Non-resonant Deck-type contributions in diffractive $\pi^-\pi^-\pi^+$ production and their appearance in PWA.

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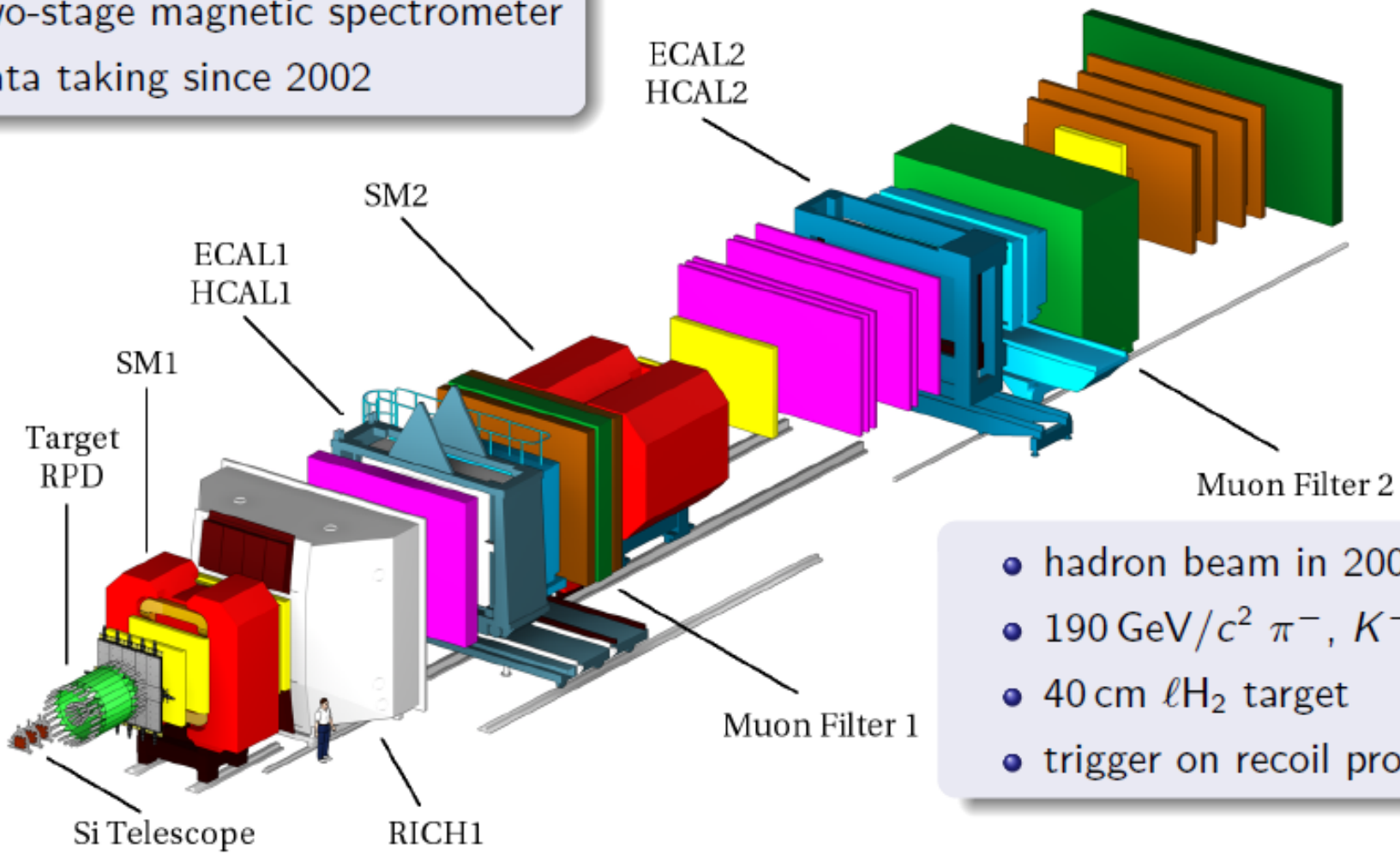
Plan of the talk

The reaction $\pi^- p \to \pi^- \pi^- \pi^+ p$ at $p_{\pi^-} = 190$ GeV

- COMPASS detector
- Mass-independent Partial-Wave Analysis (PWA) with established $(\pi\pi)$-isobars
- Mass-dependent analysis
- Deck process
  - Deck amplitude components
  - decomposition of Deck amplitude to partial waves and comparison with mass-dependent fits of 3π data
- Analysis with free amplitudes of $(\pi\pi)$- isobars

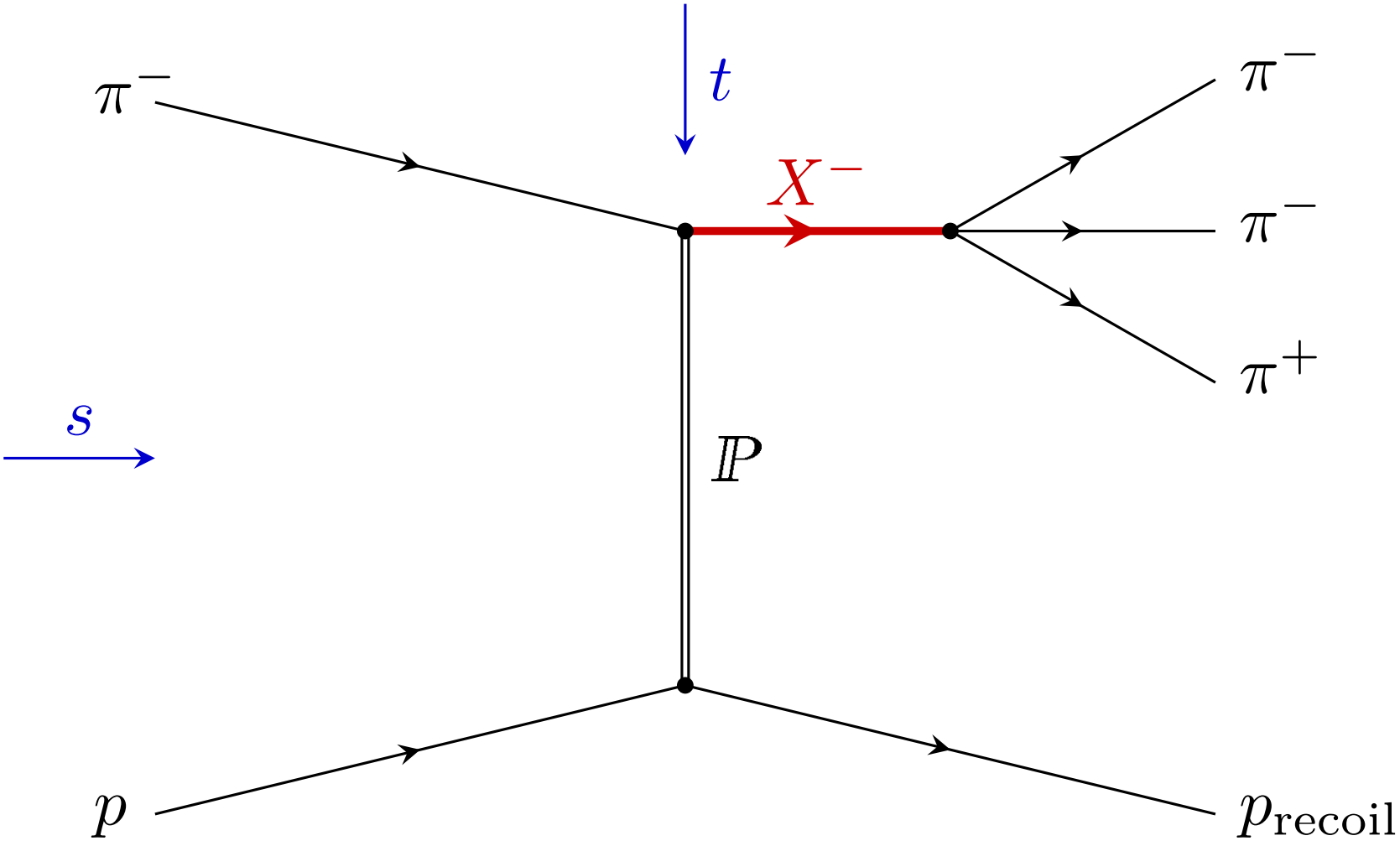
Apparatus

- fixed target experiment
- located at CERN's SPS
- two-stage magnetic spectrometer
- data taking since 2002



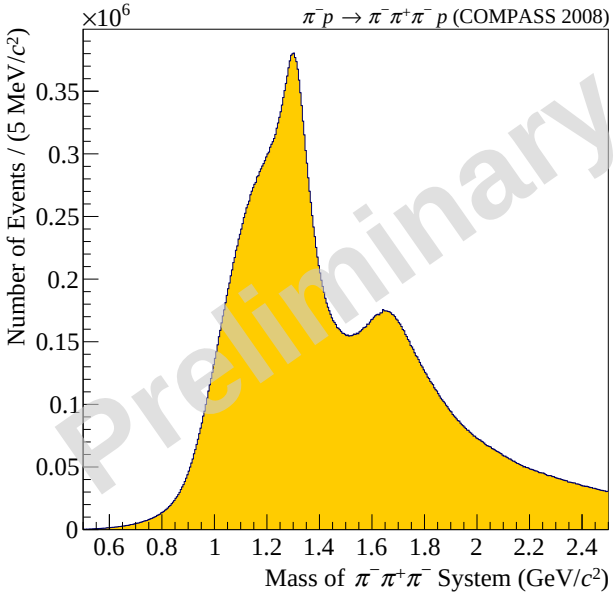
- hadron beam in 2008
- 190 GeV/c^2 π^-, K^-, $\bar{p}$
- 40 cm ℓH_2 target
- trigger on recoil proton

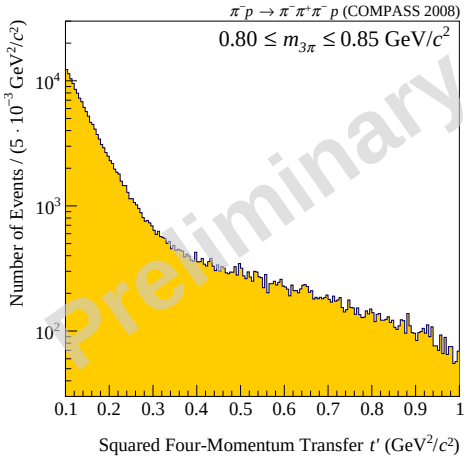
The reaction

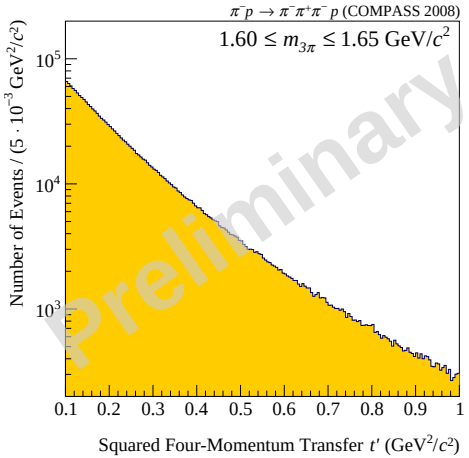


$$t = (p_{\pi^-} - p_{X^-})^2, \quad t' = |t| - |t|_{min}$$

The reaction $\pi^- p \to \pi^- \pi^- \pi^+ p$ - major spectrums

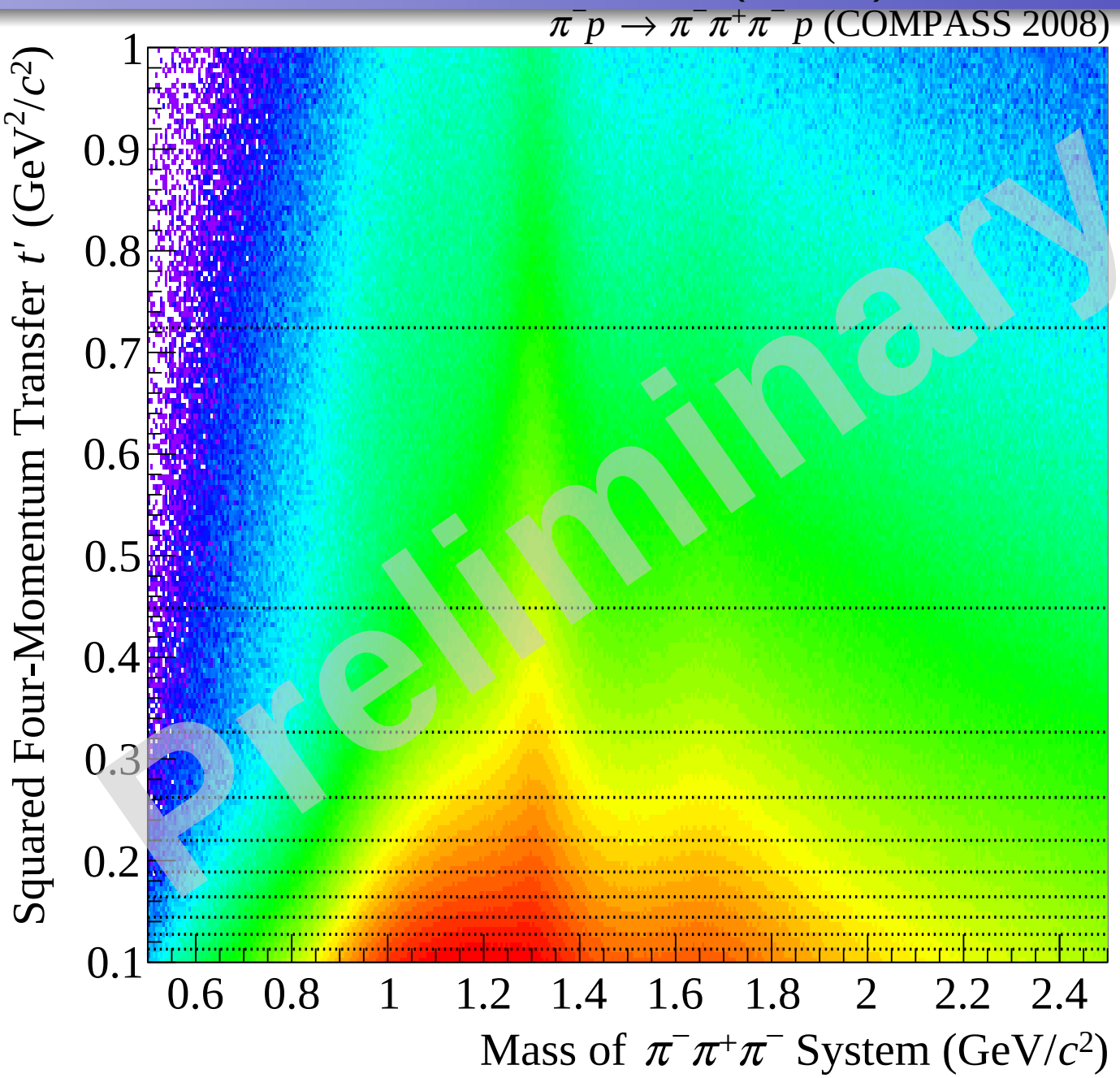




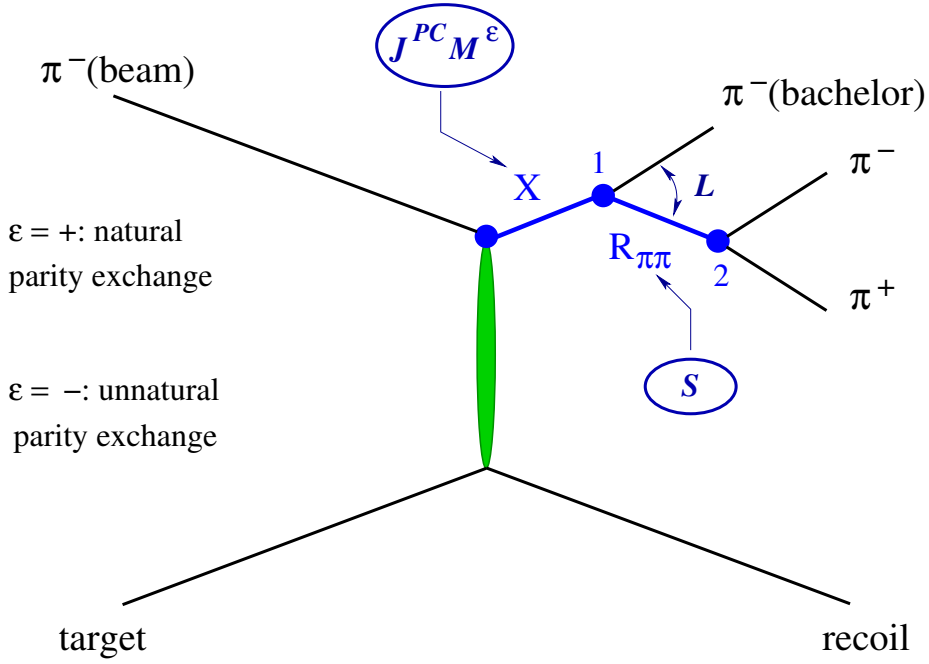


46 000 000 events for $0.5 < m(3\pi) < 2.5$ GeV and $t' = 0.1 - 1$ GeV^2

The reaction $\pi^- p \to \pi^- \pi^- \pi^+ p$ - (m, t')-spectrum

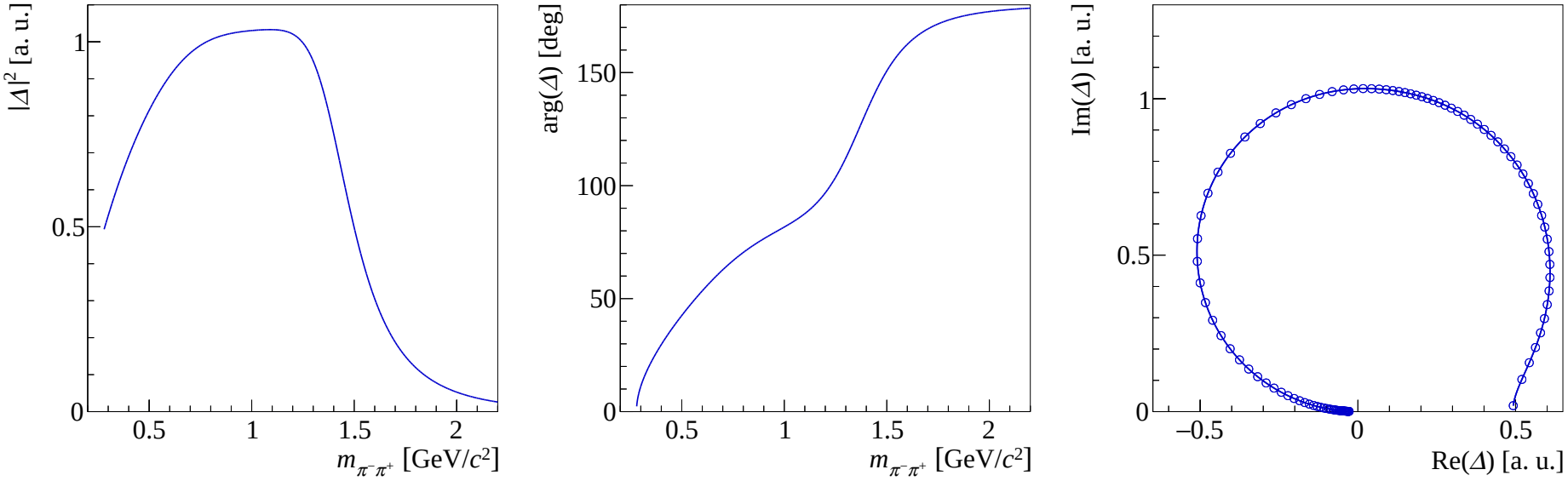


Decay Amplitudes, Isobar model, Reflectivity basis



- Reggeon exchange, naturality $\eta = P_R(-1)^{J_R}$
- Gottfried-Jackson frame: SCM of X: $Z_{GJ} \| \vec{p}^*_{beam}$, $Y_{GJ} = [\vec{p}^*_{recoil} \times \vec{p}^*_{beam}]$
- Reflectivity basis for system of mesons:
  $|JM\epsilon> = |JM> - \varepsilon P(-1)^{J-M}|J-M>$ later denoted as $\psi_i^{\varepsilon}(\tau, m)$
- At high beam energies: reflectivity ε equal to naturality η
- unpolarised target: $\varepsilon = \pm 1$ states do not interfere

Example of established isobar amplitude: $(\pi\pi)_S$



Mass-independent vs. mass-dependent

The mass-independent PWA events density:

$\mathcal{I}(m,t',\tau) = \sum_\epsilon \sum_r \left|\sum_i T^\varepsilon_{ir}(m,t')\bar{\psi}^\varepsilon_i(\tau,m)\right|^2$ (1)

The density matrix:

$\rho^\varepsilon_{i,k} = \sum_r T^\varepsilon_{ir} T^{\varepsilon *}_{kr}$

The partial wave intensities:

$I_k(m,t') = \rho^\varepsilon_{k,k}$

Phase of wave i relative to wave k:

$\phi(i-k)(m,t') = arg(\rho^\varepsilon_{i,k})$

Events intensity including production and propagation of 3π intermediate states :

$\mathcal{I}(m,t',\tau) =$

$\sum_\epsilon \sum_r \left|\sum_i \sum_l C^\varepsilon_{ilr} D_{il}(m,t',\zeta)\sqrt{\int |\psi^\varepsilon_i(\tau',m)|^2 d\Phi_3(\tau')}\bar{\psi}^\varepsilon_i(\tau,m)\right|^2$ (2)

The spin-density matrix:

$\rho^\varepsilon_{i,k} = \sum_r T^\varepsilon_{ir} T^{\varepsilon *}_{kr}$

comparing (1) and (2) mass-dependent model for spin-density matrix reads:

$\rho^\varepsilon_{i,k}(m,t') =$

$\sqrt{\int |\psi^\varepsilon_i(\tau)|^2 d\Phi_3(\tau)}\sqrt{\int |\psi^\varepsilon_k(\tau)|^2 d\Phi_3(\tau)} \sum_r \sum_{l,m} C^\epsilon_{ilr} C^{\epsilon *}_{kmr} D_{il}(m,t',\zeta) D^*_{km}(m,t',\zeta)$

Mass-independent and mass-dependent analysis

Mass-independent:

- partial waves are labelled as $J^{PC} M^{\epsilon} \xi \pi L$
- decay amplitudes for $\pi^- \pi^- \pi^+$ are constructed in the framework of helicity formalism
- 5 standart $\pi^+\pi^-$ isobars: $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$, $(\pi\pi)_S$ (AMP with $f_0(980)$ withdrawn) and $f_0(980)$ (FLATTE)
- rank=1 used (narrow m(3π) and t' bins; helicity non-flip nature of Pomeron)
- 80 waves with $\varepsilon = +1$, 7 waves with $\varepsilon = -1$ and incoherent FLAT wave

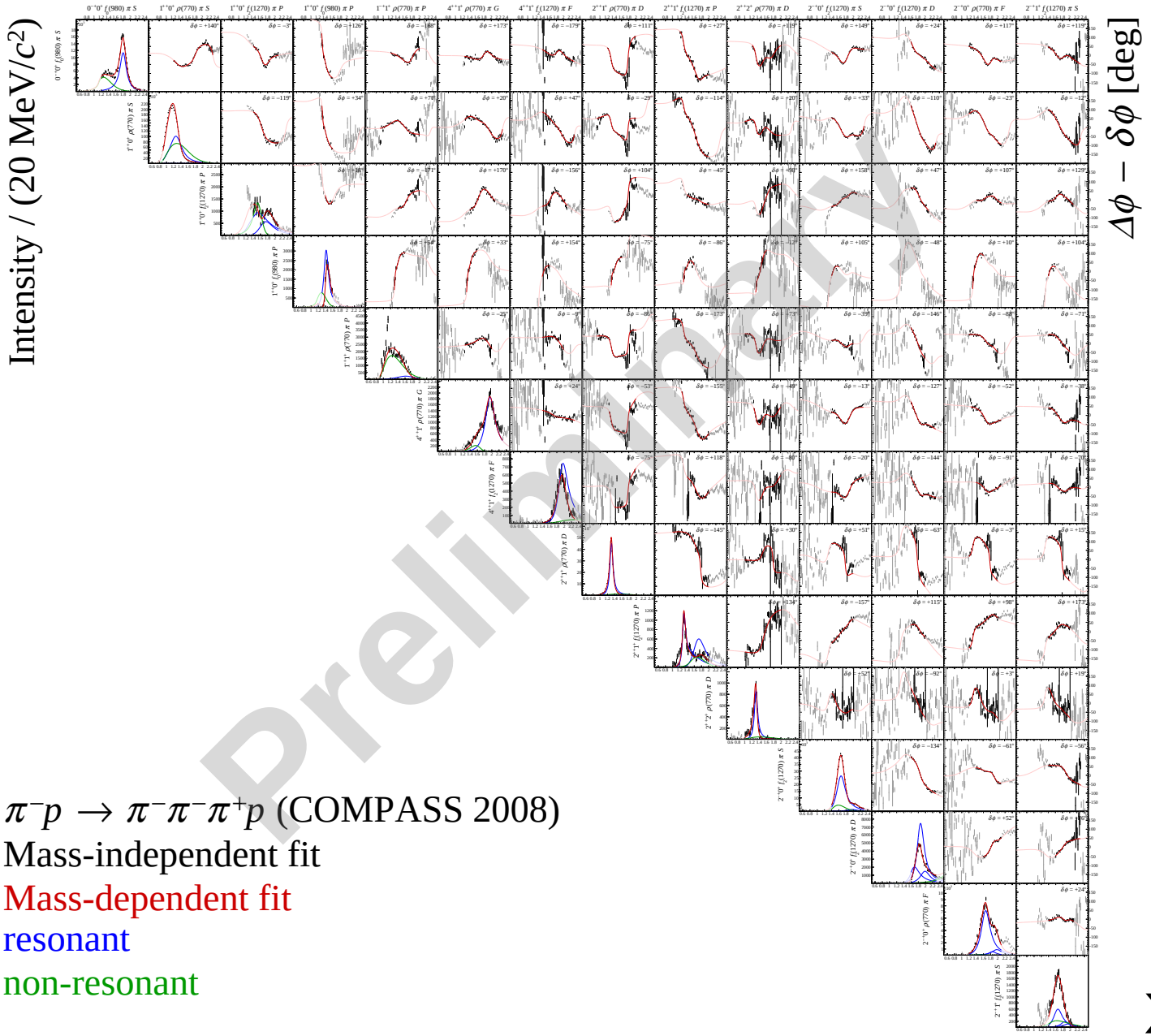
Mass-dependent:

- 14x14 sub-density matrices measured independently in $m(3\pi)$-bins and t'-bins are described by resonance model
- each partial wave is described by 1-3 resonant terms and background term
- Masses, widths and decay couplings of resonances do not depend on t', so fit should be done simultaneously in all t' intervals

Illustration of the mass-dependent sub-density matrix

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

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



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

Mass-independent fit

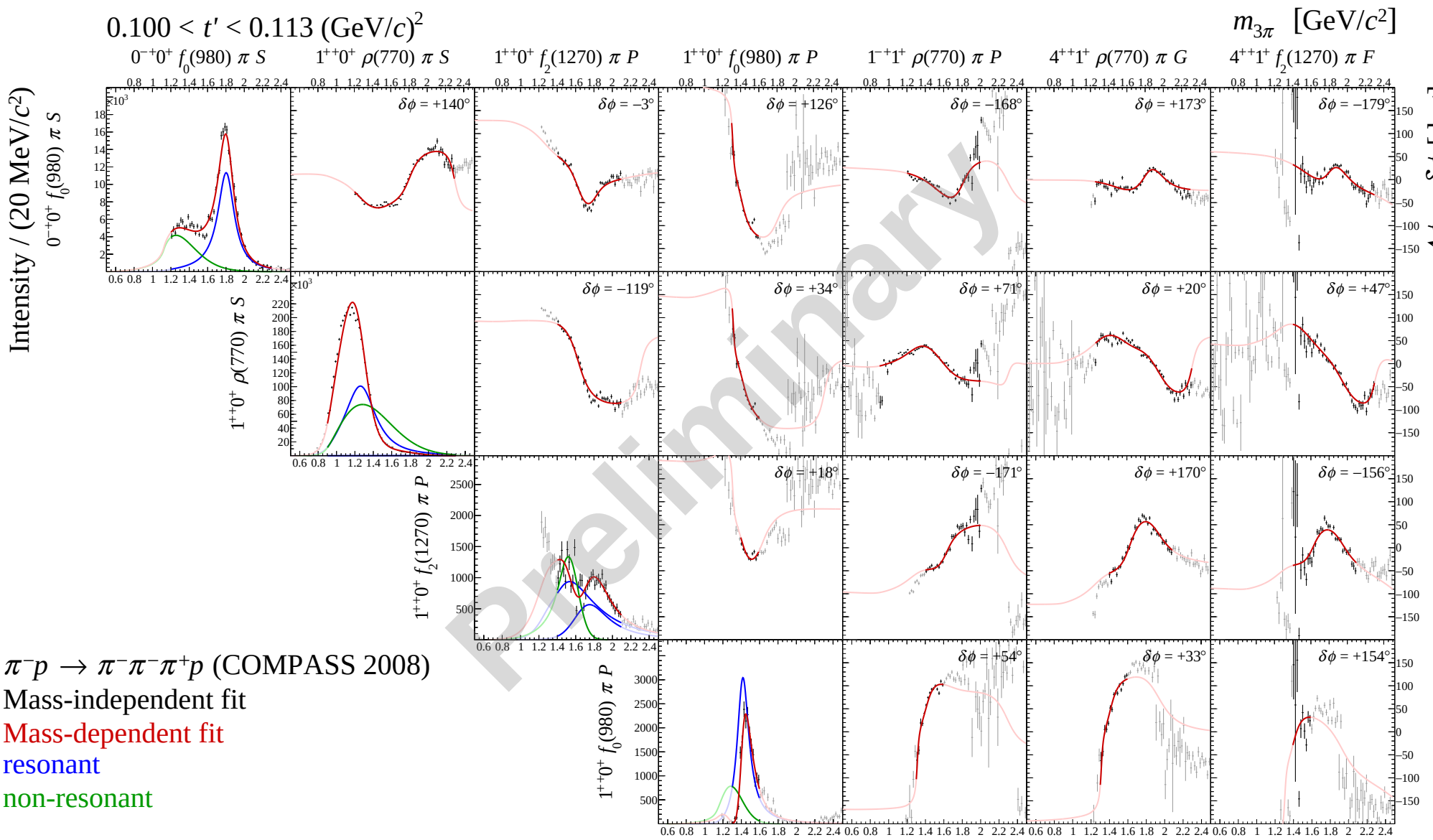
Mass-dependent fit

resonant

non-resonant

x 11

sub-density matrix in the first t' bin



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

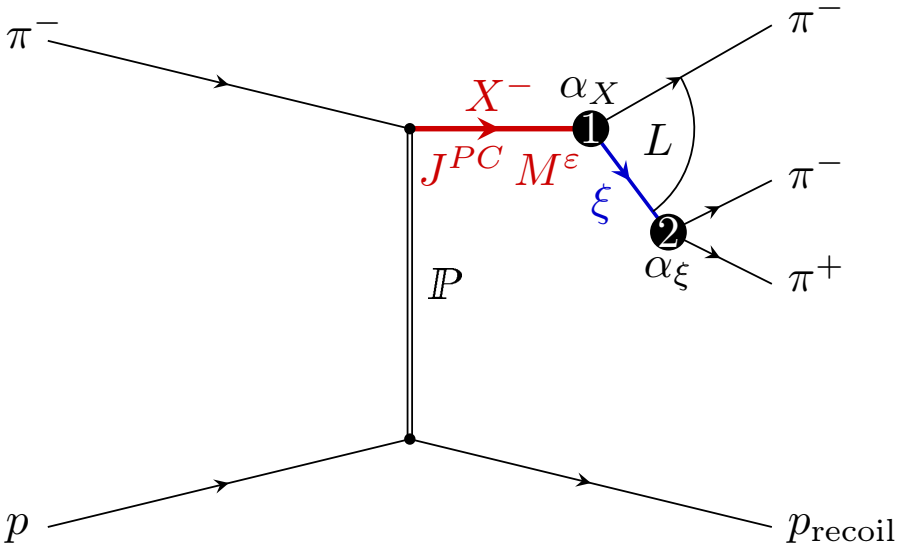
Mass-independent fit

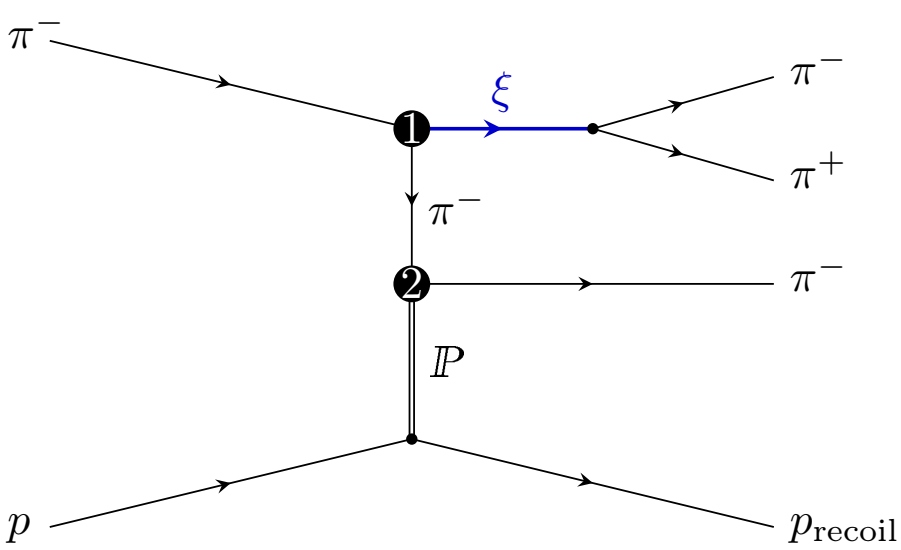
Mass-dependent fit

resonant

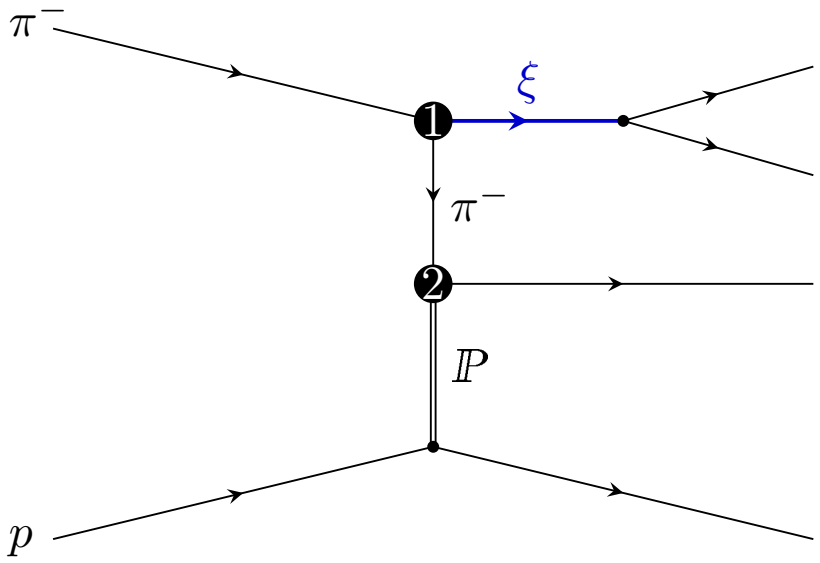
non-resonant

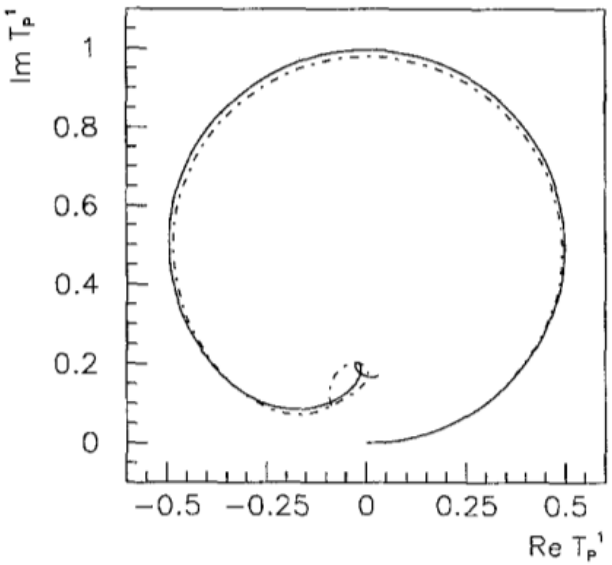
Production of 3π resonance (left) Deck process (right).





Deck process





Amplitudes for $\pi\pi \to \pi\pi$

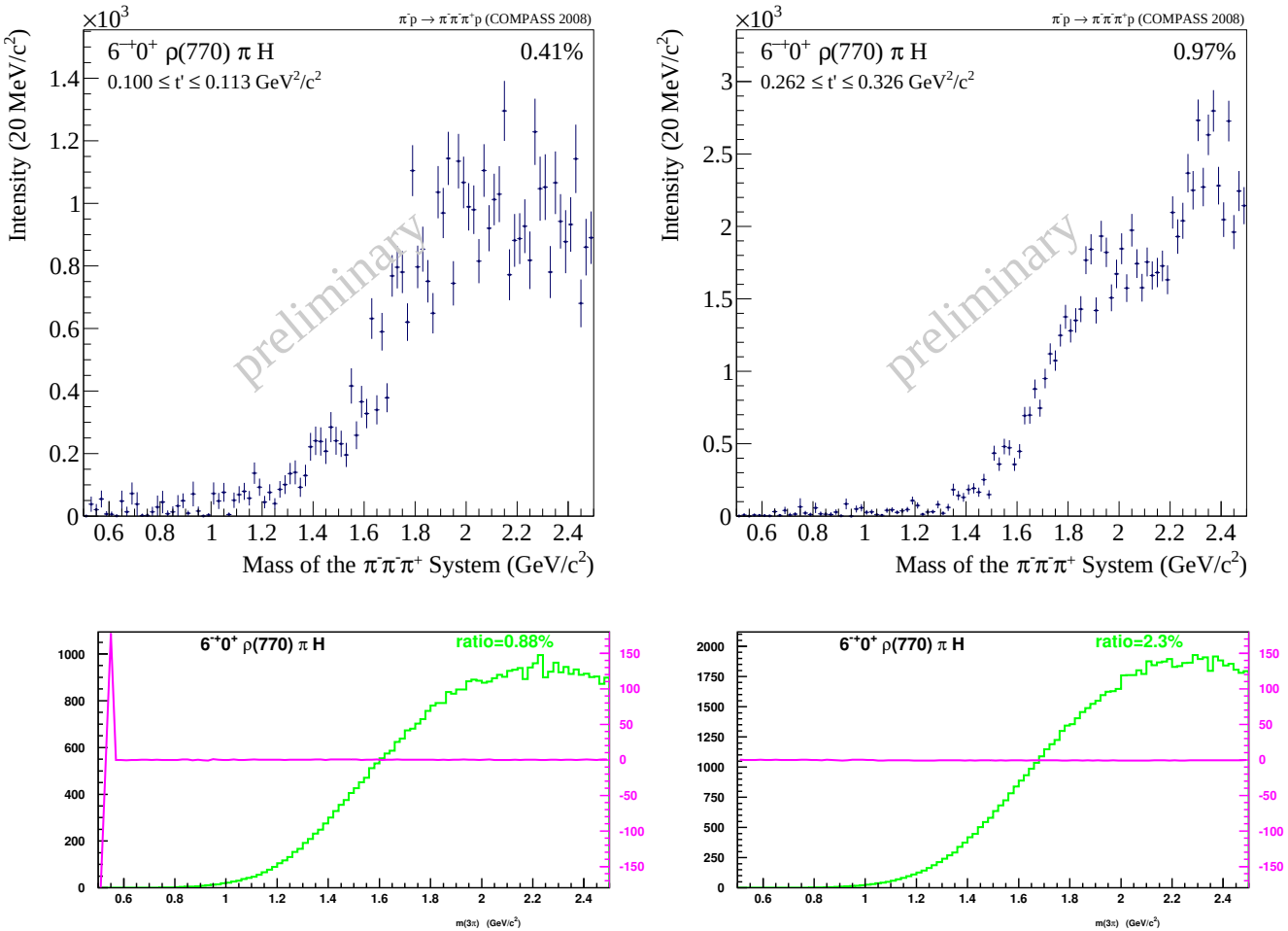
Amplitude of $\pi^- N$ scattering: $T_{\pi N}(s_{\pi N}, t') = s_{\pi N} e^{-8t'}$

Pion propagator: $P(t_\pi) = \frac{m_\pi^2 e^{bt_\pi}}{m_\pi^2 - t_\pi}$ with $\mathrm{b} = 1.7\ GeV^{-1}$ and $m_\pi = m_{\pi^c}$

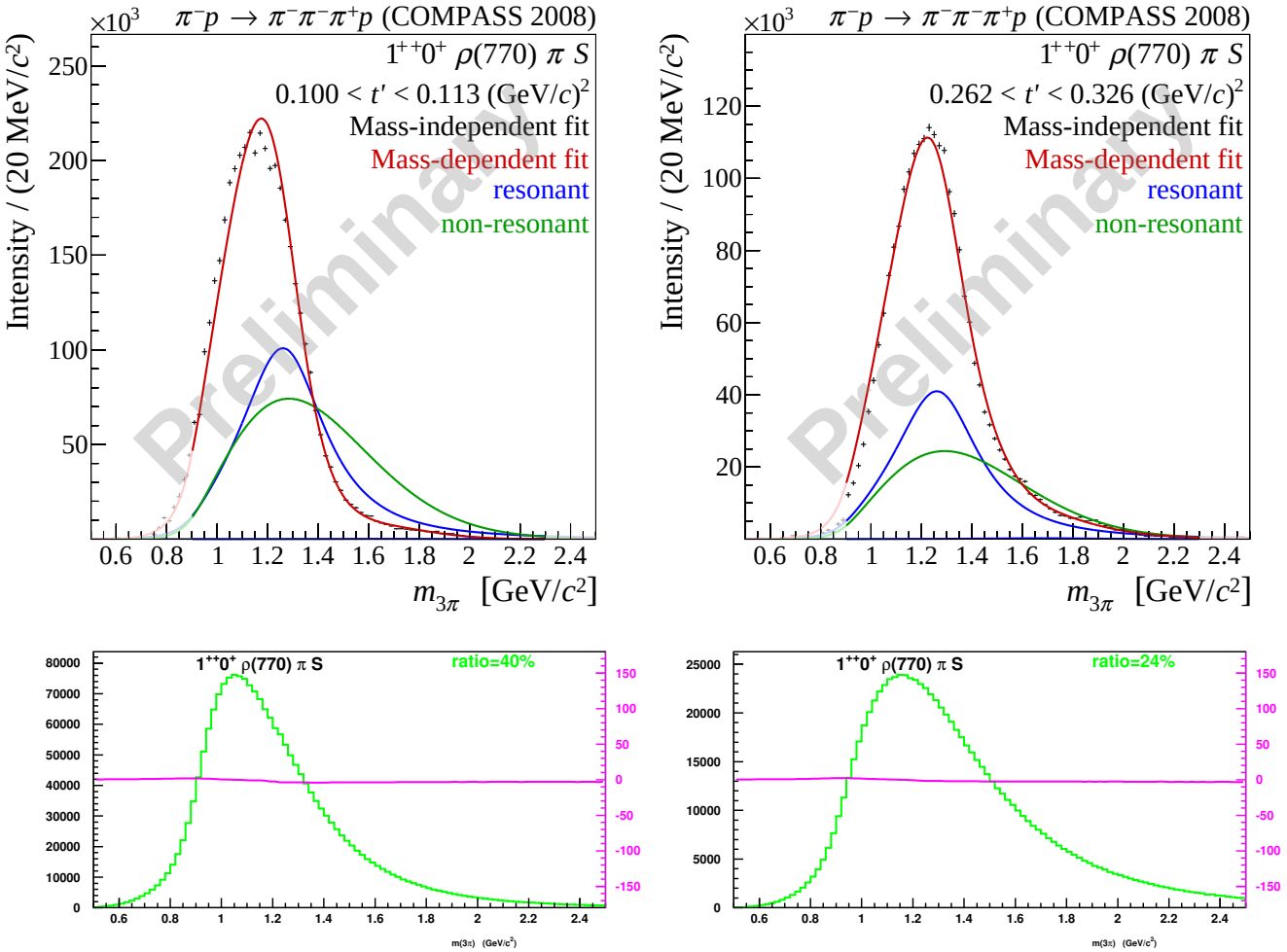
Deck decomposition to partial waves:

$$\psi_{Deck}(\tau, m, t') \sim \sum C_i(m, t') \bar{\psi}_i(\tau, m)$$

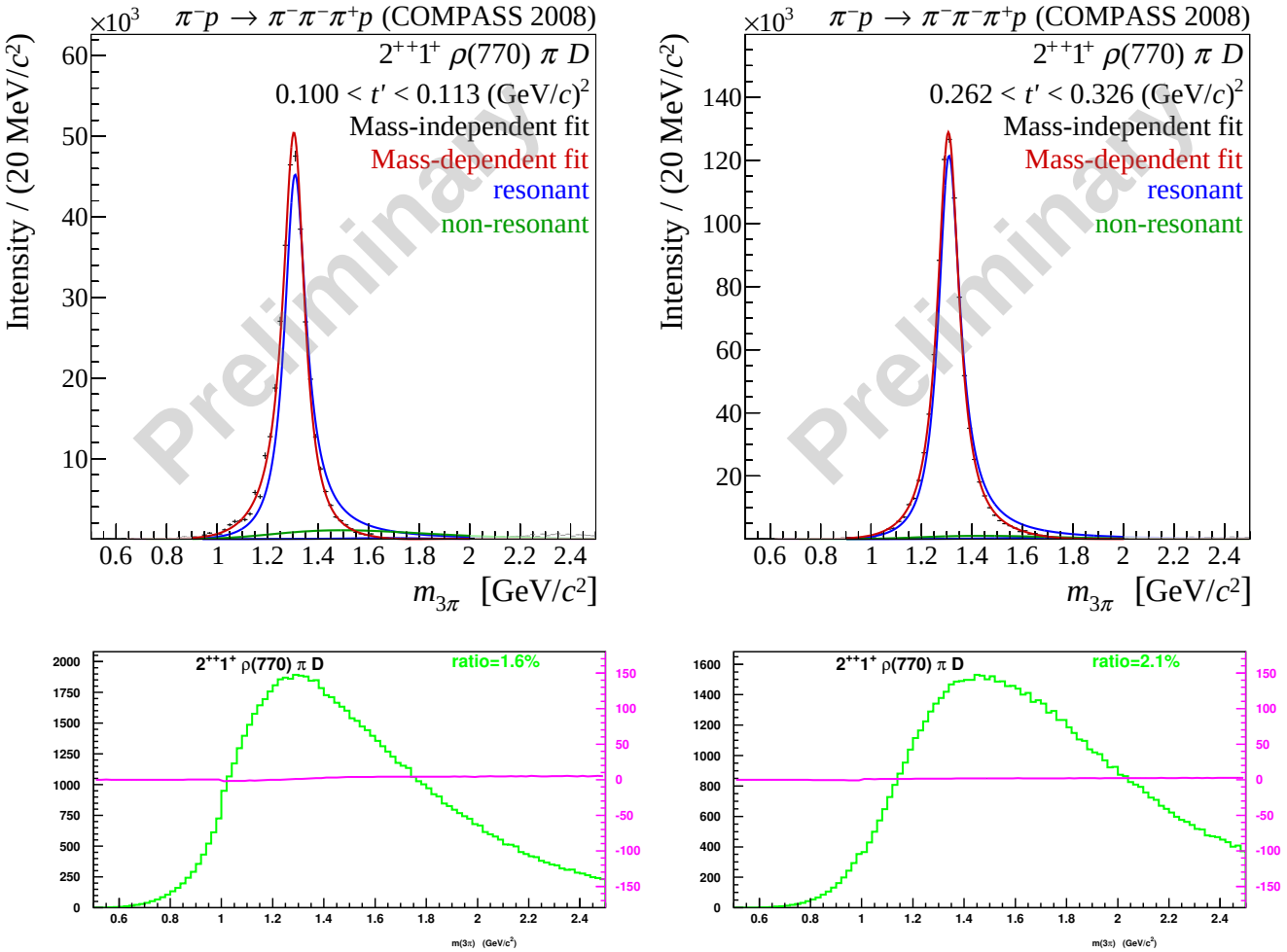
$6^{-+}0^{+}\rho\pi H$ used to normalize Deck contribution



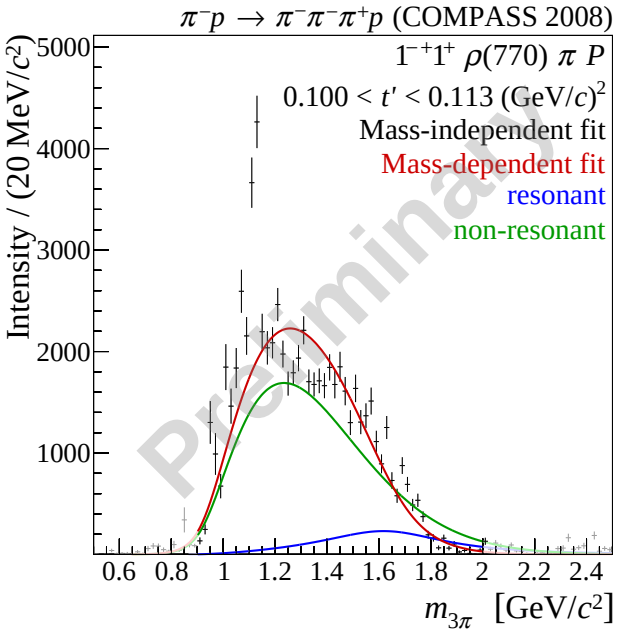
$1^{++}0^{+}$ mass-dep fit of the data vs. Deck decomposition

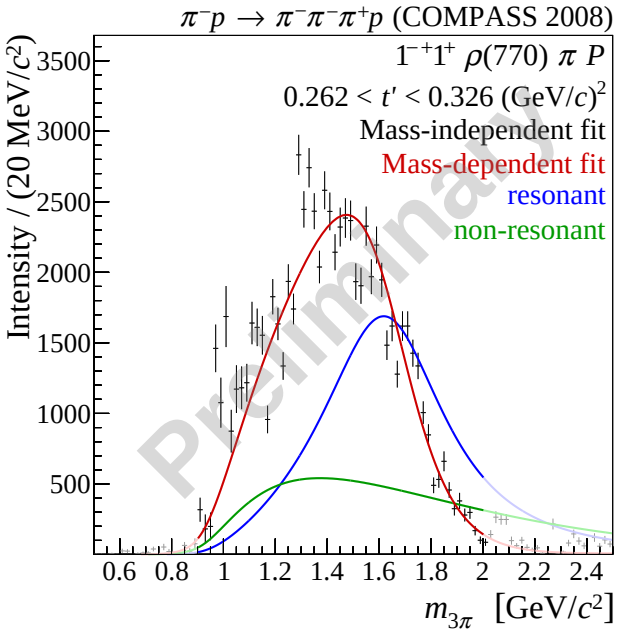


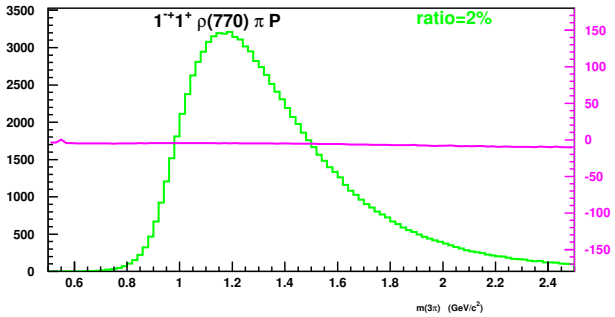
$2^{++}1^{+}$ mass-dep fit of the data vs. Deck decomposition

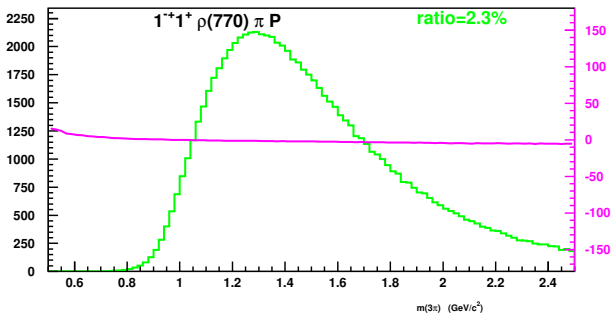


$1^{-+}1^{+}$ mass-dep fit of the data vs. Deck decomposition

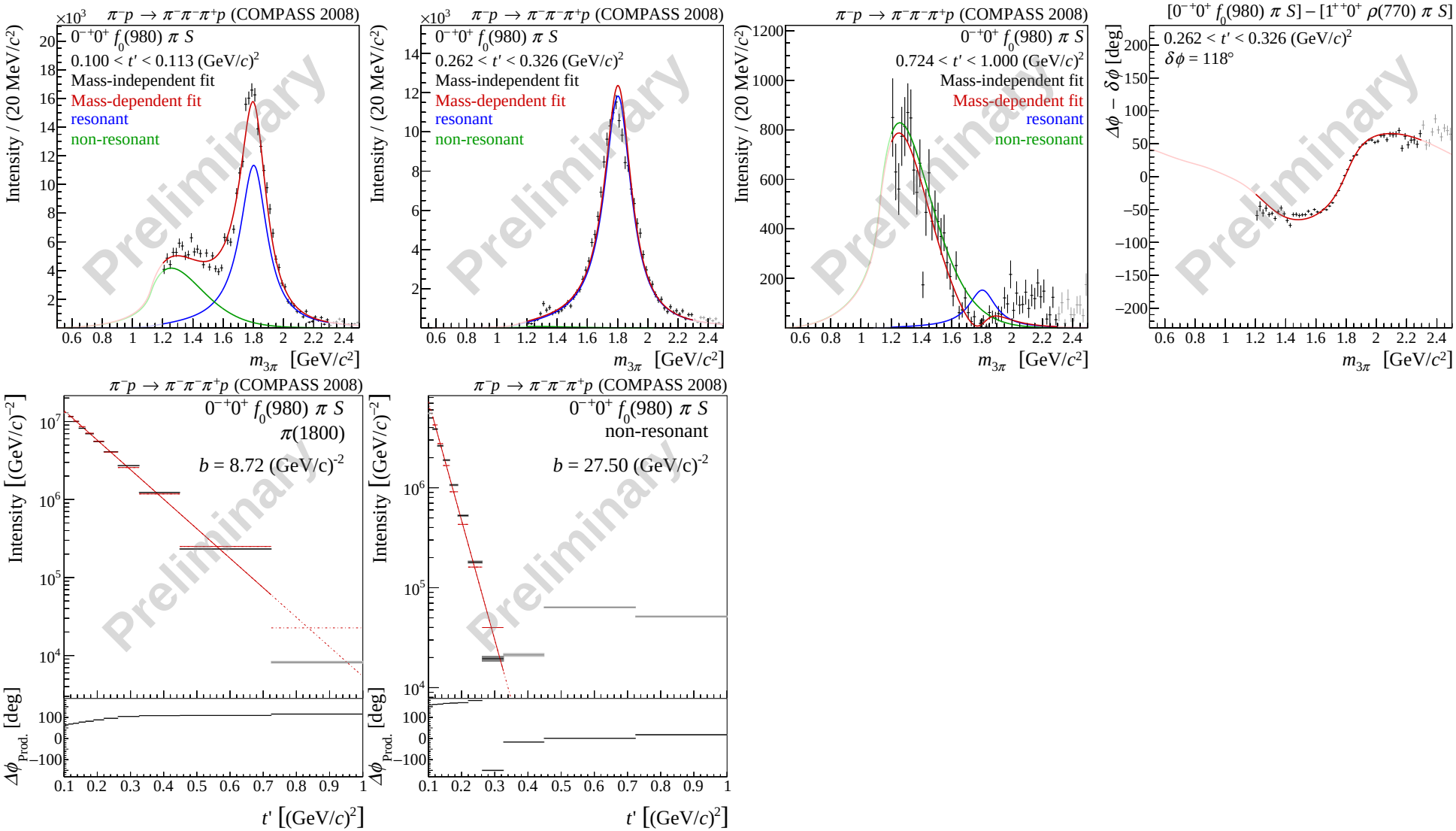








$0^{-+}0^{+}f_0(980)\pi S$- unusual t'-spectrum for BG



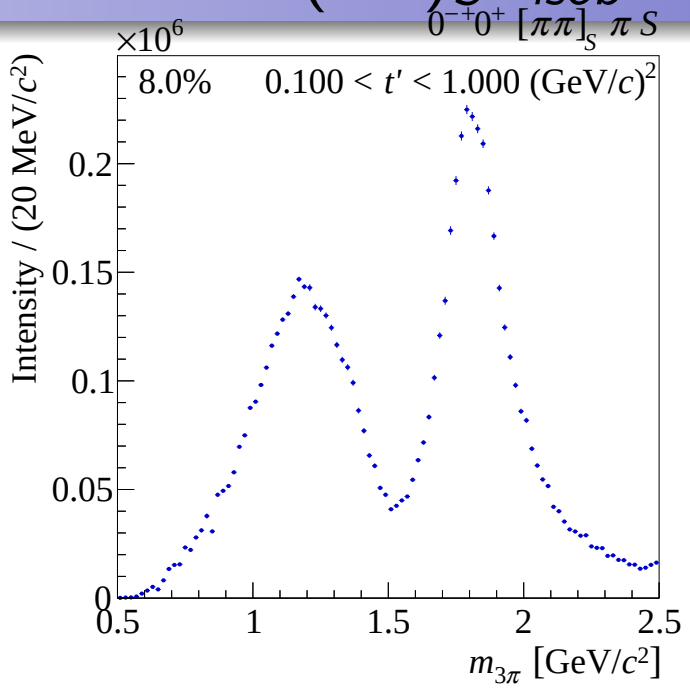
The fit with free 2π amplitudes

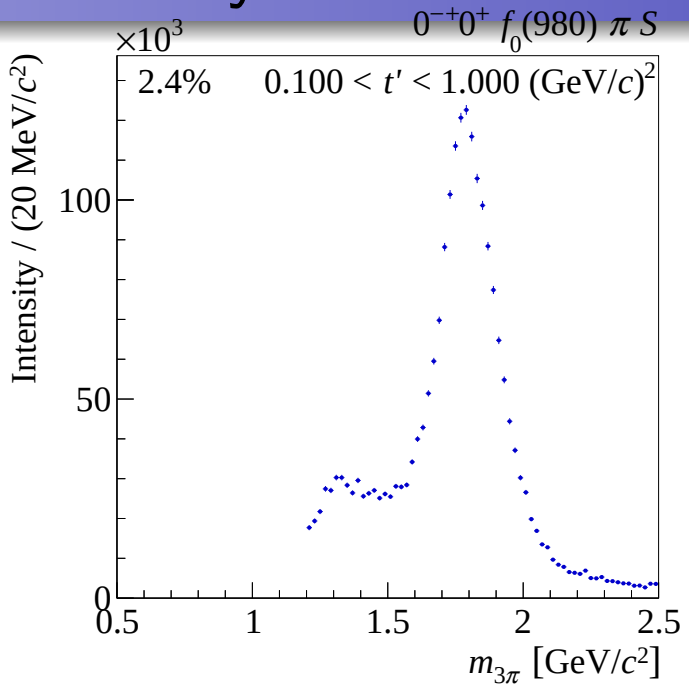
The mass-independent PWA intensity reads:
$\mathcal{I}(m,t,\tau) = \sum_\epsilon \sum_r \left|\sum_i T^\epsilon_{ir}(m,t)\bar{\psi}^\epsilon_i(\tau,m)\right|^2$
The decay amplitudes $\psi^\epsilon_i(\tau,m)$ contain multiplicative complex amplitudes of intermediate isobars.
Same multipicative functions (but depending on different kinematical variables) are contained in each linear term in case of bose- or isospin- symmetrisation – in arbitrary N-particle phase-space.

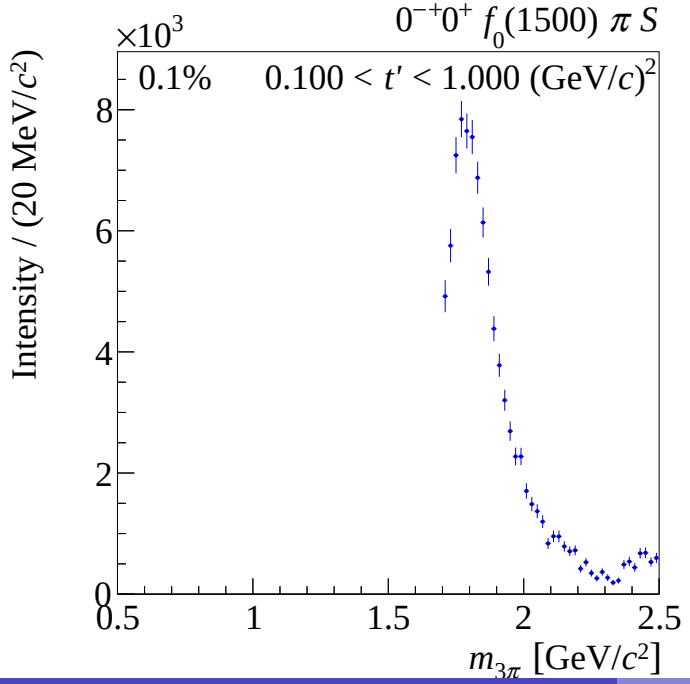
Example: $\Psi(\tau) = BW(m_{13})A(\Omega_{13},\Omega_{1(13)}) + BW(m_{23})A(\Omega_{23},\Omega_{1(23)})$

Let's express $BW(m) = \sum_k C_k\Theta_k$ Here Θk is set of functions $=1$ in each (non-equidistant) bin (m_k, m_{k+1}).
Then $\psi(\tau) = \sum_k C_k\psi_{\Theta_k}(\tau)$ where ψ_{Θ_k} has $\Theta(m_k, m_{k+1})$ instead of $BW(m)$ respectively.
Several selected amplitudes are decomposed to "theta-like" amplitudes. Using rank=1 fit will provide measurement of model-independent isobaric amplitudes in a given sub-systems, different for each decay quantum numbers.
Example: $0^{-+}, 1^{++}, 2^{-+} \to (\pi\pi)_S\pi^-$ in S,P and D waves (described below).

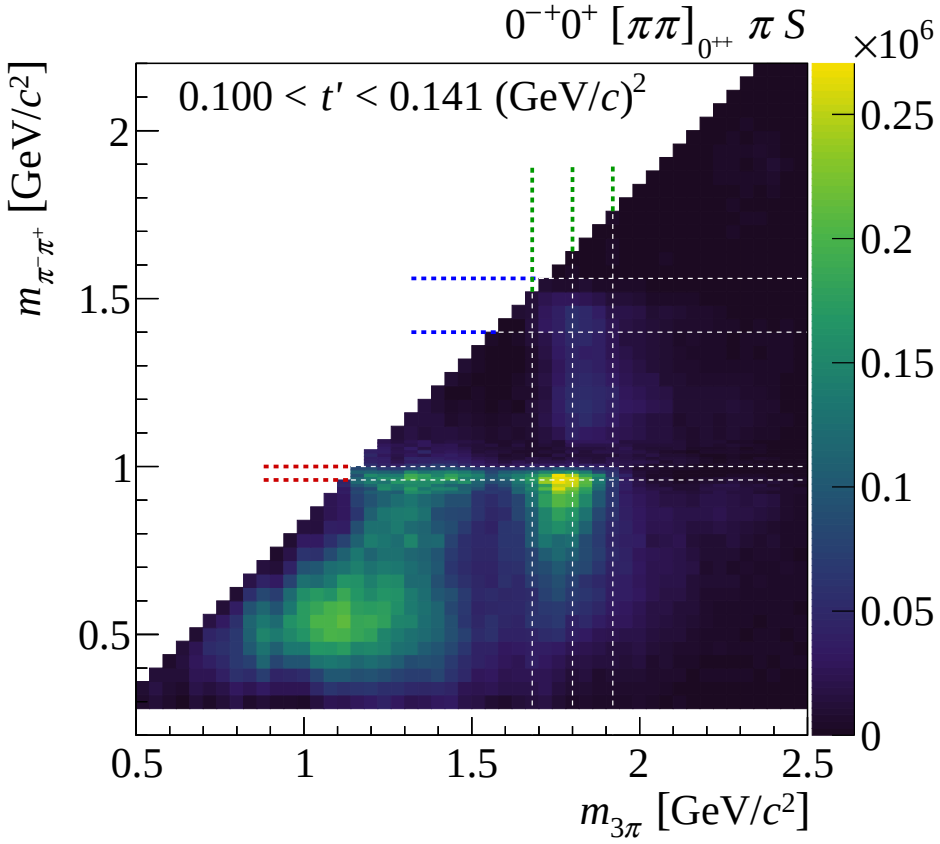
$0^{-+} \to (\pi\pi)_{S-isob}\pi$ intensity in established-isobares PWA

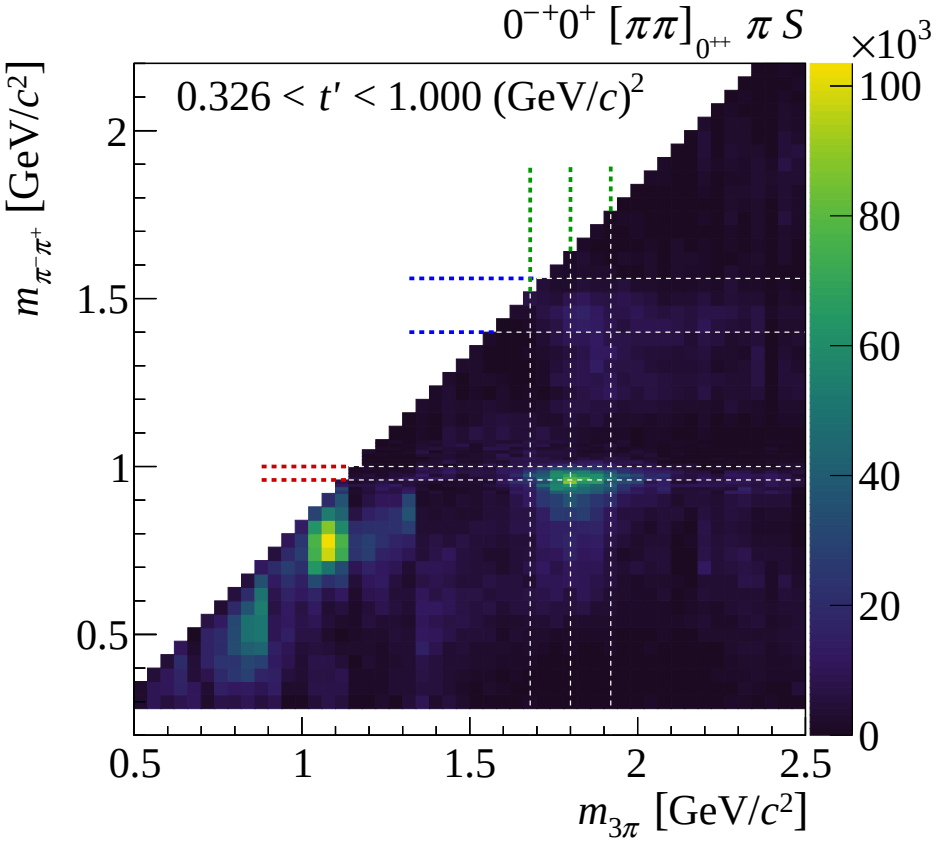




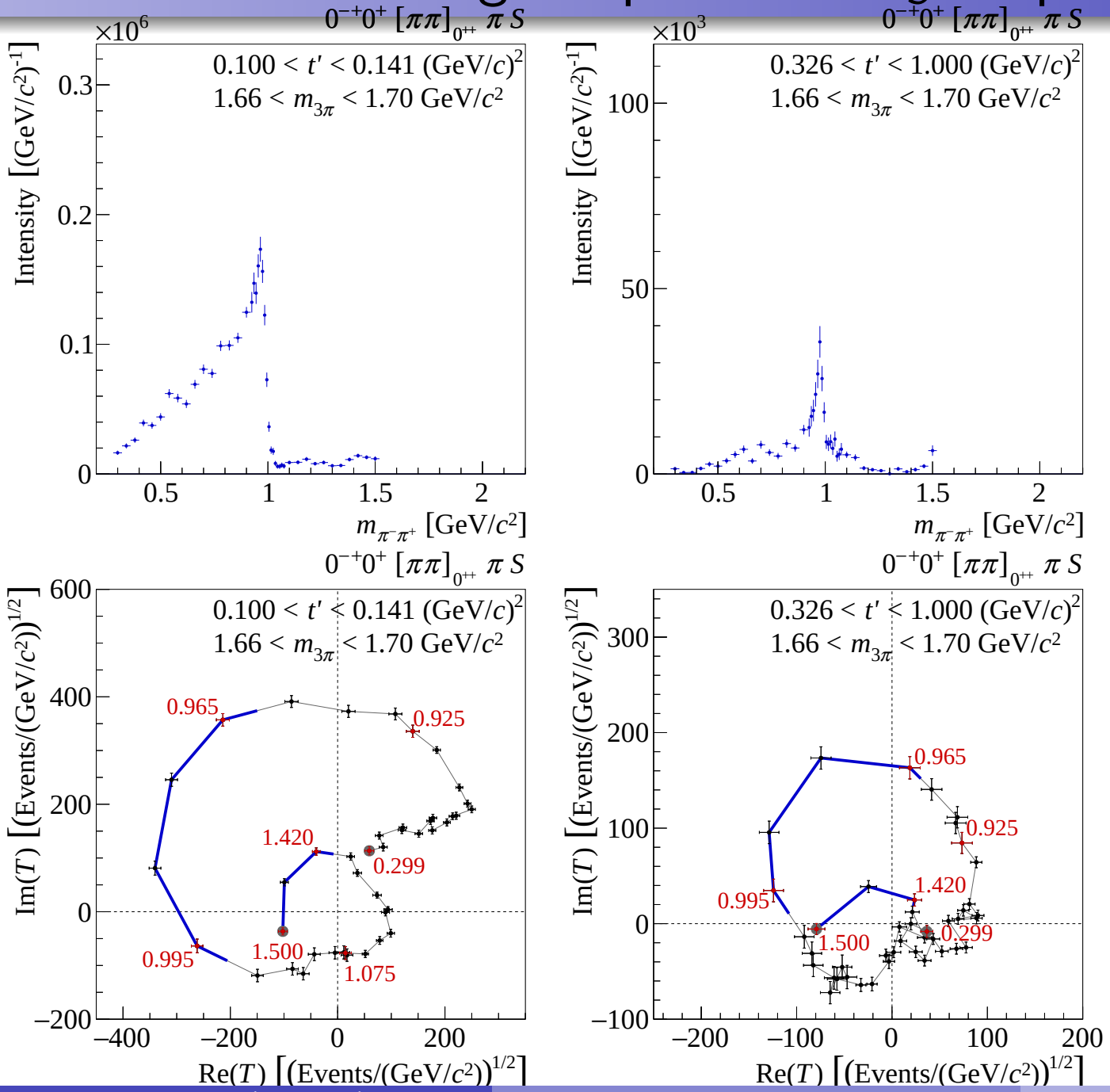


Intensity of $\pi\pi_S$ amplitude in 0^{-+} ($m(2\pi)$ vs. $m(3\pi)$)

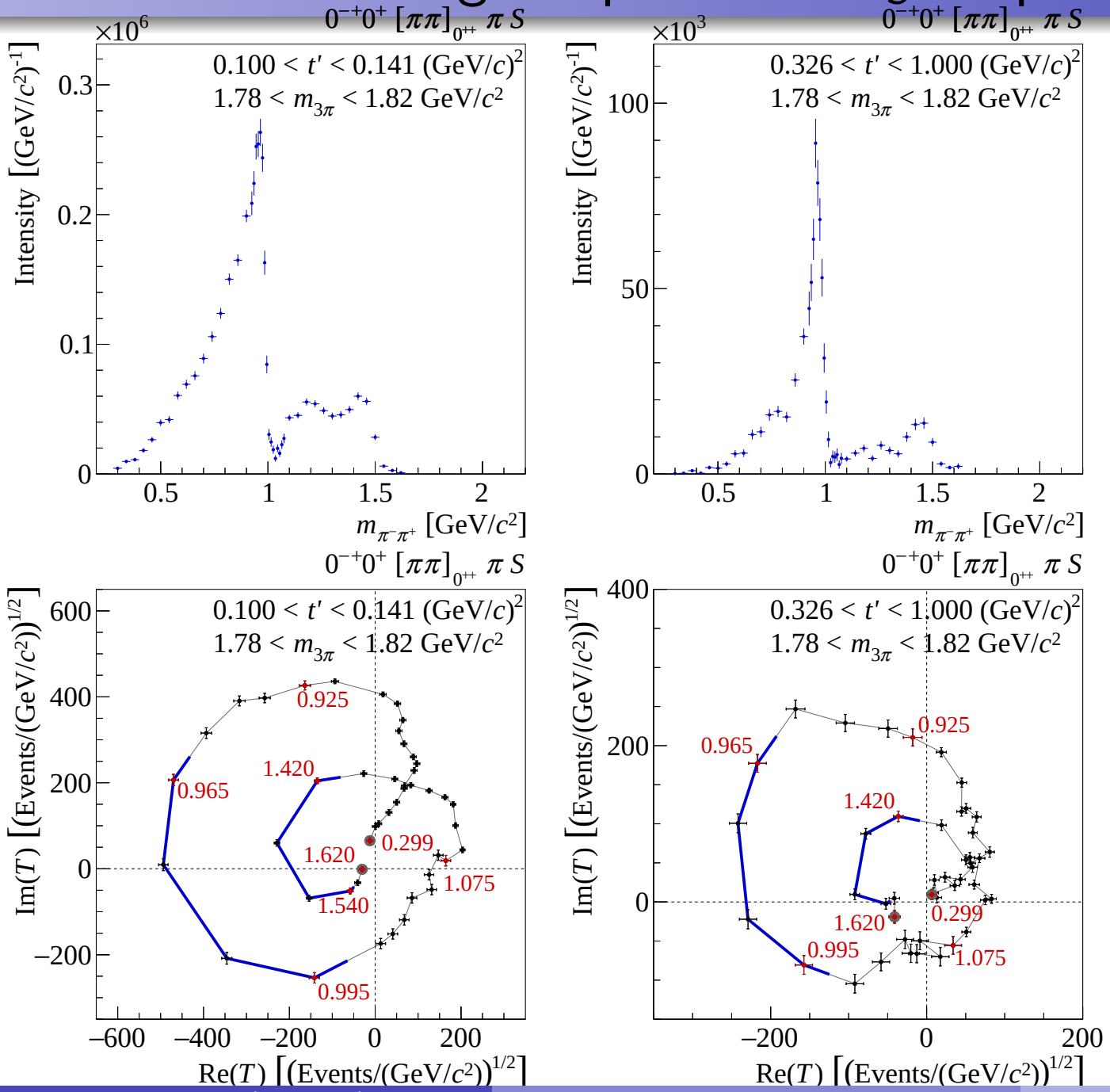




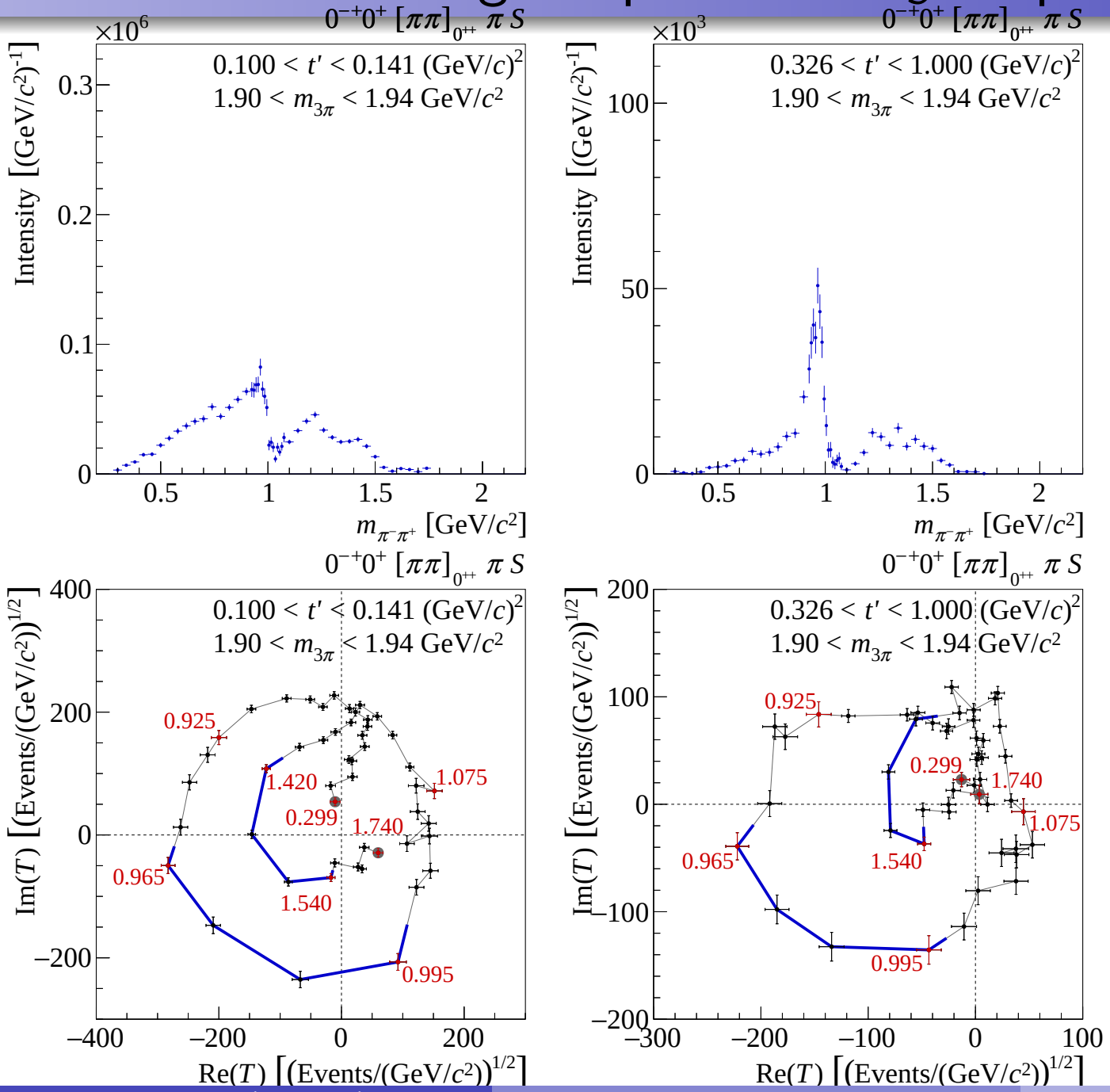
Intensities and argand plots of $\pi\pi_S$ amplitude in 0^{-+}



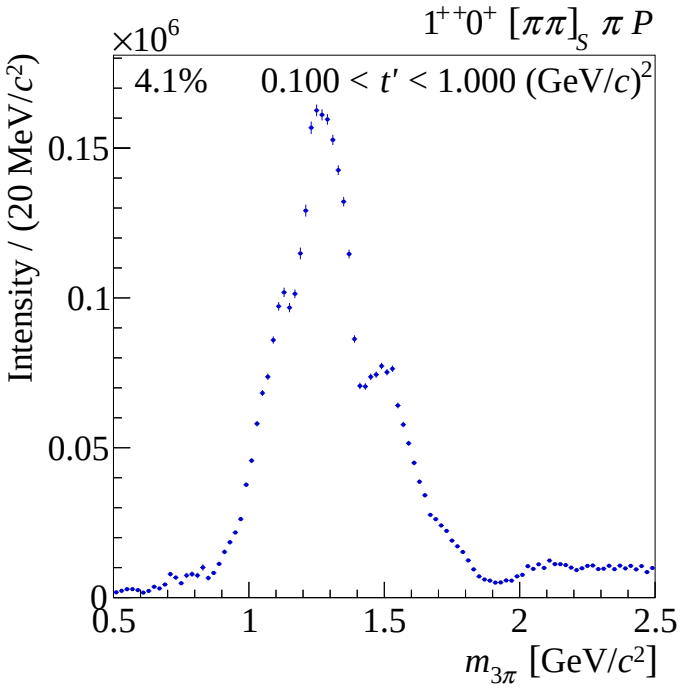
Intensities and argand plots of $\pi\pi_S$ amplitude in 0^{-+}

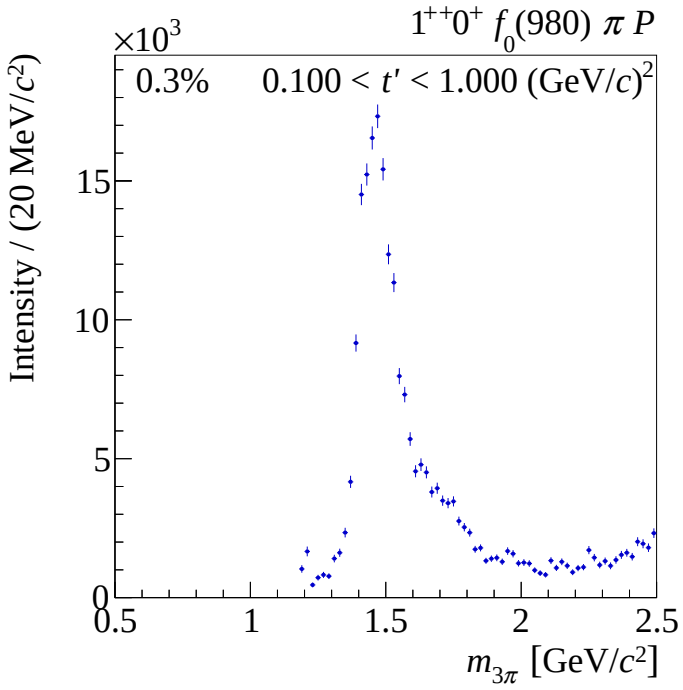


Intensities and argand plots of $\pi\pi_S$ amplitude in 0^{-+}

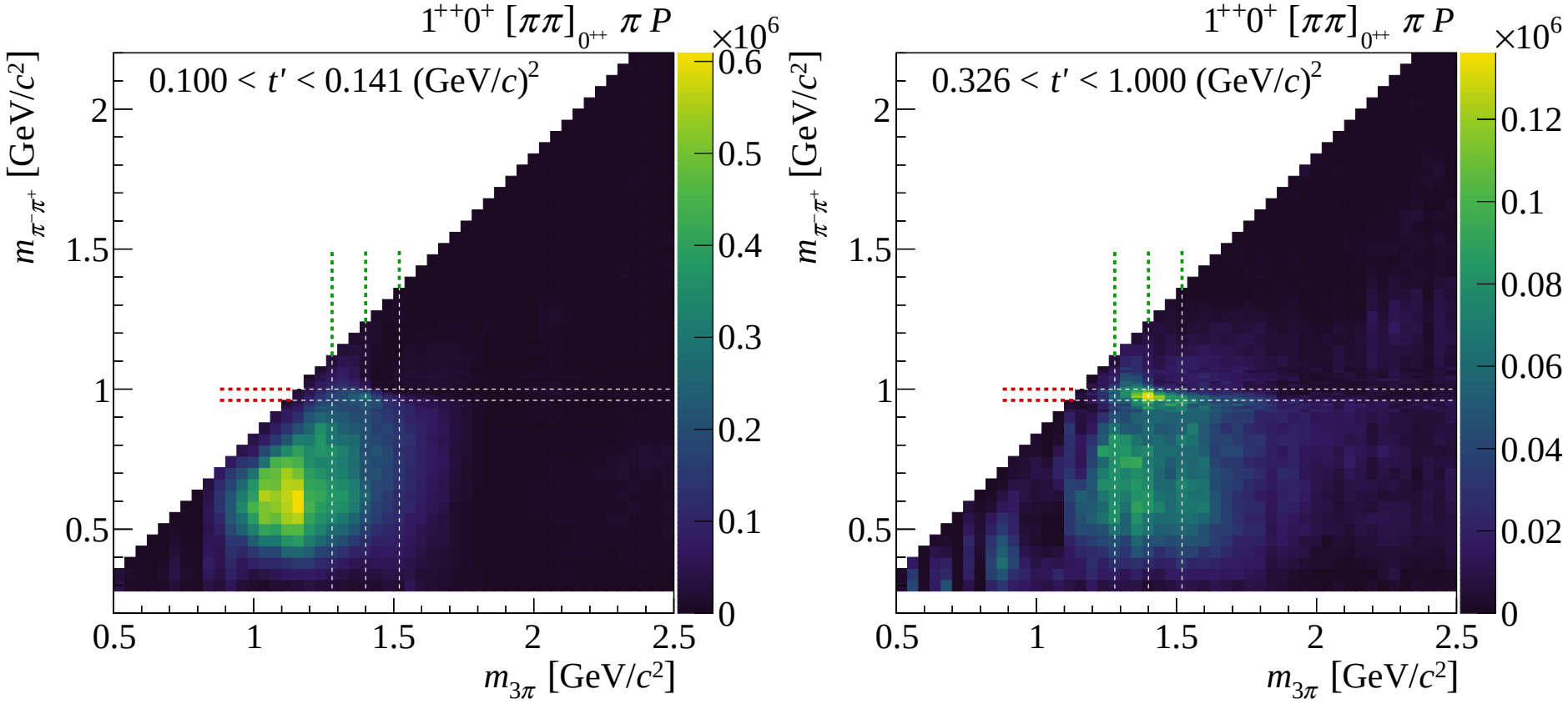


$1^{++} \to (\pi\pi)_{S-isob}\pi$ intensity in established-isobares PWA

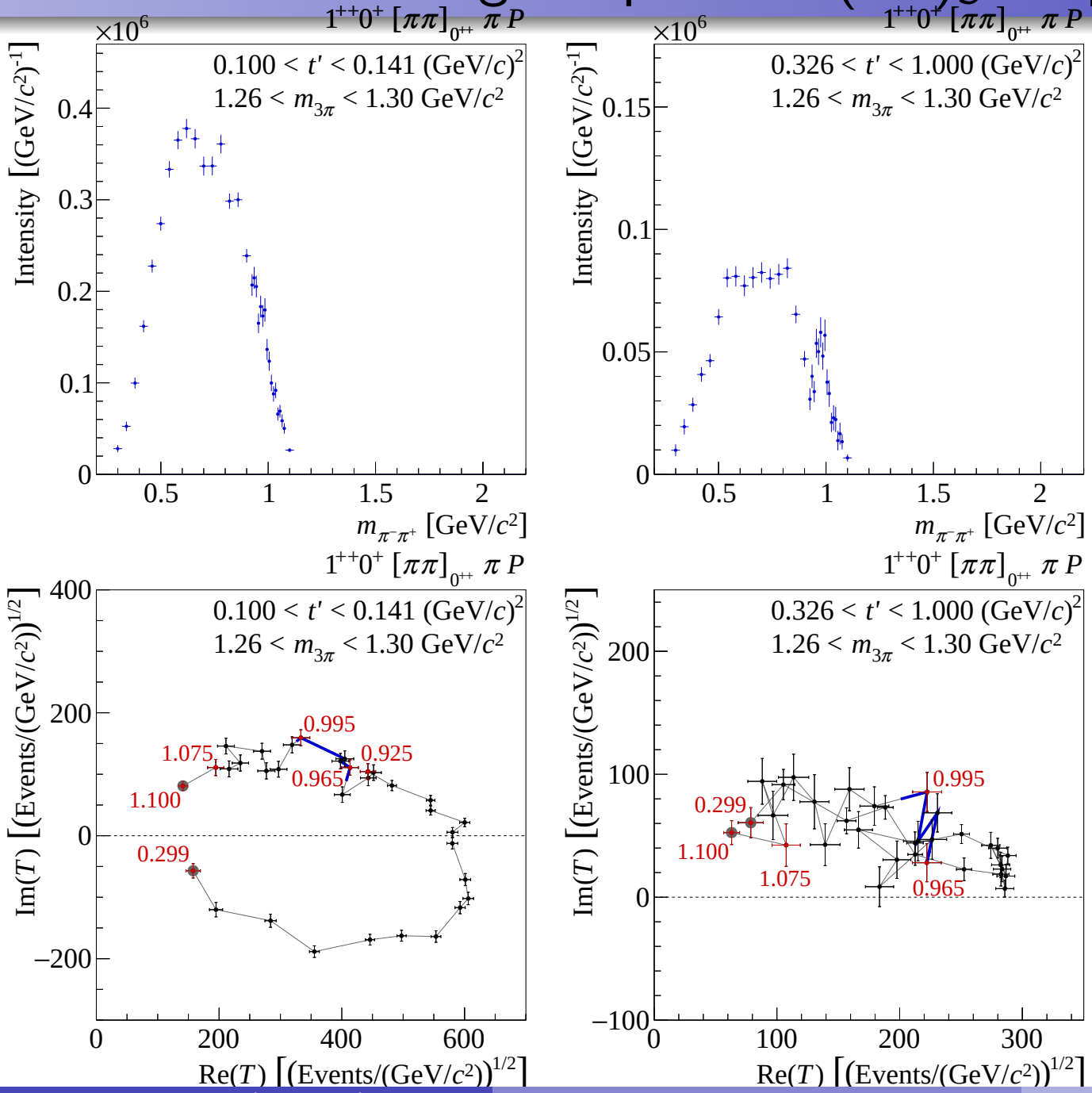




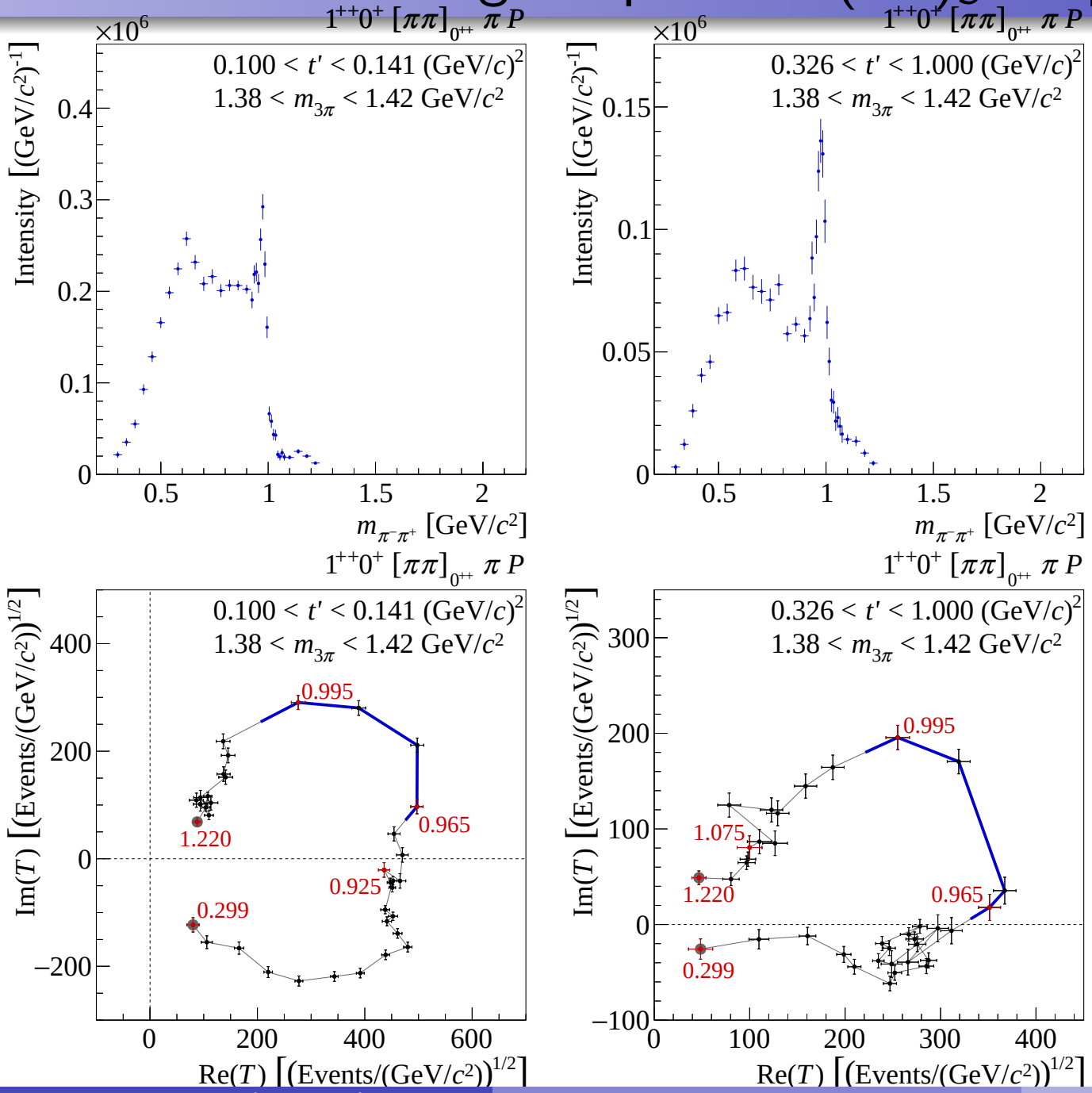
Intensity of $(\pi\pi)_S$ amplitude in 1^{++} ($m(2\pi)$ vs. $m(3\pi)$)



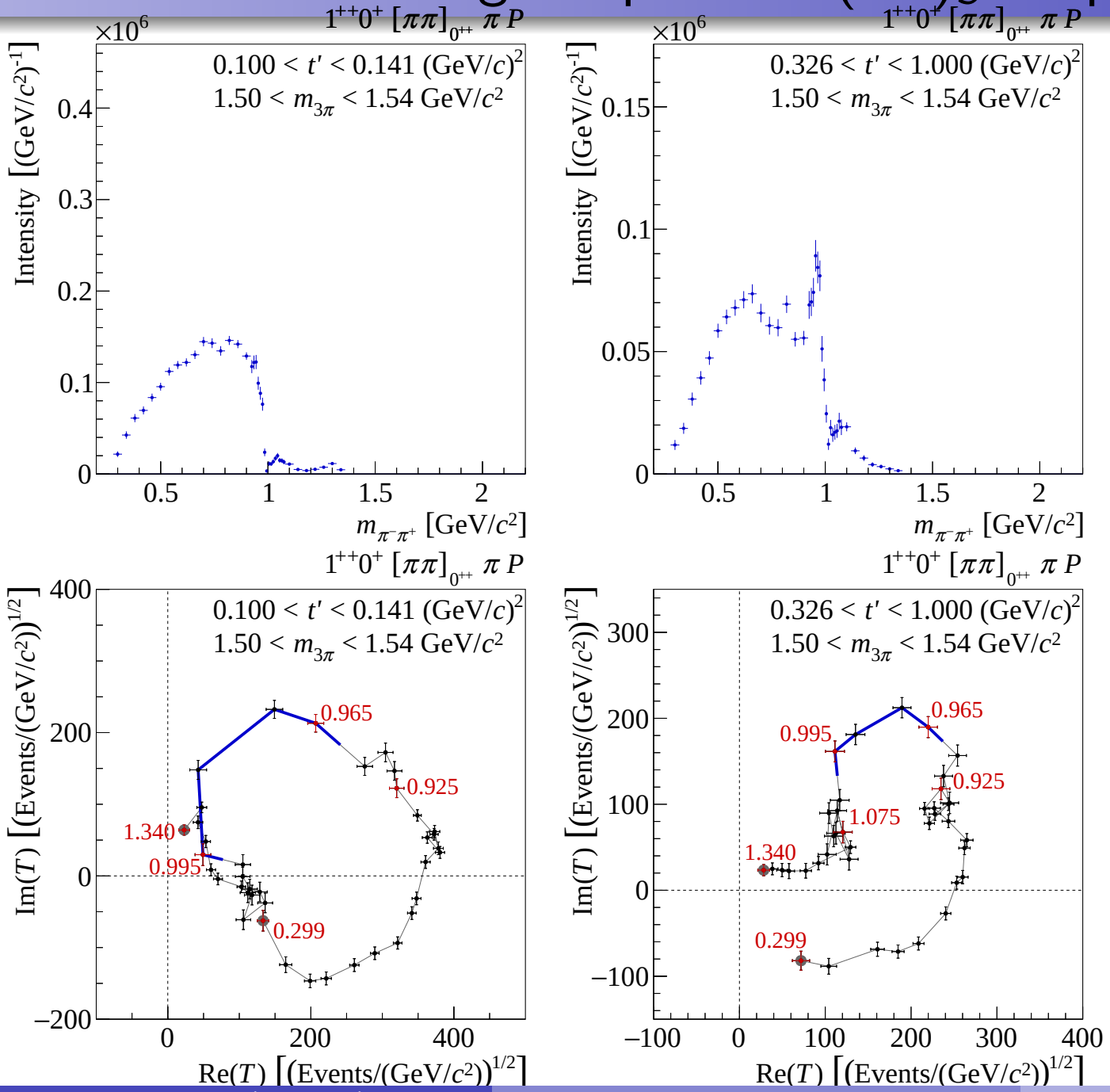
Intensities and argand plots of $(\pi\pi)_S$ amplitude in 1^{++}



Intensities and argand plots of $(\pi\pi)_S$ amplitude in 1^{++}



Intensities and argand plots of $(\pi\pi)_S$ amplitude in 1^{++}



CONCLUSIONS

- The mass-independent PWA $\pi^- p \to \pi^- \pi^- \pi^+ p$ of 46 000 000 events is carried out using set of 88 waves and for $0.1 < t' < 1.0$ GeV^2 divided into 11 t' intervals
- First time the t'-resolved mass-dependent analysis of $\pi^- \pi^- \pi^+$ is performed using 14x14 sub-density matrix
  - The extraction of resonance parameters is based on intensity shapes and relative phase motions in $m(3\pi)$ bins
  - fitting simultaneously in set of t' intervals leads to improved separation between resonant and background components
- The Deck mechanism is related to backgroud processes in diffractive production of 3π
  - The partial-wave decomposition of Deck amplitude is performed, showing dominance of $1^{++}0^+\rho(770)\pi S$ with increase of its rate at lowest t'
  - Deck model has contributions of high orbital moment states at high $m(3\pi)$
  - Deck process has narrow t'-spectrum relative to 3π resonant production
  - It contributes to $M = 1$ partial waves, this can explain, in particular, dominance of background component in exotic $J^{PC}M^{\epsilon} = 1^{-+}1^+\rho\pi$ at low t'
- The novel analysis determening complex amplitudes of $(\pi\pi)_S$ isobars is performed. It demonstrates resonant nature in 3π and 2π systems on fully model-independent level.