The virtue of precision spectroscopy : A new axial-vector meson and The structure of the ($\pi\pi$) S-wave-isobar

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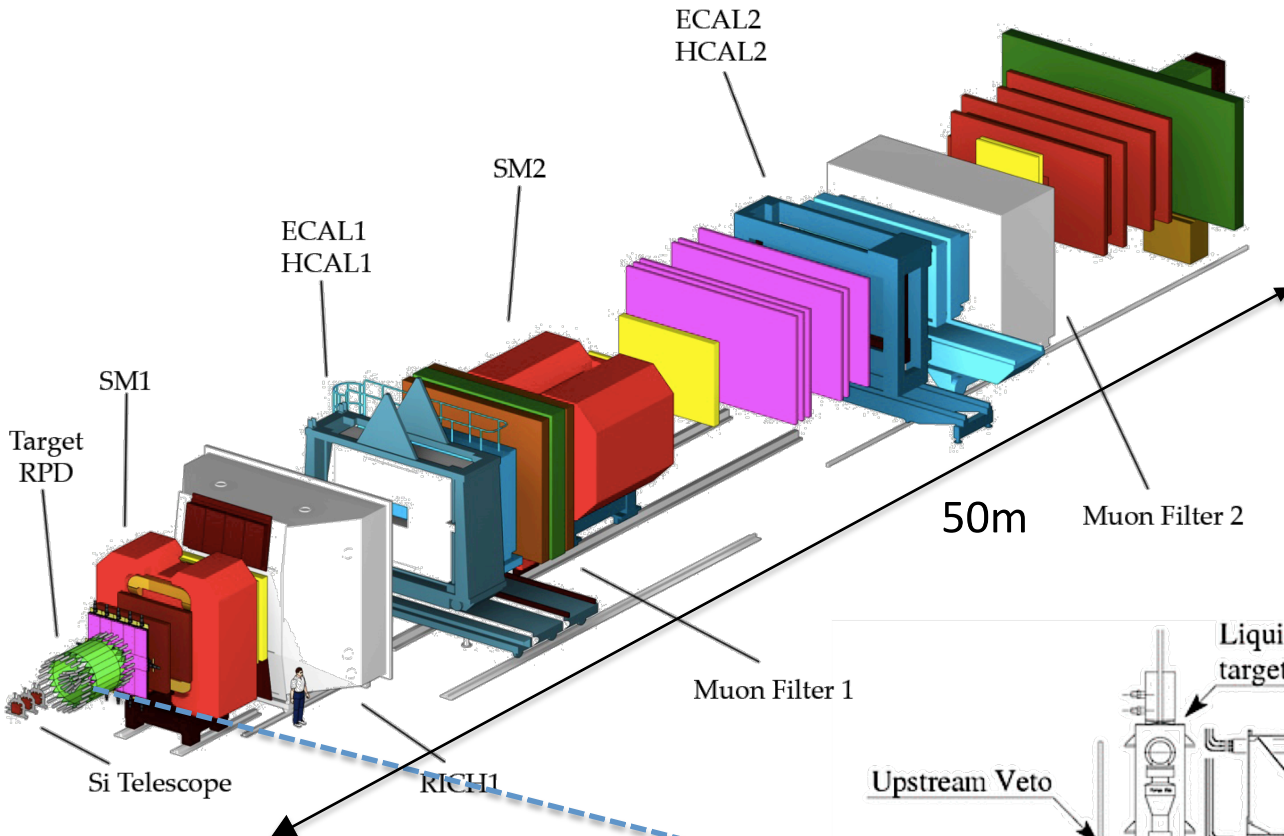
on behalf of the COMPASS Collaboration

Excellence Cluster Universe

Todays presentation

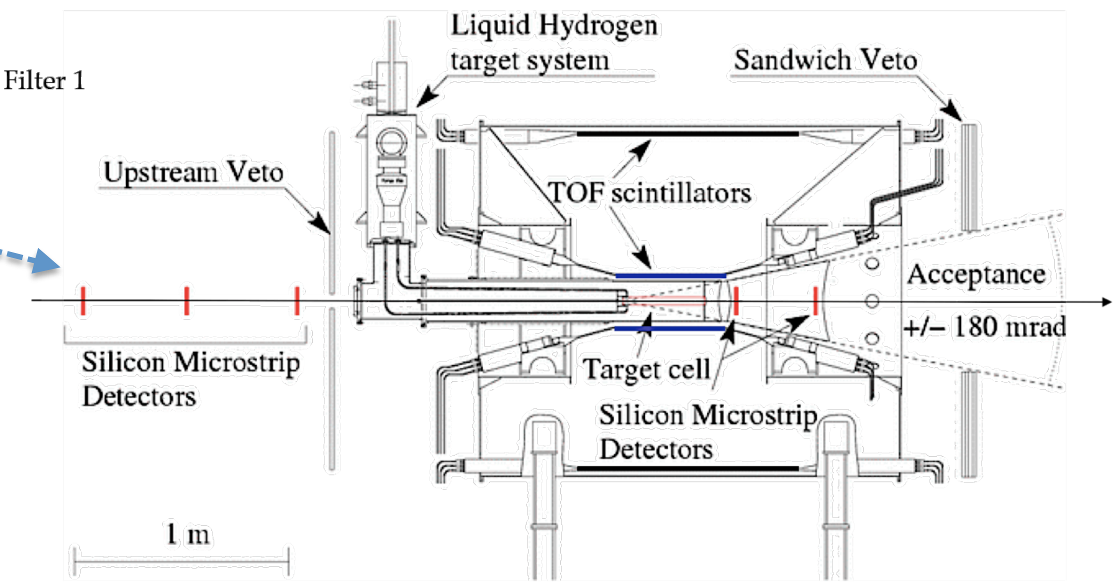
- Concentrate talk on
  - Data-set
  - mass-independent fit
  - mass-dependent fit
    - results for resonance parameters
    - A new axial vector meson: $a_1(1420)$
  - $\pi\pi$ S-wave extraction
    - results for 0^{-+}, 1^{++}, 2^{-+}
    - Role of $f_0(980)$
  - Conclusions

The COMPASS Experiment



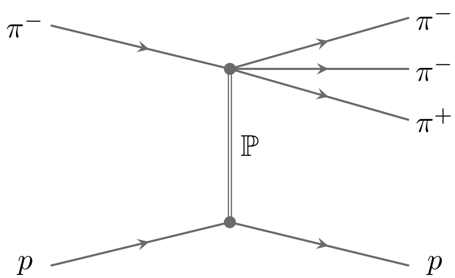
Hadron beam:

- 190 GeV/c π, K, p
- $5 \cdot 10^7$ particles/SPS-spill
- 60 days data taking 2008
- Trigger: RPD hit, beam veto

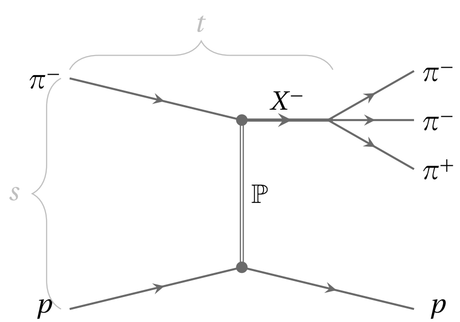


The Process

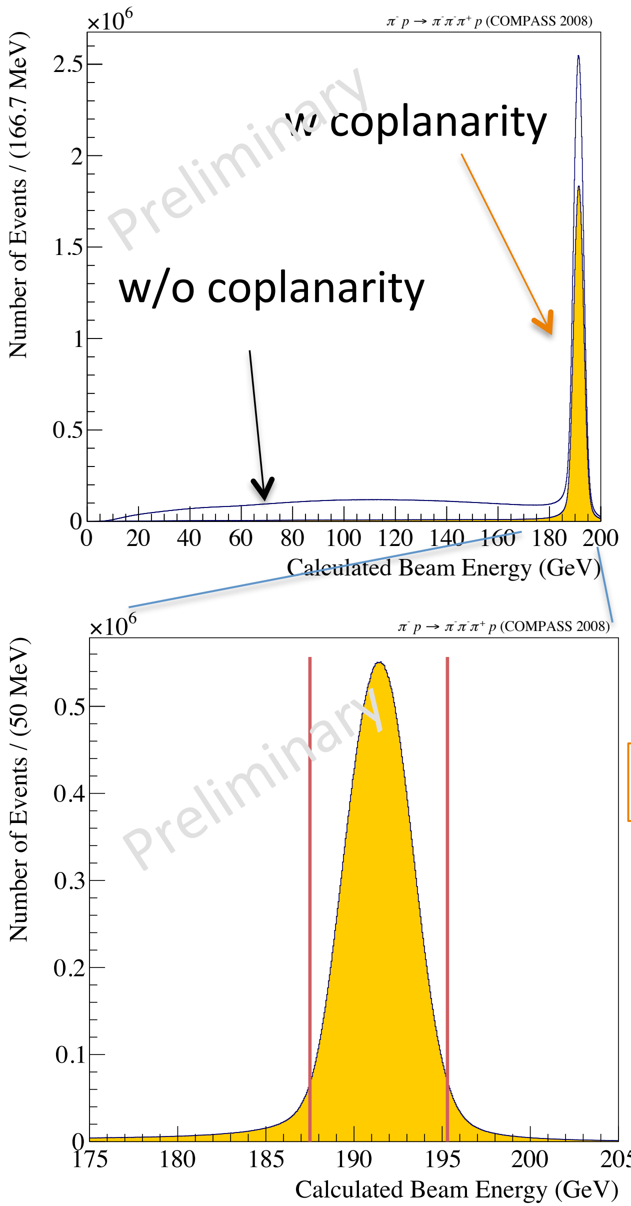
generic process



what we are after

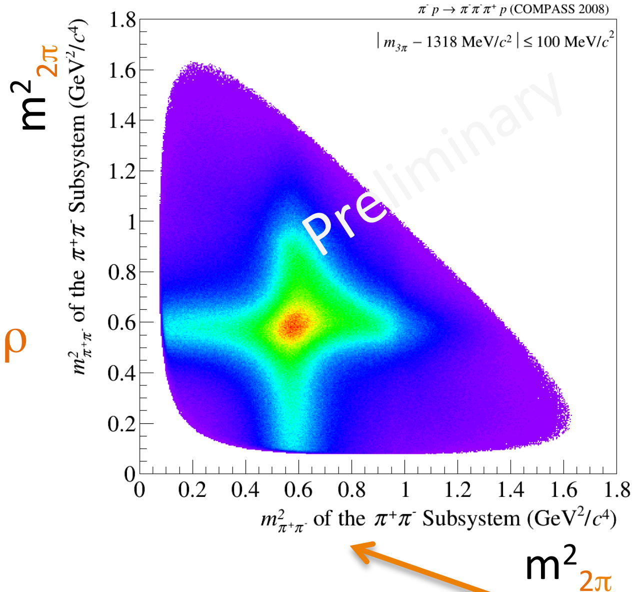


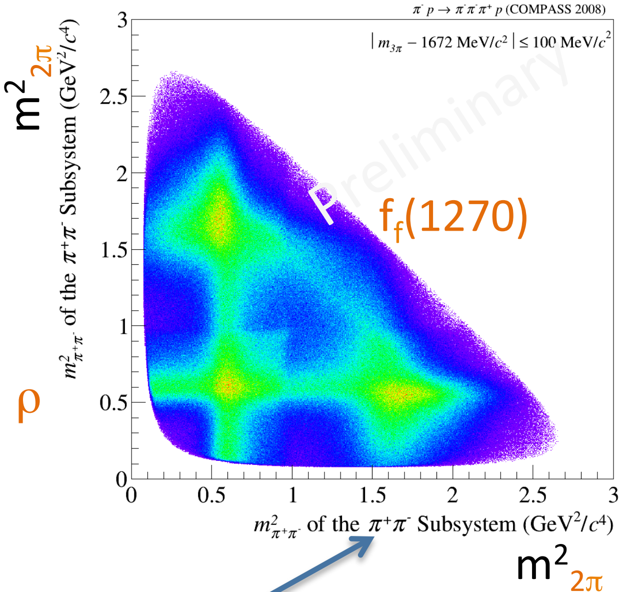
exclusive reaction

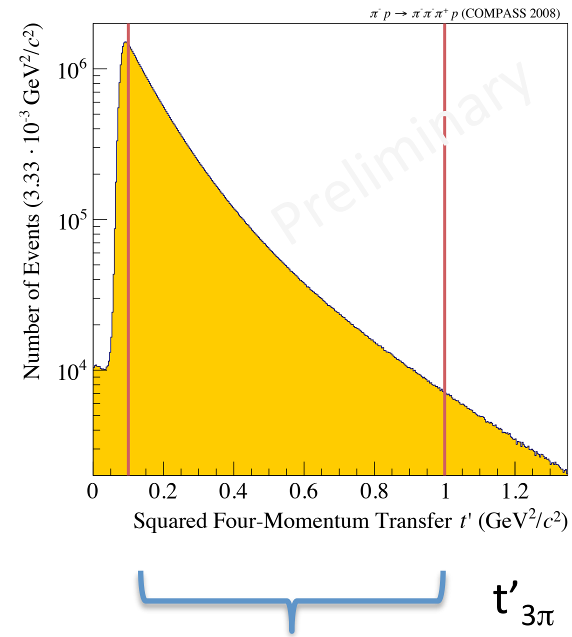


$5\cdot10^7$ evts

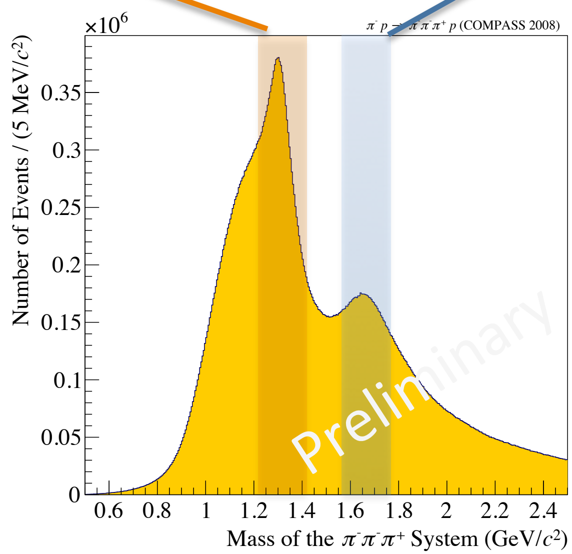
First Impressions
Motivation for Isobar Model



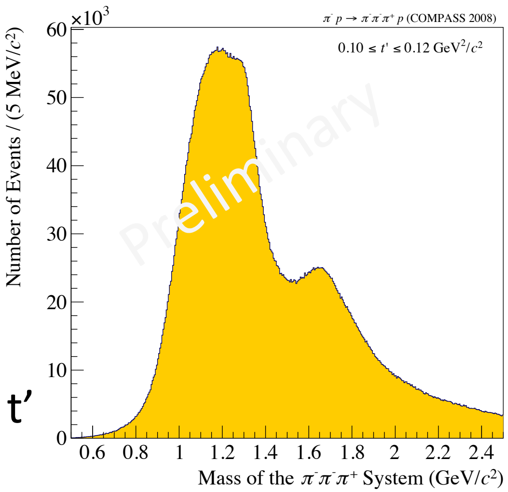




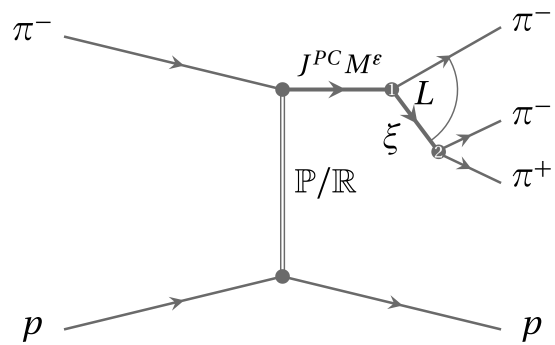
used in analysis

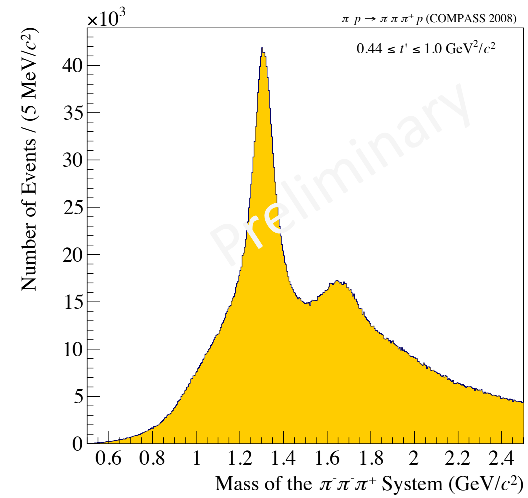


Kinematics and Isobars

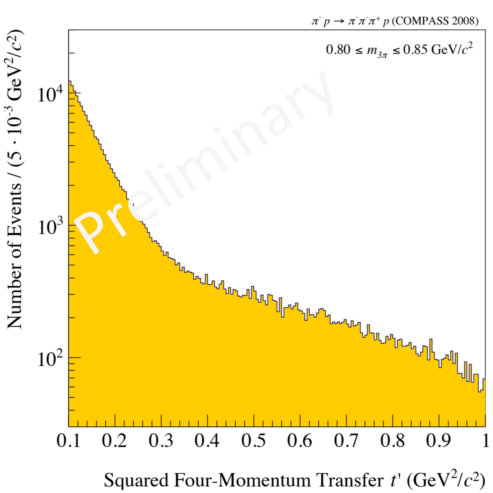


low t'

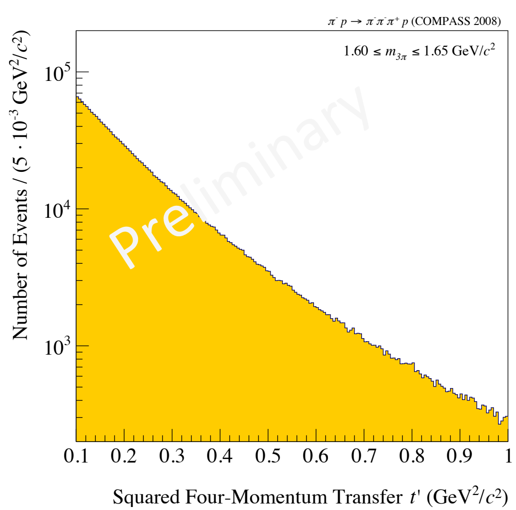




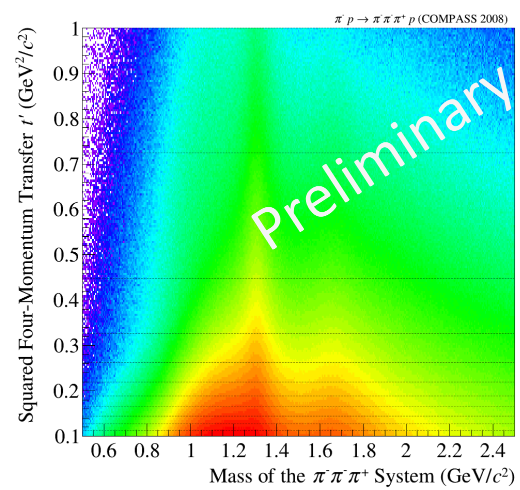
high t'



$0.8 < m_{3\pi} < 0.85$



$1.6 < m_{3\pi} < 1.65$



grid of t' used (11 bins)

Δm: 20 MeV/c^2

Fit Model - Isobars

Use 88 waves:

- 80 waves with positive naturality
- 7 waves with negative naturality
- flat wave (garbage collection)

Particle	J^{PC}	Mass $[\mathrm{MeV}/c^2]$	Width $[\mathrm{MeV}/c^2]$
$f_0(500)$	0^{++}	400 to 550	400 to 700
$f_0(980)$	0^{++}	990 ± 20	40 to 100
$f_2(1270)$	2^{++}	1275.1 ± 1.2	$185.1^{+2.9}_{-2.4}$
$f_0(1370)$	0^{++}	1200 to 1500	200 to 500
$f_0(1500)$	0^{++}	1505 ± 6	109 ± 7
$f_2'(1525)$	2^{++}	1525 ± 5	73^{+6}_{-5}
$\rho(770)$	1^{--}	775.49 ± 0.34	149.1 ± 0.8
$\rho(1450)$	1^{--}	1465 ± 25	400 ± 60
$\rho_3(1690)$	3^{--}	1688.8 ± 2.1	161 ± 10
$\rho(1700)$	1^{--}	1720 ± 20	250 ± 100

$[\pi\pi]_S$

not used

Waves with Major Resonances

Major waves

$1^{++}m^{+}[\rho]\pi S$

$2^{++}m^{+}[\rho]\pi D$

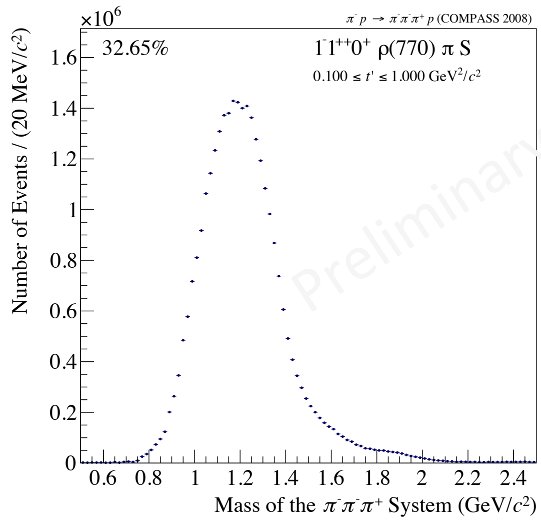
$2^{-+}m^{+}[f_2(1270)]\pi S$

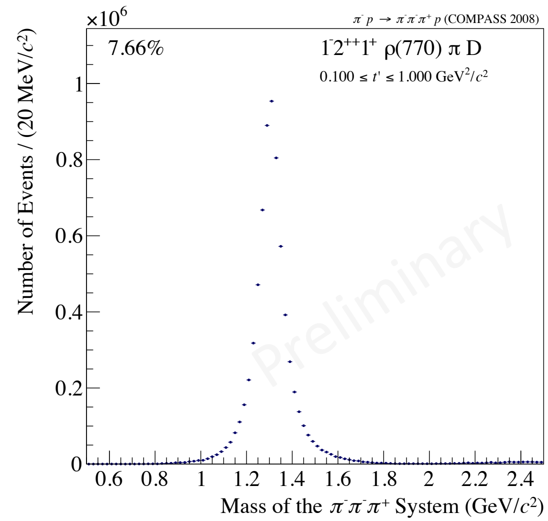
$4^{++}m^{+}[\rho]\pi G$

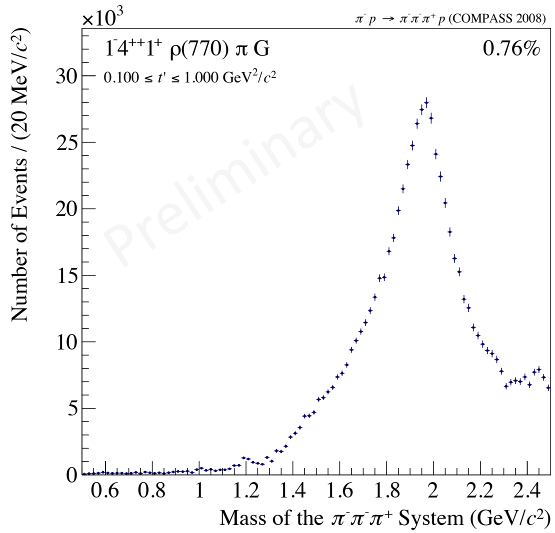
$1^{++}m^{+}[f_0(980)]\pi P$

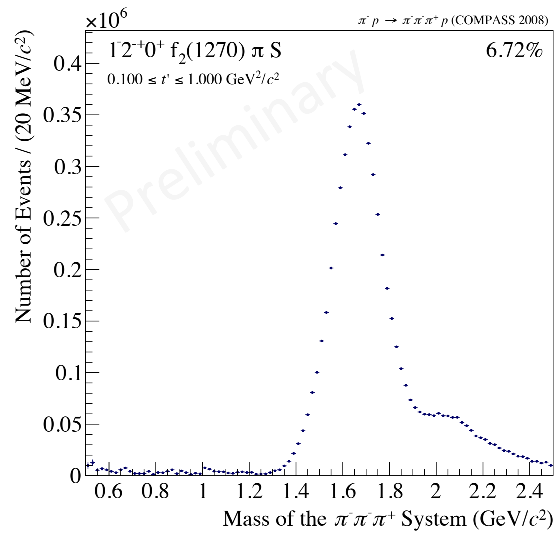
$0^{-+}m^{+}[f_0(980)]\pi S$

mass independent fits
minimal m = (0,1) waves

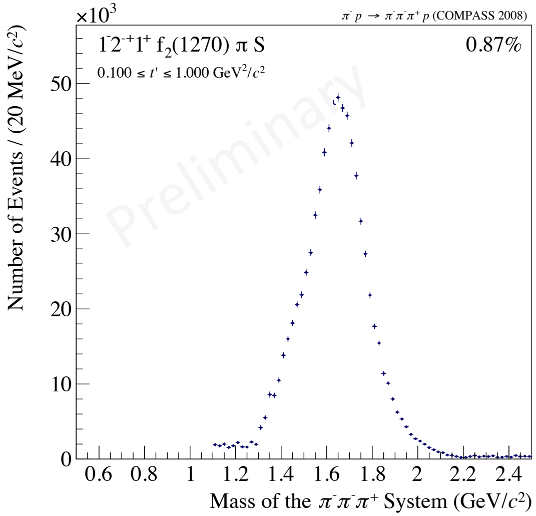


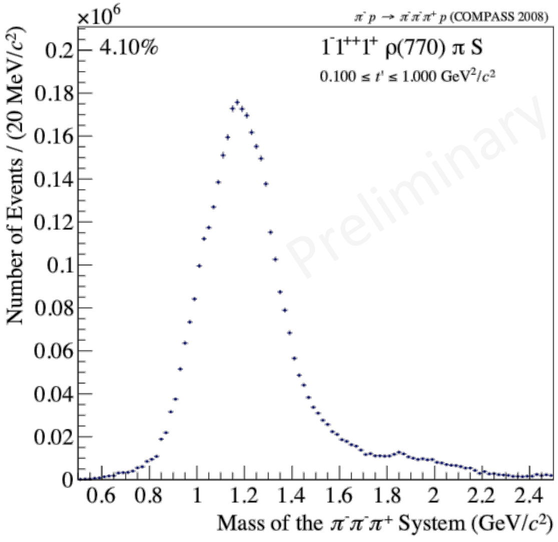






Major Waves m = 1

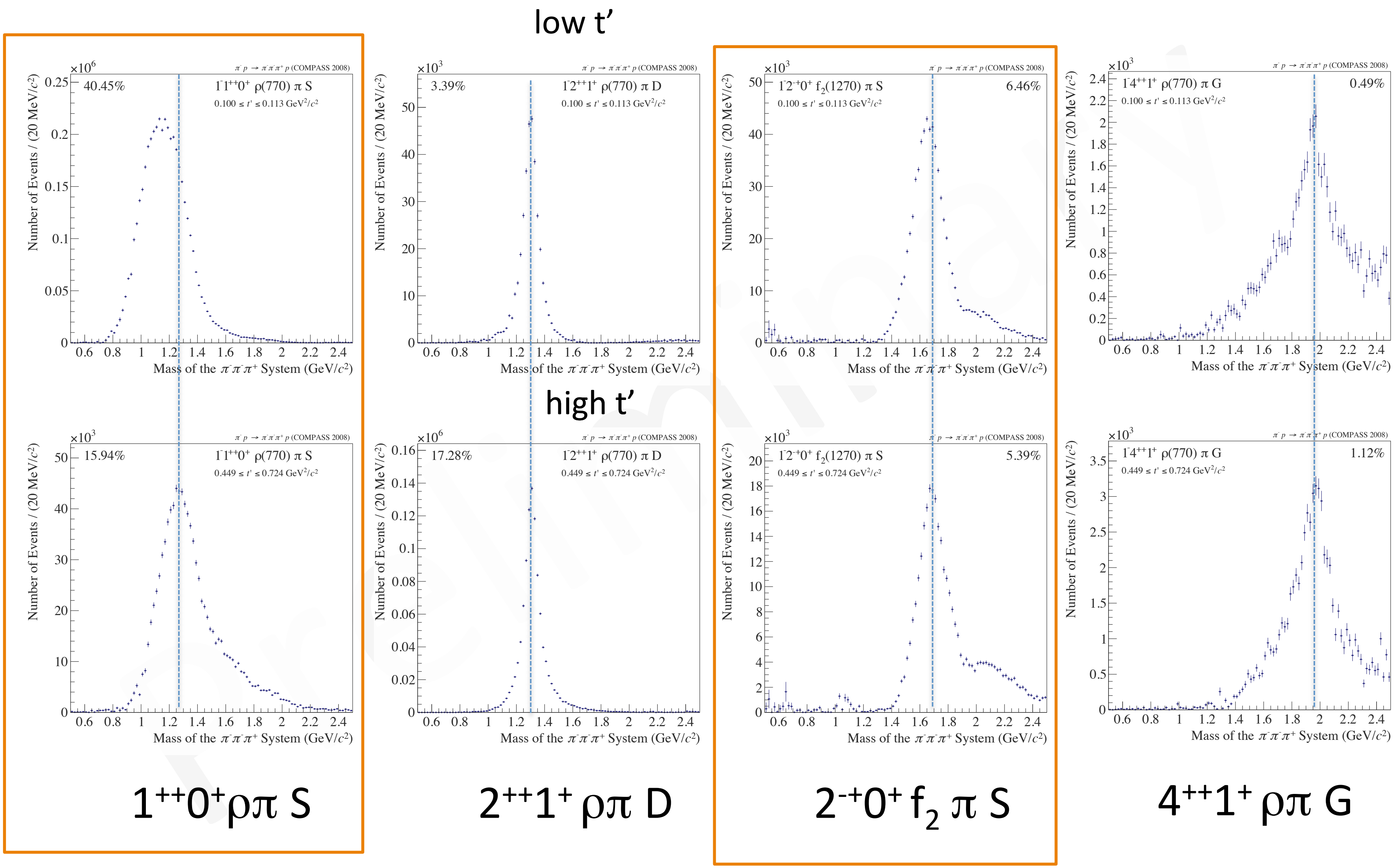




mass independent fits

m = 1 = m_{min} + 1 waves

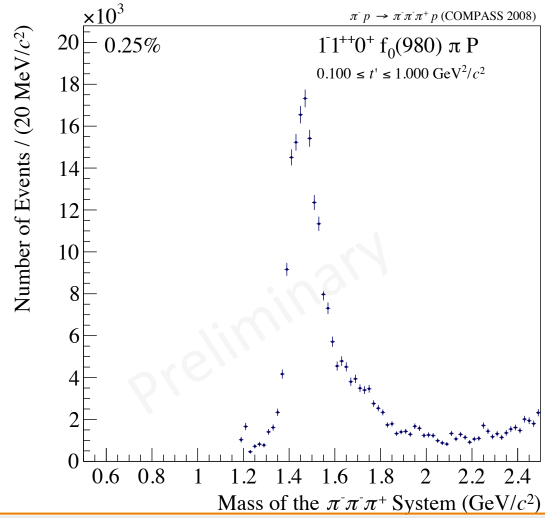
t’ dependence of mass distributions



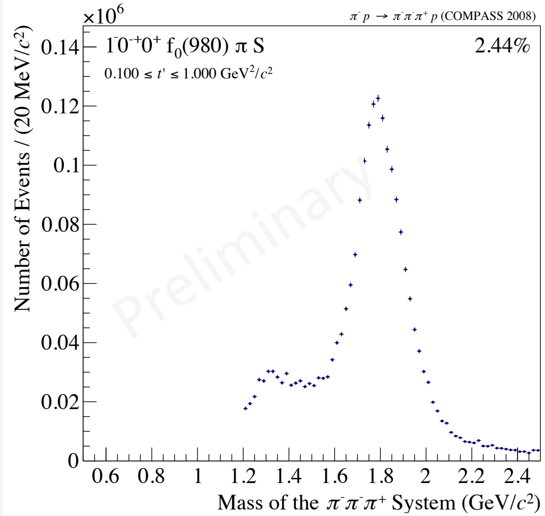
More exotic families

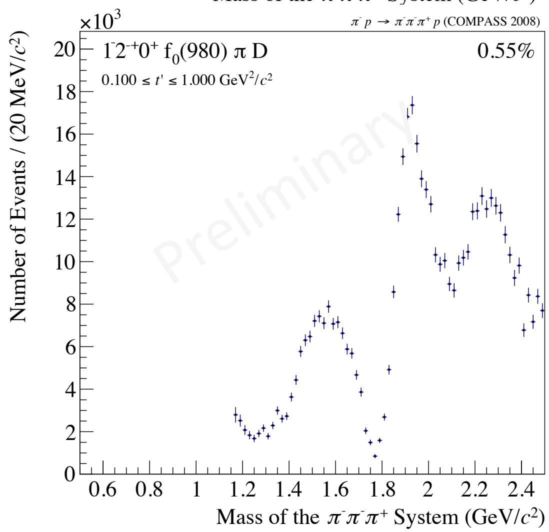
Waves involving $f_0(980)$

$1^{++}0^{+}$ $f_0(980)$ π S



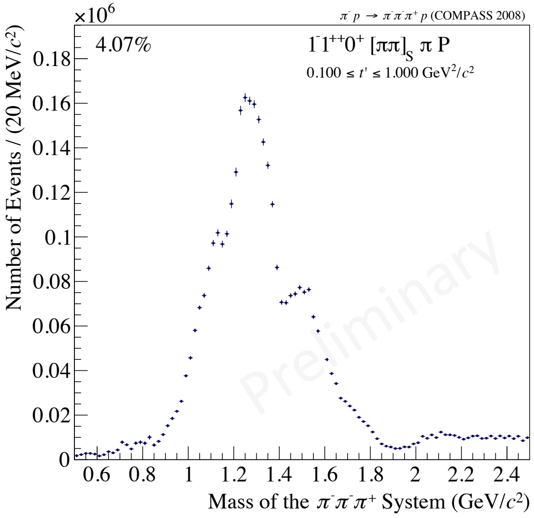
$0^{-+}0^{+}$ $f_0(980)$ π S



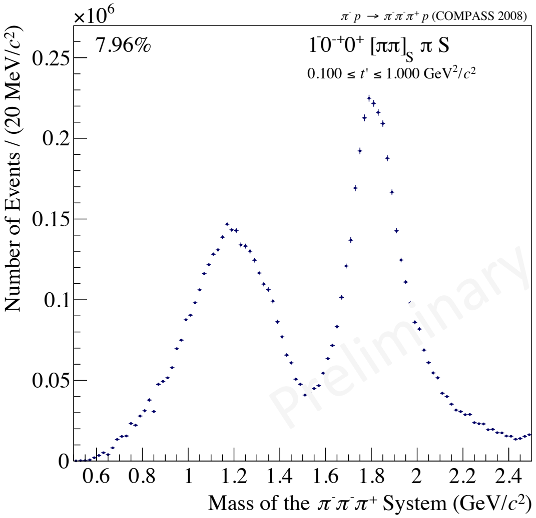


$2^{-+}0^{+}$ $f_0(980)$ π D

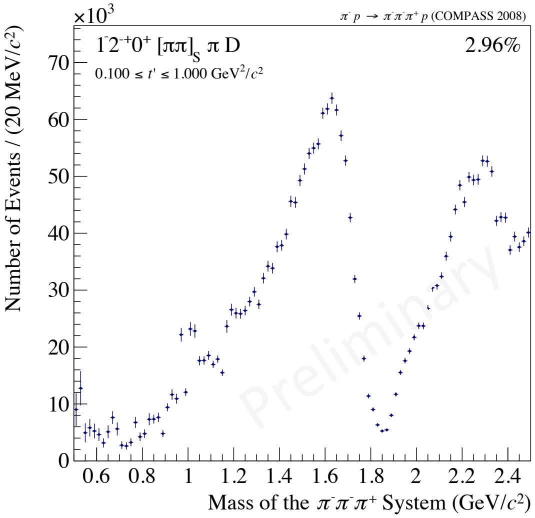
Waves involving $[\pi\pi]_S$



$1^{++}0^{+}[\pi\pi]_S\ \pi\ P$



$0^{-+}0^{+}[\pi\pi]_S\ \pi\ S$



$2^{-+}0^{+}[\pi\pi]_S\ \pi\ D$

Mass-dependent fit

Use only lowest m = 0,1 waves (so far)

This work: 6 waves + non resonant term

Model:

$1^{++}1^{+}\rho\pi$ S	2 resonances : $a_1(1260)$ and a_1' + non resonant term
$2^{++}0^{+}\rho\pi$ D	2 resonances : $a_2(1320)$ and a_2' + non resonant term
$4^{++}1^{+}\rho\pi$ G	1 resonance : $a_4(2040)$ + non resonant term
$2^{-+}0^{+} f_2 \pi$ S	2 resonances : $\pi_2(1670)$ and π_2' + non resonant term
$1^{++}f_0(980)\pi$ P	1 resonance : $a_1(1420)$ + non resonant term
$0^{-+}f_0(980)\pi$ S	1 resonance : $\pi(1800)$ + non resonant term

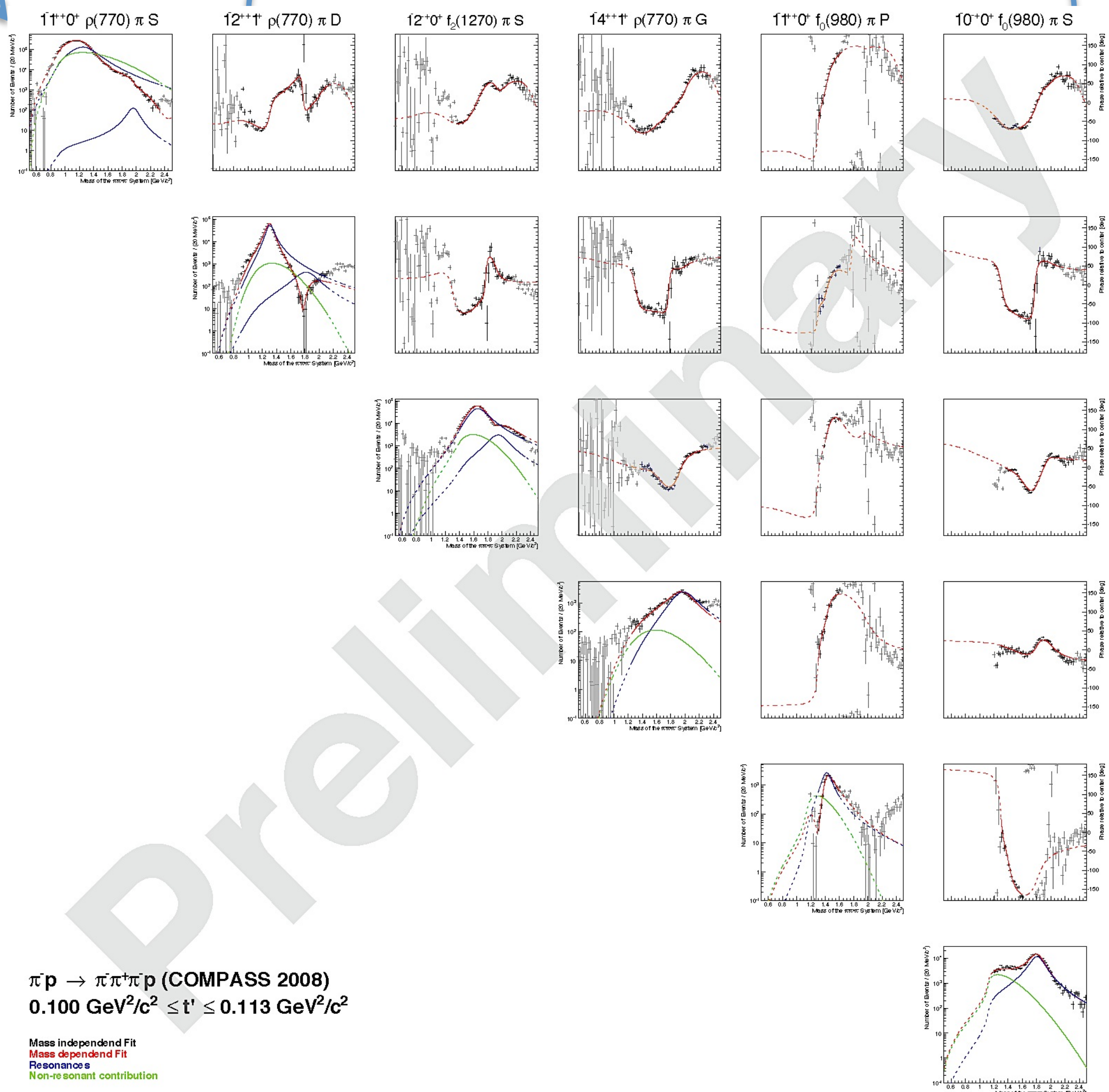
- 231 mass distributions with 23100 data points
- 352 free parameters
- systematic studies with 5 and 7 waves performed

COMPASS Spin-Density Matrix

Reference waves

Interferometry

low t'-slice only



COMPASS Spin-Density Matrix

Reference waves

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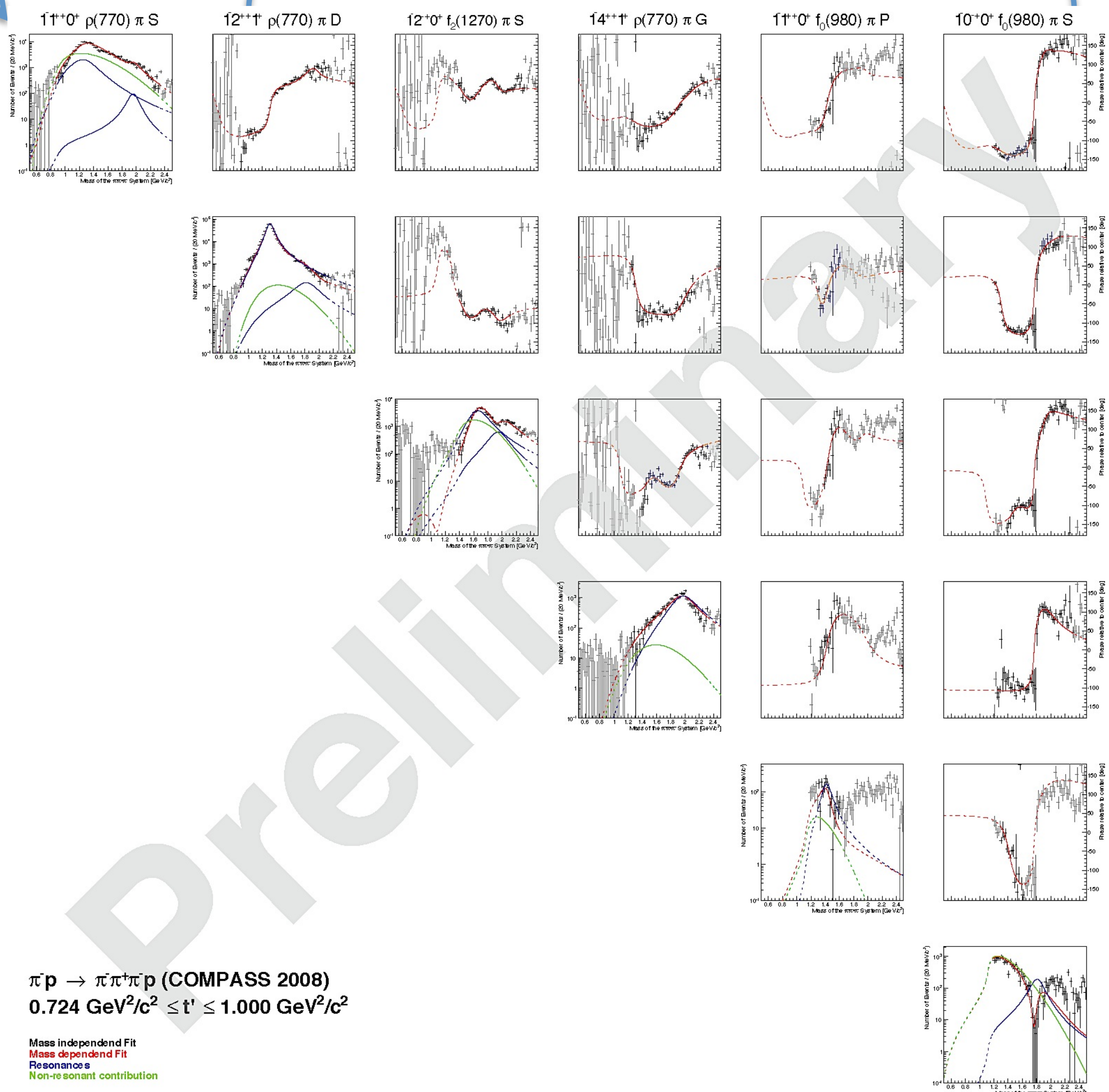
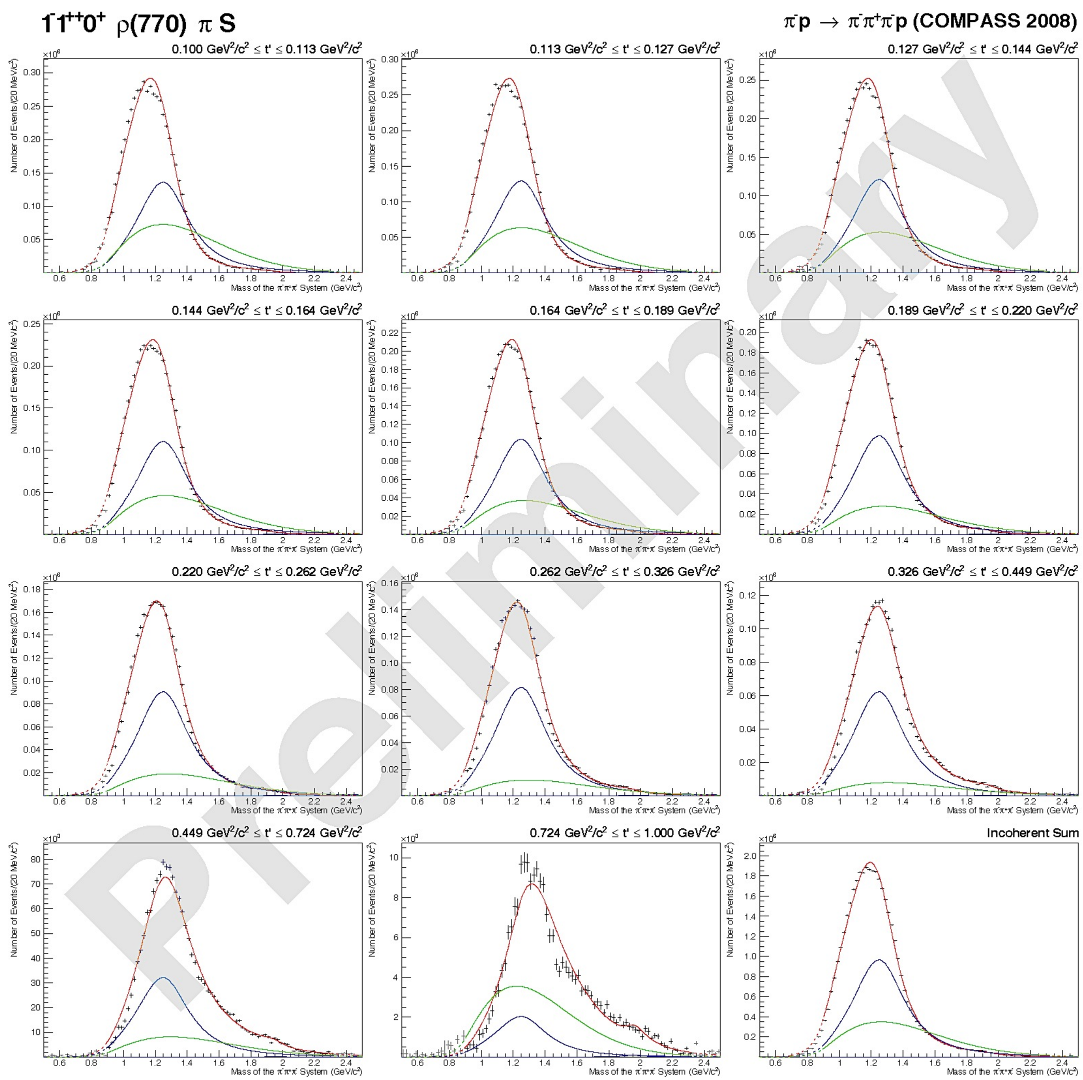


high t'-slice only

Mass dependent fits

Fit in 11 t-bins

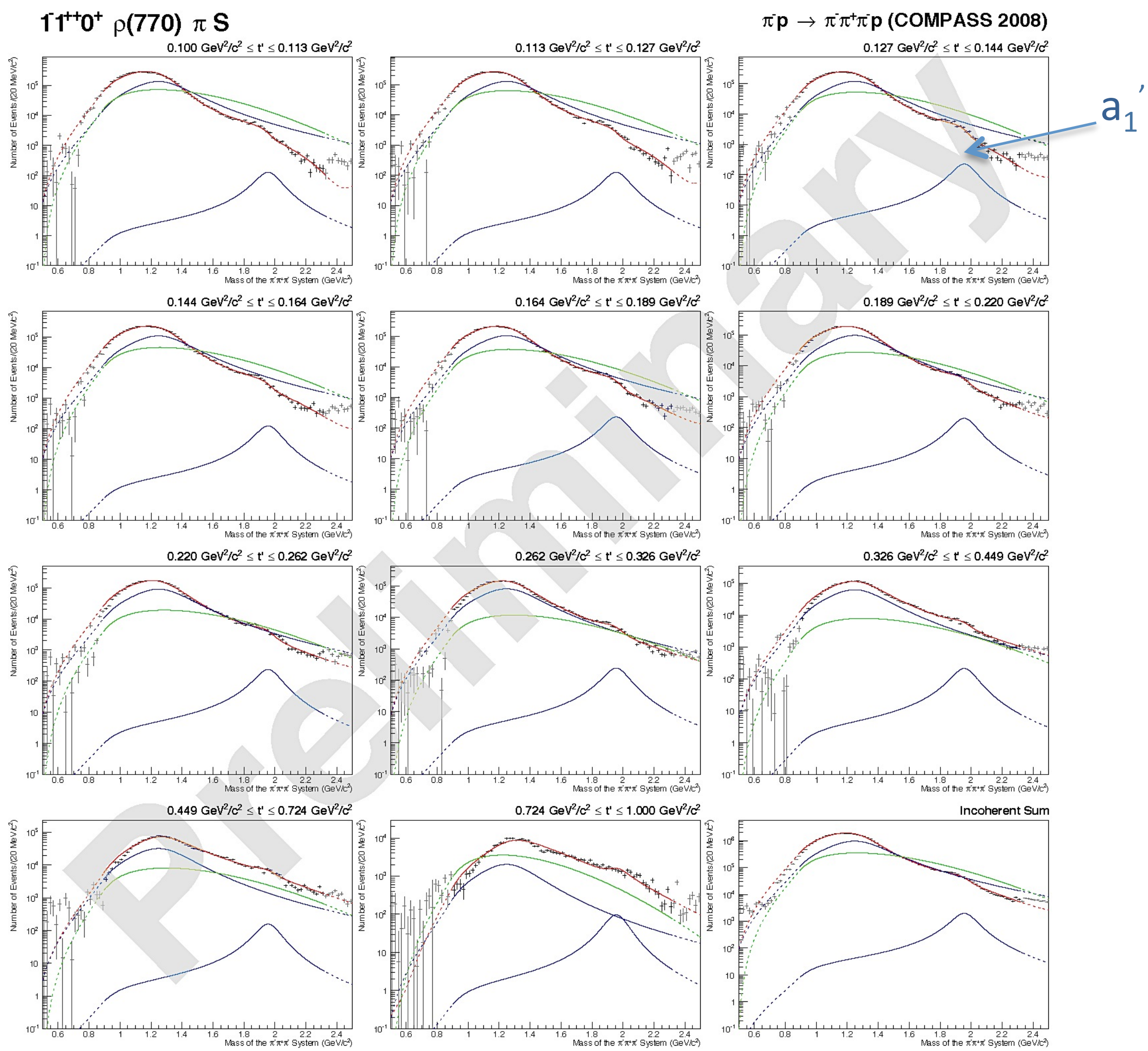


$1^{++}0^{+}\rho\pi S$

incoherent sum

Mass dependent fits

Fit in 11 t-bins

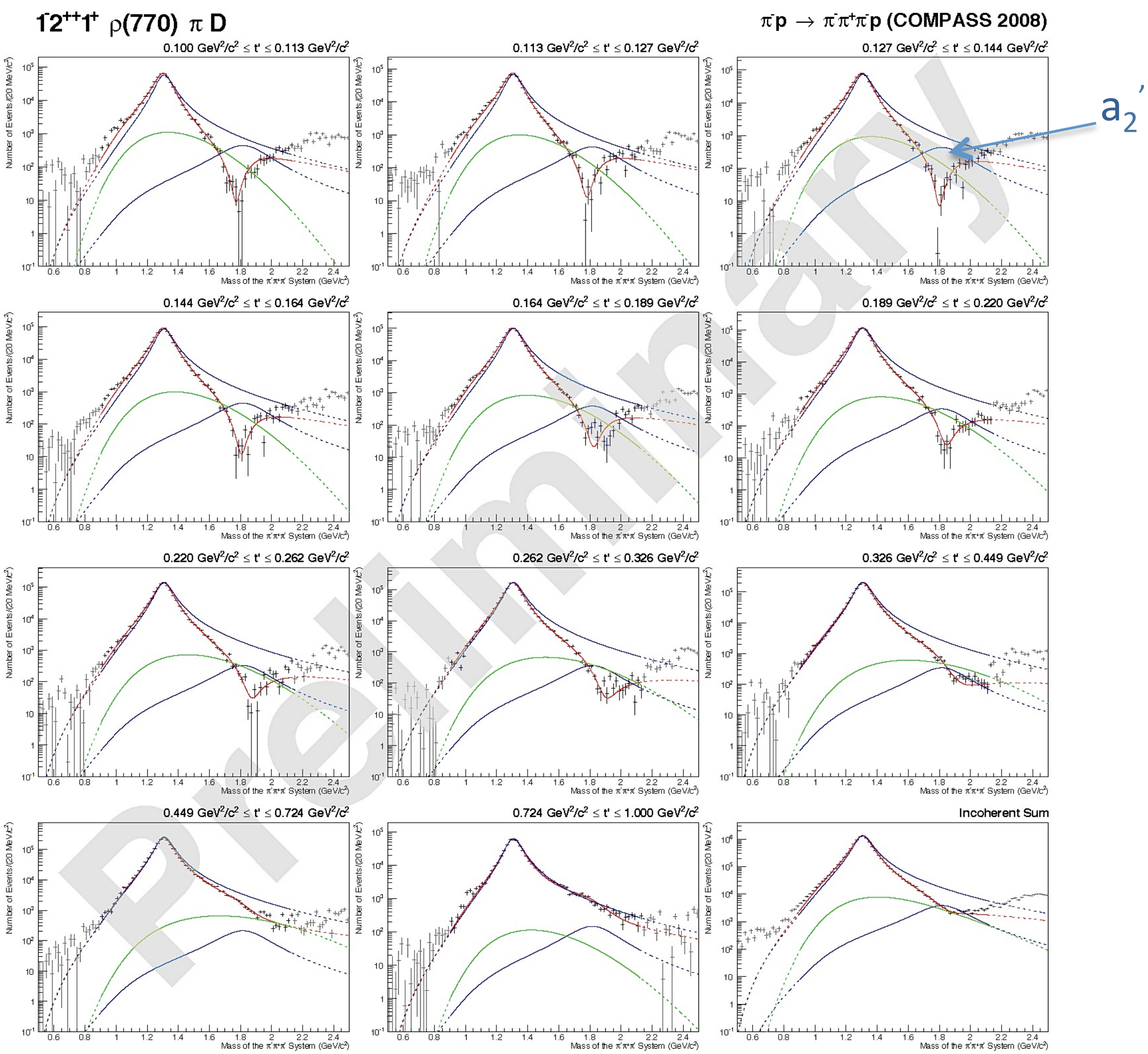


$1^{++}0^{+}\rho\pi S$

incoherent sum

Mass dependent fits

Fit in 11 t-bins

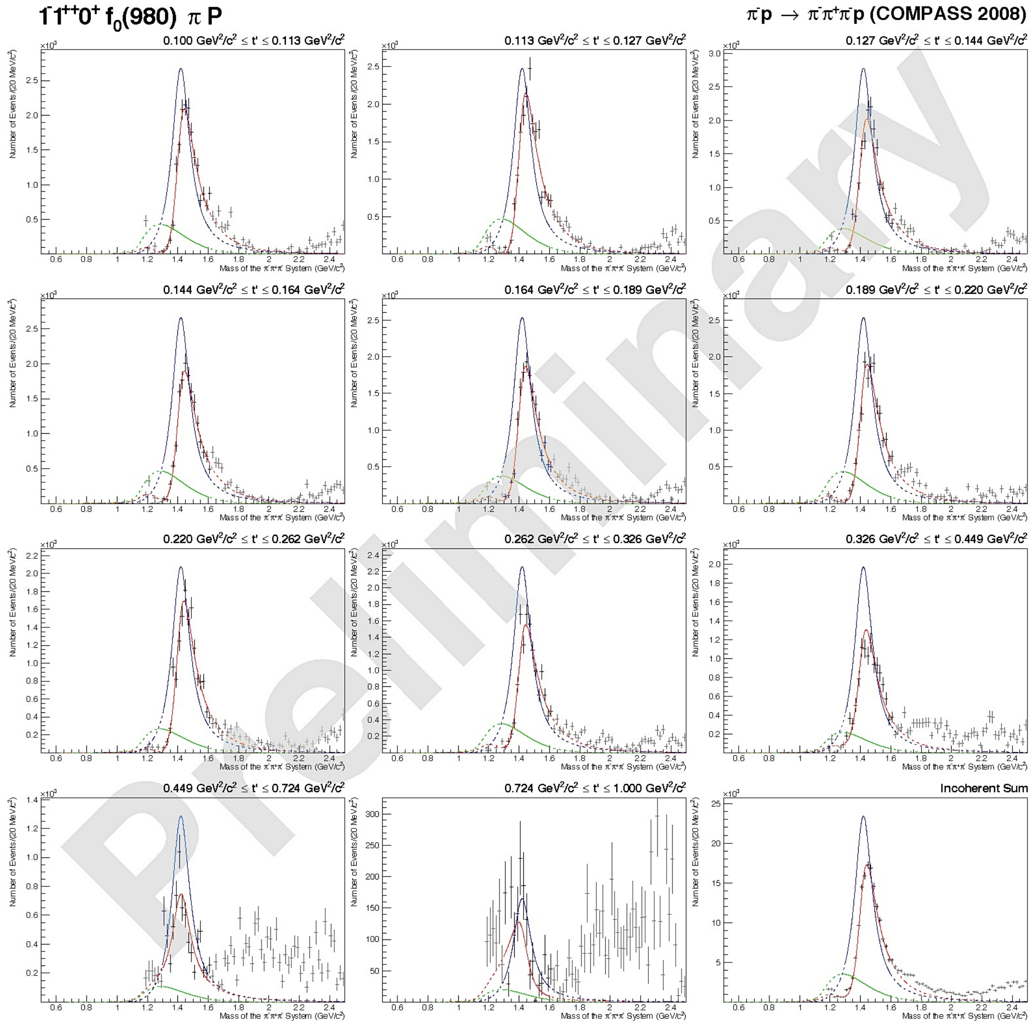


$2^{++}1^{+}\,\rho\pi$ D

incoherent sum

Mass dependent fits $a_1(1420)$

Fit in 11 t-bins

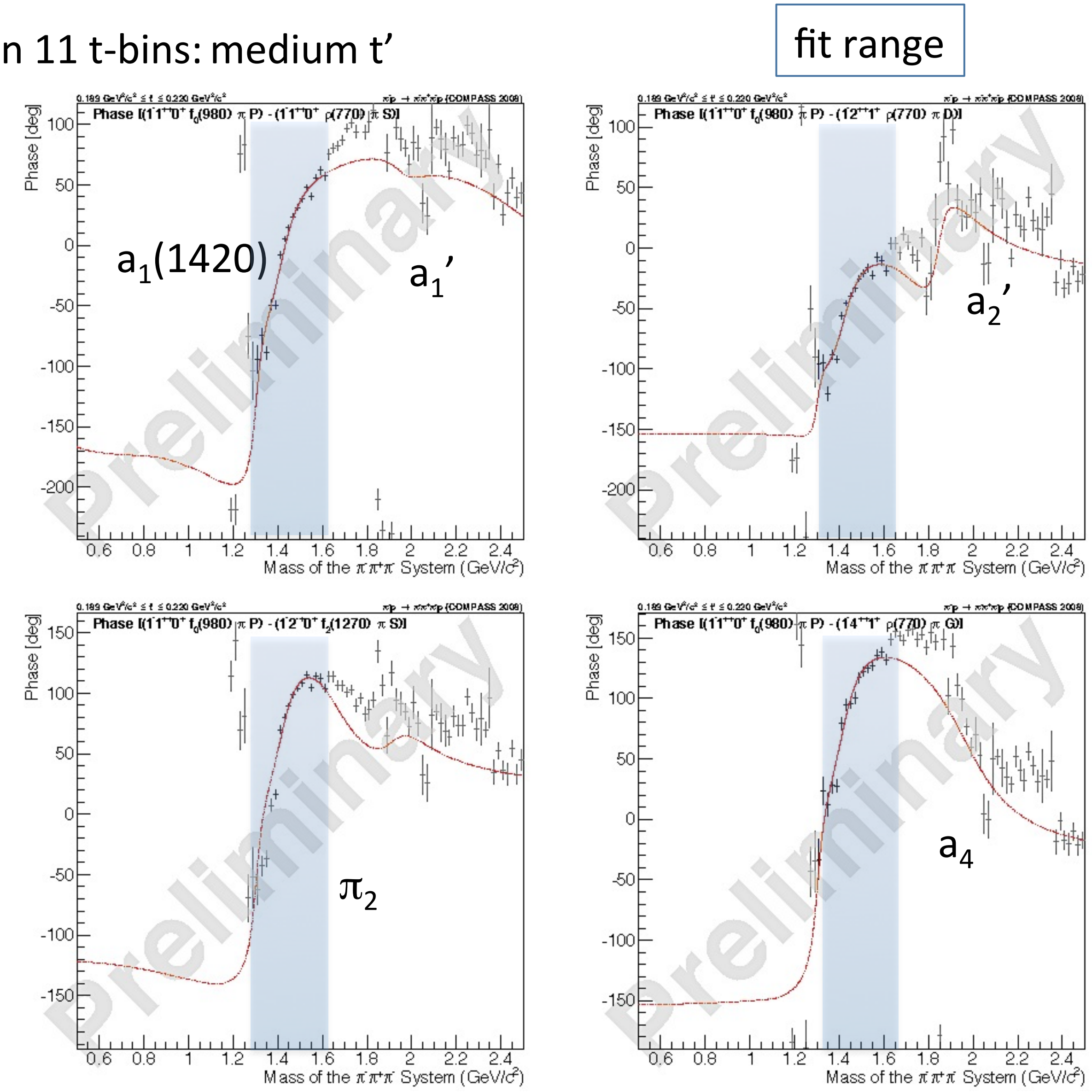


incoherent sum

$$1^{++}0^{+} f_0(980)\pi P$$

Phase: $a_1(1420)$

Fit in 11 t-bins: medium t’



Results of Mass-Dependent Fit

Particle	J^{PC}	Mass Range [MeV/c^2]	Width Range [MeV/c^2]	PDG	
"Established" states					
$a_1(1260)$	1^{++}	1260-1290	360-420	1230 ± 40	250 to 600
$a_2(1320)$	2^{++}	1312-1315	108-115	$1318.3^{+0.5}_{-0.6}$	107 ± 5
$a_4(2040)$	4^{++}	1928-1959	360-400	1996^{+10}_{-9}	255^{+28}_{-24}
$\pi_2(1670)$	2^{-+}	1635-1663	265-305	1672.2 ± 3.0	260 ± 9
$\pi(1800) \to f_0(980)\pi$	0^{-+}	1790-1807	212-230		
$\pi_2(1880)$	2^{-+}	1900-1990	210-390	1895 ± 16	235 ± 34
States not in PDG summary table					
 $a_1(1420)$	1^{++}	1412-1422	130-150		
$a_1(1930)$	1^{++}	1920-2000	155-255	1930^{+30}_{-70}	155 ± 45
$a_2(1950)$	2^{++}	1740-1890	300-555	1950^{+30}_{-70}	180^{+30}_{-70}

Compass is a bit on the low side

$(\pi\pi)_{S\text{-wave}}$

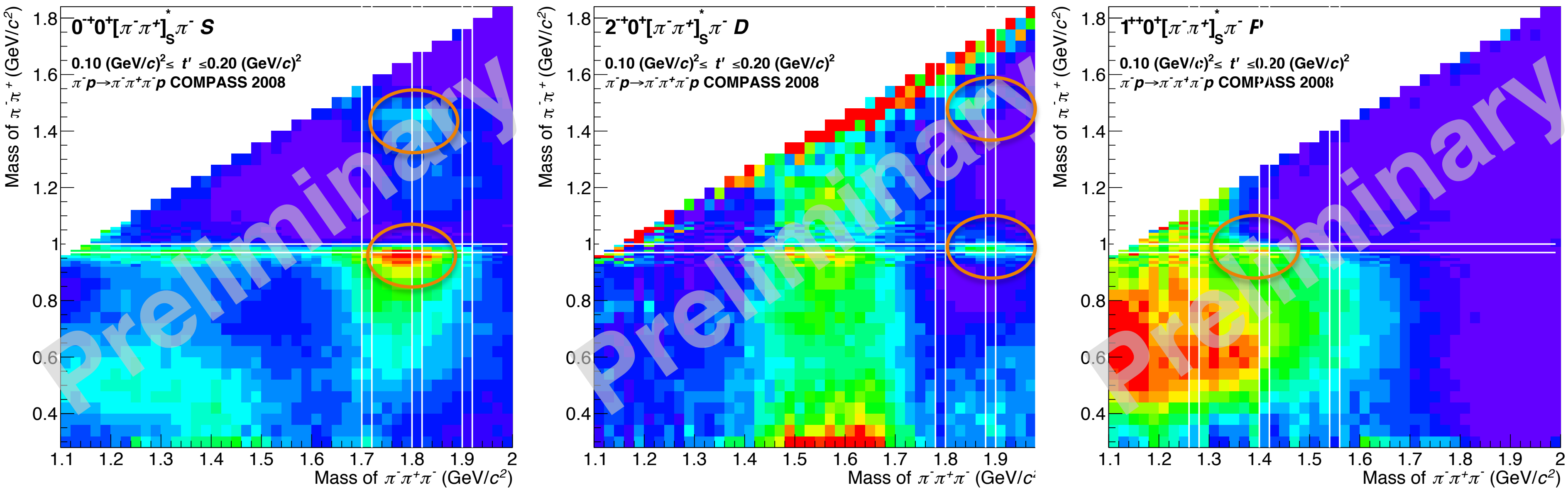
Method:

- Replace 2-body fixed parametrisation

  e.g. Breit-Wigner/Flatté description of an isobar or $(\pi\pi)_S$

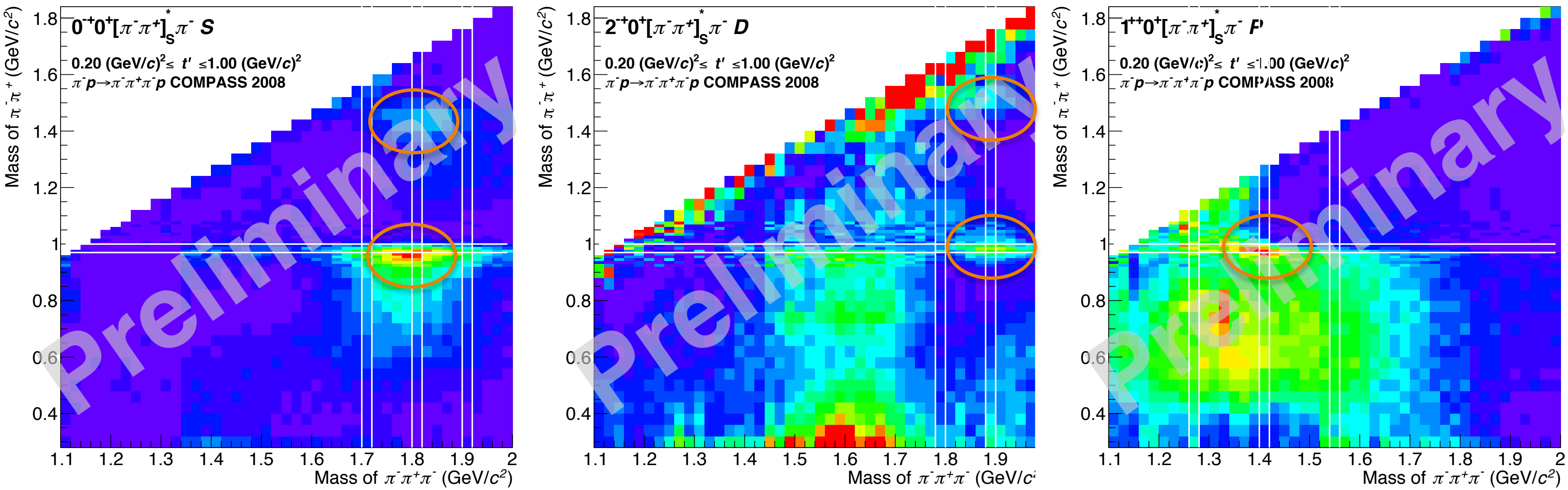
  by binned histogram
- Histogram-entries are free parameters
  - instead of e.g. 3 isobars with $J^{PC} = 0^{++}$ use n histogram bins of two body mass $[m_{12}, m_{12} + \delta m]$ with these quantum numbers
  - $\delta m = 40$ MeV/c^2
  - $\delta m = 10$ MeV/c^2 around $f_0(980)$ ($\pm$ 80 MeV/c^2)
- obtain new phase information: $\phi_{total} = \phi_{production} + \phi_{decay}$

Correlation: $m_{2\pi} - m_{3\pi}$



low t’

Correlation: $m_{2\pi} - m_{3\pi}$



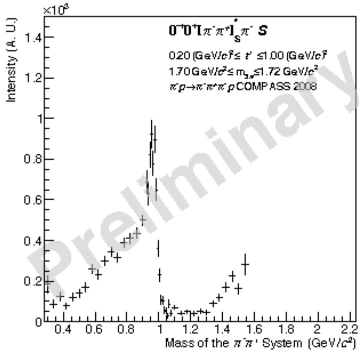
high t’

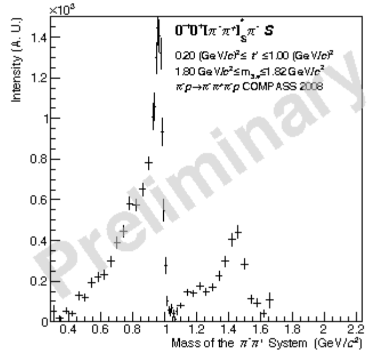
$(\pi\pi)^*_{S\text{-wave}}\ 0^{-+}$

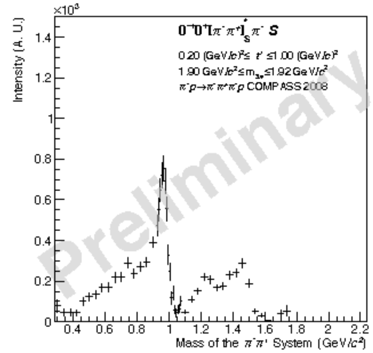
below resonance

at π(1800)

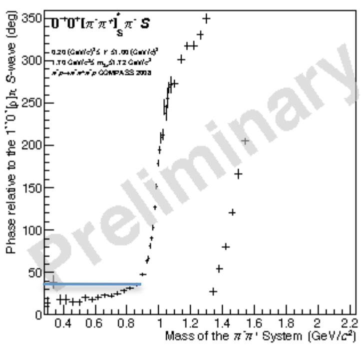
above resonance

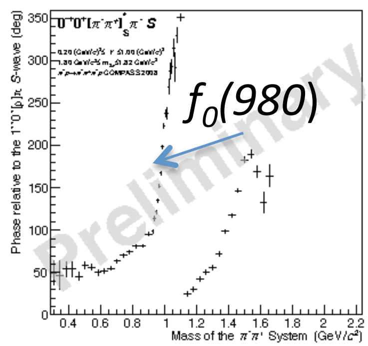


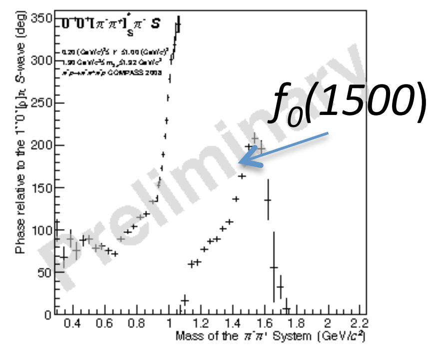




high t'







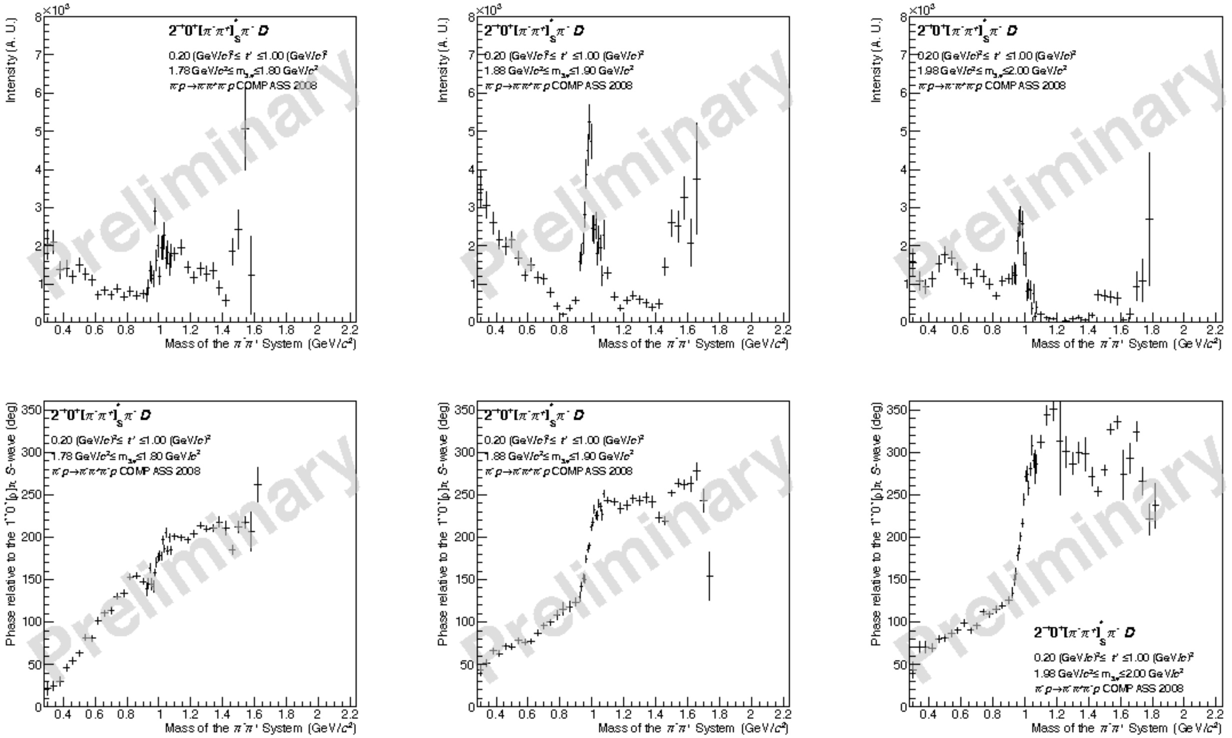
$(\pi\pi)^{*}_{S\text{-wave}}\ 2^{-+}$

below resonance

at $\pi_2(1880)$

above resonance

high t’

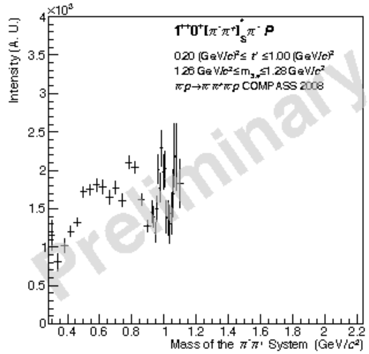


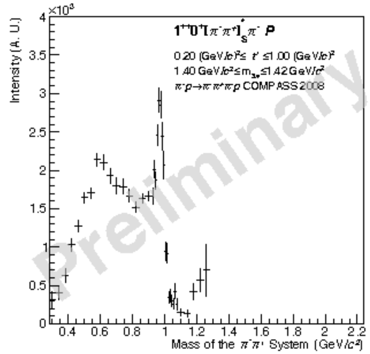
$(\pi\pi)^*_{S\text{-wave}}\ 1^{++}$

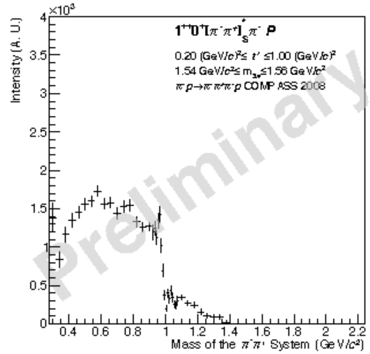
below resonance

at $a_1(1420)$

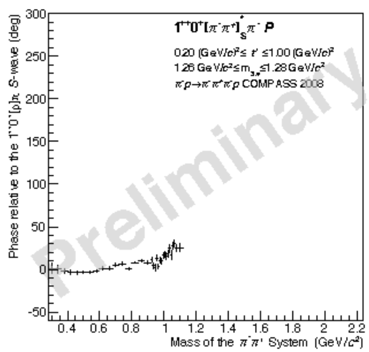
above resonance

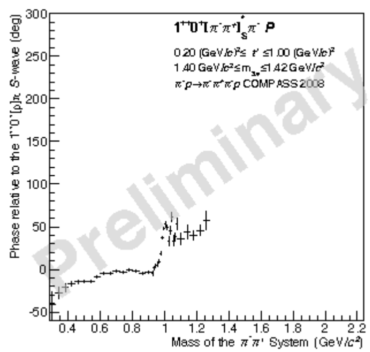


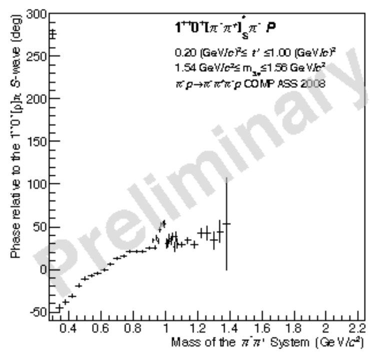




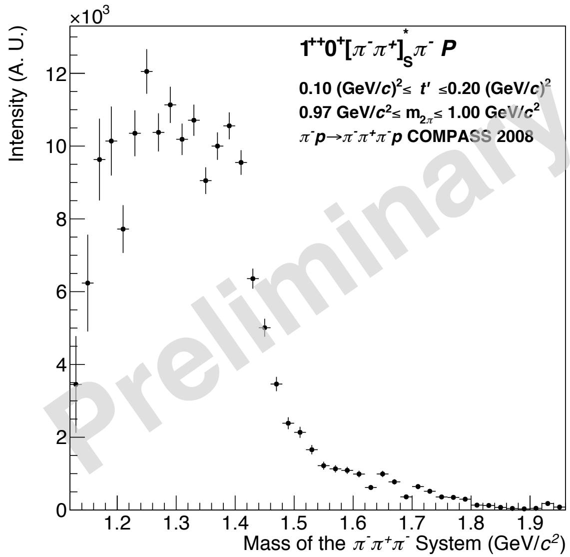
high t'



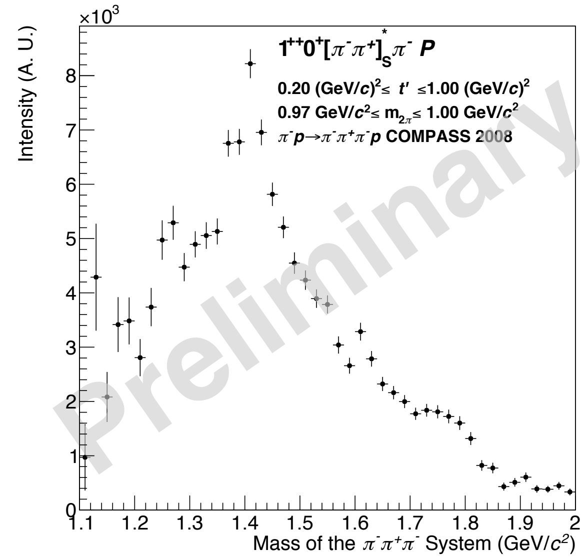




Study of $(\pi\pi=f_{980})^*_{S\text{-wave}}\ 1^{++}$



low t'

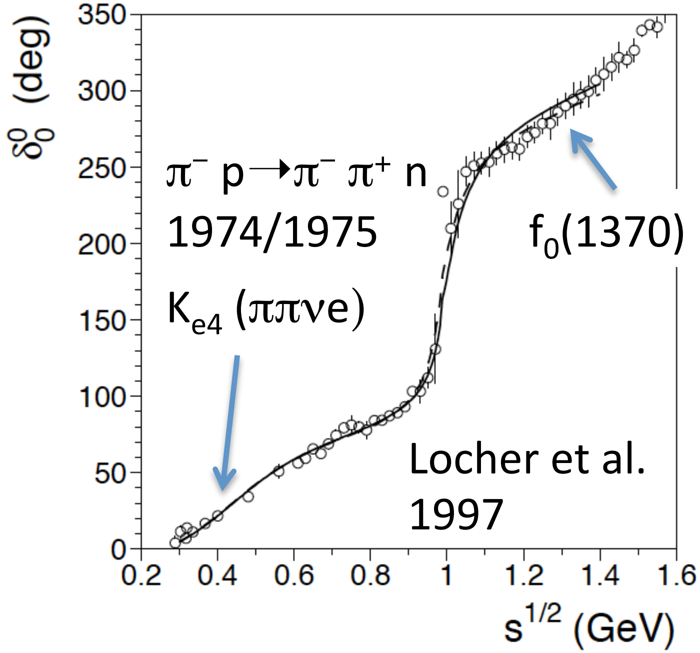


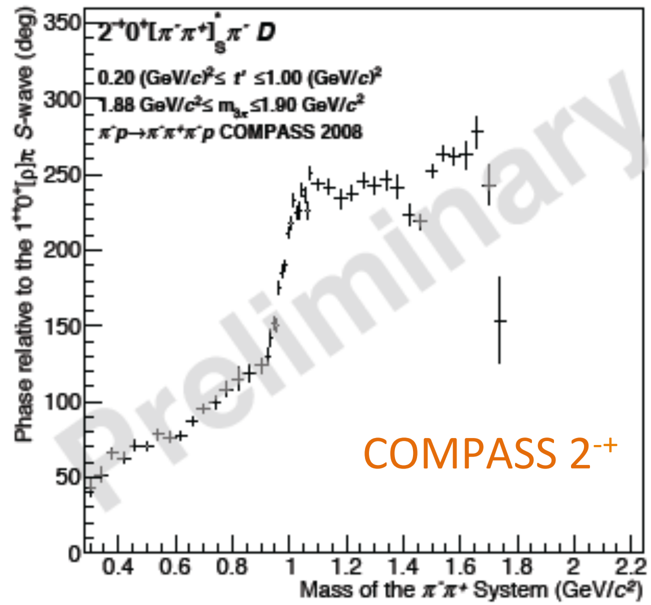
high t'

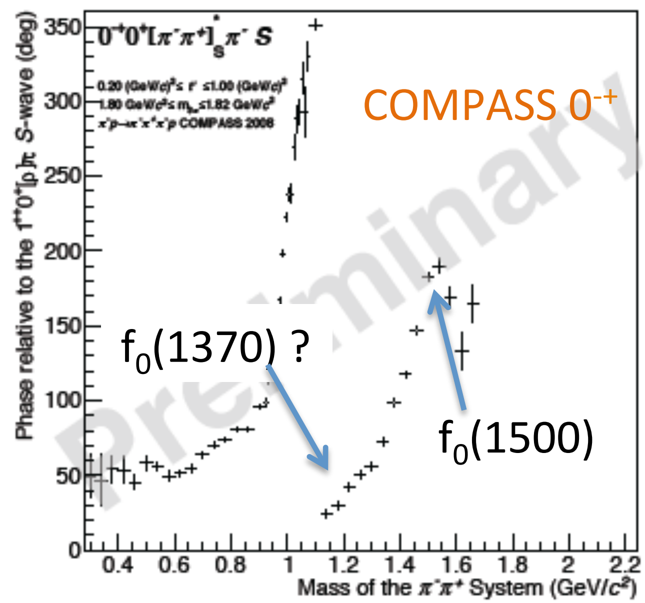
- $f_0(980)$ correlated with $a_1(1420)$
- non-resonant contributions at low t'
- warning !! just intensity cuts, amplitude selection

☞ mass dependent fit

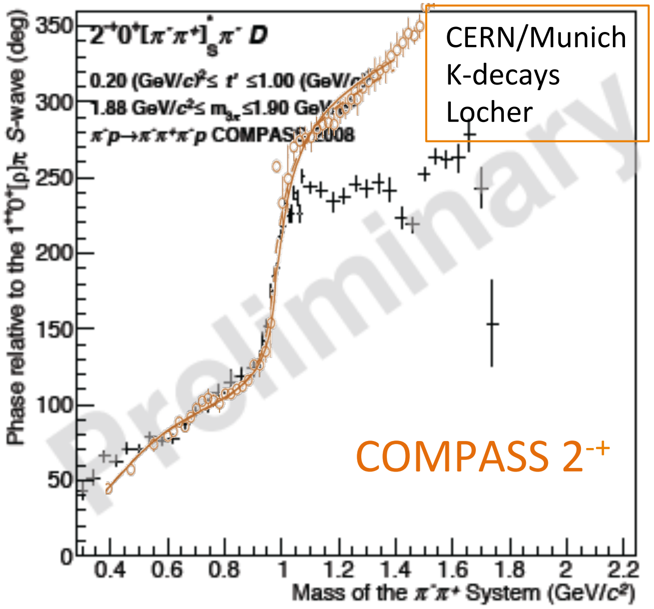
Further fun with $f_0(980)$







Further fun with $f_0(980)$



Conclusion

- Establish new “2D” fit method to perform PWA
  - mass independent: $m_{3\pi}$ bins and t’ bins
  - Observe “various components” of resonances with different t’-dependencies:
    - extract resonance parameters
    - Identify non-resonant components
- Establish new method to establish shape of isobar-spectrum
  - first application: $[\pi\pi]_S^*$:
    - Shows strong dependence on mother wave
    - Shows strong dependence on $m_{3\pi}$
    - no unique parametrization yet
  - Reveals information on scalar isobars
  - Reveals different faces of $f_0(980)$
  - Allows to measure phases in decays

Conclusion I

- Study of $a_1(1260)$
  - Observe “various components” of $a_1(1260)$ with different t’-dependencies: Strong constraints on resonance parameters (w.r.t. PDG)
  - $M_{a1(1260)}$ = 1260-1290 MeV/c^2 , $\Gamma_{a1(1260)}$ = 360 – 420 MeV/c^2
- Find new iso-vector state $a_1(1420)$
  - $M_{a1(1420)}$ = 1412-1422 MeV/c^2 , $\Gamma_{a1(1420)}$ = 130-150 MeV/c^2
  - decay into $f_0(980)\pi$ in relative P-wave
  - observe full phase motion with respect to reference waves
  - coupling seems exclusively to $f_0(980)$
  - Phase-behavior of $(\pi\pi)_S$ hints to strong ss-component

    Phase behavior opposite to $(\pi\pi)_S$ – coupling of $\pi(1800)$ and $\pi_2(1880)$
  - Nature of $a_1(1420)$? Isospin partner of $f_1(1420)$ (considered to be exotic) ?

Conclusion II

- Sort out higher excitations of a_1 , a_2

  States observed in reanalysis of CB-data
  - both states found at being at phase-space boundary by Bugg et al.

  COMPASS:
  - reasonable constraints on a_1'

    $M_{a1(1930)}$ = 1920-2000 MeV/c^2 , $\Gamma_{a1(1930)}$ = 155 – 255 MeV/c^2
  - poorer constraints on a_2'

    $M_{a2(1950)}$ = 1740-1800 MeV/c^2 , $\Gamma_{a2(1950)}$ = 300 – 555 MeV/c^2
- Radial excitation of π
  - π(1800) well known: COMPASS observes decay into f_0(980) and f_0(1500) with two full circles from the Argand-diagram. Shape of f_0(980) and f_0(1500) to be investigated
  - $M_{\pi(1800)}$ = 1768-1807 MeV/c^2 , $\Gamma_{\pi(1800)}$ = 215 – 280 MeV/c^2

Conclusion III

- Orbital-excitation of π
  - $\pi_2(1670)$ well known: COMPASS observes decay into $f_2(1270)$

    $M_{\pi 2(1670)}$ = 1635-1663 MeV/c^2 , $\Gamma_{\pi 2(1670)}$ = 265-305 MeV/c^2
  - no evidence so far for coupling into $[\pi\pi]_S^*$
  - $\pi_2(1880)$: Clear signal observed in f_2 and f_0. Strong coupling to iso-scalar sector
  - COMPASS: Decays observed into $f_0(980)$ and $f_2(1270)$

    $M_{\pi 2(1880)\rightarrow f2(1270)\,\pi}$= 1900-1990 MeV/$c^2$, $\Gamma_{\pi 2(1880)\rightarrow f2(1270)\,\pi}$= 210-390 MeV/$c^2$
- Other mesons:
  - $a_2(1320)$ clearly identified:

    $M_{a2(1320)}$ = 1312-1315 MeV/c^2 , $\Gamma_{a2(1320)}$ = 108-115 MeV/c^2
  - $a_4(2040)$ clearly identified:

    $M_{a4(2040)}$ = 1928-1959 MeV/c^2 , $\Gamma_{a4(2040)}$ = 360-400 MeV/c^2

    comes our lighter and broader than PDG consistent with 2004 and $\eta(')\pi$