Meson Spectroscopy at COMPASS

D. Ryabchikov

Institute for High Energy Physics, Protvino

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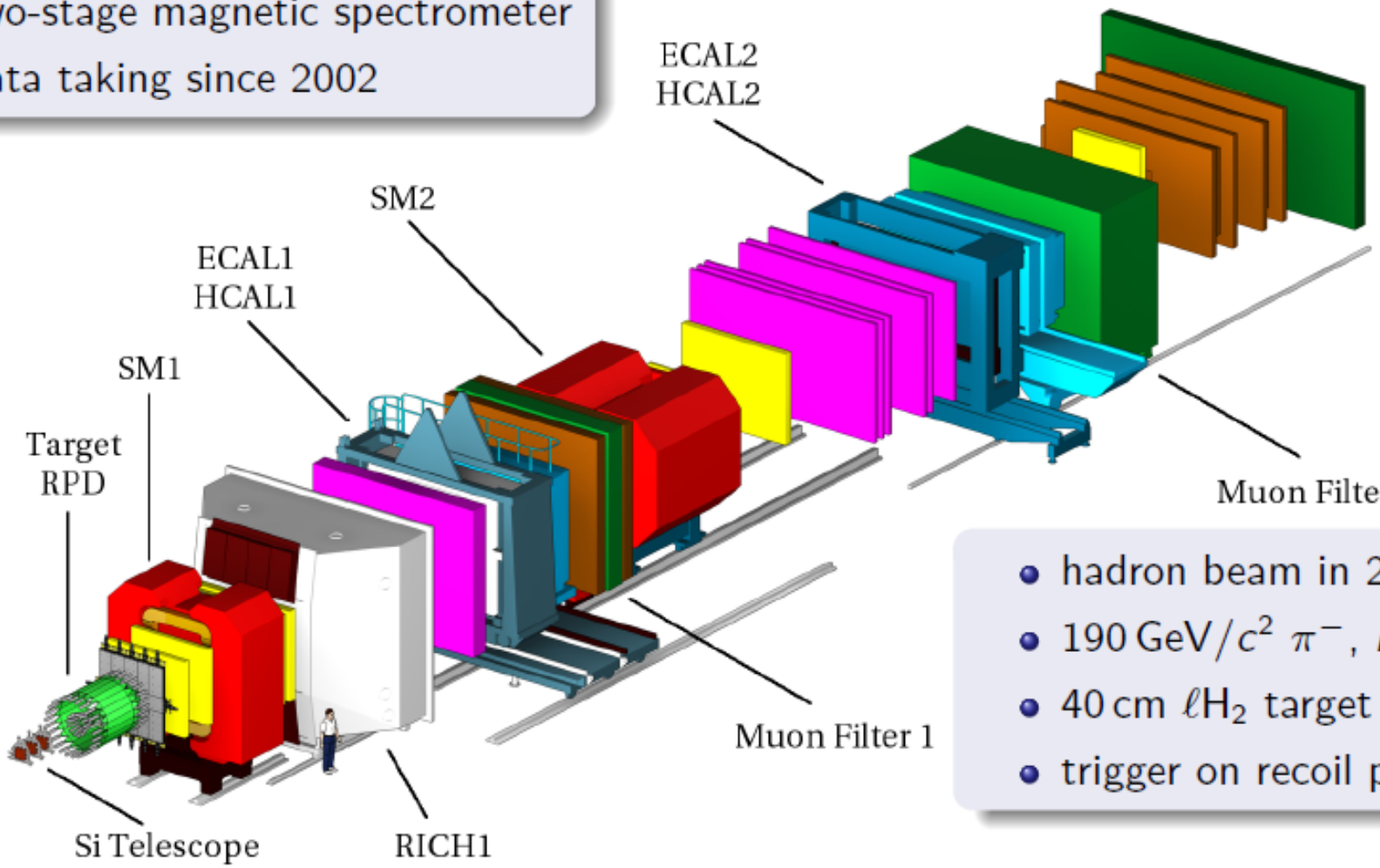
Содержание

- Реакции $\pi^- p \to \pi^-\pi^-\pi^+ p$ и $\pi^- p \to \pi^-\pi^0\pi^0 p$ при $p_{\pi^-} = 190$ ГэВ
  - Масс-независимый Парциально-Волновой Анализ
  - Масс-зависимый фит
  - Модельно-независимая параметризация изобар $(\pi\pi)_S$
- Реакции $\pi^- p \to \eta\pi^- p$ и $\pi^- p \to \eta'\pi^- p$
- Реакция $\pi^- Pb \to \pi^-\pi^-\pi^+ Pb$ при $t' = 0 - 0.001$ ГэВ^2

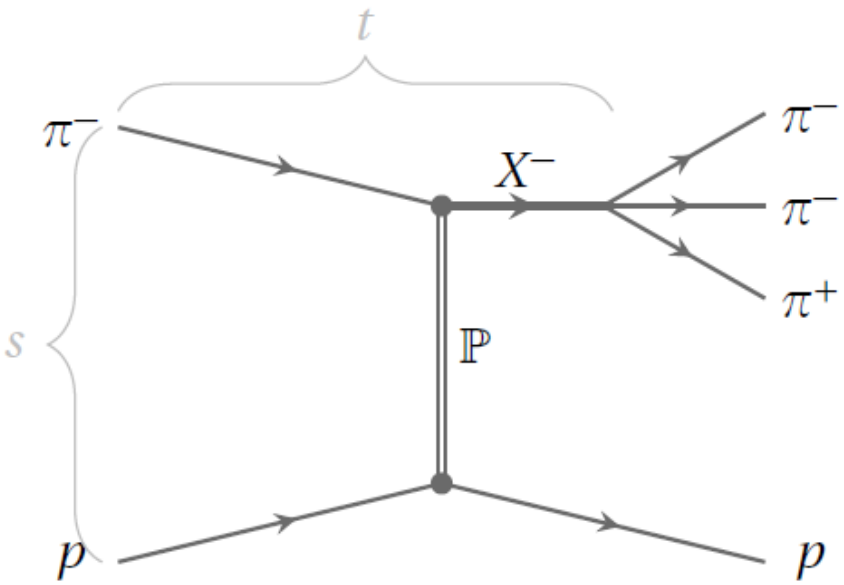
Apparatus

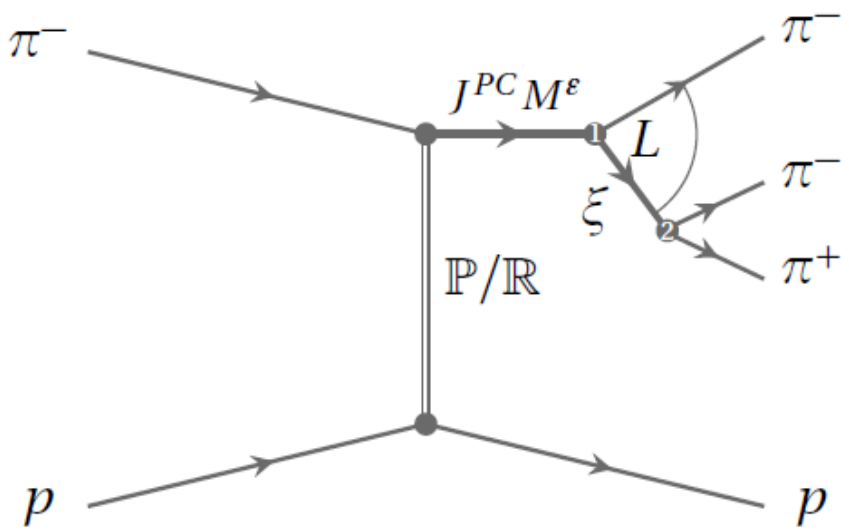
- fixed target experiment
- located at CERN's SPS
- two-stage magnetic spectrometer
- data taking since 2002



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

PWA assumptions





$$\|J^P\,M^{\varepsilon}\rangle \equiv \Theta(M)\left[|J^P\,M\rangle - \varepsilon\,P\,(-)^{J-M}\;|J^P\;-M\rangle\right] \quad \text{with} \quad \Theta(M) = \begin{cases} 1/\sqrt{2} & \text{for} M > 0 \\ 1/2 & \text{for} M = 0 \\ 0 & \text{for} M < 0 \end{cases}$$

$$\mathcal{I}(m_X, t', \tau) = \sum_{i,k}\sum_{j,l} \rho_{ik}(m_X, t')\,\psi_{i,j}(m_X, \tau)\,\psi^*_{k,l}(m_X, \tau) \quad \text{with} \quad \rho_{ik}(m_X, t') = \sum_{r}^{N_r} \widetilde{T}^r_i\,\widetilde{T}^{r*}_k$$

PWA - "isospin symmetry"aspect

Spin formalism using D-functions is applied for both $\pi^-\pi^0\pi^0$ and $\pi^-\pi^-\pi^+$.

Decay amplitudes for $(\pi\pi)_{I=1}\pi$ channels are connected only for isospin I(3π)=1 :

$$\sqrt{\tfrac{1}{2}}\left(\tfrac{1}{\sqrt{2}}[(\pi^-_{(1)}\pi^+)\pi^-_{(2)} + (\pi^-_{(2)}\pi^+)\pi^-_{(1)}]\right) \rightarrow -\sqrt{\tfrac{1}{2}}\left(\tfrac{1}{\sqrt{2}}[(\pi^-\pi^0_{(1)})\pi^0_{(2)} + (\pi^-\pi^0_{(2)})\pi^0_{(1)}]\right)$$

Decay amplitudes for $(\pi\pi)_{I=0}\pi$ channels have I(3π)=1 and so are always connected:

$$\sqrt{\tfrac{2}{3}}\left(\tfrac{1}{\sqrt{2}}[(\pi^-_{(1)}\pi^+)\pi^-_{(2)} + (\pi^-_{(2)}\pi^+)\pi^-_{(1)}]\right) \rightarrow -\sqrt{\tfrac{1}{3}}\left((\pi^0_{(1)}\pi^0_{(2)})\pi^- \right)$$

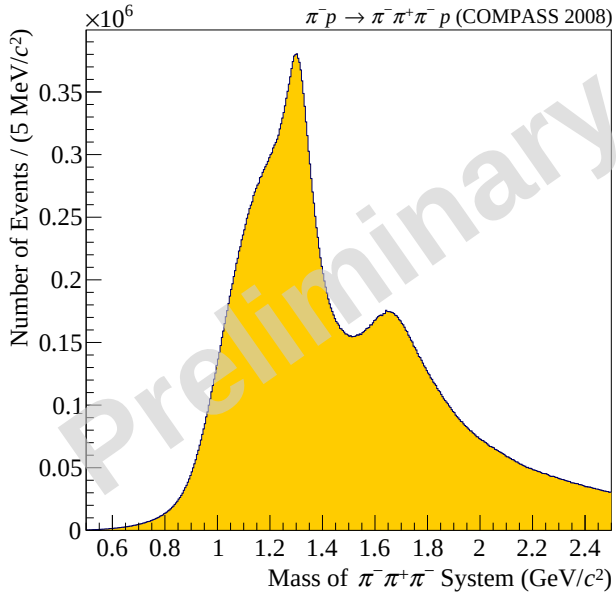
Connection means same production amplitudes. If so, ratio of integrals of decay amplitudes squared gives Br=N($\pi^-\pi^0\pi^0$)/N($\pi^-\pi^-\pi^+$)

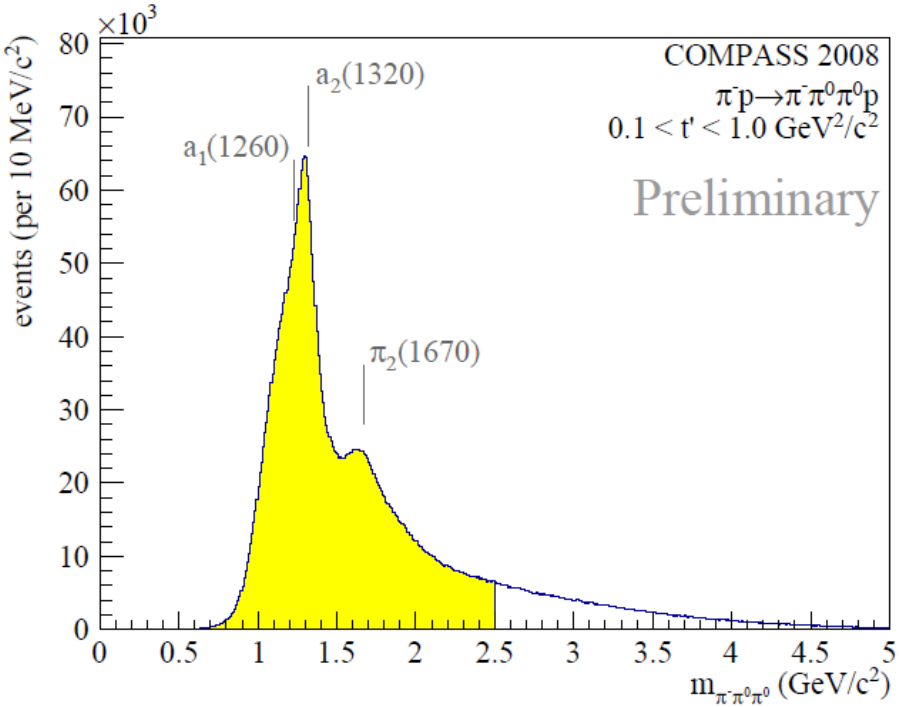
1) assuming isospin I(3π)=1 in $(\pi\pi)_{I=1}\pi$, obtain relative Br = 1, as decay amplitudes squared have same Dalitz-plot structure (if $m(\pi^{+/-}) = m(\pi^0)$).

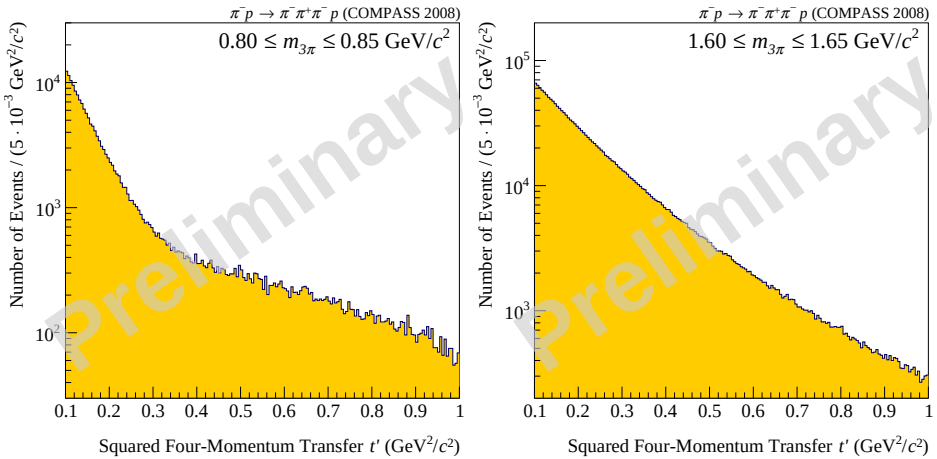
2) for $(\pi\pi)_{I=0}\pi$ we have I(3π)=1 but Br can differ from 0.5 in case of big term 2 Re($(\pi^-_{(1)}\pi^+)\pi^-_{(2)}$ $(\pi^-_{(2)}\pi^+)\pi^{-*}_{(1)}$) on $\pi^-\pi^-\pi^+$ Dalitz-plot.

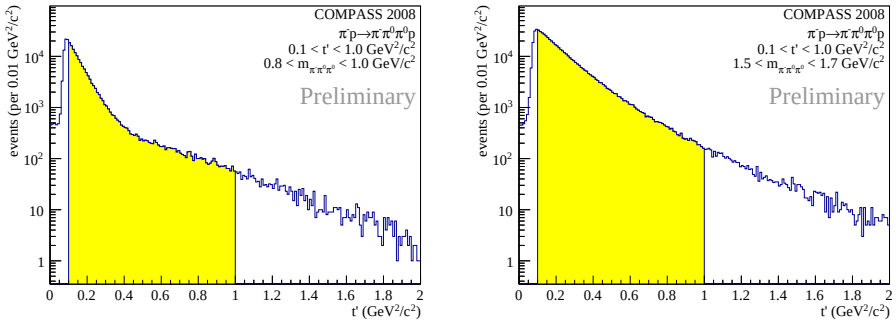
3) for I(3π)=1 in $(\pi\pi)_{I=1}\pi$ all corresponding relative phases in $\pi^-\pi^0\pi^0$ and $\pi^-\pi^-\pi^+$ must be equal (if "spin analyzers"directions are chosen accordingly)

Спектры инвариантных масс и t' $\pi^-\pi^-\pi^+$ и $\pi^-\pi^0\pi^0$





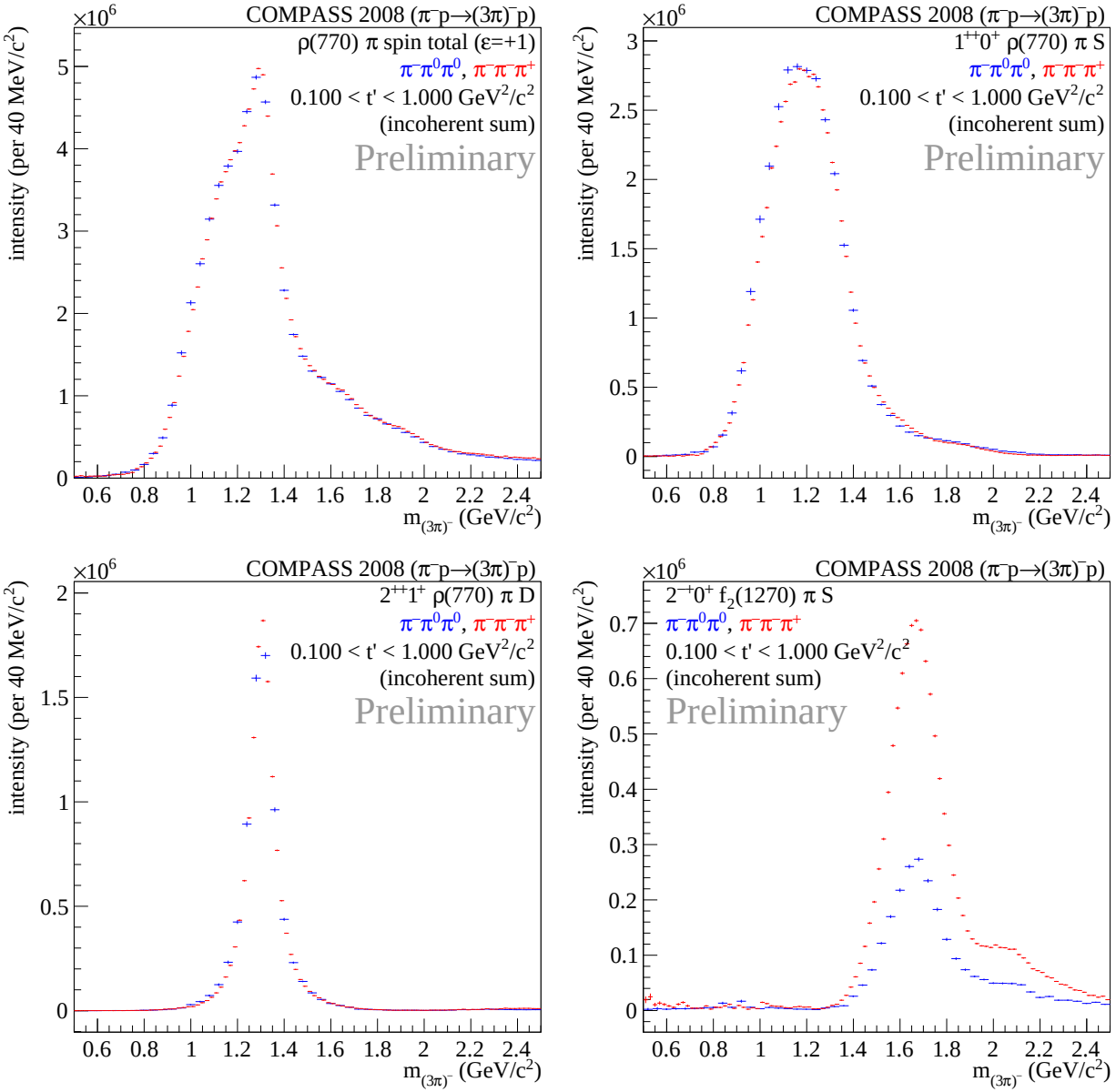




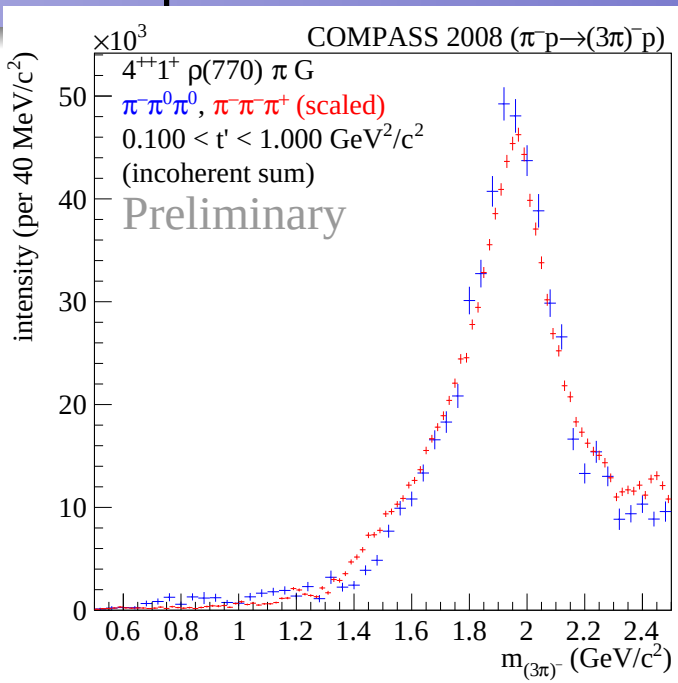
50 million of $\pi^-\pi^-\pi^+$

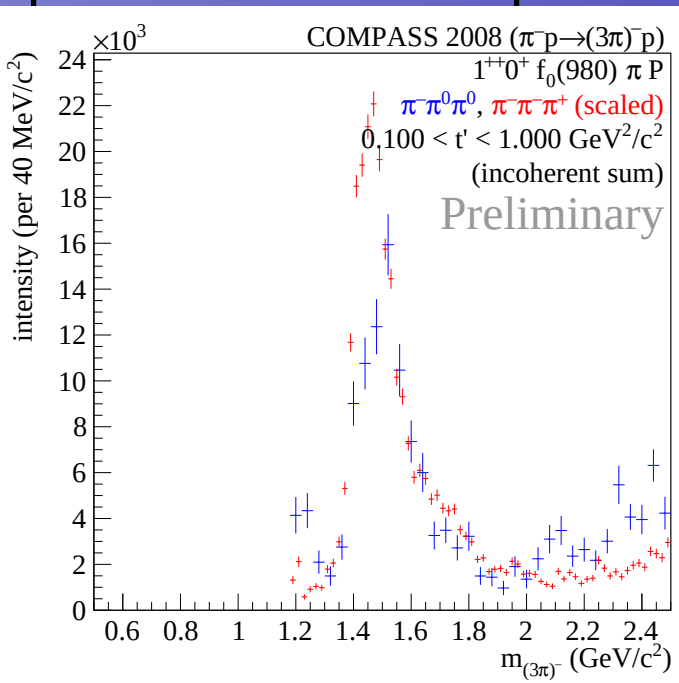
3.5 million of $\pi^-\pi^0\pi^0$

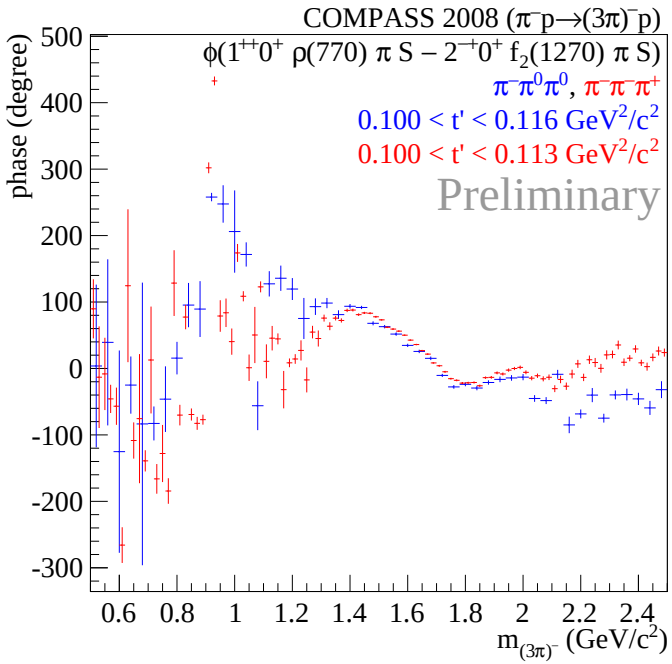
Сравнение интенсивностей в $\pi^-\pi^-\pi^+$ $\pi^-\pi^0\pi^0$

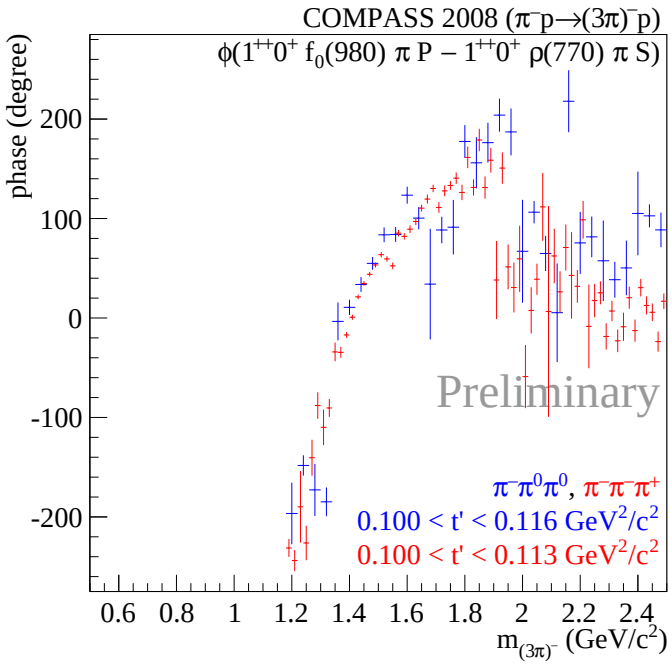


Smaller amplitudes and examples of relative phases

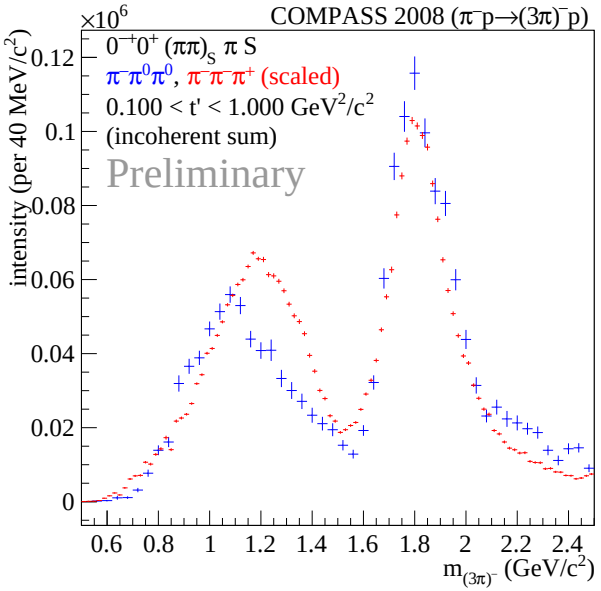


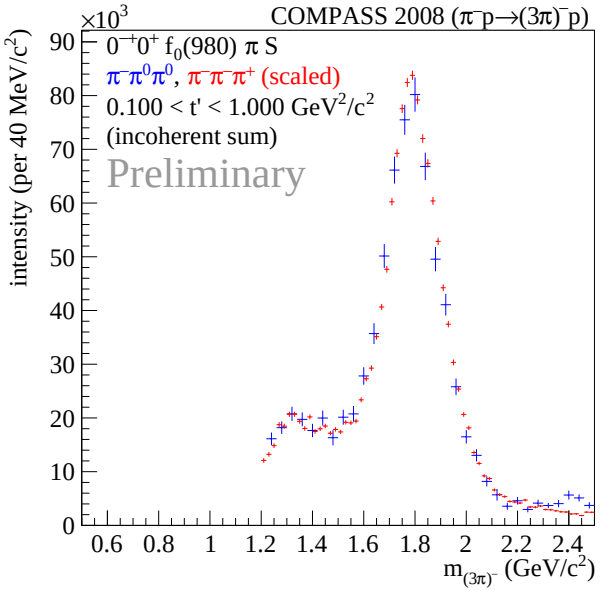


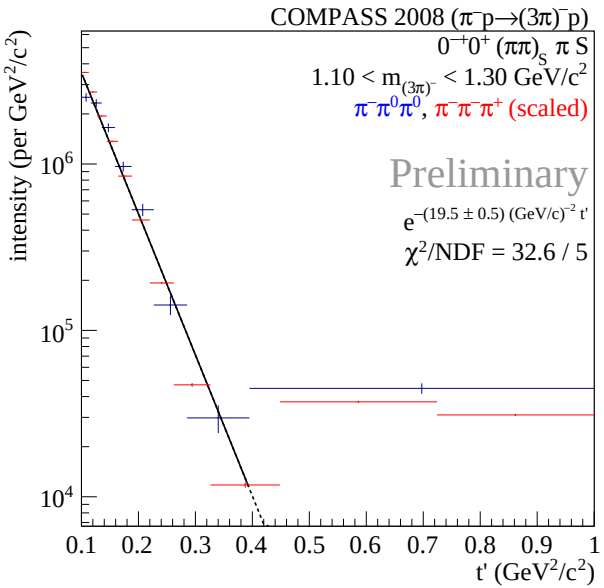


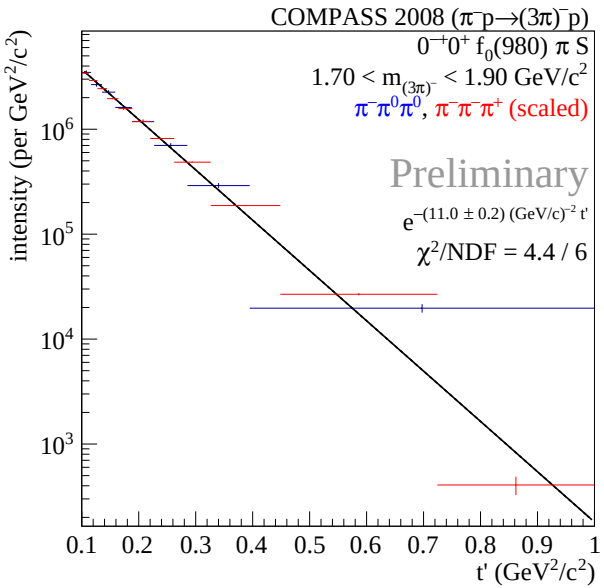


0^{-+} intensities and examples of t-slopes

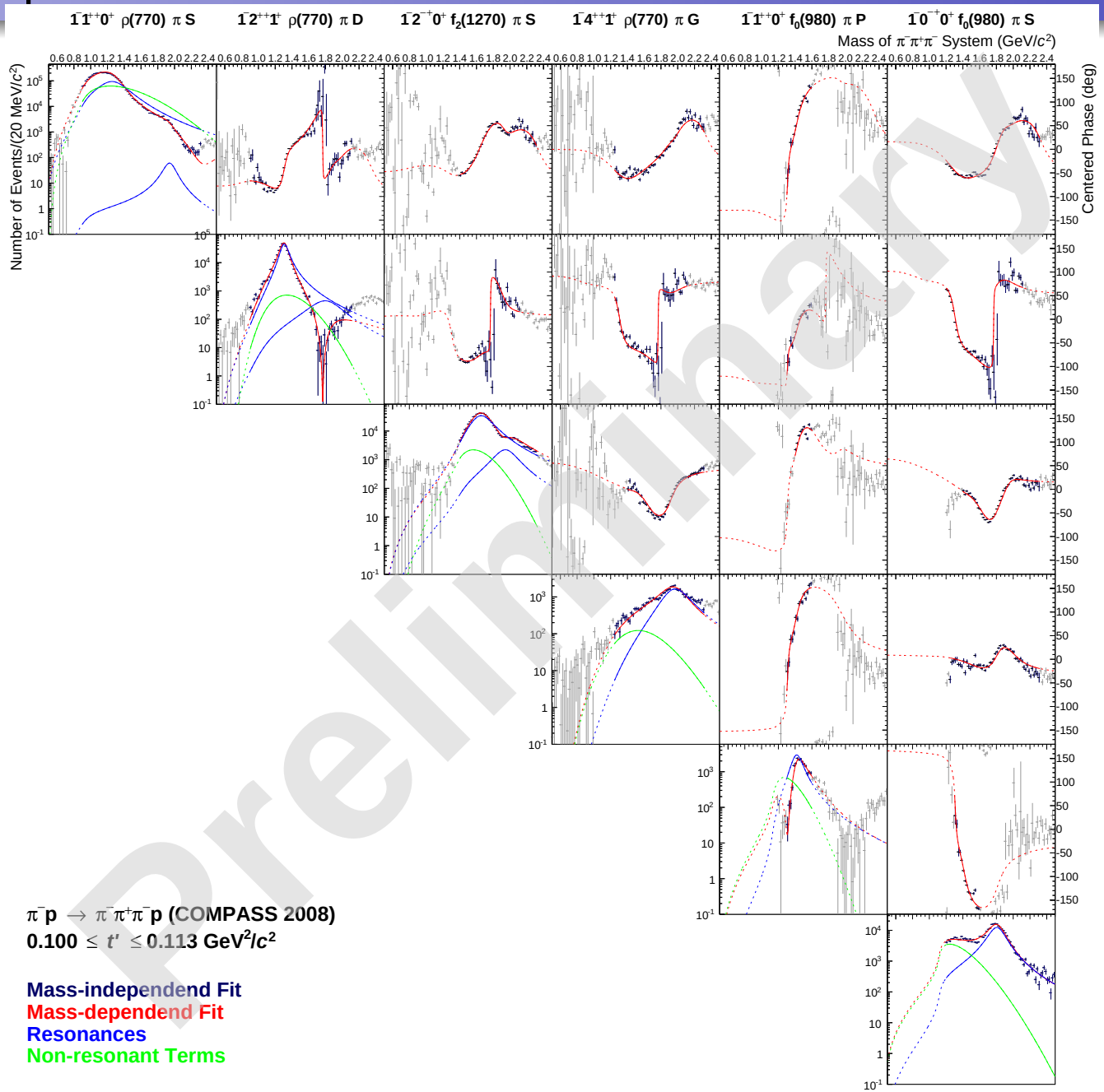








Mass-dependent fit in $\pi^-\pi^-\pi^+$ - "sub-matrix"lowest t'

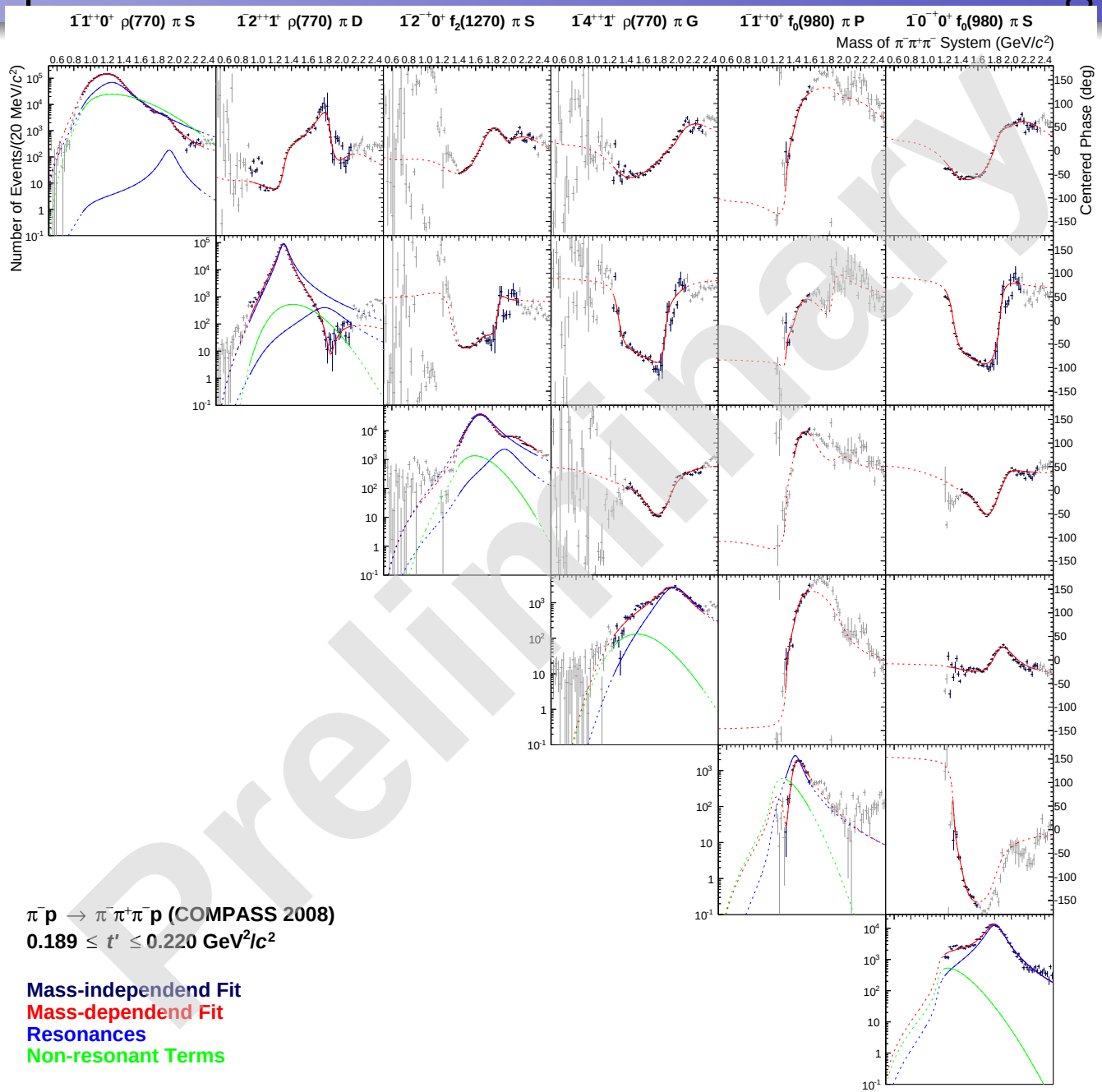


Preliminary

$\pi^-p \rightarrow \pi^-\pi^+\pi^-p$ (COMPASS 2008)
$0.100 \leq t' \leq 0.113$ GeV$^2/c^2$

Mass-independend Fit
Mass-dependend Fit
Resonances
Non-resonant Terms

Mass-dependent fit in $\pi^-\pi^-\pi^+$ - "sub-matrix"higher t'

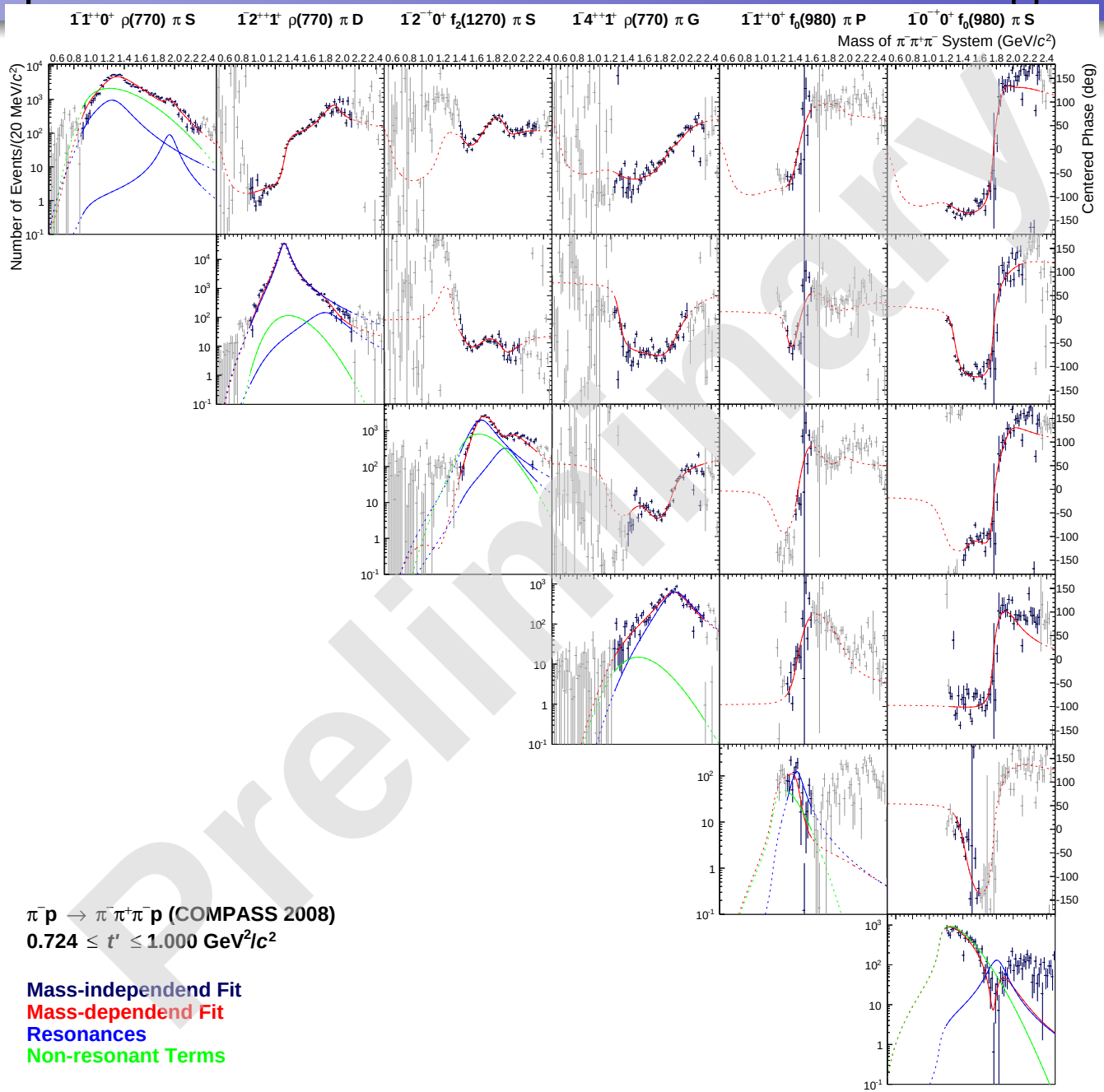


Preliminary

$\pi^-p \rightarrow \pi^-\pi^+\pi^-p$ (COMPASS 2008)
$0.189 \leq t' \leq 0.220$ GeV$^2/c^2$

Mass-independend Fit
Mass-dependend Fit
Resonances
Non-resonant Terms

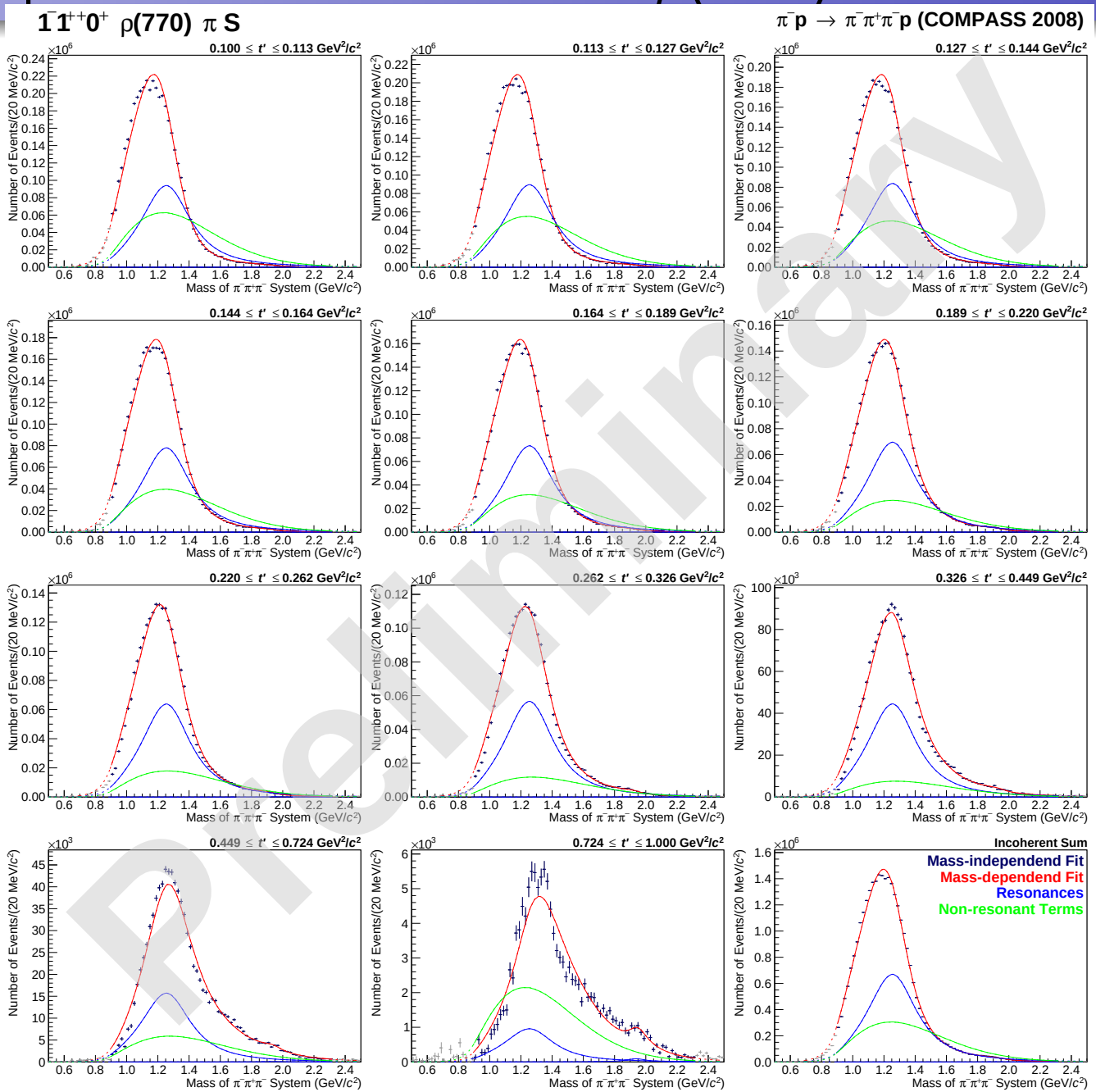
Mass-dep. fit in $\pi^-\pi^-\pi^+$ - "sub-matrix"the highest t'



$\pi^-p \rightarrow \pi^-\pi^+\pi^-p$ (COMPASS 2008)
$0.724 \leq t' \leq 1.000$ GeV$^2/c^2$

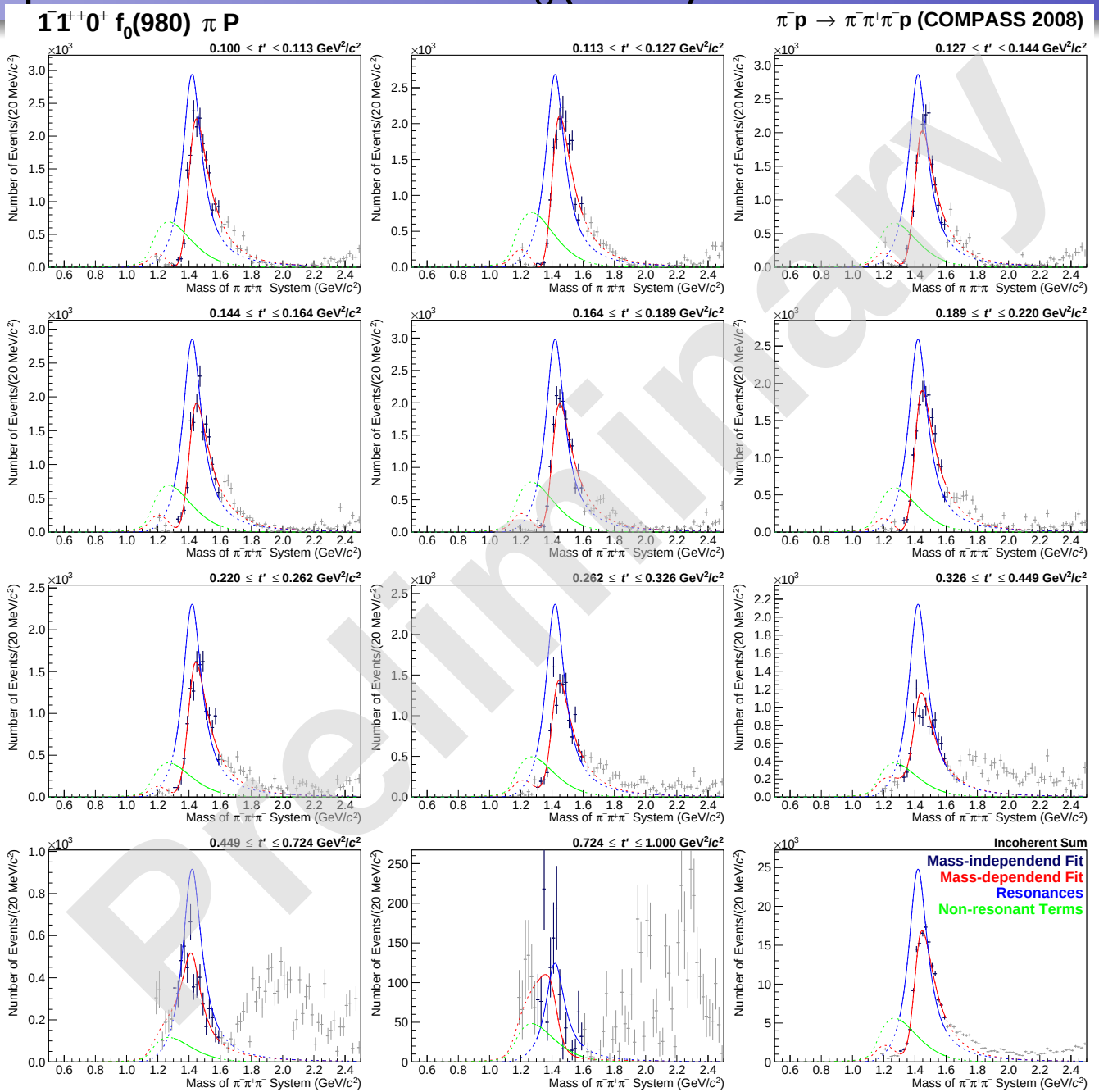
Mass-independend Fit
Mass-dependend Fit
Resonances
Non-resonant Terms

Mass-dep. fit in $\pi^-\pi^-\pi^+$ $1^{++}0^+\rho(770)\pi^-$ in 11 t' bins



Preliminary

Mass-dependent fit: $1^{++}0^+ f_0(980)\pi^-$ in 11 t' bins

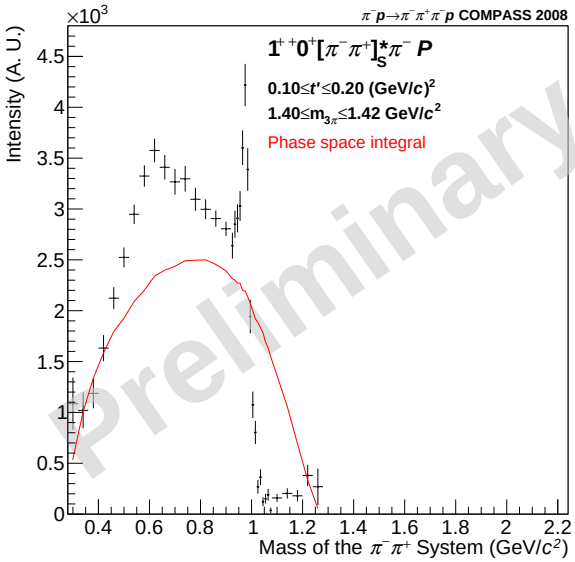


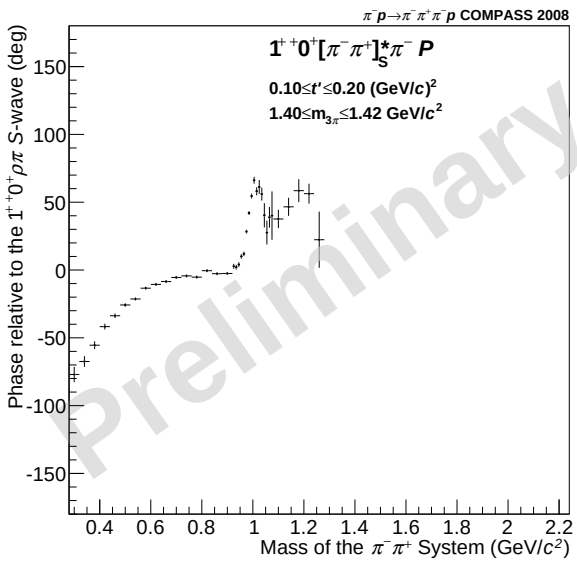
Mass-dependent fit in $\pi^-\pi^-\pi^+$ resonance parameters table

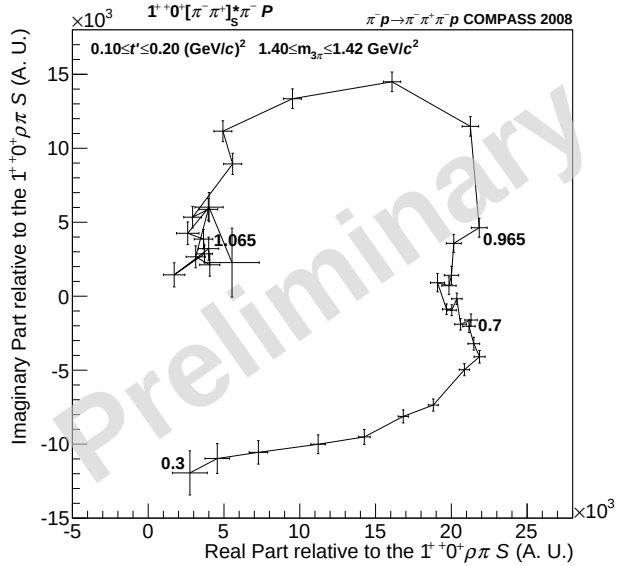
	J^{PC}	mass range (MeV/c^2)	width range (MeV/c^2)	PDG	
major waves					
$a_1(1260)$	1^{++}	$1260 - 1290$	$360 - 420$	1230 ± 40	$250 - 400$
$a_2(1320)$	2^{++}	$1312 - 1315$	$108 - 115$	$1318.3^{+0.5}_{-0.6}$	$105^{+1.6}_{-1.9}$
$\pi_2(1670)$	2^{-+}	$1635 - 1663$	$265 - 305$	1672.2 ± 3.0	260 ± 9
$a_4(2040)$	4^{++}	$1928 - 1959$	$360 - 400$	1996^{+10}_{-9}	255^{+28}_{-24}
$\pi(1800)$	0^{-+}	$1790 - 1807$	$212 - 230$	1812 ± 12	208 ± 12
$\pi_2(1880)$	2^{-+}	$1900 - 1990$	$210 - 390$	1895 ± 16	235 ± 34
states not in PDG summary table					
$a_1(1930)$	1^{++}	$1920 - 2000$	$155 - 255$	1930^{+30}_{-70}	155 ± 45
$a_2(1950)$	2^{++}	$1740 - 1890$	$300 - 555$	1950^{+30}_{-70}	180^{+30}_{-70}
$a_1(1420)$	1^{++}	$1412 - 1422$	$130 - 150$		

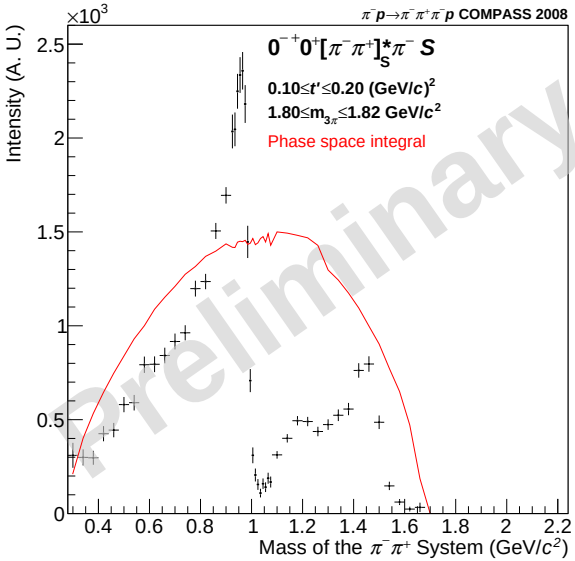
No candidate for $a_1(1420)$ in PDG

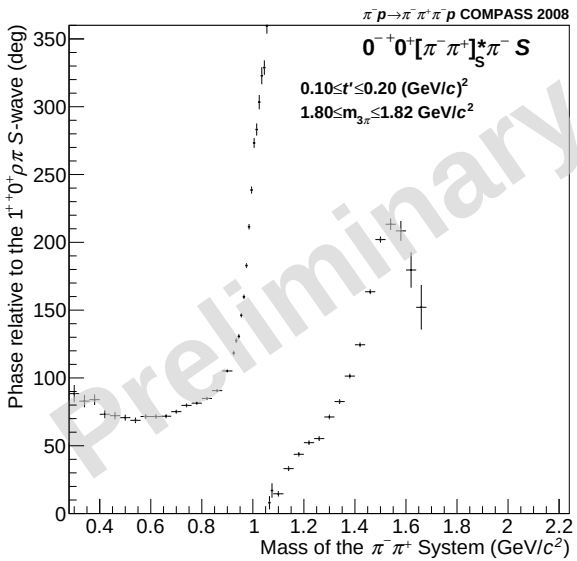
Свободная параметризация изобары $(\pi\pi)_S$ волны

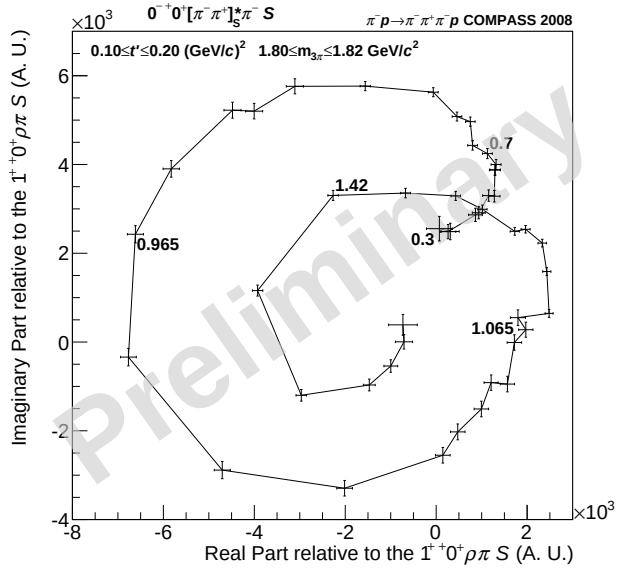




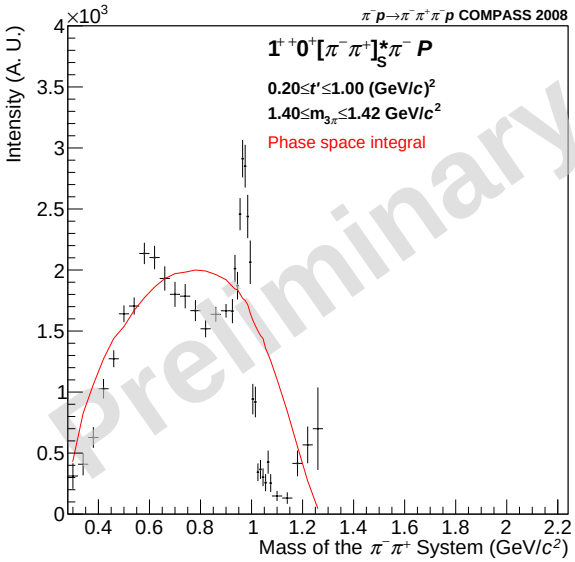


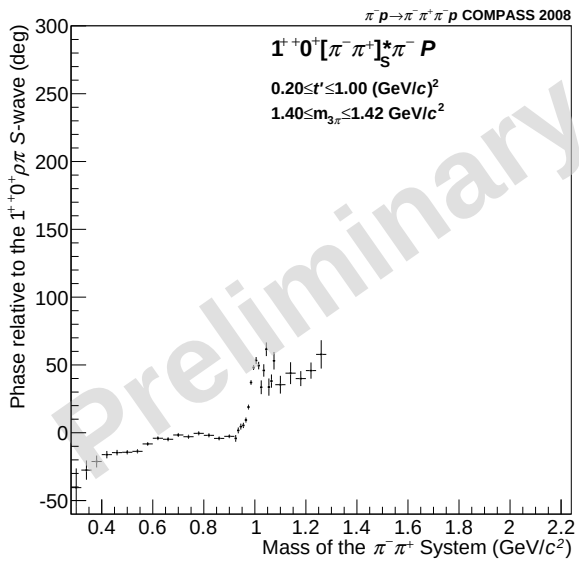


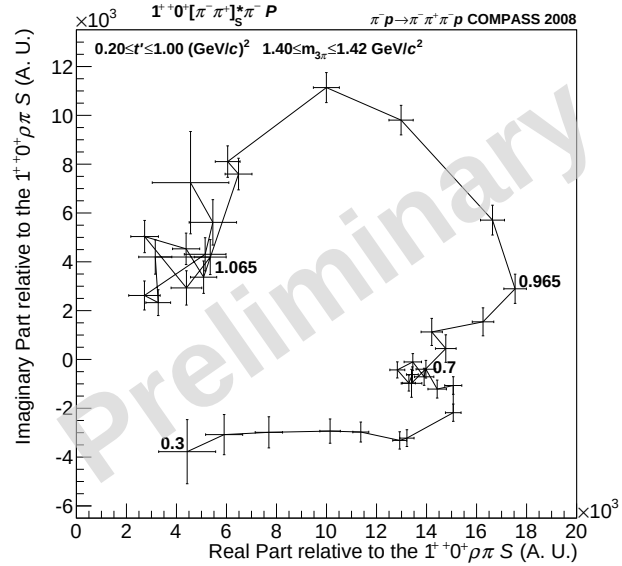


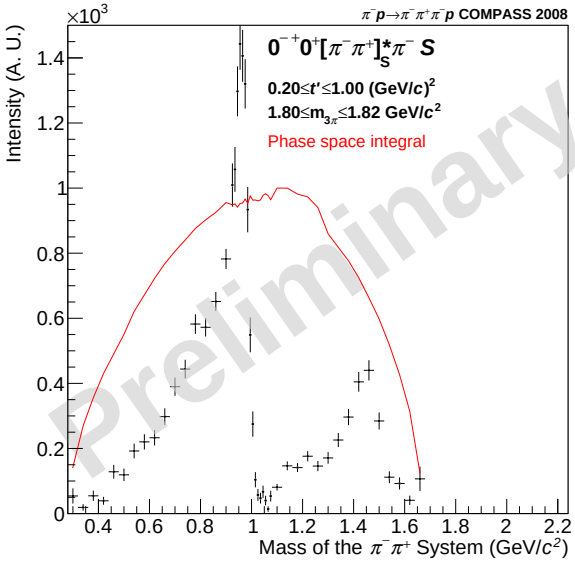


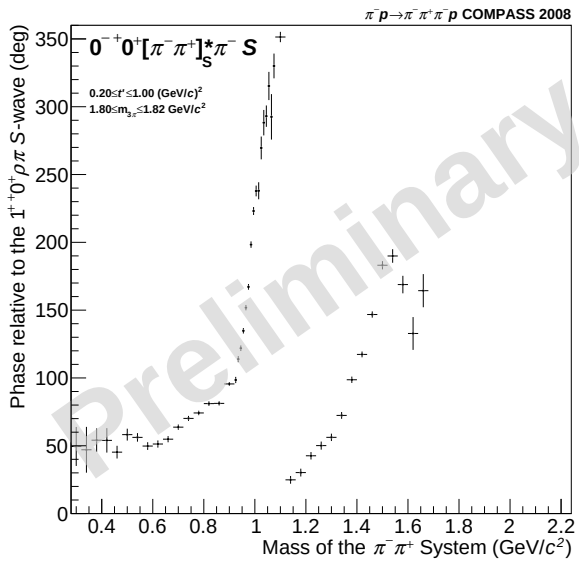
Свободная параметризация изобары $(\pi\pi)_S$ волны

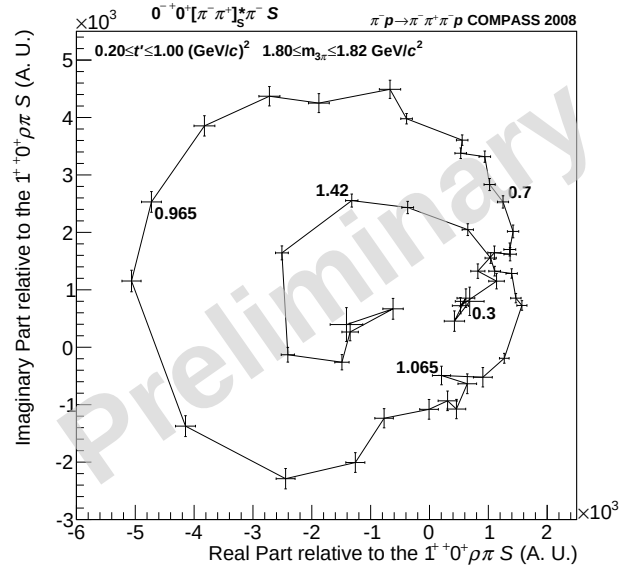




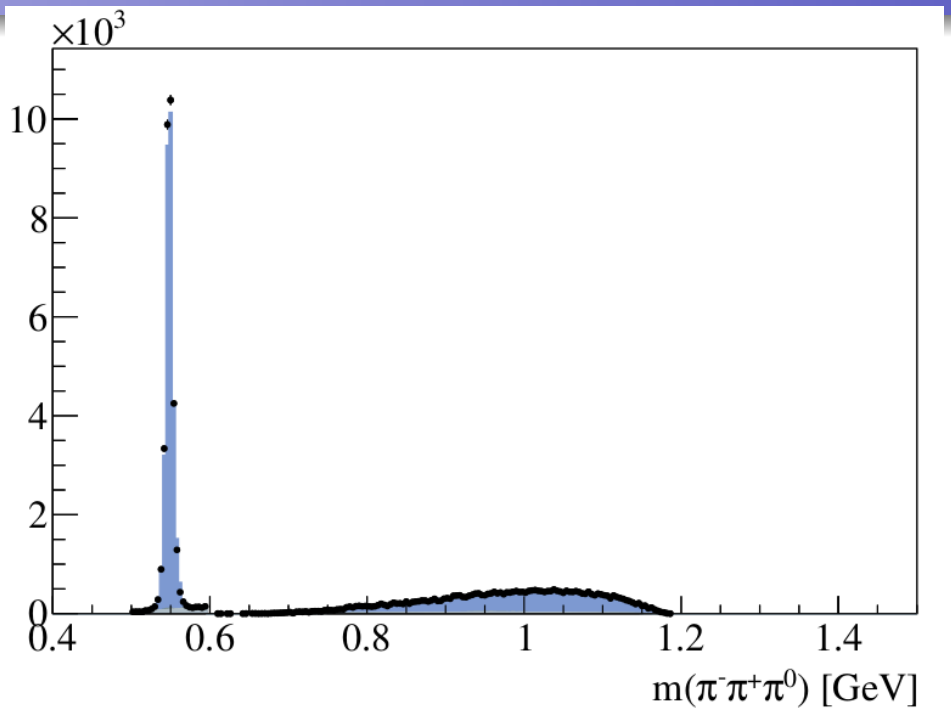


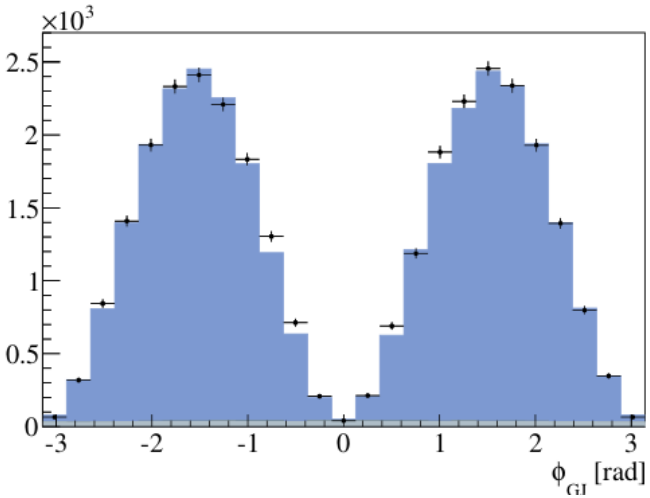


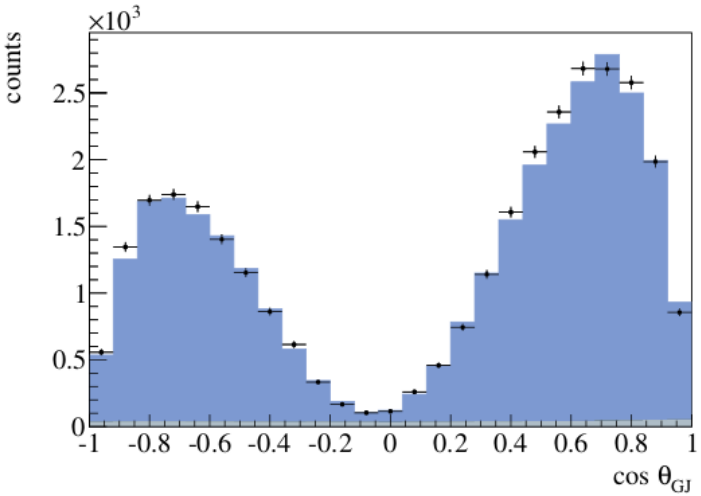




$\pi^- p \to \eta\pi^- p$

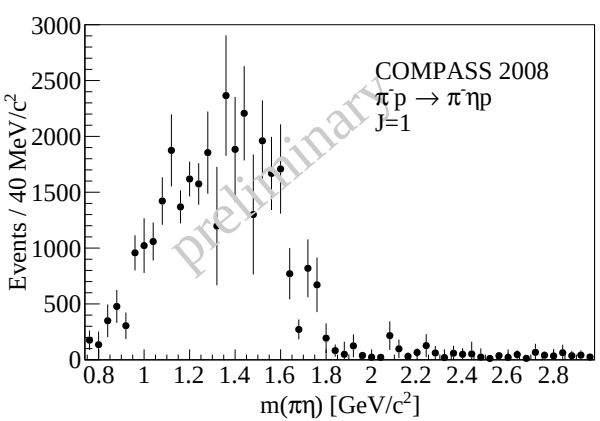


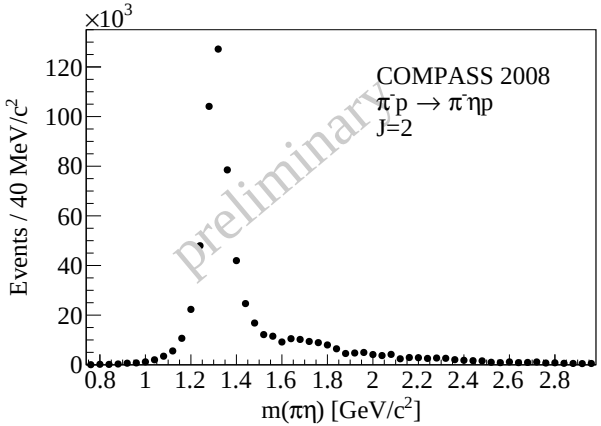


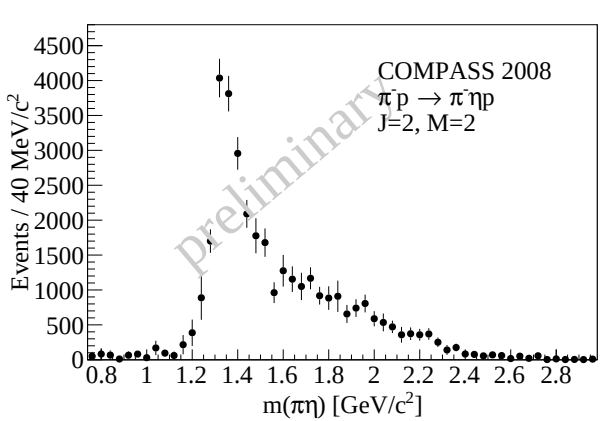


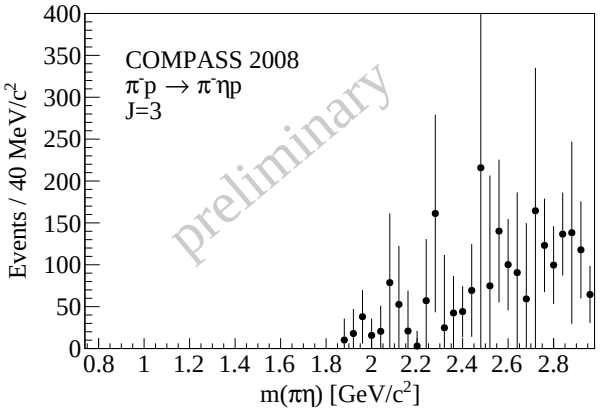
ϕ_{TY}; $sin^2(\phi_{TY})$ implies M=1 NPE dominance

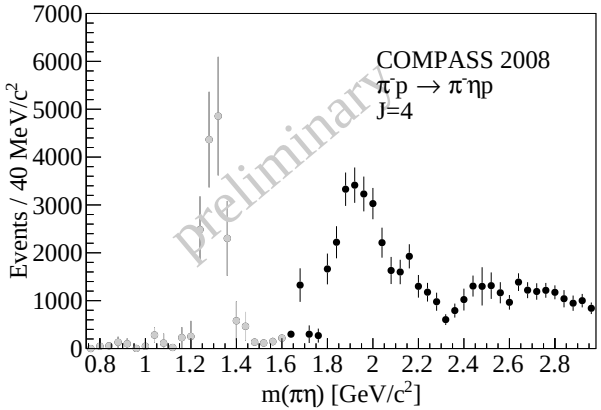
$\pi^- p \to \eta\pi^- p$

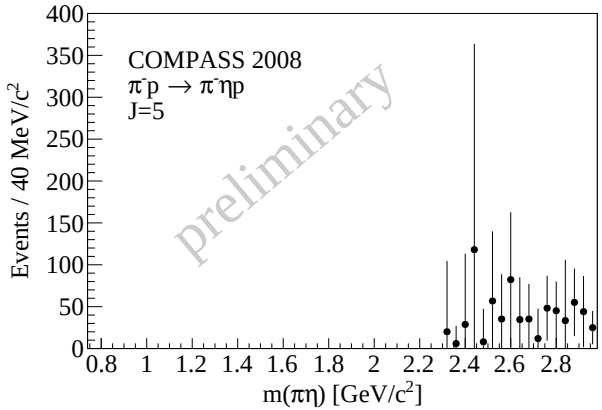


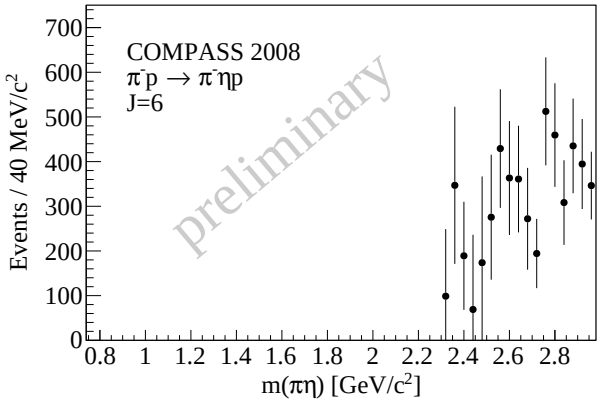




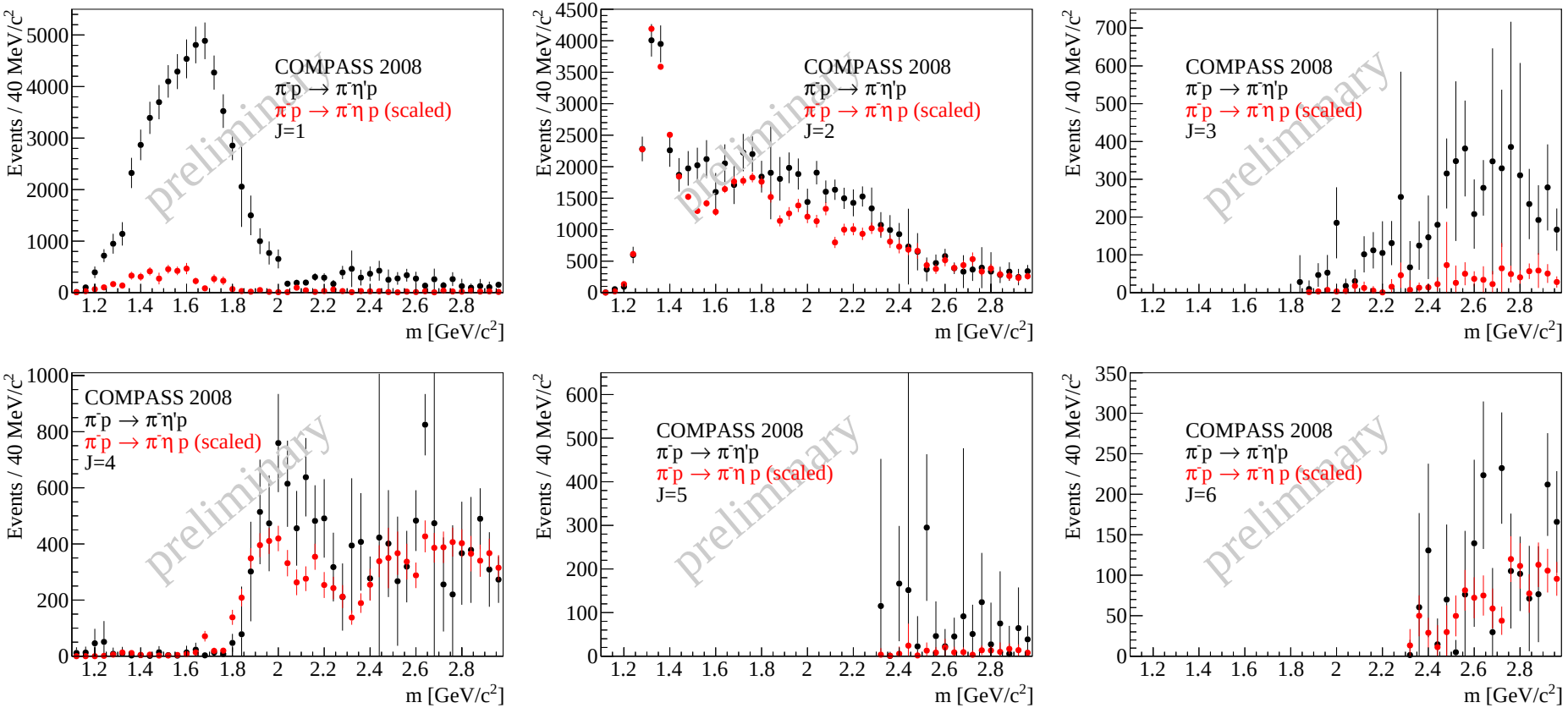








$\eta'\pi^-$(black) vs. scaled $\eta\pi^-$ (red)



Rescale: $(p(\eta')/p(\eta))^{(2J+1)} = 0.045$ (m=1.320, J=2) $= 0.170$ (m=1.950, J=4)

$a_2(1320)$ M=1315 ± 12 MeV $\Gamma = 119 \pm 14$ MeV

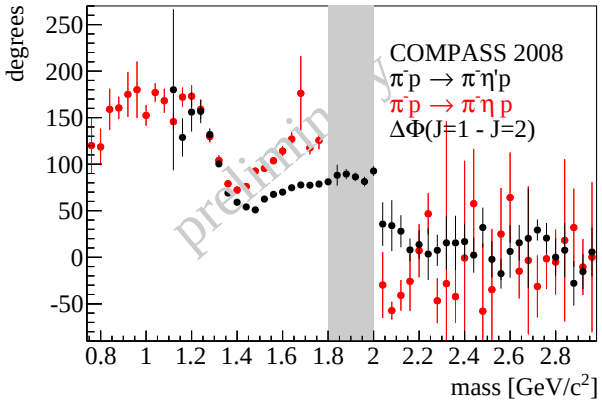
$a_4(2050)$ M=1900^{+80}_{-20} MeV $\Gamma = 300^{+80}_{-100}$ MeV

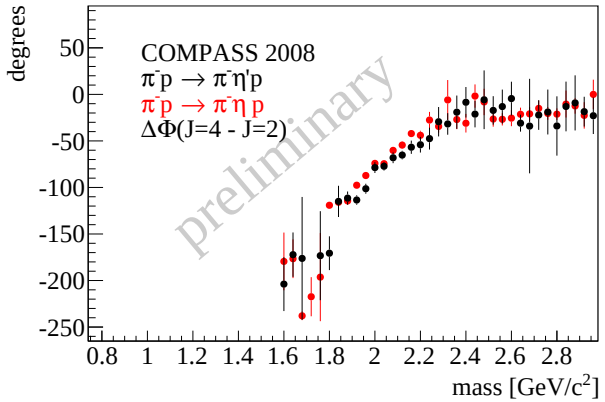
$$\frac{BR(a_2 \to \eta'\pi)}{BR(a_2 \to \eta\pi)} = (5 \pm 2)\%$$

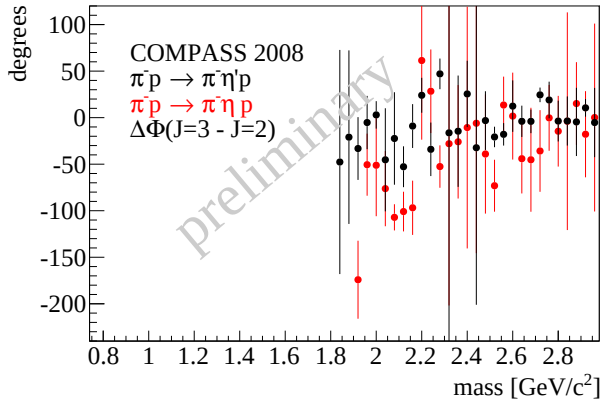
$$\frac{BR(a_4 \to \eta'\pi)}{BR(a_4 \to \eta\pi)} = (23 \pm 7)\%$$

Input stat: 110 000 of $\eta\pi^-$ 35 000 of $\eta'\pi^-$

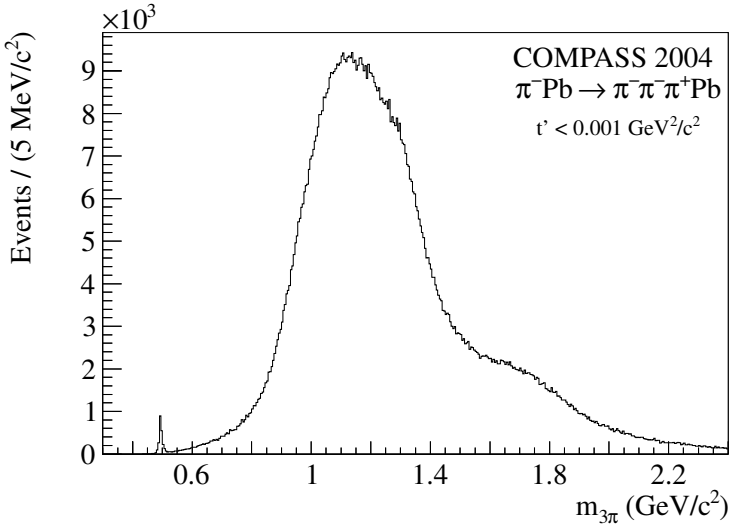
движения фаз в системах $\eta\pi^-$ и $\eta'\pi^-$

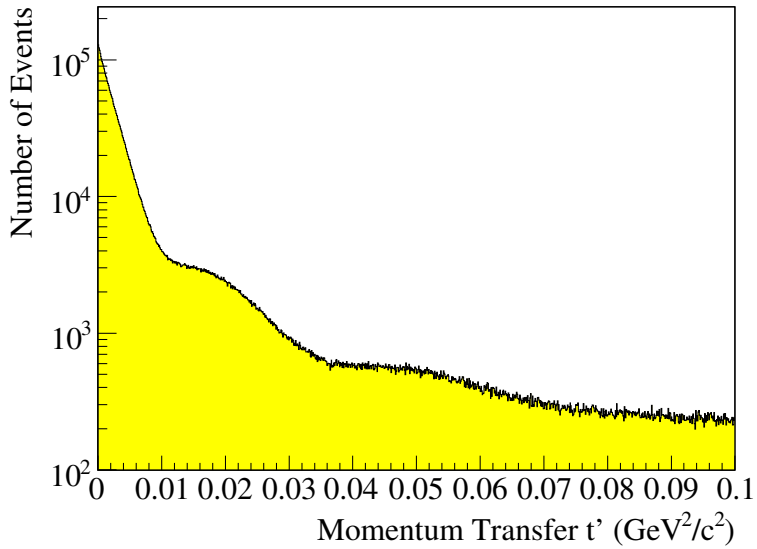


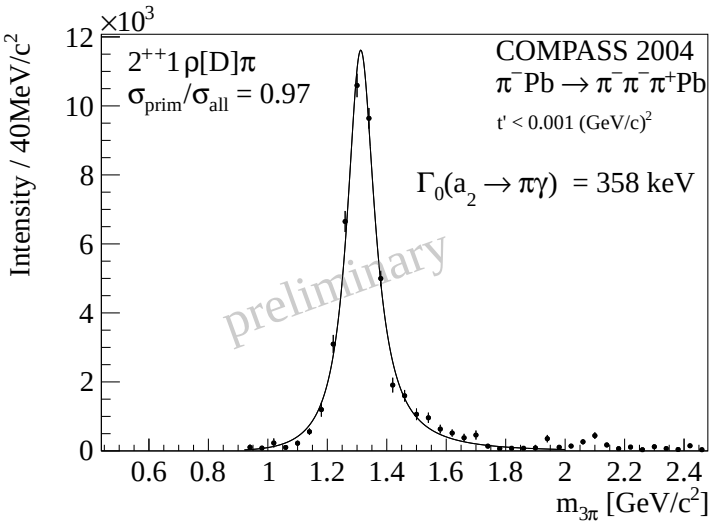


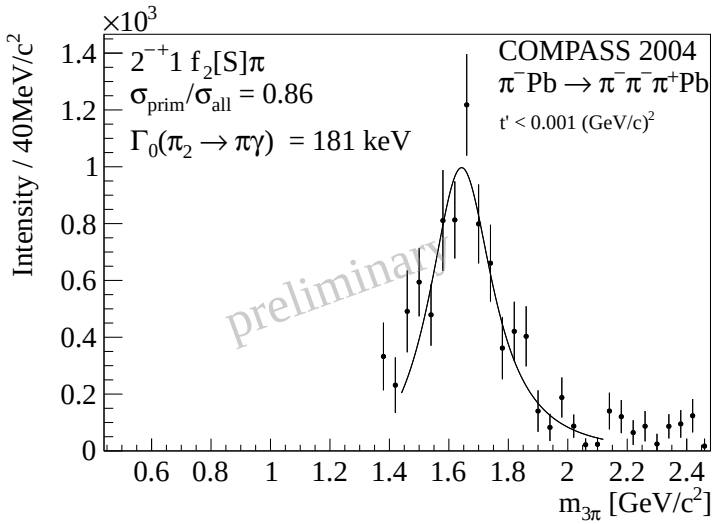


$\pi^- Pb \to \pi^-\pi^-\pi^+ Pb$





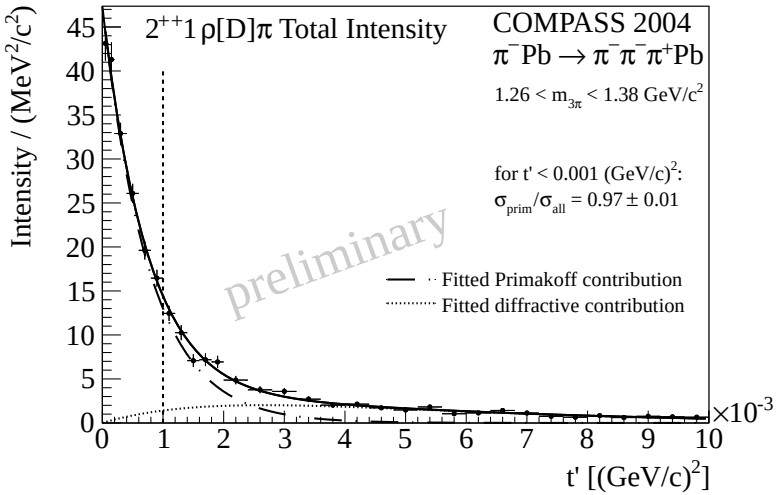


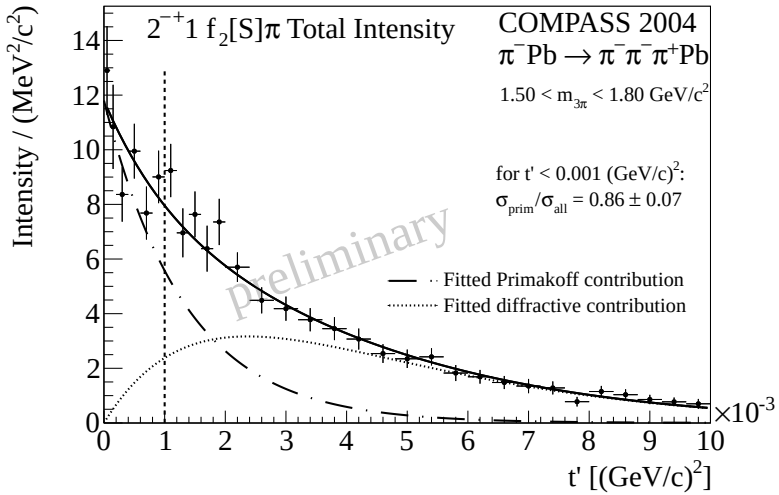


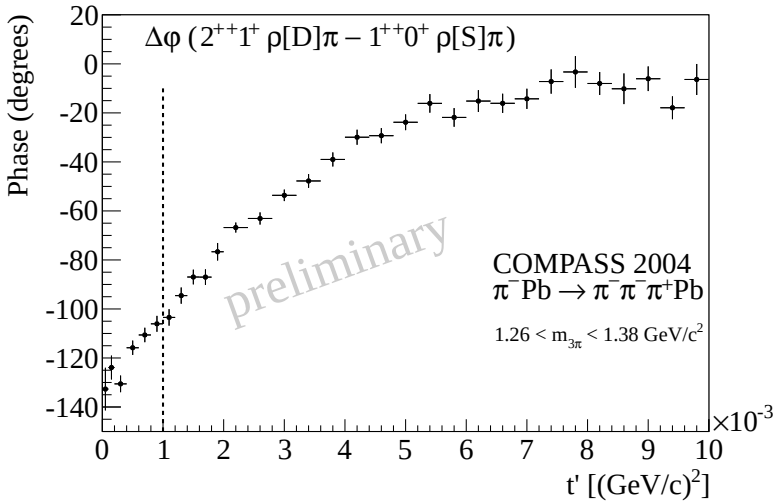
$\Gamma_0(a_2(1320) \to \pi\gamma) = (358 \pm 6_{stat} \pm 42_{syst})$ keV

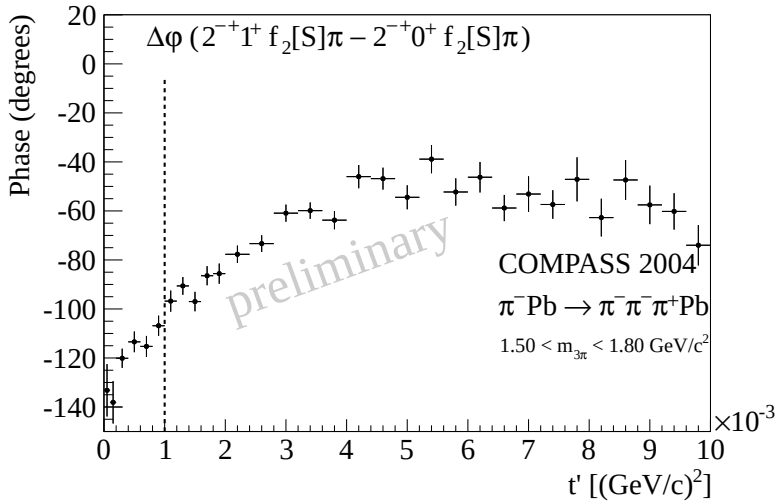
$\Gamma_0(\pi_2(1670) \to \pi\gamma) = (181 \pm 11_{stat} \pm 27_{syst})\eta_B R$ keV with $\eta_B R = 0.56/BR_{f_2\pi\,true}$

Validation of the Primakoff nature: intens and phases

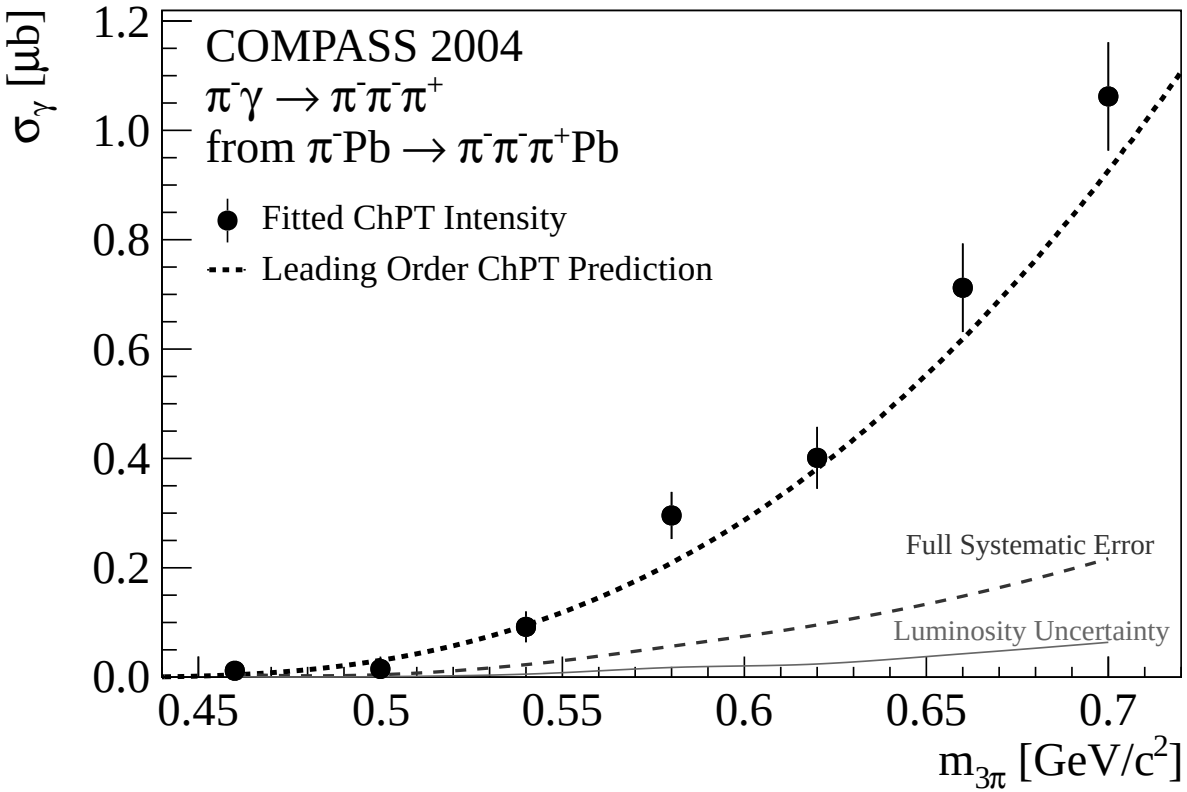








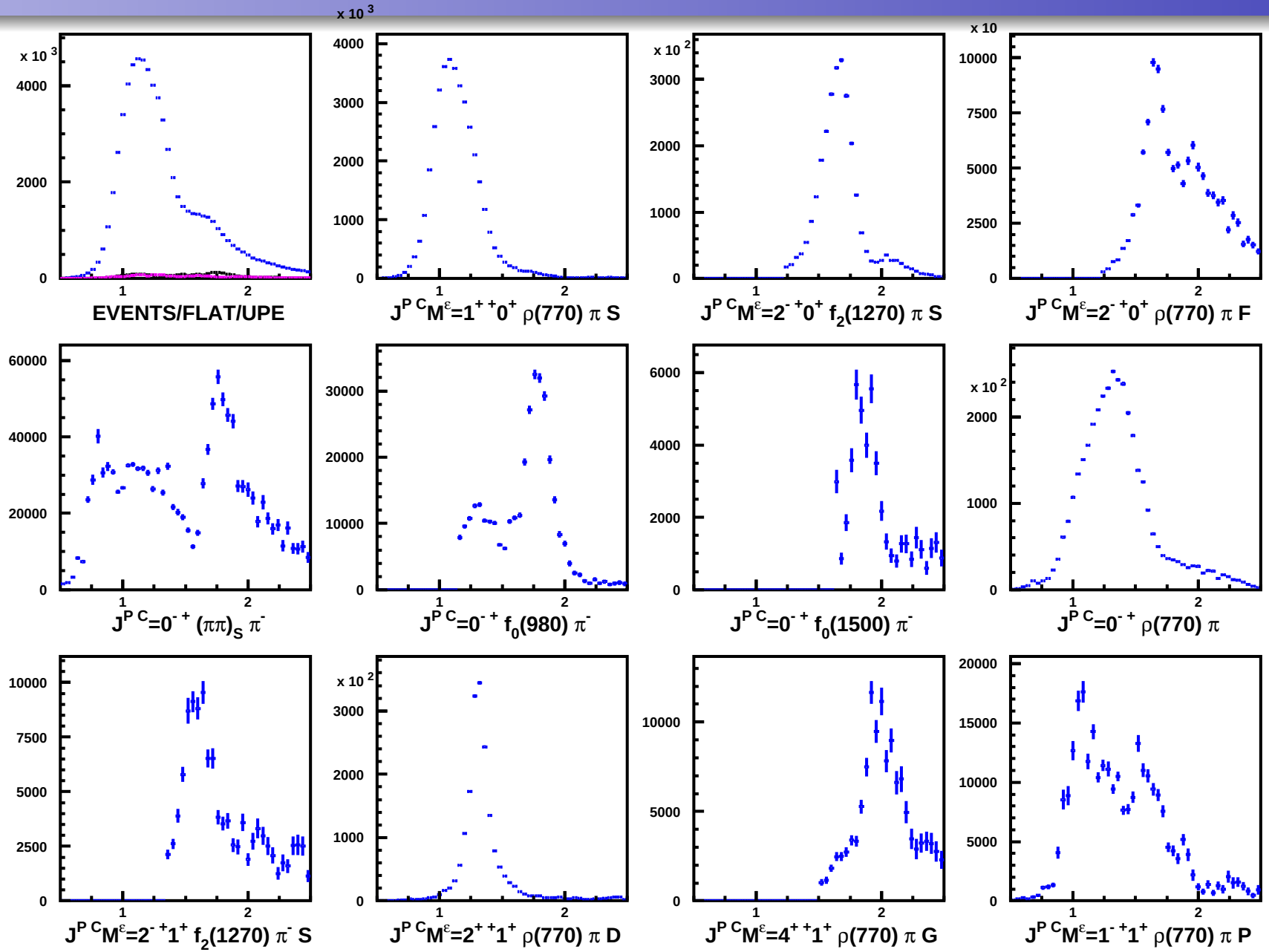
$\pi^- Pb \to \pi^-\pi^-\pi^+ Pb$



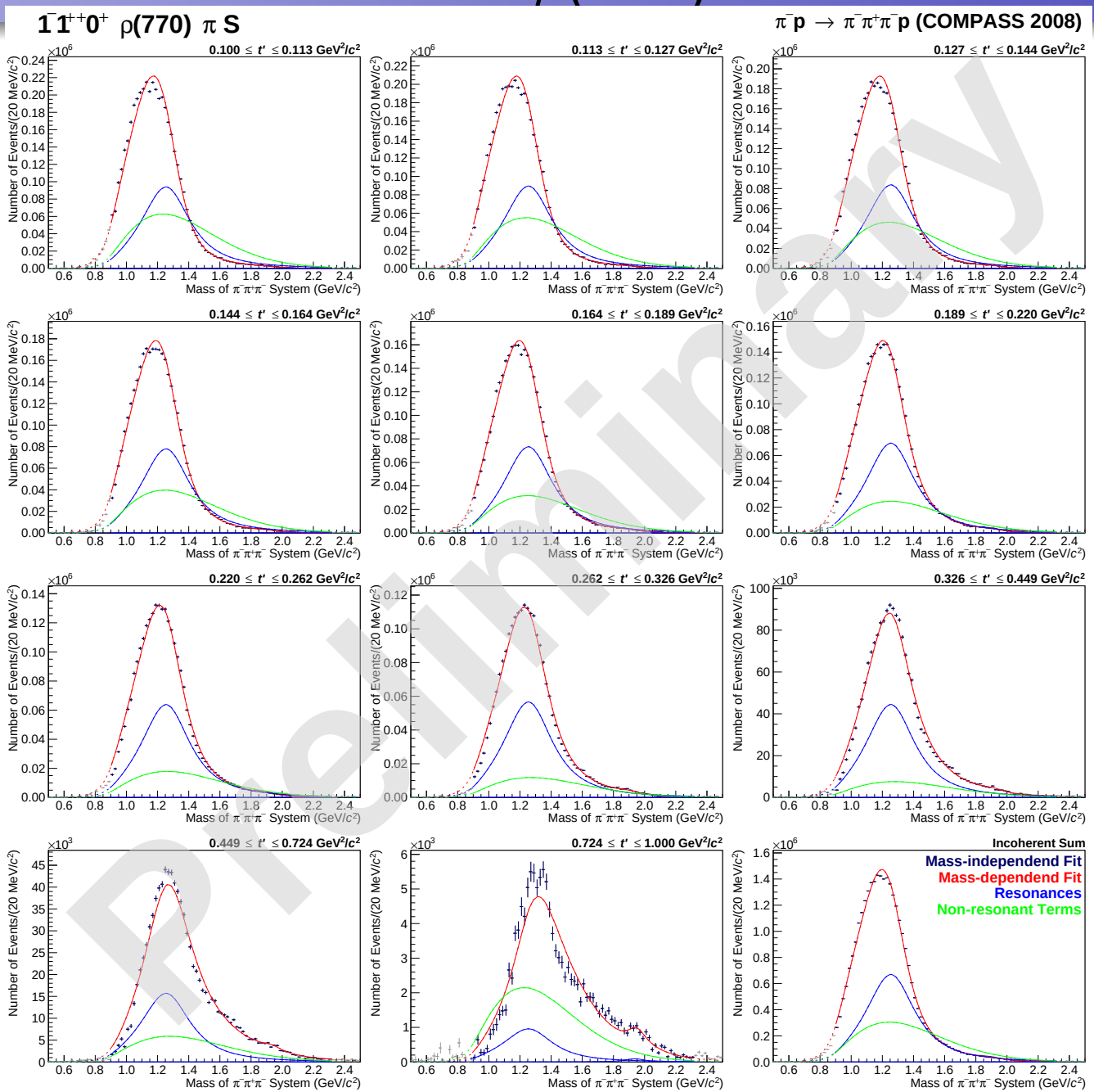
Summary

- The reactions $\pi^- p \to \pi^-\pi^-\pi^+ p$ and $\pi^- p \to \pi^-\pi^0\pi^0 p$
  - mass-independent fits show precize isospin symmetry for intensities (when expected)
  - mass-dependent fit: stable parameters of "first"resonance in each of 6 partial waves fitted
  - $a_1(1420)$ M = 1412-1422 MeV/c^2, Γ=130-150 MeV/c^2
  - model-independent parametrization of $(\pi\pi)_S$ once done in $0^{-+}, 1^{++}0^+$ and $2^{-+}0^+$ amplitudes in 3π systems - work in progress
- The reactions $\pi^- p \to \eta\pi^- p$ and $\pi^- p \to \eta'\pi^- p$
  - scaled mass-independent fit intensities and relative phases show similar nature of spin-even waves
  - Branching ratios $a_2(1320) \to \frac{\eta'\pi}{\eta\pi}$ and $a_4(2050) \to \frac{\eta'\pi}{\eta\pi}$ (first estimate !)
  - spin-odd waves enhanced in $\eta'\pi$
- The reaction $\pi^- Pb \to \pi^-\pi^-\pi^+ Pb$ at very low t'
  - Rad. widths $\Gamma(a_2(1320) \to \pi\gamma)$ and $\Gamma(\pi_2(1670) \to \pi\gamma)$ (first measurement !)
  - Chiral perturbation theory works for the measured cross-section for $\pi^-\gamma \to \pi^-\pi^-\pi^+$

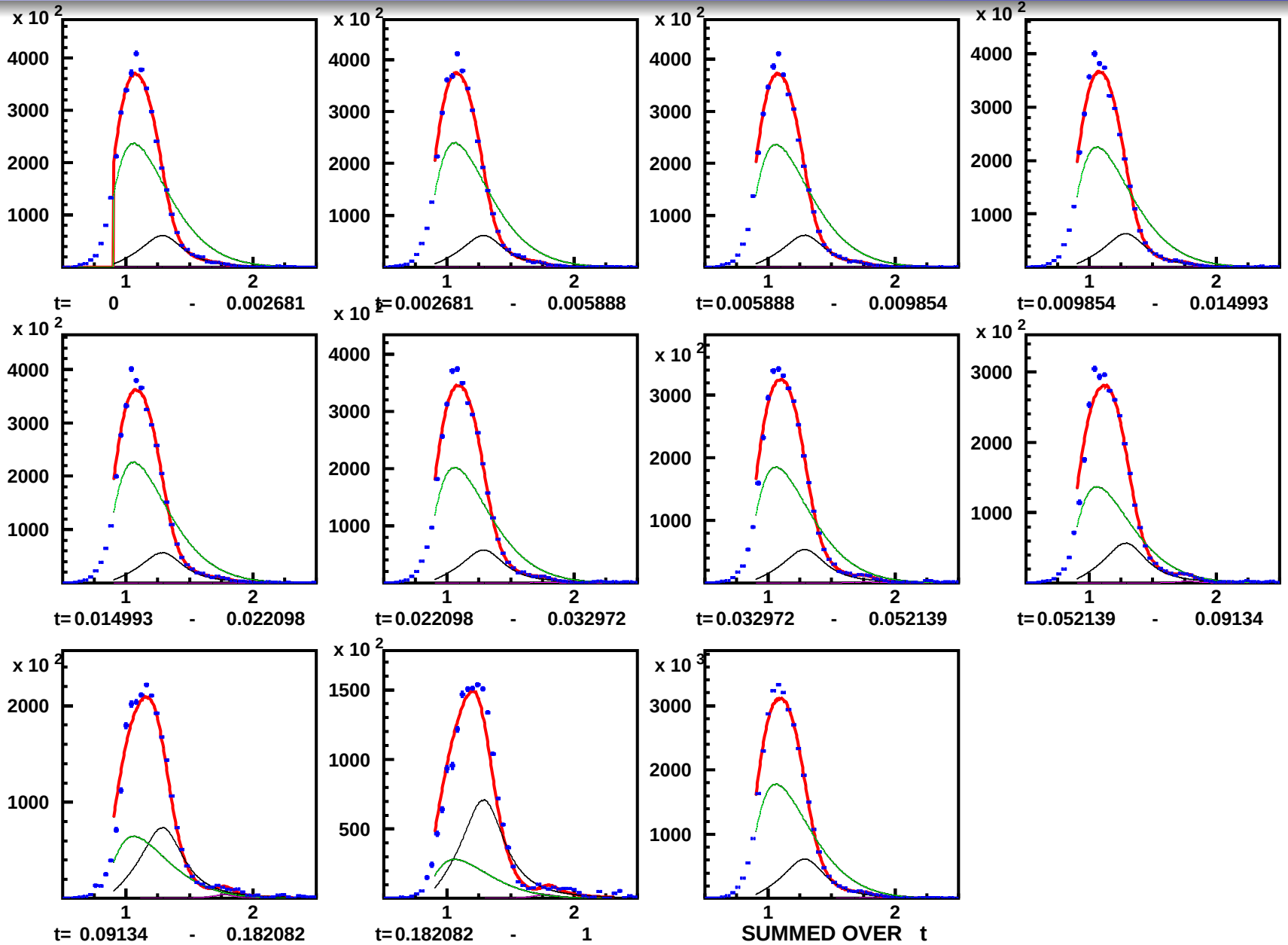
VES $\pi^-\pi^0\pi^0$



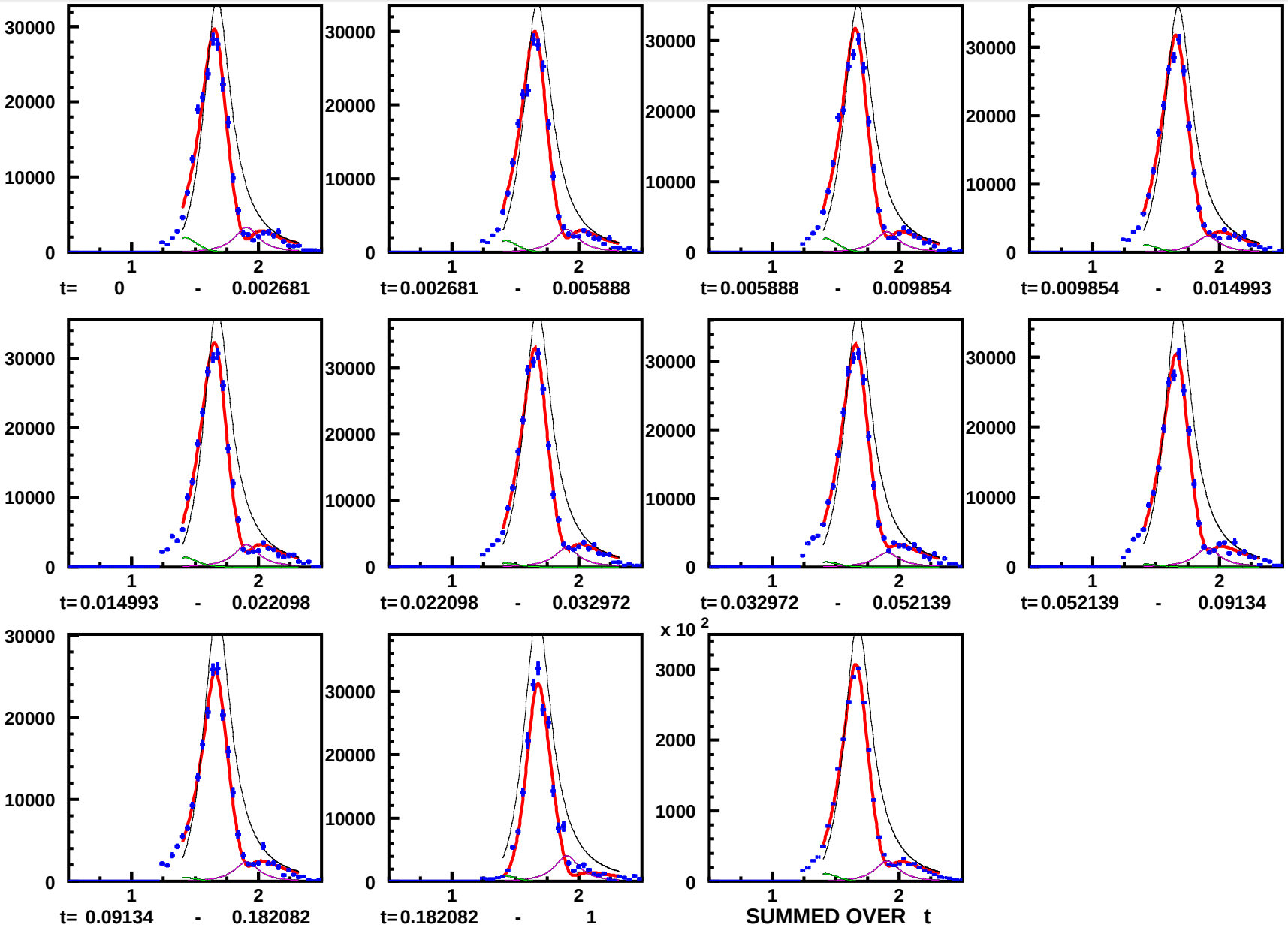
COMPASS $\pi^-\pi^-\pi^+$ $1^{++}0^+\rho(770)\pi^-$ in 11 t' bins

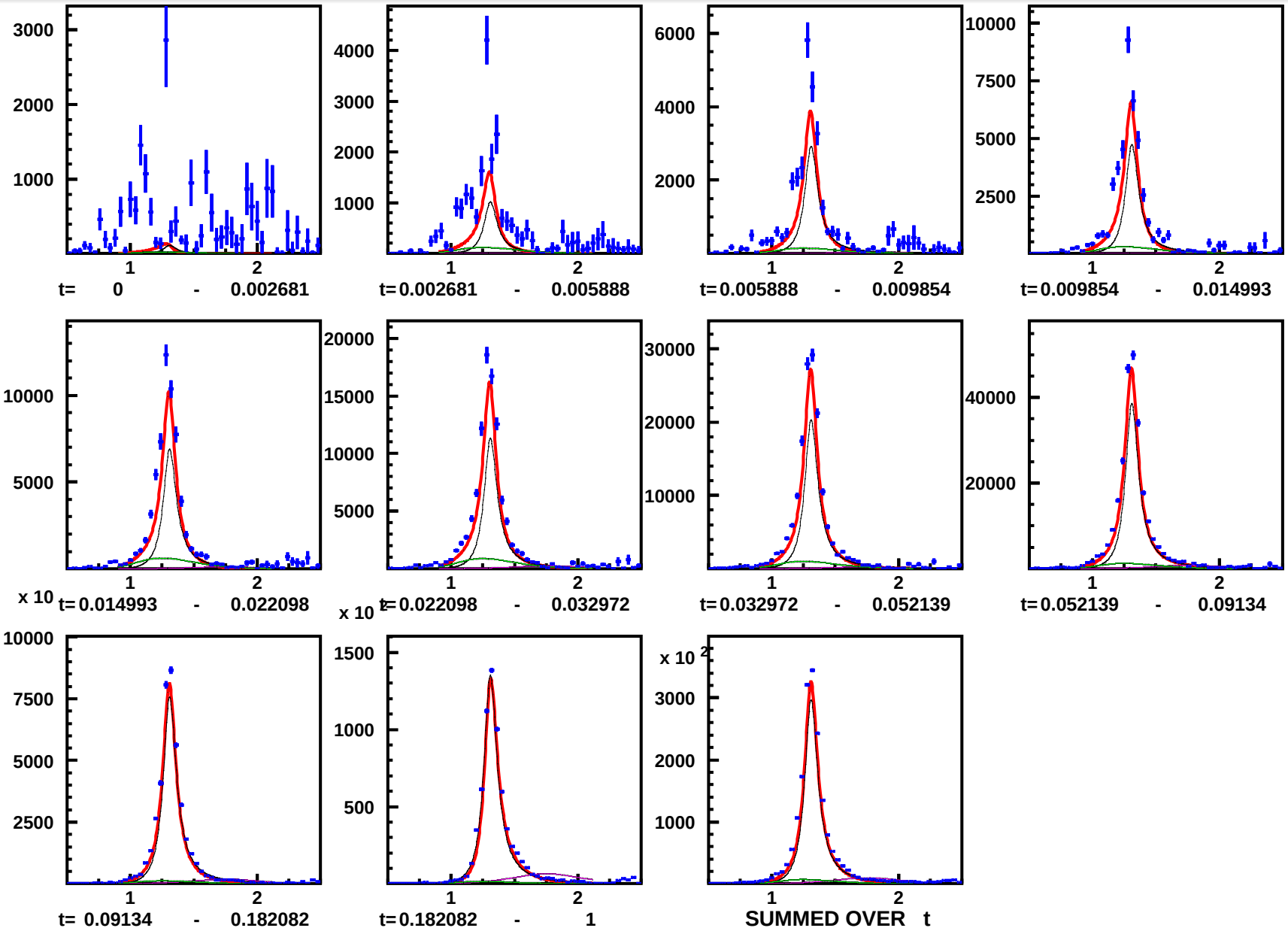


Preliminary


x 10 2
4000
3000
2000
1000
1
2
t= 0 - 0.002681
t= 0.002681 - 0.005888
t= 0.005888 - 0.009854
t= 0.009854 - 0.014993
t= 0.014993 - 0.022098
t= 0.022098 - 0.032972
t= 0.032972 - 0.052139
t= 0.052139 - 0.09134
t= 0.09134 - 0.182082
t= 0.182082 - 1
x 10 3
SUMMED OVER t

$J^{PC}M^{\varepsilon}=2^{-+}0^{+}$ $f_2(1270)$ π S

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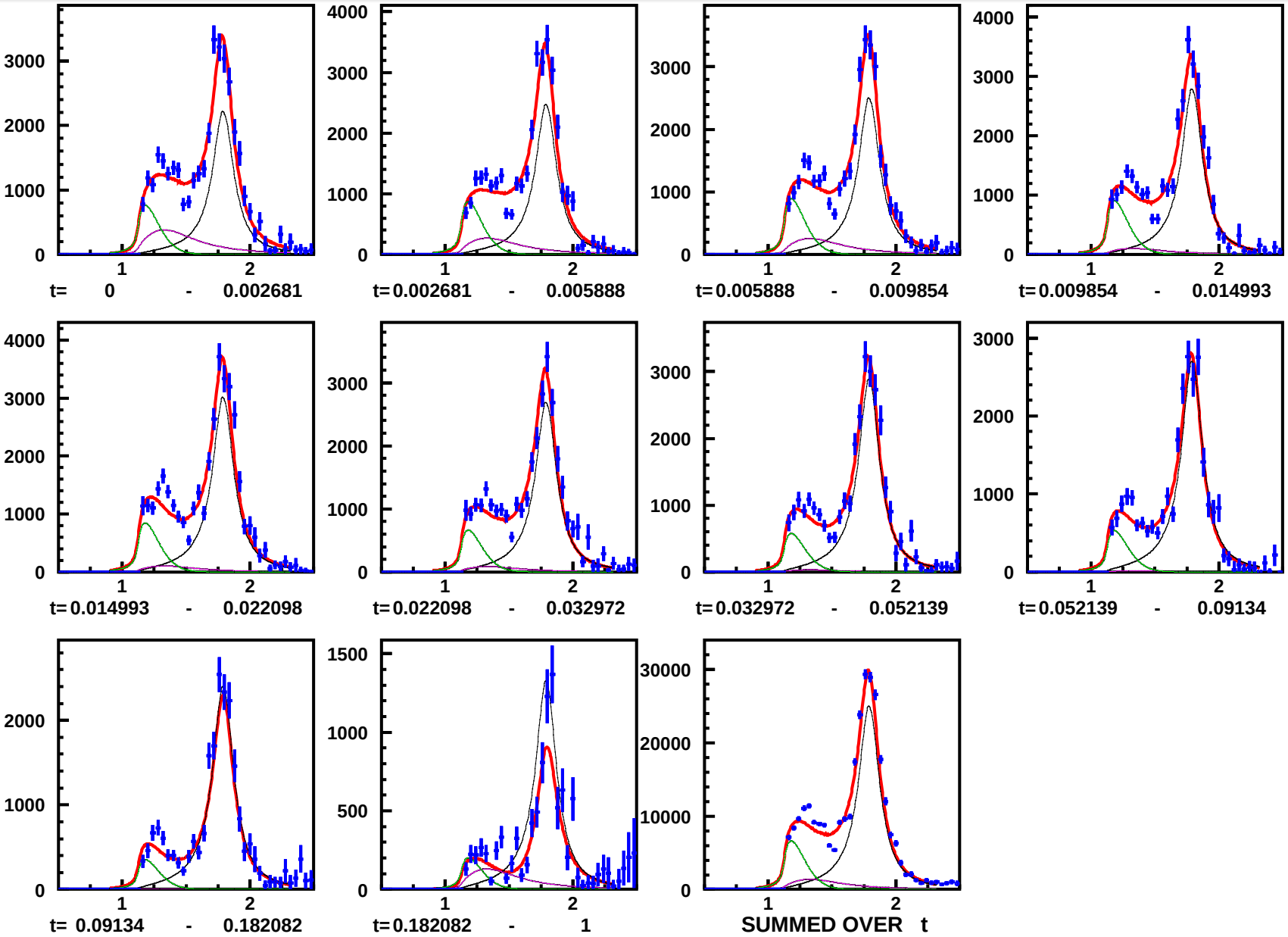
t= 0.009854 - 0.014993
x 10
t= 0.014993 - 0.022098
x 10
t= 0.022098 - 0.032972
t= 0.032972 - 0.052139
t= 0.052139 - 0.09134
t= 0.09134 - 0.182082
t= 0.182082 - 1
x 10 2
SUMMED OVER t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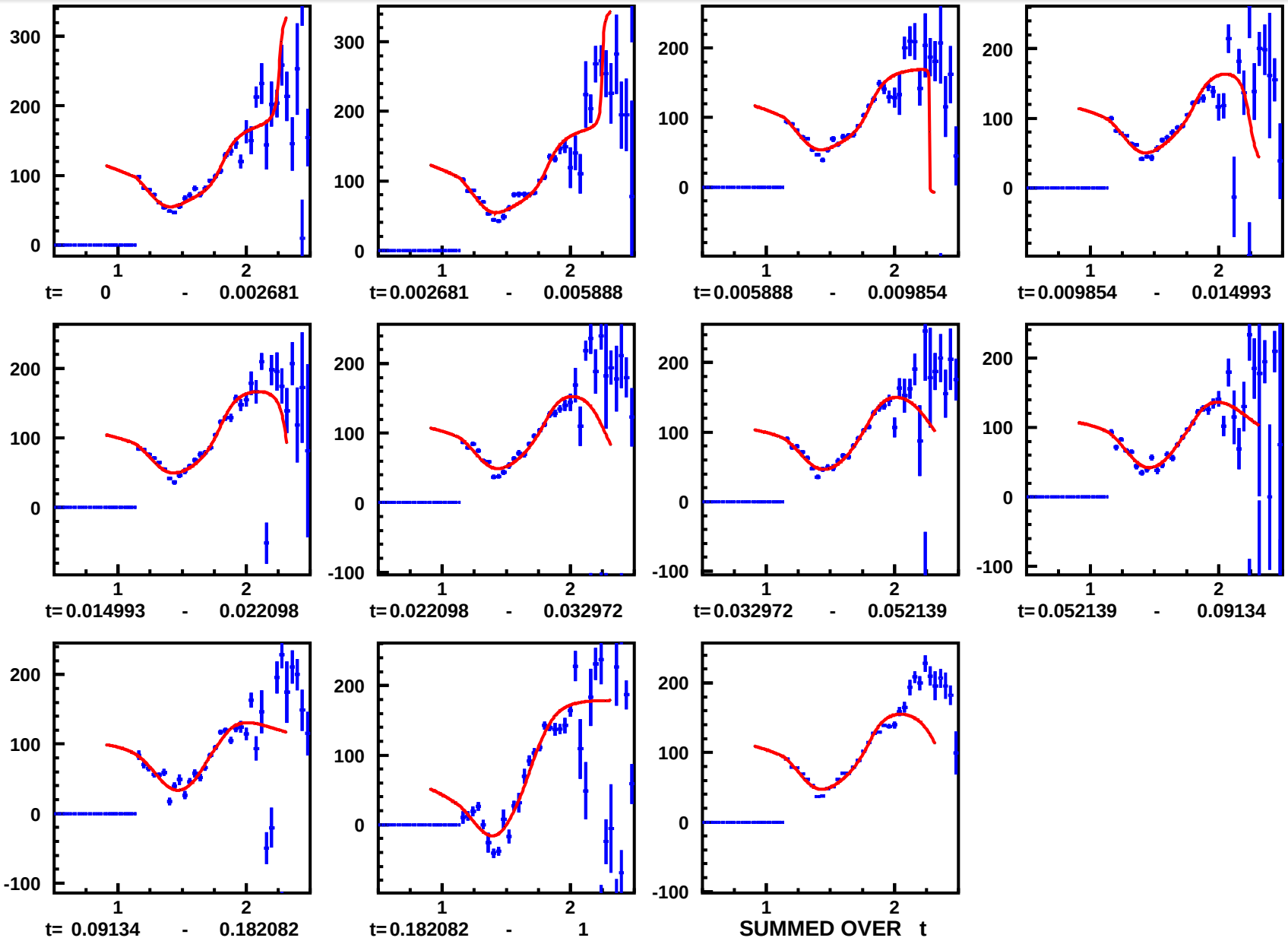
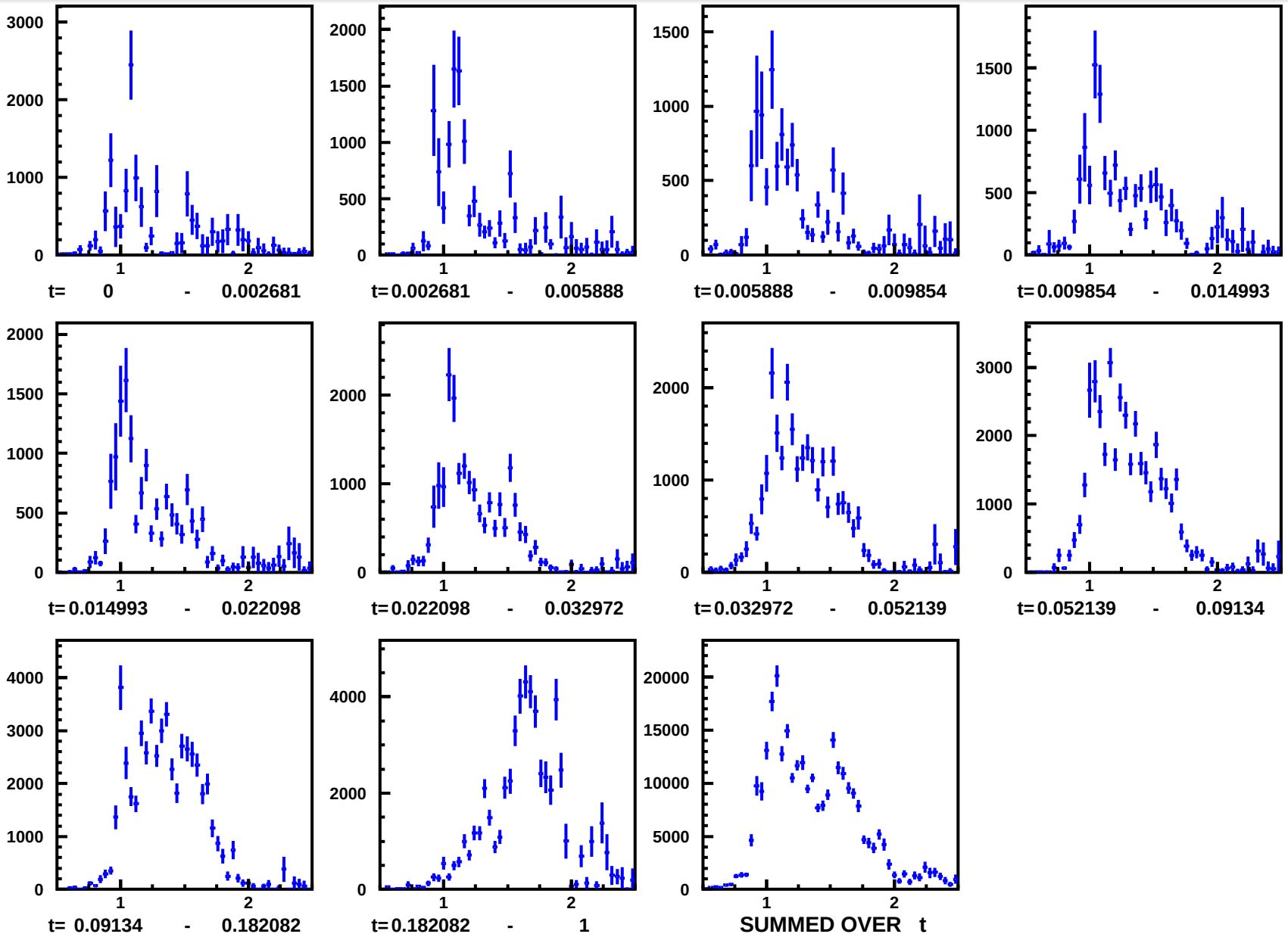
t= 0.022098 - 0.032972
t= 0.032972 - 0.052139
t= 0.052139 - 0.09134
t= 0.09134 - 0.182082
t= 0.182082 - 1
SUMMED OVER t

$\phi(\ 0^{-+}\ f_0(980)\ \pi$ - $1^{++}\ \rho\pi)$

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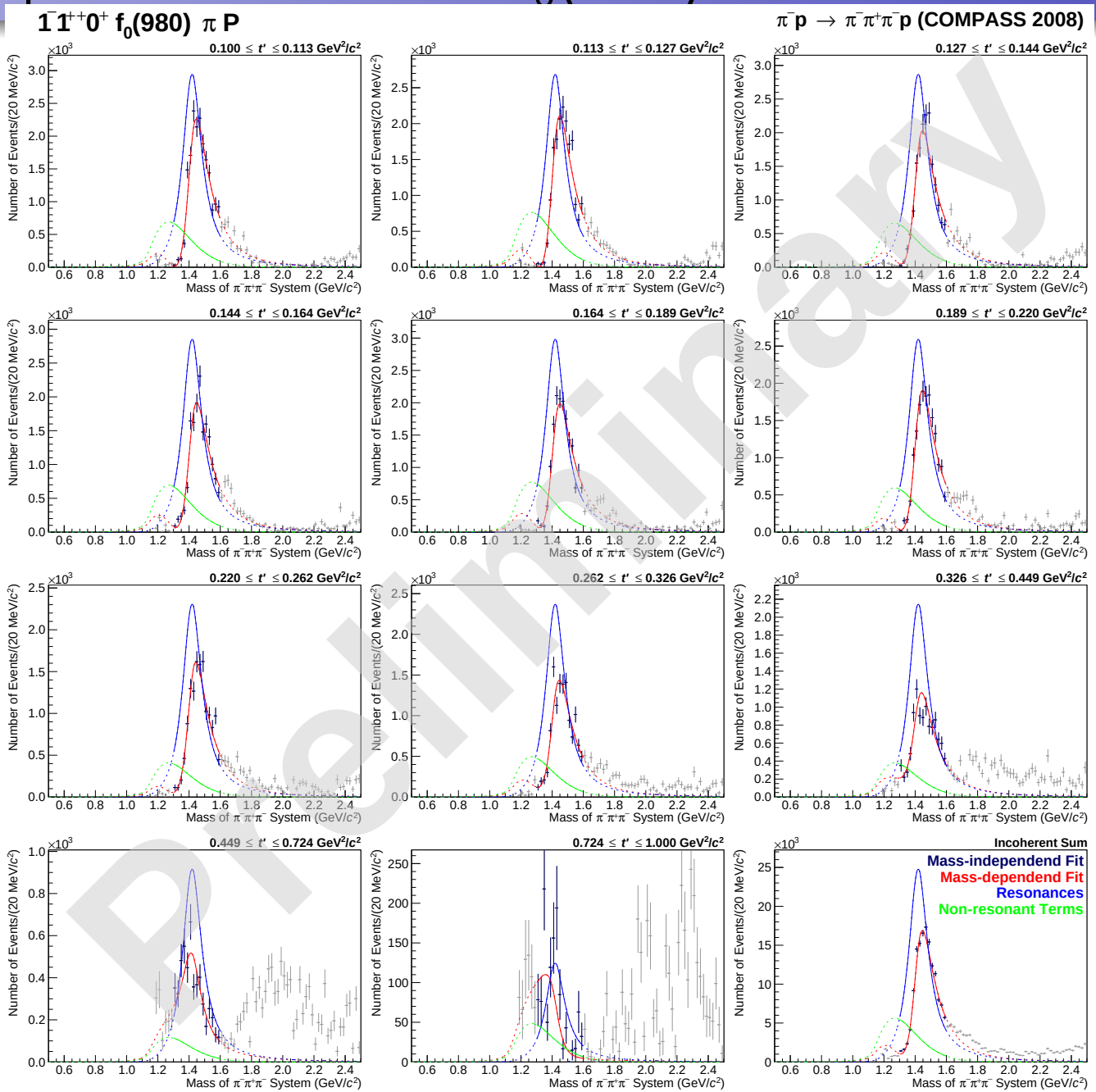
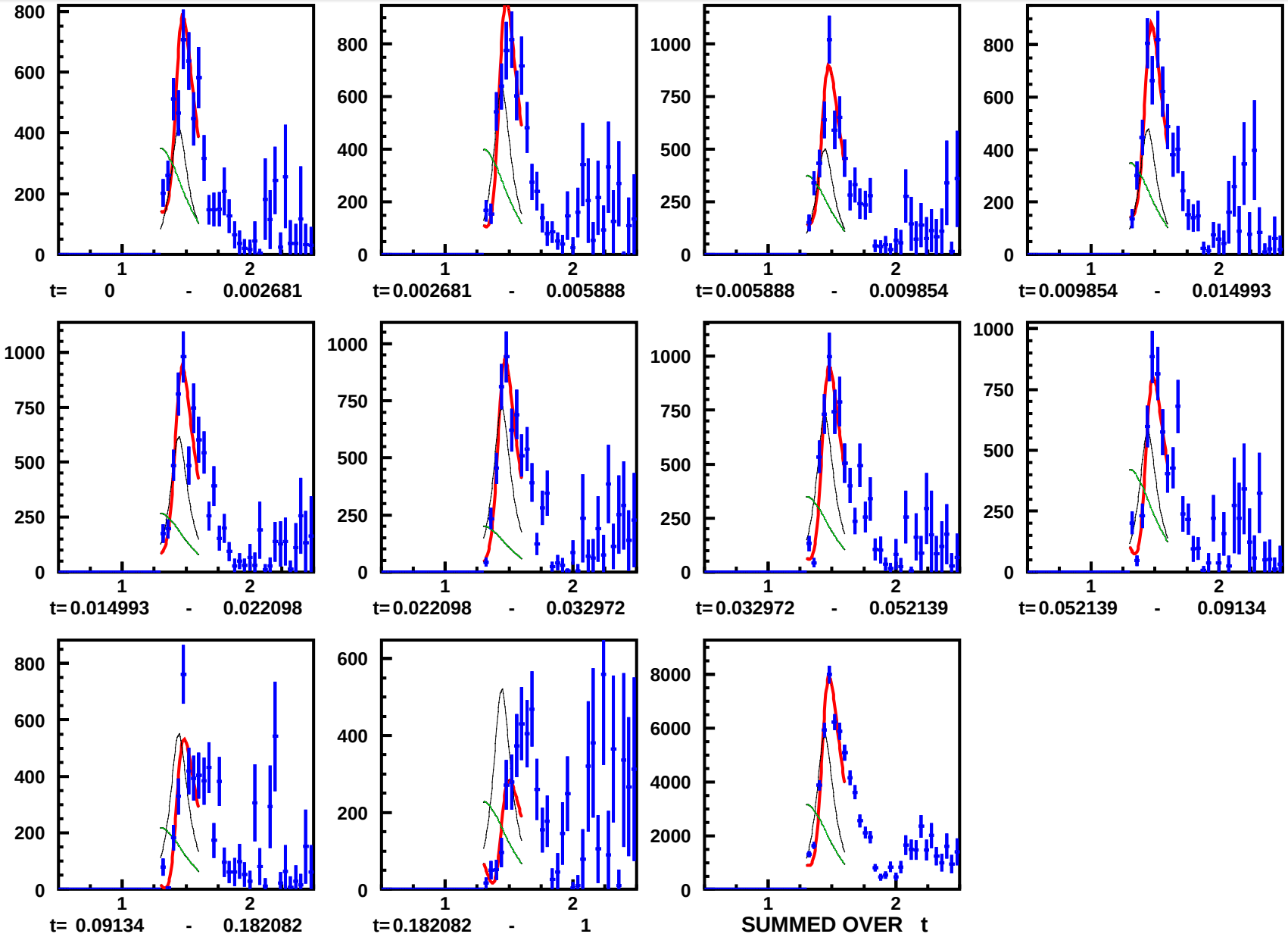
t=0.014993 - 0.022098
t=0.022098 - 0.032972
t=0.032972 - 0.052139
t=0.052139 - 0.09134
t= 0.09134 - 0.182082
t=0.182082 - 1
SUMMED OVER t

Mass-dependent fit: $1^{++}0^+ f_0(980)\pi^-$ in 11 t' bins



Preliminary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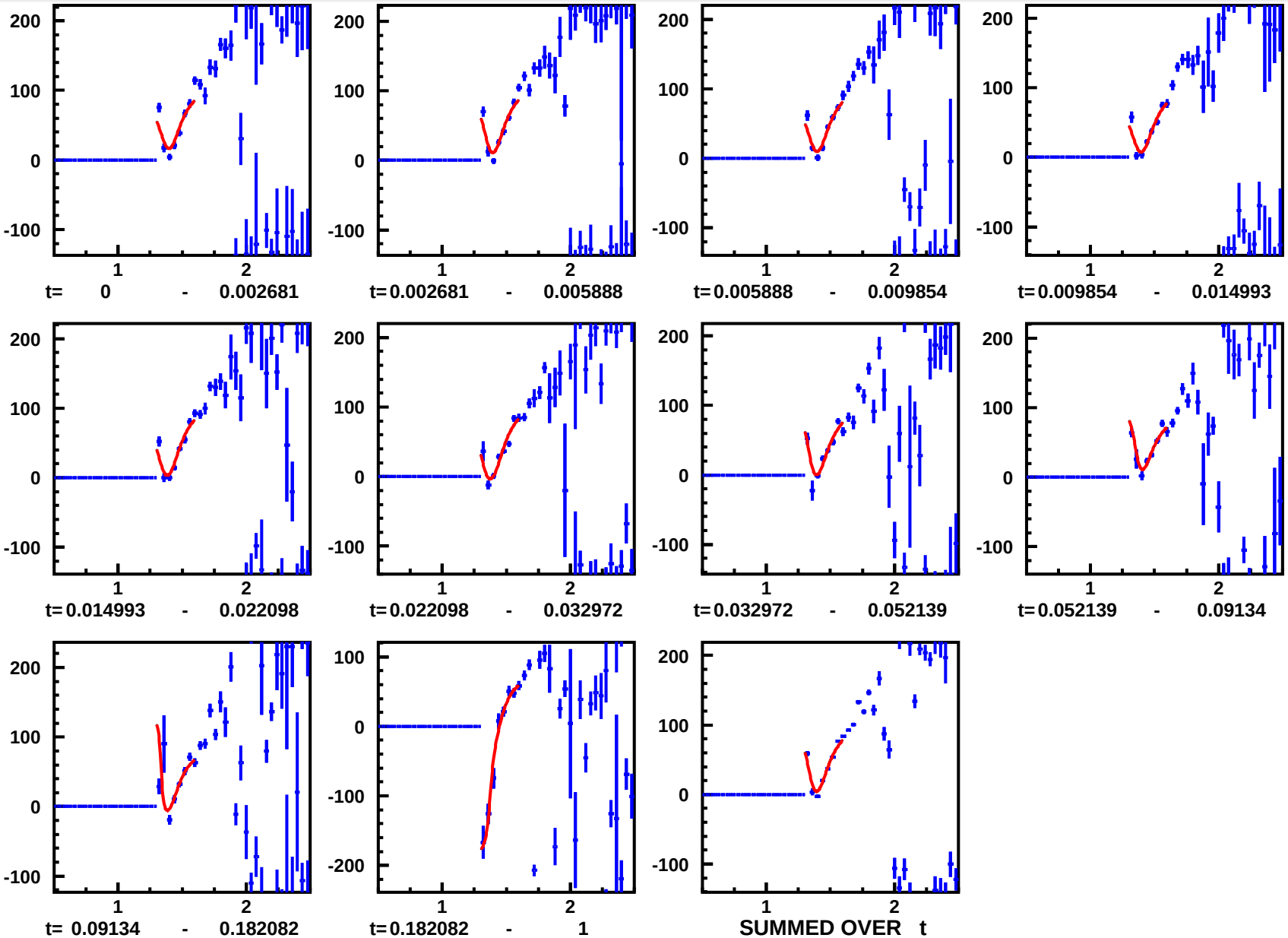
t= 0.014993 - 0.022098
t= 0.022098 - 0.032972
t= 0.032972 - 0.052139
t= 0.052139 - 0.09134
t= 0.09134 - 0.182082
t= 0.182098 - 1
SUMMED OVER t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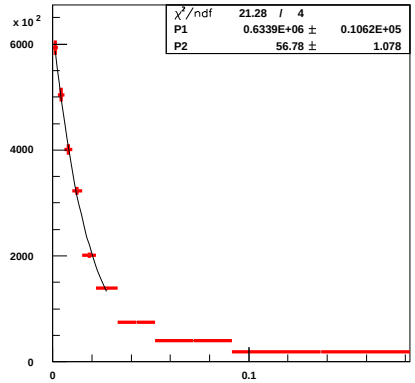
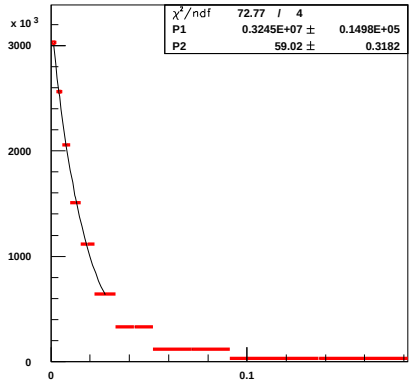
t= 0.005888 - 0.009854
t= 0.009854 - 0.014993
t= 0.014993 - 0.022098
t= 0.022098 - 0.032972
t= 0.032972 - 0.052139
t= 0.052139 - 0.09134
t= 0.09134 - 0.182082
t= 0.182082 - 1
SUMMED OVER t

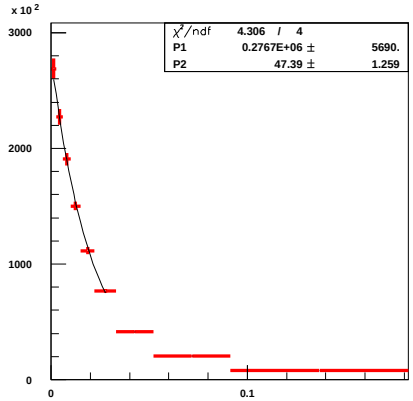
VES $\pi^-\pi^0\pi^0$



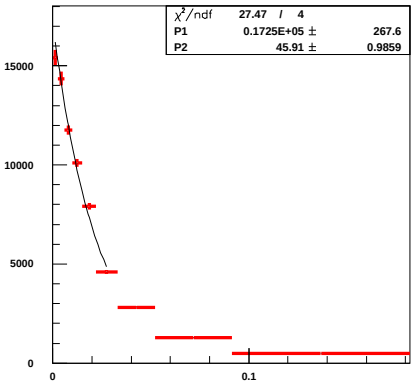
$a_1(1260)$



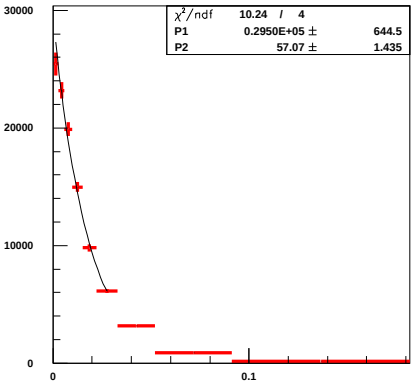
1++ Background



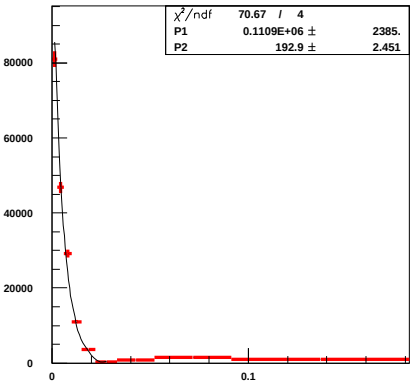
$\pi_2(1670)$



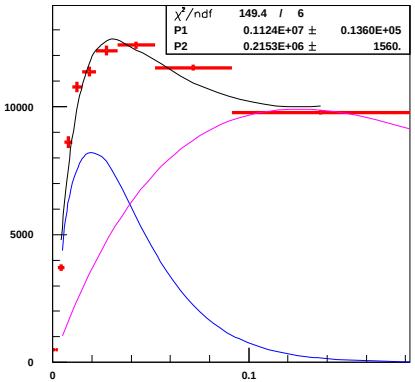
$\pi(1800)$ to $f_0(980)$ π

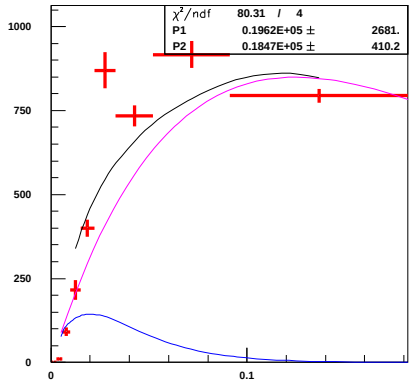


$\pi(1800)$ to $(\pi\pi)_S$ π

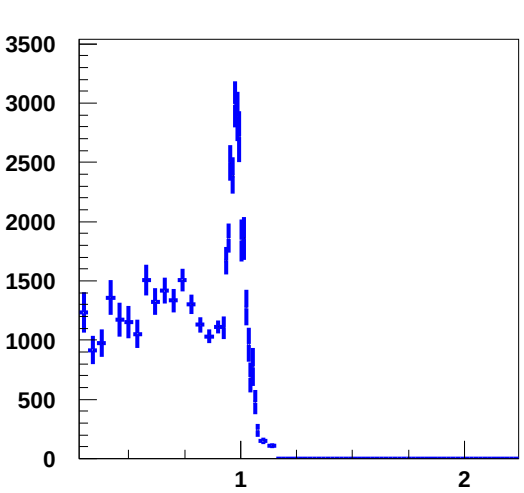


Background to $(\pi\pi)_S$ π

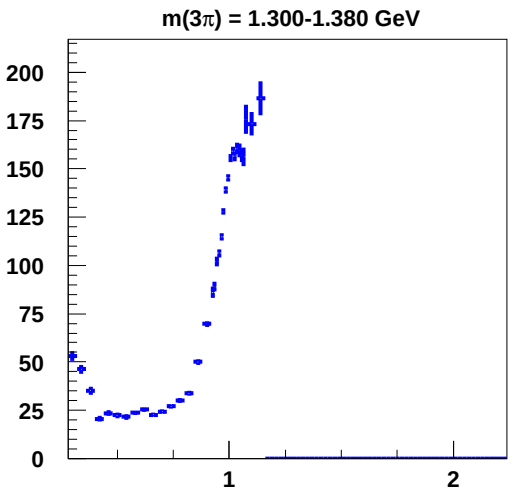




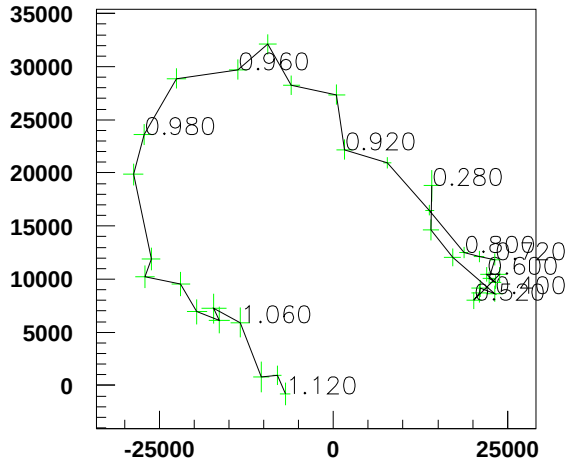
VES $\pi^-\pi^0\pi^0$

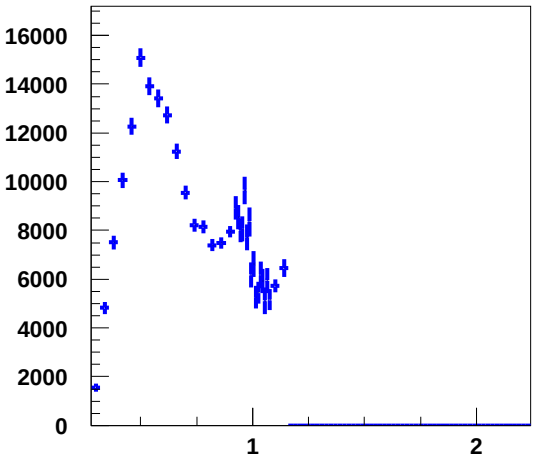


INTENS m(3pi)= 1.300 0-+0+

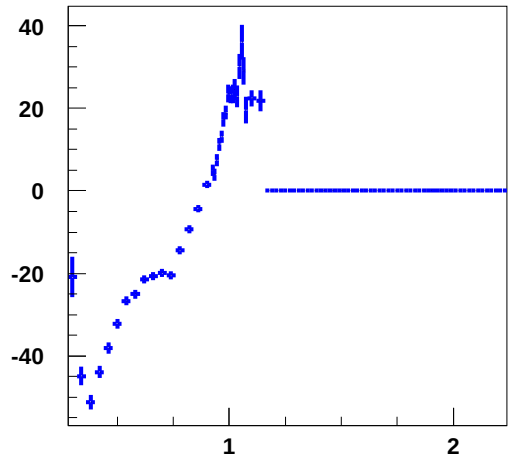


phase m(3pi)= 1.300 0-+0+

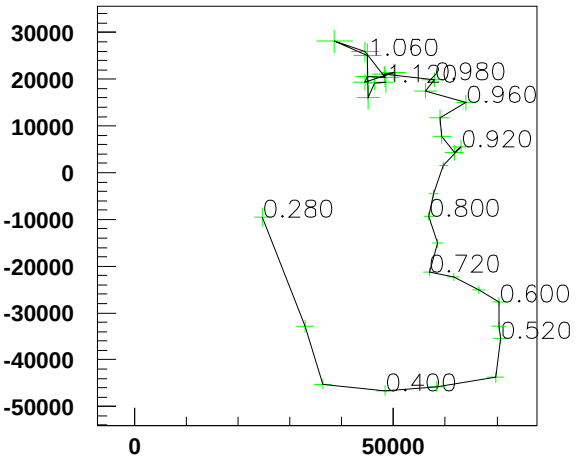




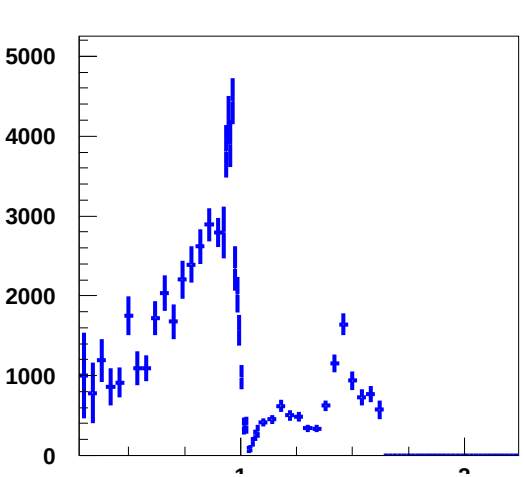
INTENS m(3pi)= 1.300 1++0+

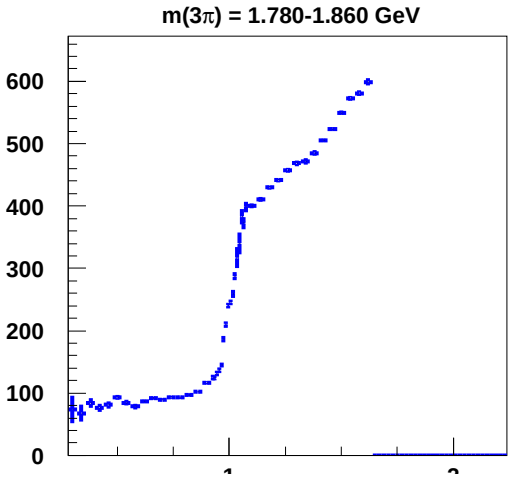


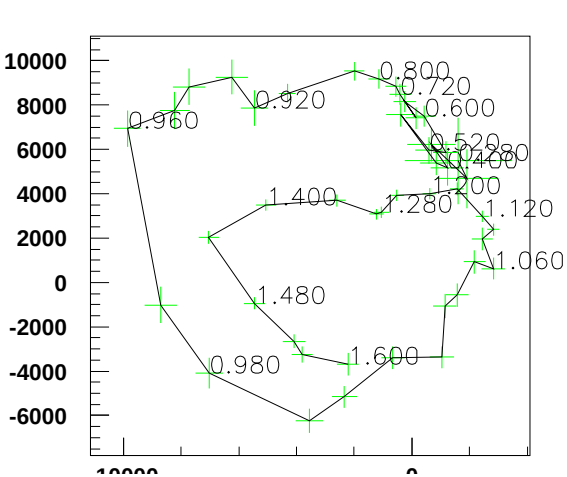
phase m(3pi)= 1.300 1++0+

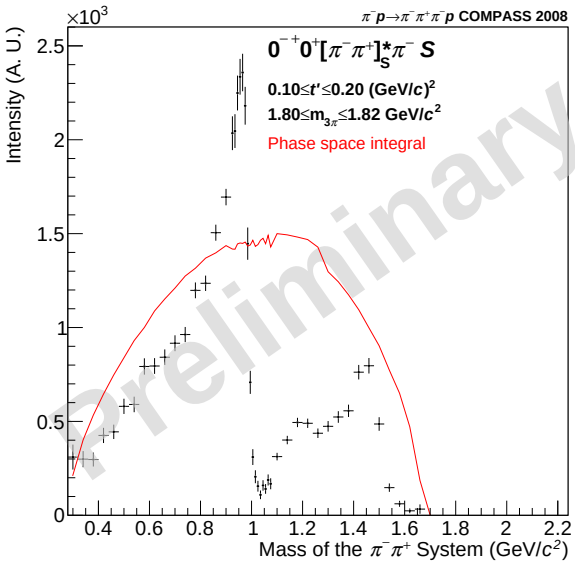


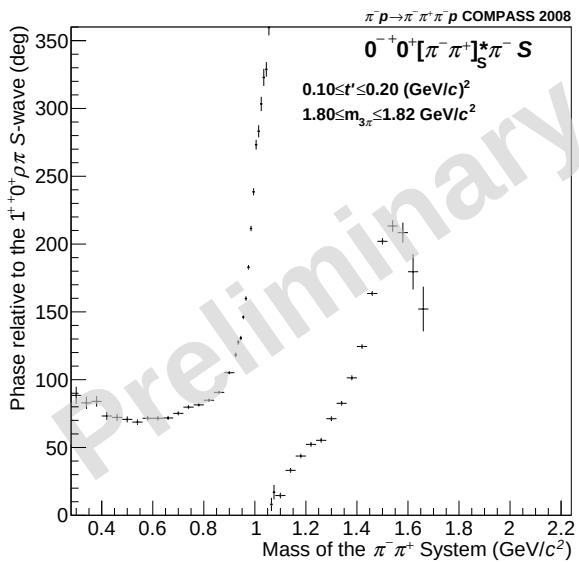
VES $\pi^-\pi^0\pi^0$

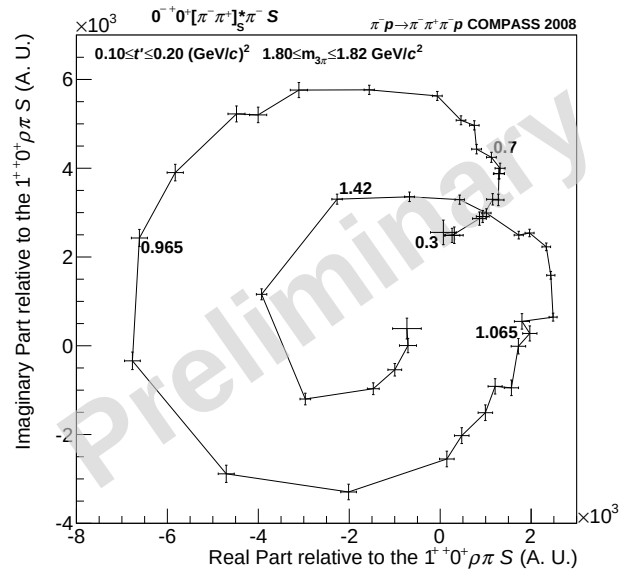












Mass-dependent fit in $\pi^-\pi^-\pi^+$ resonance parameters table

	J^{PC}	mass range (MeV/c^2)	width range (MeV/c^2)
		major waves	
$a_1\,(1260)$	1^{++}	$1260 - 1290$	$360 - 420$
$a_2\,(1320)$	2^{++}	$1312 - 1315$	$108 - 115$
$\pi_2\,(1670)$	2^{-+}	$1635 - 1663$	$265 - 305$
$a_4\,(2040)$	4^{++}	$1928 - 1959$	$360 - 400$
$\pi\,(1800)$	0^{-+}	$1790 - 1807$	$212 - 230$
$\pi_2\,(1880)$	2^{-+}	$1900 - 1990$	$210 - 390$
		states not in PDG summa	
$a_1\,(1930)$	1^{++}	$1920 - 2000$	$155 - 255$
$a_2\,(1950)$	2^{++}	$1740 - 1890$	$300 - 555$
$a_1\,(1420)$	1^{++}	$1412 - 1422$	$130 - 150$

$a_1(1260)$	M=1.325+0.-0.015	Γ=0.384+0.020-0.019
$a_1(1800)$	1.773+0.074-0.	0.208+0.023-0.
$a_2(1260)$	1.317+0.006-0.003	0.128+0.002-0.005
(Unfolding of resolution is not applied!)		
$a_2(1700)$	1.774+0.031-0.025	0.697+0.-0.125
$\pi_2(1670)$	1.662+0.002-0.009	0.274+0.019-0.043
$\pi_2(1880)$ (??)	1.904-0.020+0.010	0.233-0.028+0.00
$a_4(2040)$	1.926+0.017-0.003	0.298+0.017-0.07
$\pi(1800)$	1.792+0.006-0.001	0.202+0.013-0.010
$\pi(1300)$ (????)	1.200 +0.200-0.	0.750 +0.-0.400