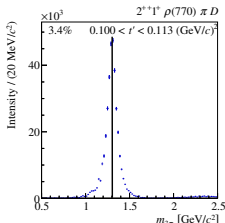
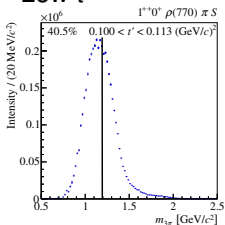
Low  $t'$



High  $t'$

## Selected Waves (2 of 88)

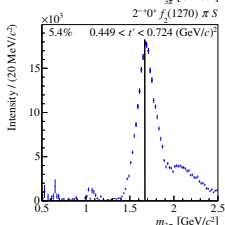
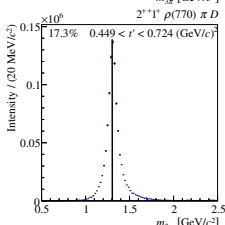
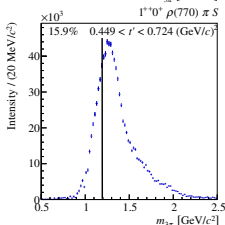
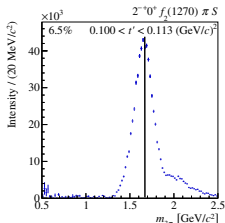
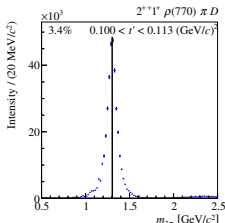
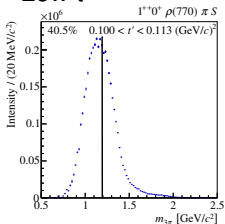
Low  $t'$



High  $t'$

## Selected Waves (3 of 88)

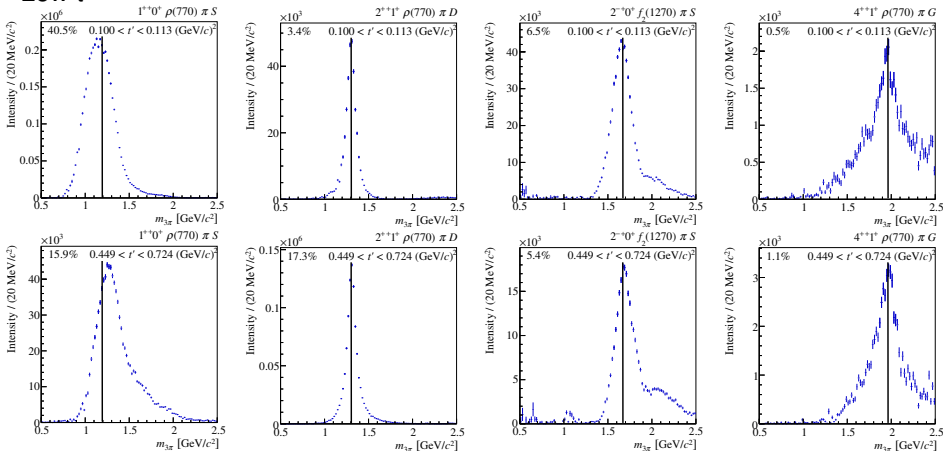
Low  $t'$



High  $t'$

## Selected Waves ( 4 of 88)

Low  $t'$



High  $t'$

## Spin-Density Matrix:

- Diagonal elements: Intensities:  $\text{SDM}_{ii} = |T_i|^2$
- Off-diagonal elements: Phases:  $\text{SDM}_{ij} = -\text{SDM}_{ji} = \arg(T_i T_j^*)$

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- $14 \times 14$  submatrix of  $88 \times 88$  SDM
- Same model for every bin in  $t'$

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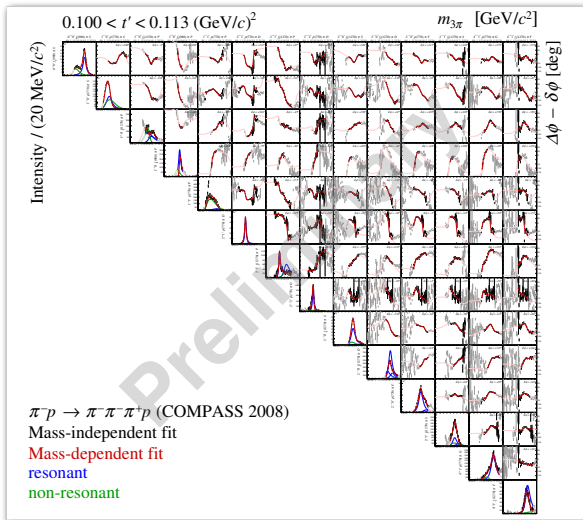


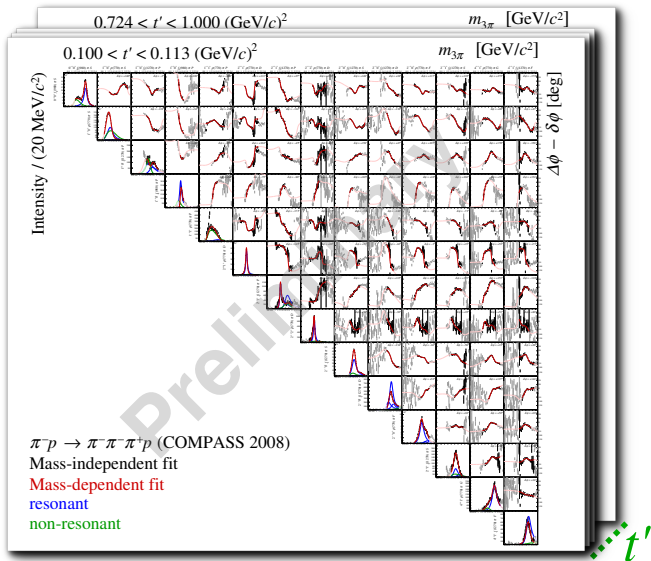
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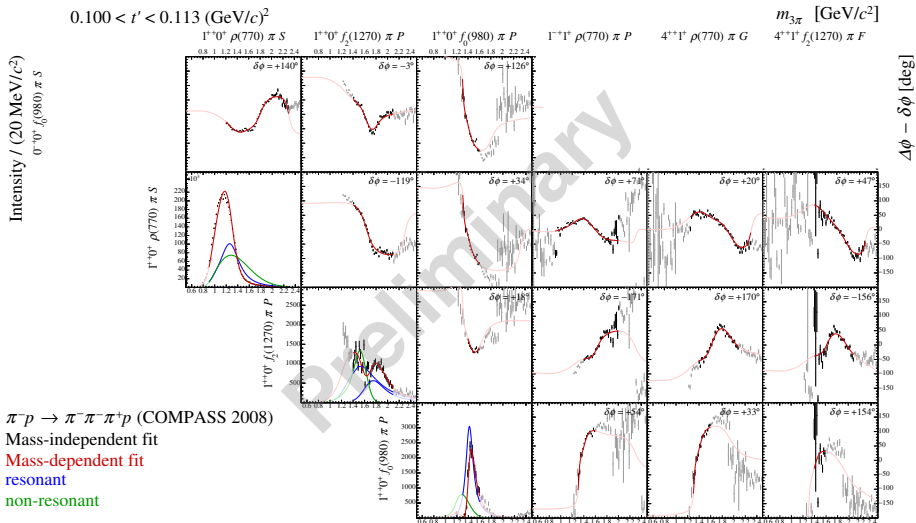
- $14 \times 14$  submatrix of  $88 \times 88$  SDM
- Same model for every bin in  $t'$
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- Add non-resonant background
  - ▶ Phenomenological parametrization or Deck
- 722 free parameters
- 76505 data points

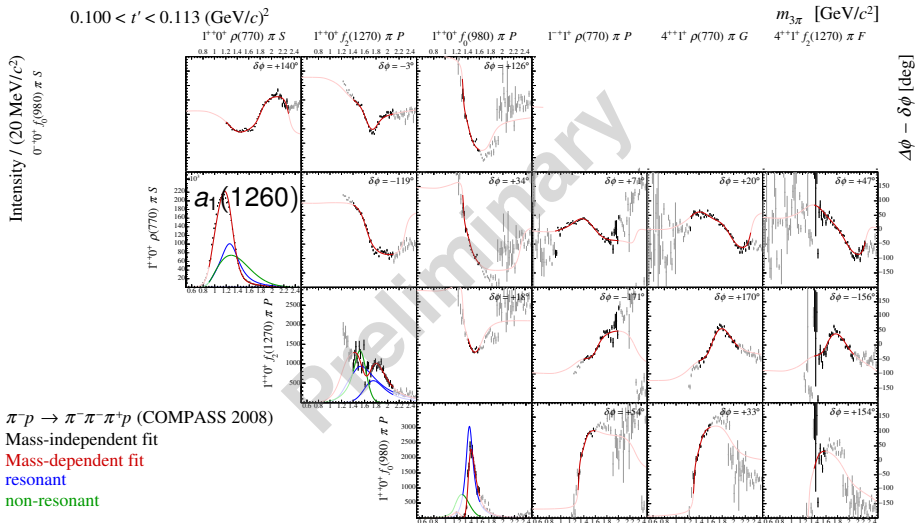


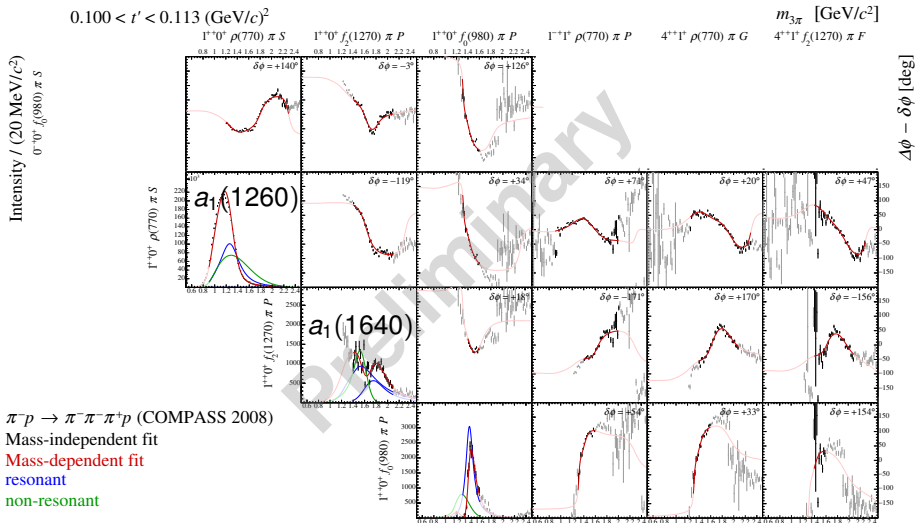


× 11 bins in  $t'$

$J^{PC} = 1^{++}$  sector



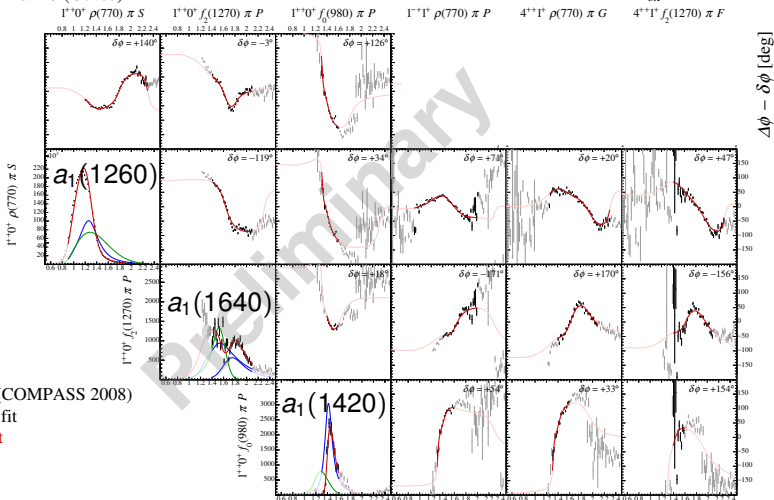




Intensity / (20 MeV/c<sup>2</sup>)  
0<sup>++</sup> f<sub>0</sub>(980) π S

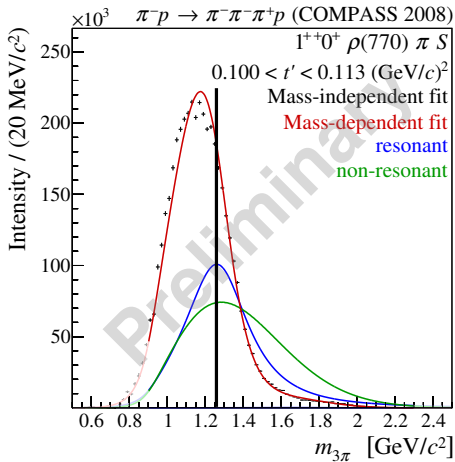
0.100 < t' < 0.113 (GeV/c)<sup>2</sup>

m<sub>3π</sub> [GeV/c<sup>2</sup>]

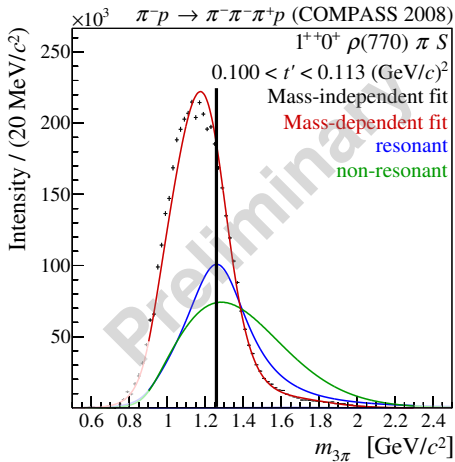




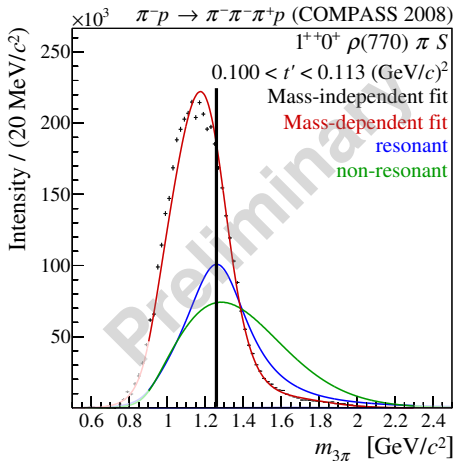
- Resonance parameters do not depend on production mechanism



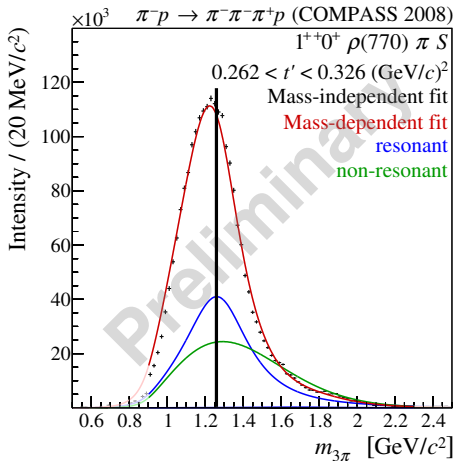
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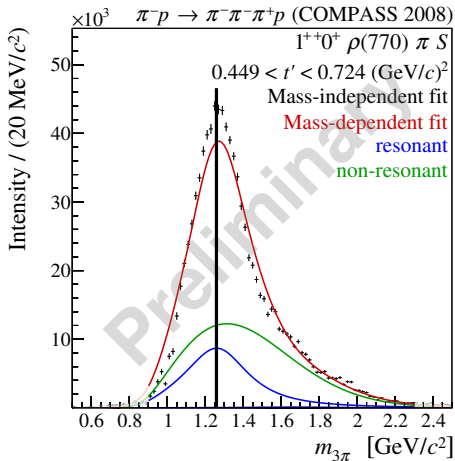
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- Disentangle resonant and non-resonant part



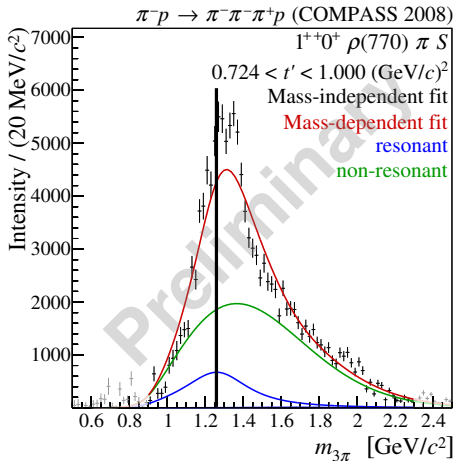
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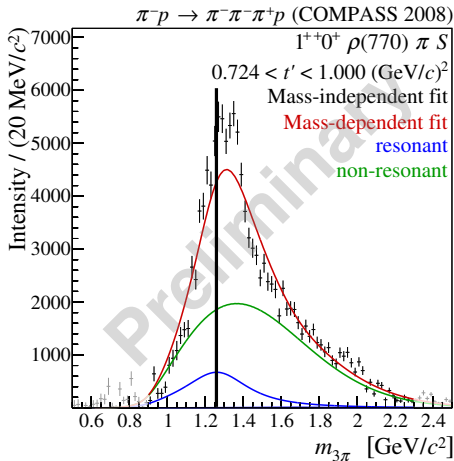
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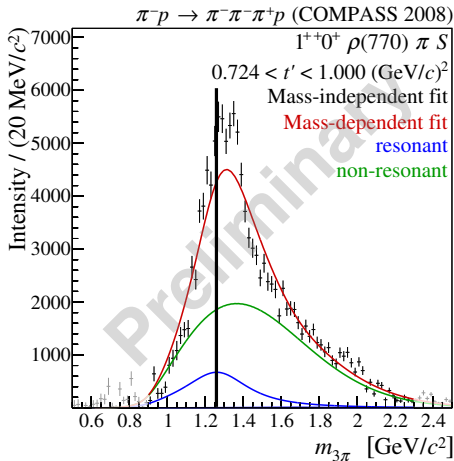
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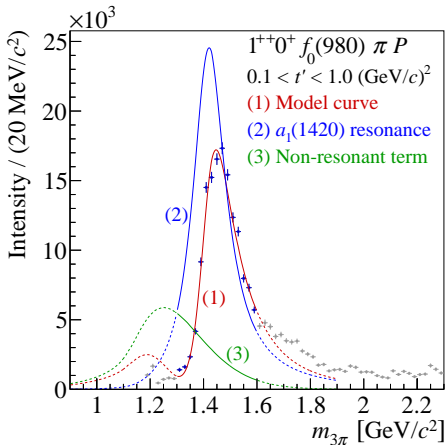
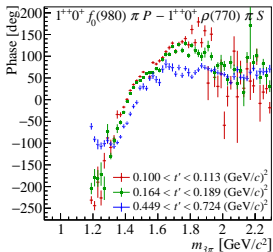
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- Disentangle resonant and non-resonant part
- $a_1(1260)$  reproduced

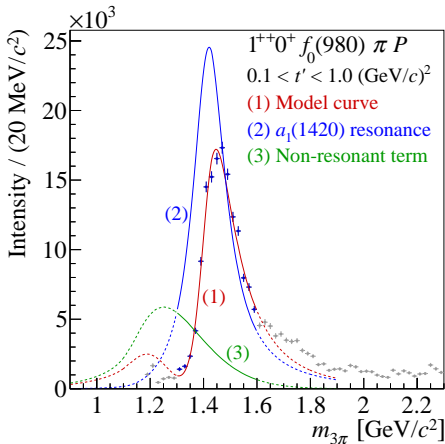
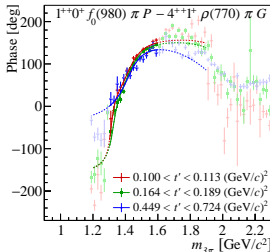
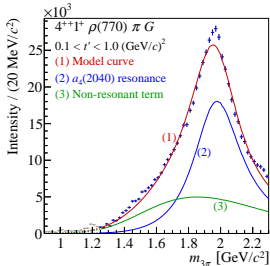


- Resonance parameters do not depend on production mechanism
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- Disentangle resonant and non-resonant part
- $a_1(1260)$  reproduced
- Excited  $a_1(1640)$  found (only visible in log-scale)

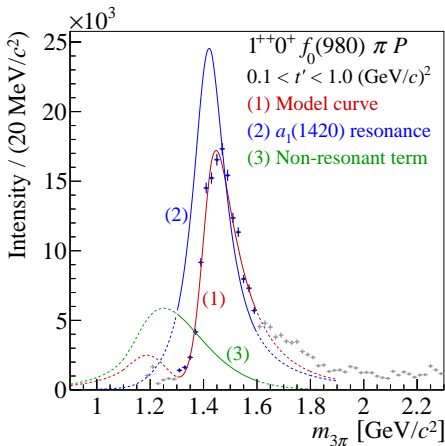




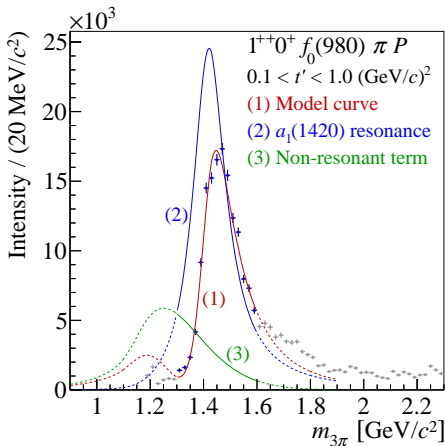




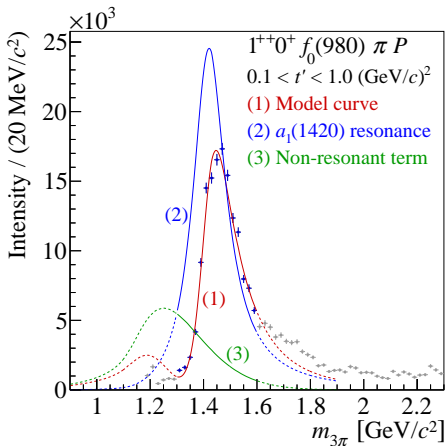
- New signal:  $a_1(1420)$
- Decay to  $f_0(980)\pi$



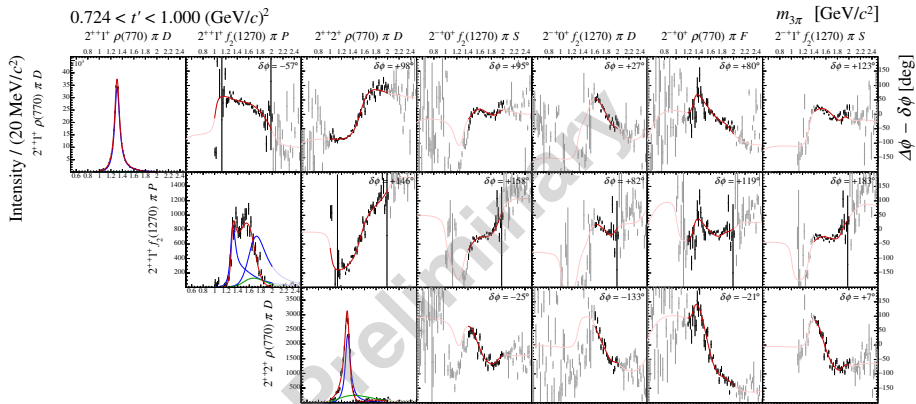
- New signal:  $a_1(1420)$
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- Many possible explanations:
  - ▶ Triangle diagram
  - ▶ Interference with Deck amplitude



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- Decay to  $f_0(980)\pi$
- Many possible explanations:
  - ▶ Triangle diagram
  - ▶ Interference with Deck amplitude
- Mass:  
 $m_{a_1(1420)} = 1411.8^{+1.0}_{-4.4} \text{ MeV}/c^2$
- Width:  
 $\Gamma_{a_1(1420)} = 158^{+8}_{-8} \text{ MeV}/c^2$



$J^{PC} = 2^{++}$  sector



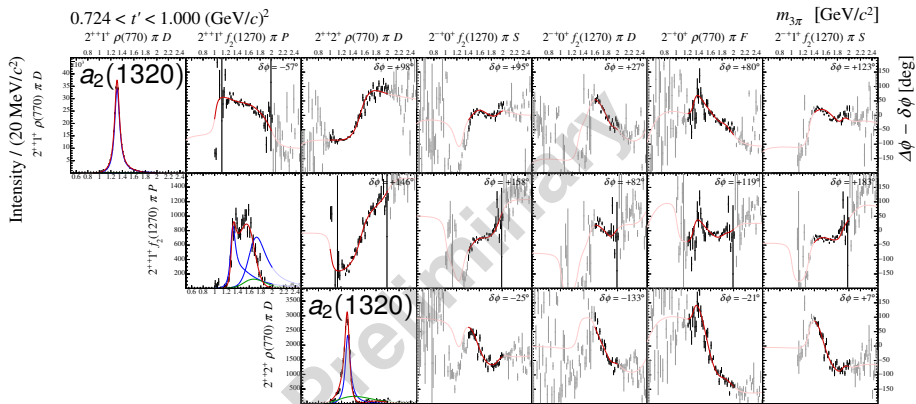
$\pi p \rightarrow \pi^- \pi^+ \pi^0 p$  (COMPASS 2008)

Mass-independent fit

Mass-dependent fit

resonant

non-resonant


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

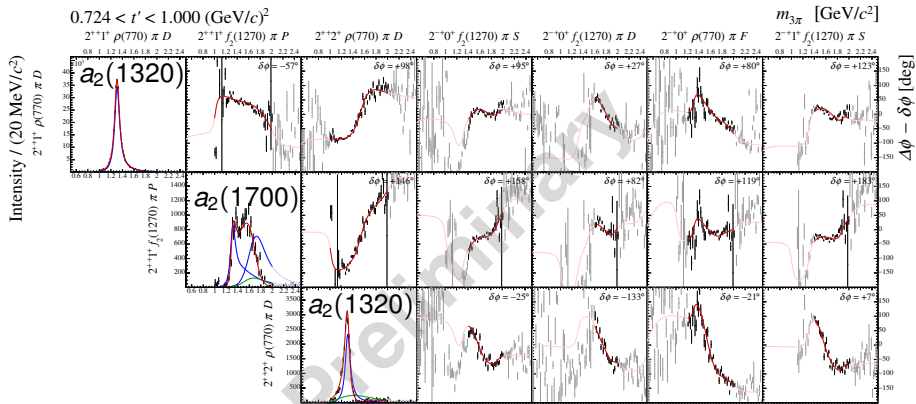
Mass-independent fit

Mass-dependent fit

resonant

non-resonant





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

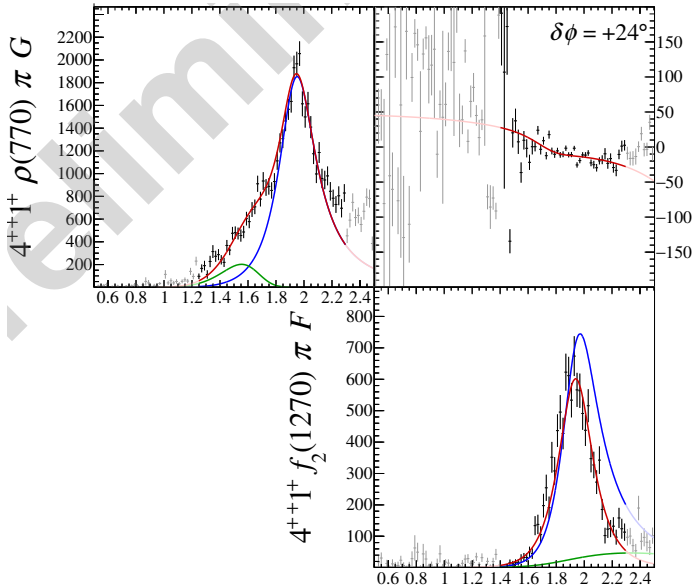
Mass-independent fit

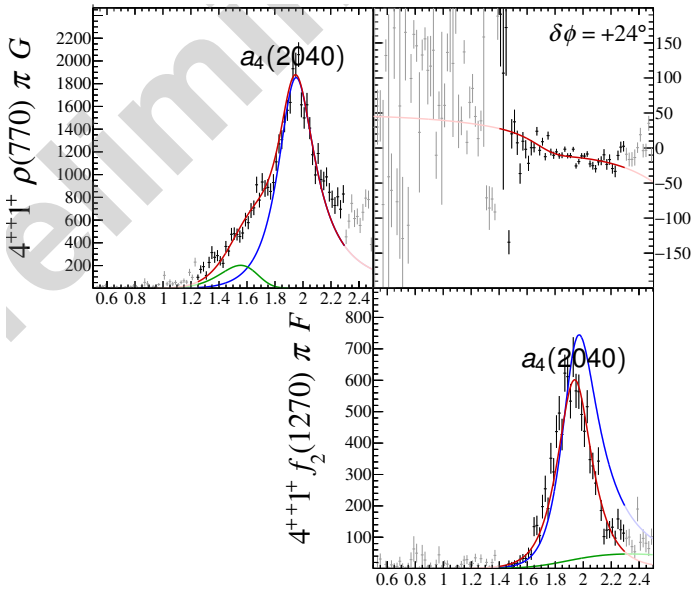
Mass-dependent fit

resonant

non-resonant

$J^{PC} = 4^{++}$  sector





$J^{PC} = 1^{++}$  sector:

- $a_1(1260)$  and  $a_1(1640)$  resonances in the main  $1^{++}$  waves
- Distinguish from non-resonant part due to  $t'$  dependence
- New  $a_1(1420)$  signal found in the  $1^{++}0^+ f_0(980)\pi P$  wave

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- $a_4(2040)$  resonance found

$$0^{-+}0^{+}f_0(980)\pi S$$

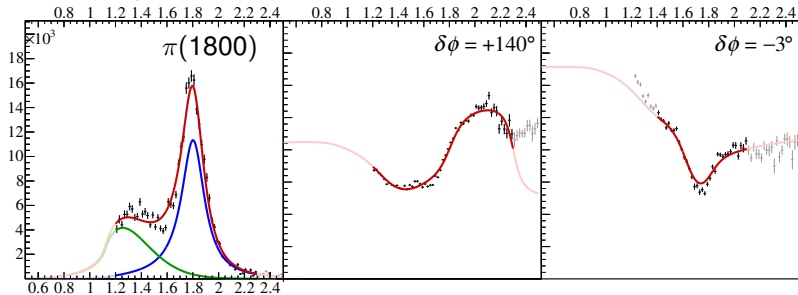


$$0.100 < t' < 0.113 \text{ (GeV}/c)^2$$

 $0^{-+}0^{+} f_0(980) \pi S$ 
 $1^{++}0^{+} \rho(770) \pi S$ 
 $1^{++}0^{+} f_2(1270) \pi P$ 

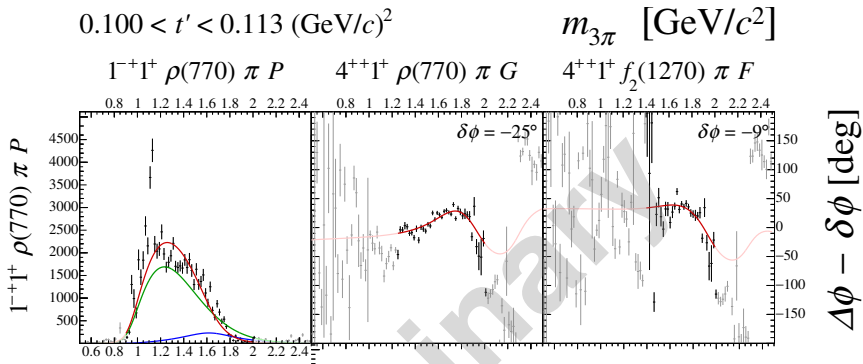
Intensity / (20 MeV/c<sup>2</sup>)

$0^{-+}0^{+} f_0(980) \pi S$



$$1^{-+} 1^{+} \rho(770) \pi P$$

Intensity / (20 MeV/c<sup>2</sup>)



$0.449 < t' < 0.724 \text{ (GeV}/c^2\text{)}$

$m_{3\pi} \text{ [GeV}/c^2\text{]}$

$1^{-+}1^{+} \rho(770) \pi P$

$4^{++}1^{+} \rho(770) \pi G$

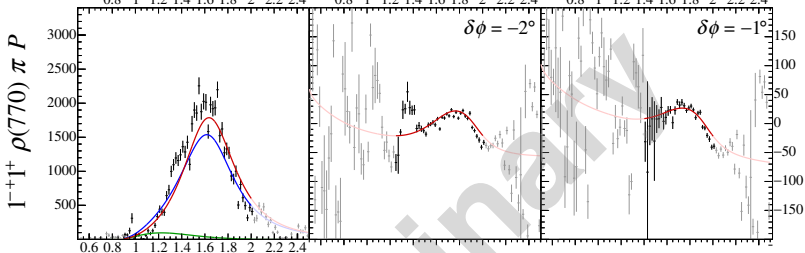
$4^{++}1^{+} f_2(1270) \pi F$

0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4

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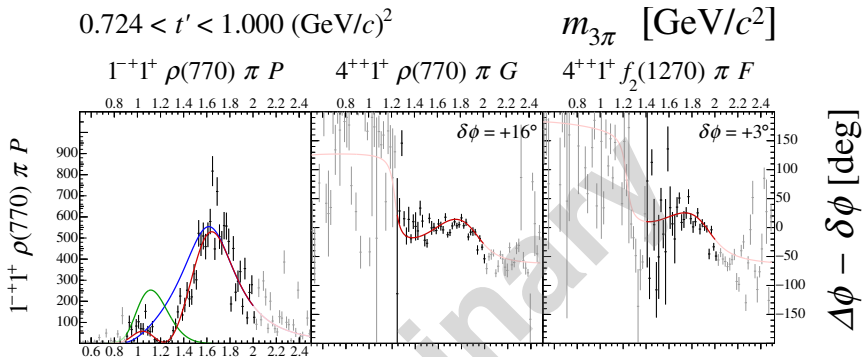
0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4

Intensity / (20 MeV/c<sup>2</sup>)



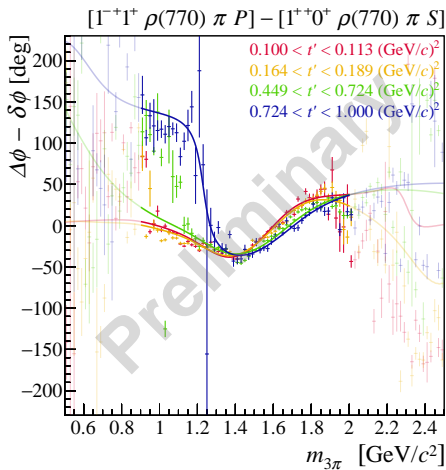
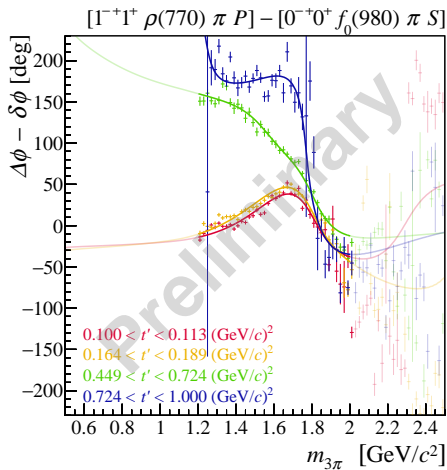
$\Delta\phi - \delta\phi \text{ [deg]}$

Intensity / (20 MeV/c<sup>2</sup>)

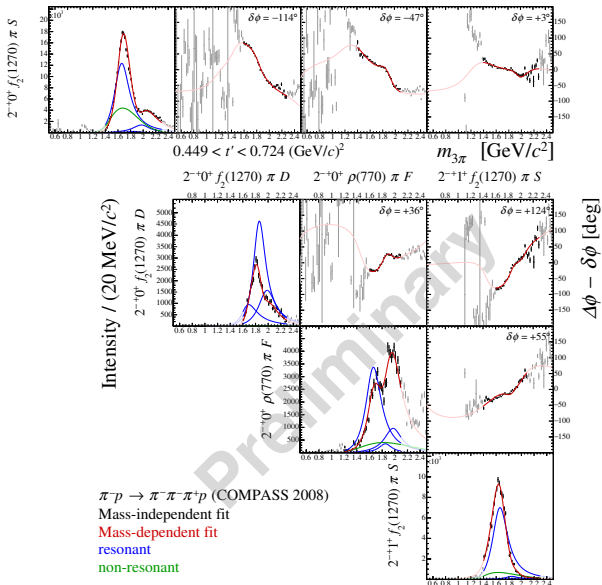


# The $1^{-+}1^{+}\rho(770)\pi P$ wave

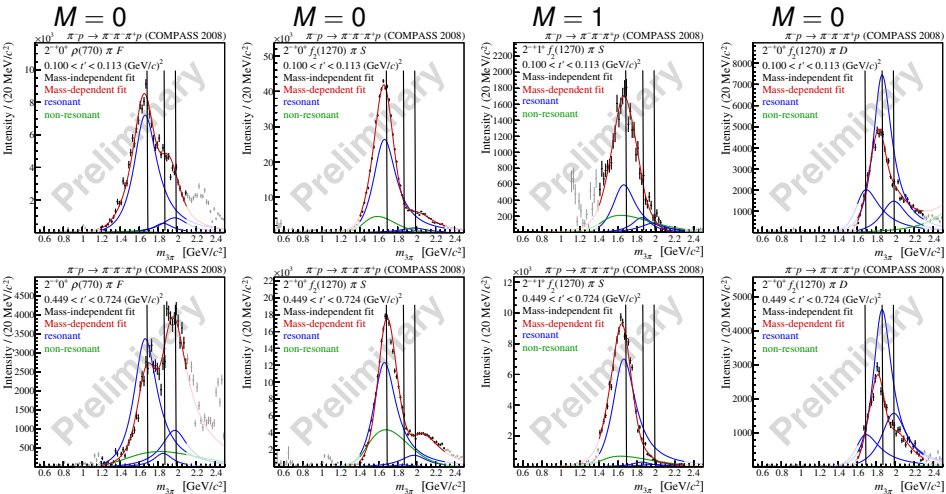
Phase-motion

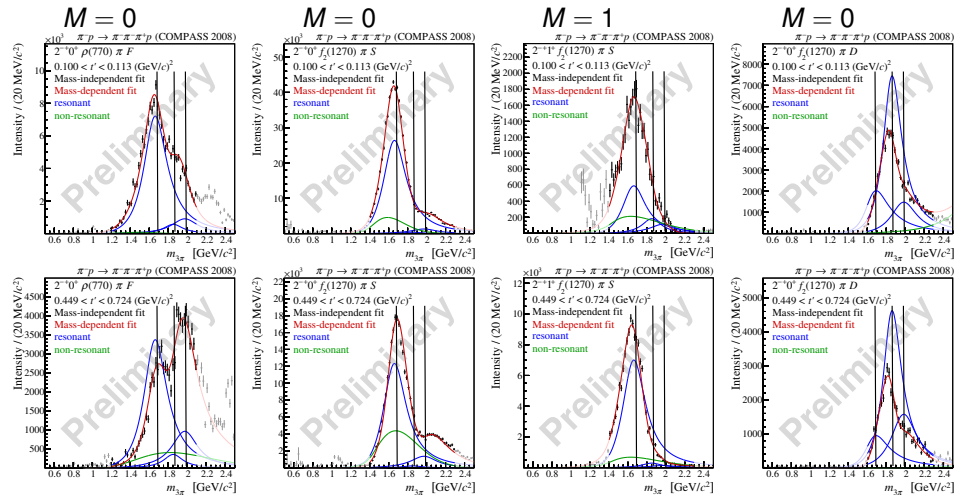


$J^{PC} = 2^{-+}$  sector









$\pi_2(1670)$ ,  $\pi_2(1880)$  and  $\pi_2(2005)$

# Summary of $\pi_J(\dots)$ section

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- Resonance can't be explained within the simple quark model

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$J^{PC} = 2^{-+}$  sector

- Three  $2^{-+}$  resonances included
- $\pi_2(1670)$ ,  $\pi_2(1880)$  and  $\pi_2(2005)$ 
  - ▶  $\pi_2(1670)$  dominant in  $S$ -wave decays
  - ▶  $\pi_2(1880)$  dominant in  $D$ -wave decays
  - ▶  $\pi_2(2005)$  only seen once before

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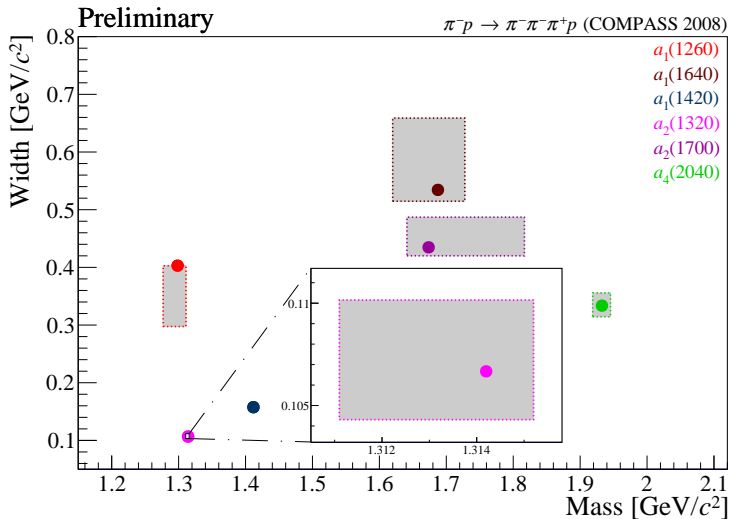


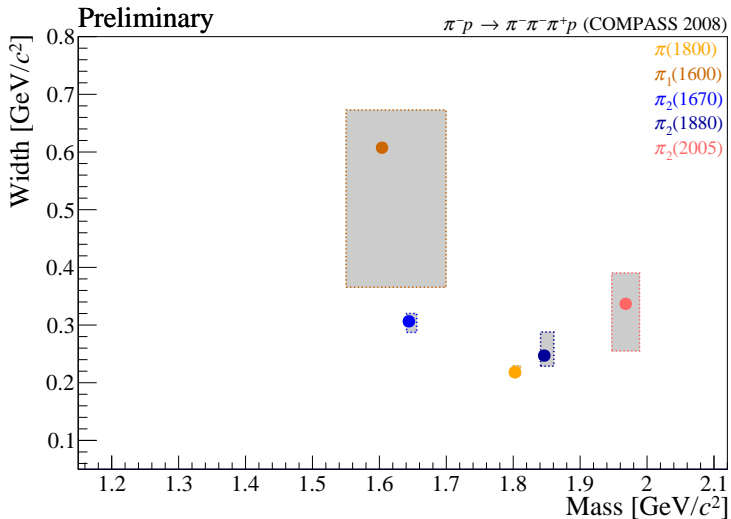
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    - ★ Resonance parametrizations
    - ★ Non-resonant parametrizations

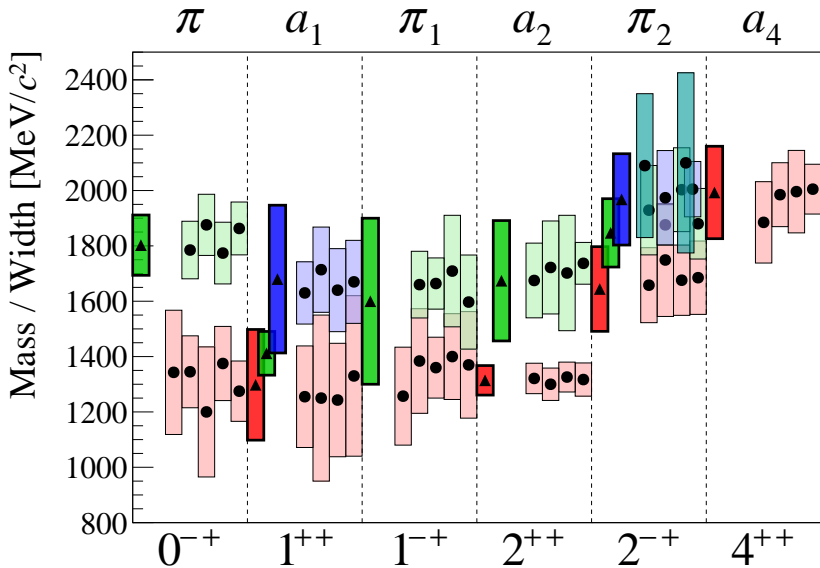
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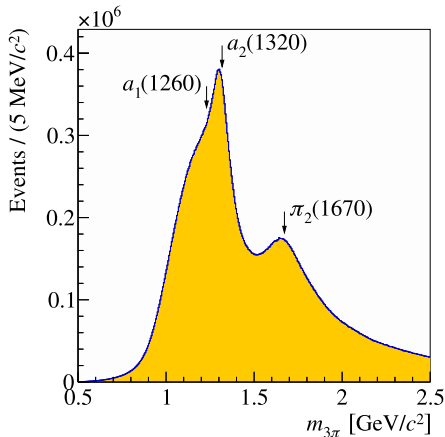
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- → Systematic uncertainties under control





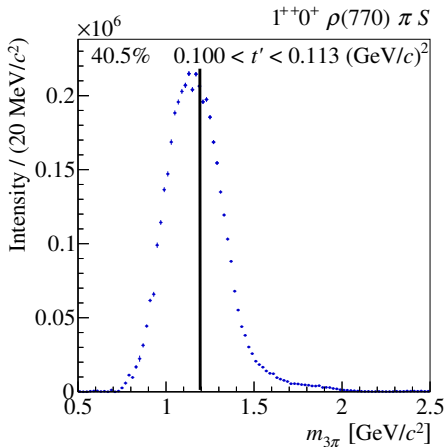


- $46 \cdot 10^6$  events for  $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$  collected by COMPASS
- Two-step analysis:

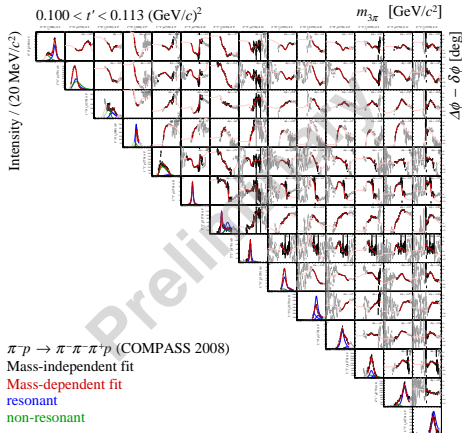




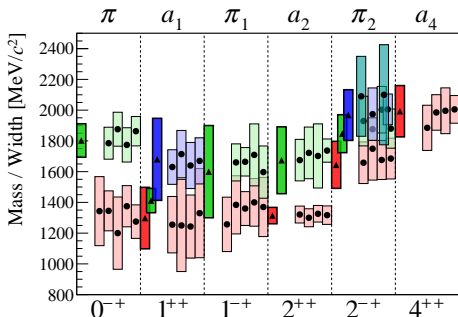
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- Publication in preparation

