Measurement of the Radiative Widths of $a_2(1320)$ and $\pi_2(1670)$ at COMPASS

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Outline

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Introduction

Primakoff Production of $a_2(1320)$ and $\pi_2(1670)$

Extraction of Radiative Widths

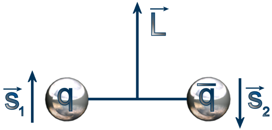
Radiative Decays of Mesons $X \to \pi\gamma$

Investigation of internal structure

- Quark Models:

  $q\bar{q}$ systems with J^{PC} composed of s_1, s_2, L

  $X \to \pi\gamma \Leftrightarrow$ Electromagnetic transition probabilities

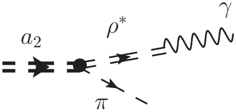


E1	$\Delta J = 1, \Delta P \neq 0$	e.g. $J^{PC} = 1^{++} \to 0^{-+}$
E2	$\Delta J = 2, \Delta P = 0$	e.g. $J^{PC} = 2^{-+} \to 0^{-+}$ $(\pi_2(1670) \to \pi)$
M1	$\Delta J = 1, \Delta P = 0$	
M2	$\Delta J = 2, \Delta P \neq 0$	e.g. $J^{PC} = 2^{++} \to 0^{-+}$ $(a_2(1320) \to \pi)$

- Vector Meson Dominance Model:

  ρ, ω, ϕ have same $J^{PC} = 1^{--}$ like photons

  Decay channel $X \to \rho\pi \leftrightarrow X \to \pi\gamma$



Present Status of Radiative Widths

Theory:

- $\Gamma(a_2(1320) \to \pi\gamma)$:
  - Vector Meson Dominance Model: 348 keV
  - Relativistic quark model: 324 keV
  - Covariant oscillator quark model: 235 keV
- $\Gamma(\pi_2(1670) \to \pi\gamma)$:
  - Covariant oscillator quark model: 119 keV

Measurements:

- $a_2(1320)$:
  - (May et al. : $\Gamma(a_2(1320)^\pm \to \pi^\pm\gamma) = 460 \pm 110$ keV)
  - E272 : $\Gamma(a_2(1320)^- \to \pi^-\gamma) = 295 \pm 60$ keV
  - SELEX : $\Gamma(a_2(1320)^- \to \pi^-\gamma) = 284 \pm 25 \pm 25$ keV
- $\pi_2(1670)$: radiative width not published yet

Measurement Technique:

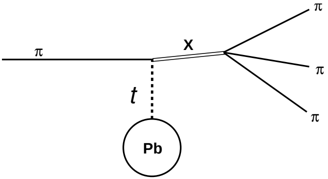
- $\pi\gamma$ decays difficult to access experimentally
  $\to$ $\pi\gamma$ scattering in Primakoff production

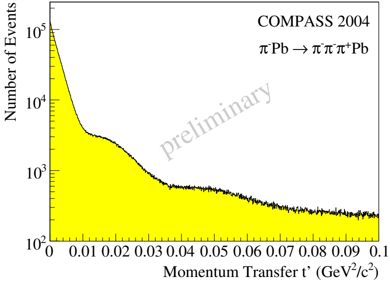
Outline

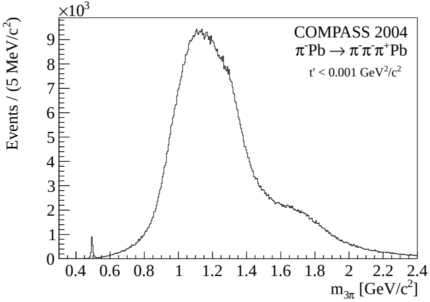
$\pi^-\text{Pb} \to \pi^-\pi^-\pi^+\text{Pb}$ Data

Pilot Hadron Run 2004

- 190 GeV π^- beam on Pb target
- Trigger: Multiplicity trigger
- $\approx$ 4 000 000 exclusive 3π events
  $\approx$ 1 000 000 with
  $t' = |t| - |t|_{\text{min}} < 10^{-3}\,(\text{GeV}/c)^2$

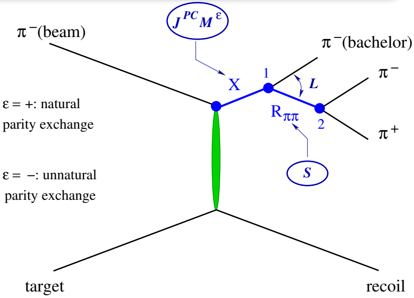






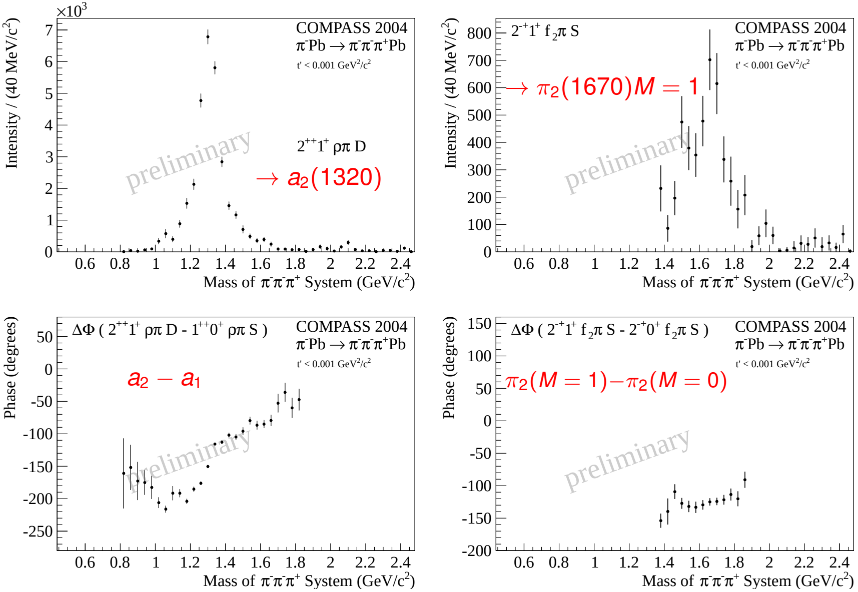
Characteristics of PWA at very low t'

- Isobar model: Intermediate 2-particle decays
- Partial wave in reflectivity basis:
  $J^{PC} M^{\epsilon} [isobar] L$
- PWA in mass bins ($40\,\mathrm{MeV}/c^2$)
  Fit of angular dependence of partial waves, interferences



- Diffractive dissociation (Pomeron exchange)
  $\sigma \propto t'^{|M|} \exp(-bt')$
  $\rightarrow$ only $M = 0$ at very low t'
- Primakoff (photon exchange)
  quasi-real $\gamma \rightarrow M = 1$

PWA in mass bins ($t' < 0.001\ (\mathrm{GeV}/c)^2$)



Outline

Extraction from Data

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Primakoff Production → Radiative widths

- Primakoff production of a broad resonance X from pion beam:

$$\frac{d\sigma}{dM\,dt'} = 16\alpha Z^2(2J+1)\left(\frac{M}{M^2-m_\pi^2}\right)^3 \frac{m_0^2\,\overbrace{dyn_{\pi\gamma}(m)\cdot\Gamma_0(X\to\pi\gamma)}^{\Gamma_{\pi\gamma}(m)}\,\Gamma_{\text{final}}(m)}{(M^2-m_0^2)^2+m_0^2\Gamma_{\text{total}}(m)^2}\,\frac{t'\cdot|F(t')|^2}{(t'+t_{\min})^2}$$

- Radiative width and the absolute cross-section $\sigma_{\text{Primakoff}}$:

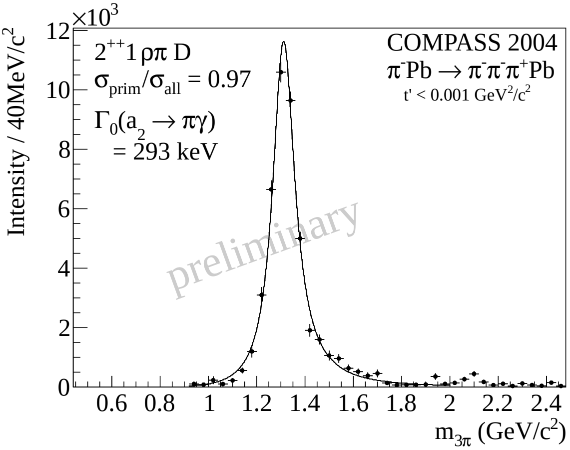
$$\sigma_{\text{Primakoff}} = \int_{m_1}^{m_2}\int_{t'_1=0}^{t'_2}\frac{d\sigma}{dM\,dt'}\,dt'\,dM = \Gamma_0(X\to\pi\gamma)\cdot C$$

- Radiative width from the experimentally observed intensity N_X

$$\Gamma_0(X\to\pi\gamma) \propto \frac{N_X/\epsilon}{C\cdot L}$$

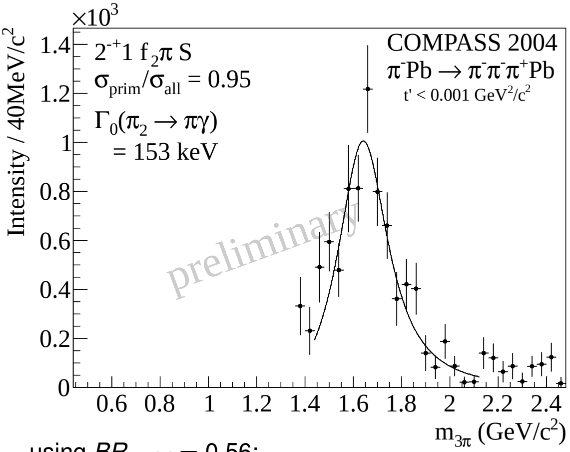
  - N_X/ϵ from Breit-Wigner fit to the acceptance-corrected PWA intensity
  - Calculation of C for specific resonance
  - Luminosity L from the decays of beam $K^- \to \pi^-\pi^-\pi^+$

$a_2(1320)$



$$\Gamma_0(a_2(1320) \to \pi\gamma) = (293 \pm 5_{stat} \pm 26_{syst})\,\text{keV}$$

$\pi_2(1670)$



using $BR_{model} = 0.56$:

$$\Gamma_0(\pi_2(1670) \rightarrow \pi\gamma) = (153 \pm 10_{stat} \pm 21_{syst})\,\text{keV} \cdot BR_{model}/BR_{true}$$

Conclusion

Measurement of radiative widths at COMPASS

- Reliable extraction of the intensities by PWA
- $a_2(1320)$ (M2 transition) compatible with results from previous experiments

  $$\Gamma_0(a_2(1320) \to \pi\gamma) = (293 \pm 5_{\text{stat}} \pm 26_{\text{syst}})\,\text{keV}$$
- First number for $\pi_2(1670)$ (E2 transition) available

  $$\Gamma_0(\pi_2(1670) \to \pi\gamma) = (153 \pm 10_{\text{stat}} \pm 21_{\text{syst}})\,\text{keV} \cdot BR_{model}/BR_{true}$$

BACKUP SLIDES

Estimation of uncertainties

	$a_2(1320)$	$\pi_2(1670)$
Statistical	1.8%	6.25%
Systematic		
diff. background	1%	3%
kaon normalization	6%	6%
PWA models	5%	7.7%
BW fits (mass-dep. Parametr.)	3.7%	8.9%
quadr. added	8.7%	3.5%

- $\Gamma_0(a_2(1320) \to \pi\gamma) = (293 \pm 5 \pm 26)\,\text{keV}$
- $\Gamma_0(\pi_2(1670) \to \pi\gamma) = (153 \pm 10 \pm 21)\,\text{keV} \cdot BR/BR_{real}$

From PWA in t' bins ($\Delta m_{3\pi}$ around m_0)

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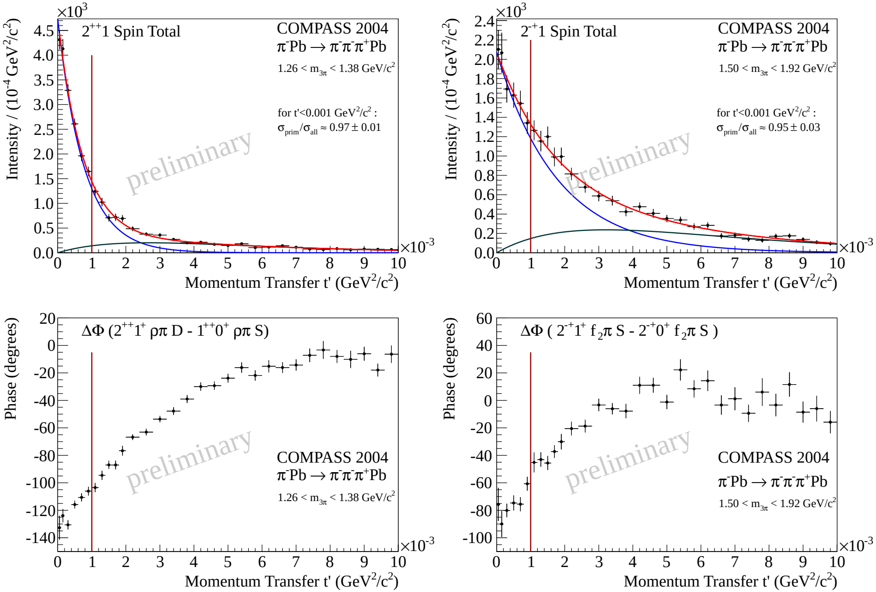
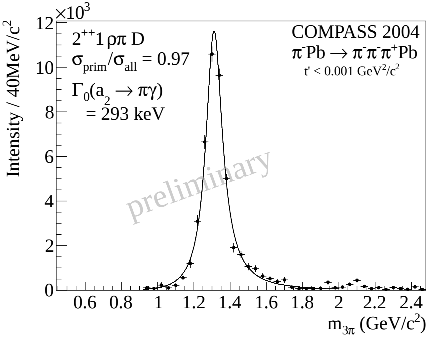


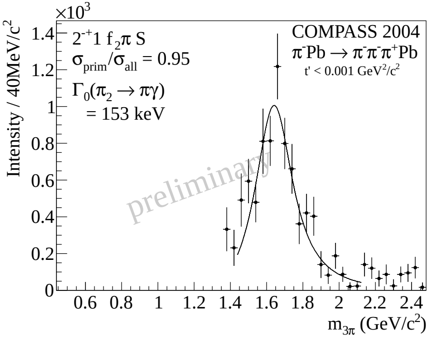
$a_2(1320)$



- Γ(all) from $a_2 \to \rho\pi$ and $a_2 \to \eta\pi$
  - $\rho\pi$ described by $\int |\psi|^2 d\tau$
  - $\eta\pi$ described by F_L terms (sharp η)
- $\omega\pi\pi$ and $K\bar{K}$ decays omitted
- Using $C_{\mathrm{COMPASS},a_2} \approx 2759$, $\epsilon_{resol} = 0.74$, $BR = 0.7$, $CG = 0.5$

$$\Gamma_0(a_2(1320) \to \pi\gamma) = 293 \pm 5_{\mathrm{stat}} \pm 26_{\mathrm{syst}}\ \mathrm{keV}$$

$\pi_2(1670)$



- Situation for $\Gamma(all)$ more difficult:
  $\pi_2(1670) \to 3\pi \ \approx 0.96$
  $3\pi = \{f_2\pi, \rho\pi, \sigma\pi, (\pi\pi)_S\pi\}$
  but: interference! charged and neutral??
- For the moment: just $f_2\pi$ decay, also for Γ(all)
  $f_2\pi$ described by $\int |\psi|^2 d\tau$
- Using $C_{COMPASS,\pi_2} \approx 759$,
  $\epsilon_{resol} = 0.732$, $BR = 0.56$, $CG = 2/3$

$$\Gamma_0(\pi_2(1670) \to \pi\gamma) = (153 \pm 10_{stat} \pm 21_{syst}\,\text{keV}) \cdot BR/BR_{real}$$

Absolute Normalization: Beam K^- Decays

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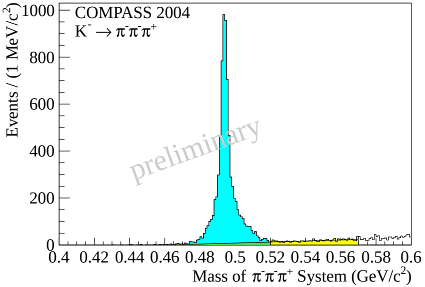
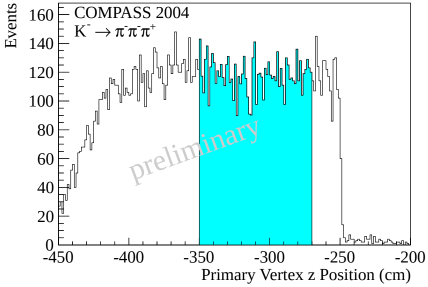
Number of reactions (events) = $\epsilon_{\text{bin}} \cdot \int \mathcal{L}\mathrm{d}t \cdot \sigma_{abs}$

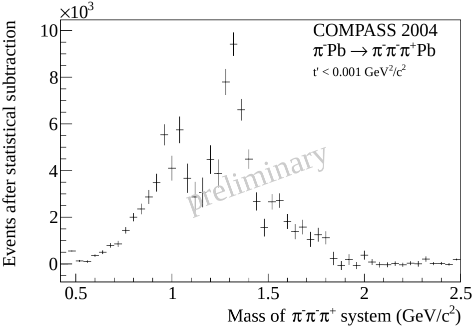
COMPASS π^- beam features K^- component
$\rightarrow$ beam flux from $K^- \rightarrow \pi^+\pi^-\pi^-$ decays





BACKUP: Primakoff mass spectrum from statistical subtraction

- Statistical subtraction for $40\,\mathrm{MeV}/c^2$ mass bins
- Integrate remaining spectra for $t' < 10^{-3}\,(\mathrm{GeV}/c)^2$
  $\rightarrow$ nb. of events / mass bin



Selex, Phys. Lett. B 521(2001), 171-180

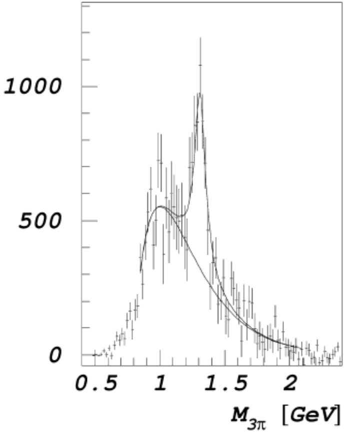


Fig. 3. $M_{3\pi}$ mass distribution for the Cu target after subtraction of diffractive background. The curve shows fit with a sum of pure Coulomb contribution and smooth background.

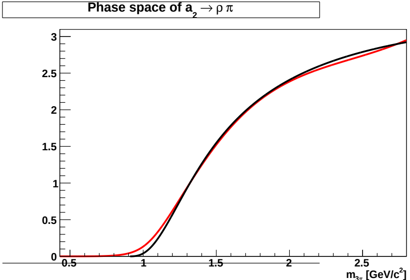
Breit-Wigner fits to the total intensities

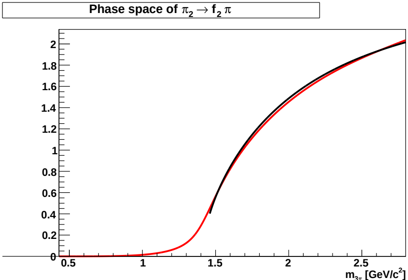
$$\frac{d\sigma}{dM} = 16\alpha Z^2(2J+1)\left(\frac{M}{M^2 - m_\pi^2}\right)^3 \frac{m_0^2\,\Gamma(\pi\gamma)\,\Gamma(\mathrm{final})}{(M^2 - m_0^2)^2 + m_0^2\Gamma(\mathrm{all})^2}$$

with $\Gamma(\pi\gamma) = dyn(\pi\gamma)\cdot\Gamma_0(X\to\pi\gamma)$, $\Gamma(final) = dyn(\pi\{isob\})\cdot\Gamma_0(X\to\pi\{\mathrm{isob}\})$

$\Gamma(all) = \sum_n \Gamma_{0\,n}\, c_n\, dyn(n)$ with $\Gamma_{0\,n} = \Gamma_n(m_0)$

$dyn() = \frac{k}{k_0}\,\frac{m_0}{m}\,\frac{F_L^2(k)}{F_L^2(k_0)}$ or (incl. widths) $dyn() = \frac{m_0}{m}\int \left|\psi_{\pi\{isob\}\ L}\right|^2 d\tau$





The “extended” ChPT Amplitude incl. loops and ρ

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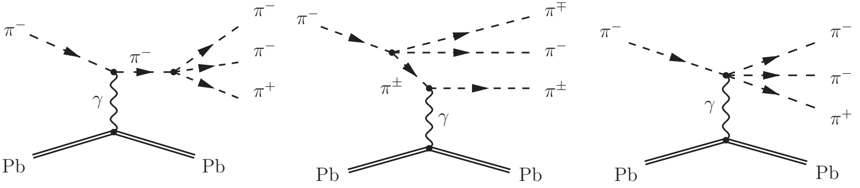
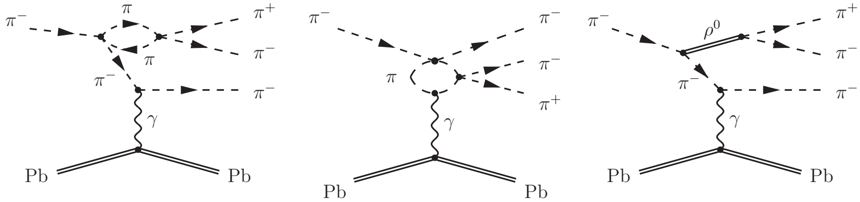
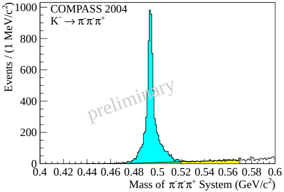
used for previous release:

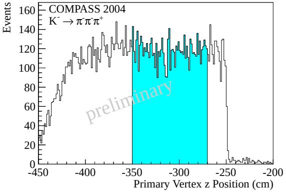


now additionally included (examples):

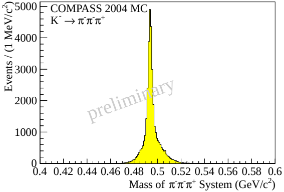


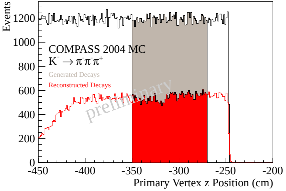
BACKUP: Beam K^- decays from data and MC





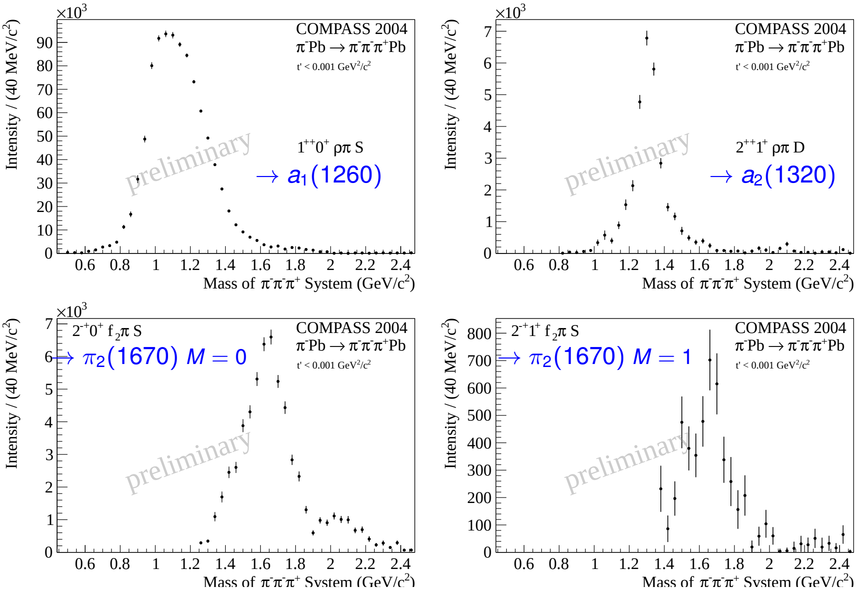
- N(K^-) = 7730 in 80 cm window around target
- $\mathcal{L} = 9,55 \cdot 10^4$ events/mb (measured)



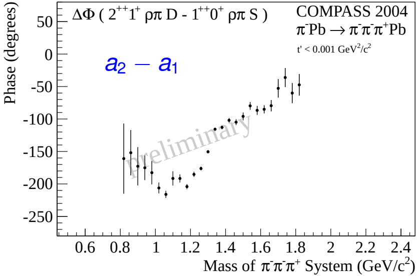


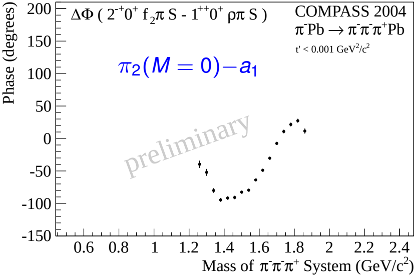
- Cuts as for real data: Exclusivity, t', trigger, kaon mass, vertex position
- Acceptance $\approx$ 0.459

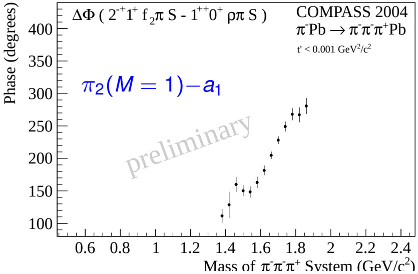
BACKUP: Intensities of selected waves, $t' < 0.001\ (\mathrm{GeV}/c)^2$

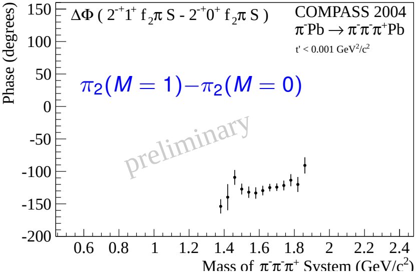


BACKUP: Phases between selected waves

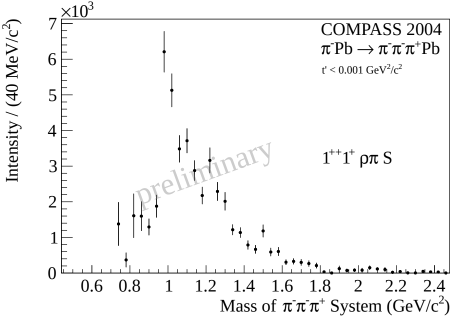


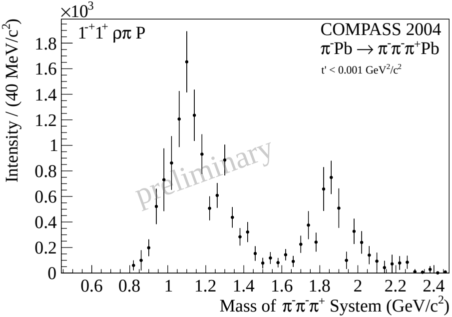






BACKUP: Intensities of selected waves, $t' < 0.001\ (\mathrm{GeV}/c)^2$

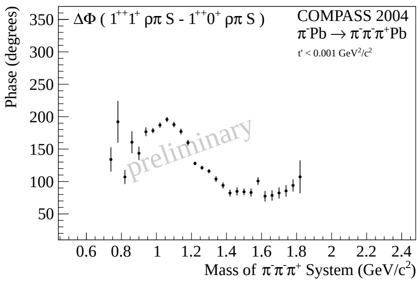


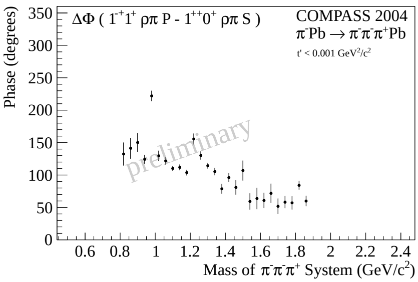


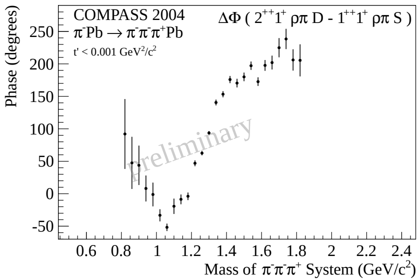
$1^{++}1^{+}$ candidate for Primakoff-produced $a_1(1260)$?

$1^{-+}1^{+}$ some spin-exotic resonance ?

BACKUP: Phases between selected waves







No indication for resonance in $1^{++}1$ or $1^{-+}1$ waves

BACKUP: Partial Wave Analysis Formalism

- Mass-independent PWA (narrow mass bins):

$$\sigma_{\mathrm{indep}}(\tau, m, t') = \sum_{\epsilon=\pm 1} \sum_{r=1}^{N_r} \left| \sum_i T_{ir}^{\epsilon} f_i^{\epsilon}(t') \psi_i^{\epsilon}(\tau, m) \Big/ \sqrt{\int |f_i^{\epsilon}(t')|^2 \mathrm{d}t'} \sqrt{\int |\psi_i^{\epsilon}(\tau', m)|^2 \mathrm{d}\tau'} \right|^2$$

  - Production strenght assumed constant in single bins
  - Decay amplitudes $\psi_i^{\epsilon}(\tau, m)$, with t' dependence $f_i^{\epsilon}(t')$
  - Production amplitudes $T_{ir}^{\epsilon} \rightarrow$ Extended log-likelihood fit
  - Acceptance corrections included

- Spin-density matrix: $\rho_{ij}^{\epsilon} = \sum_r T_{ir}^{\epsilon} T_{jr}^{\epsilon *}$

  $\rightarrow$ Physical parameters:

$$\mathrm{Intens}_i^{\epsilon} = \rho_{ii}^{\epsilon},$$

relative phase Φ_{ij}^{e}

$$\mathrm{Coh}\ _{i,j}^{\epsilon} = \sqrt{(\mathrm{Re}\ \rho_{ij}^{\epsilon})^2 + (\mathrm{Im}\ \rho_{ij}^{\epsilon})^2} \Big/ \sqrt{\rho_{ii}^{\epsilon} \rho_{jj}^{\epsilon}}$$

- Mass-dependent χ^2-fit (not presented here):
  - X parameterized by Breit-Wigner (BW) functions
  - Background can be added